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ORIGINAL RESEARCH ARTICLE

EVALUATION OF HY-8 MODELING TOOL FOR HYDRAULIC ANALYSIS OF SELECTED CULVERTS ALONG ILORIN -JEBBA ROAD, KWARA STATE, NIGERIA

A. G. Adeogun[1], M. A. Akinpelu[1], M. A. Yusuf[2] and R. A. Animashaun[2]
([1]Department of Civil Engineering, Kwara State University, P.M.B.1530, Malete, Kwara State, Nigeria
[2]Index Engineering Consults Nigeria Ltd, off Pipeline Road, Ilorin, Kwara State, Nigeria
**Corresponding Author: adeniyi.adeogun@kwasu.edu.ng*

ARTICLE INFORMATION

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ABSTRACT
In this study, selected culverts along Ilorin – Jebba road, Kwara State were hydraulically analyzed using HY-8 modelling tool. Hydrological analyses of the culverts were performed using rational method for the computation of design discharges. On site information such as tail water data such as channel type and bottom width, roadway data such as crest length and culvert data such as culvert material and span were collected from each of the culverts and were used in conjunction with estimated design discharge as input data for HY-8 modeling tool to facilitate the hydraulic analysis of the culverts. Hydrological analysis showed that the highest design flow of 9.09 m^3/s was obtained at culvert located at Km 11+775 while the least design flow of 1.83 m^3/s was obtained at culvert located at Km 3+300. Hydraulic analysis revealed that seven of the analyzed culverts have adequate capacity to convey the design flow while three culverts were found inadequate to convey the design flow and therefore, need to be resized. The outcome of this study will arouse the interest of engineers in the usage of the tool in sizing hydraulic culverts most especially in Nigeria and other Saharan African countries.

1.0 Introduction

The provision for adequate drainage facilities is an integral part of roadway infrastructural design and cannot be overemphasized. The presence of excess water within the roadway adversely affects the engineering properties of the materials with which it was constructed. Cut or fill failures, road surface erosion, and weakened subgrades followed by a mass failure are all products of inadequate or poorly designed roadway drainage system. Culverts are typical drainage facilities used to convey water across urban and rural roadways.

Over the years, manual analysis of the hydrology and hydraulics of culverts have been in practice most especially in developing countries. This process is not only cumbersome and tedious, but also prone to error as the numbers of hydraulic culverts to be analyzed increase. Several software programs such as HY-8 (FHA,1996), THYSYS Culvert (TSDH, 2007), Culvert Analysis Program (CAP) as documented by Fulford, (1995), HEC-RAS (Brunner, 2010), FishX-ing (Bates, et al, 2003) and Culvert Master (Bentley, 2003) have been developed to assist engineers in the design and analysis of culverts in a road project. While each of the developed programs for culvert analysis has unique characteristics, they all provide automated solution to culvert analysis and design problem. Out of all the available software packages for culvert analysis, HY-8 is the most widely used and distributed among users (Rowley, 2016). One of the advantages of using HY-8 for culvert analysis is its ability to consider outlet-control situations and address issues relating to inlet control of culverts which significantly improves the output in terms of sizing of culverts. It is important to state that proper analysis of inlet control is critical when evaluating alternative material types such as corrugated metal, reinforced concrete, and smooth plastics. (Peterson, 2019). Therefore, this paper investigate the use and application of HY-8 tool for hydraulic analysis of selected culverts along Ilorin Jebba road in Kwara State, Nigeria

1.1 Description of Study Area

Selected culverts for analysis are located along Ilorin –Jebba road in Kwara State of Nigeria (Figure 1). The road is about 91.0 km long and takes off from Ilorin on the Ogbomoso-Ilorin dualized road at about 1km from Eyenkorin, Ilorin. The host city is at latitude 4°30’05’S, Longitude 8° 30’W and runs in a Northern direction before terminating at Jebba, km 90+906 at Latitude 4° 40’N and longitude 9° 15’ 05”E. It has a varying width of 7.3m, 9m and 11m at different locations along the road alignment. The road is also characterised with washout shoulders on either side. The project road lies within the North Central part of Nigeria.

The existing road is a two-lane single carriageway highway that links Ilorin with Jebba via Ilorin-East and Moro local government area of Kwara State. It is unarguably a vital route or link for transporters travelling to and from the Federal Capital Territory and the North Western and South Eastern part of Nigeria. The road consists of 74 culverts out of which 44 are box culverts while the remaining 30 are pipe culverts of different sizes. Selected culverts are located between Km 0+00 and Km 15+00 and consist of 5 pipe and box culverts each making a total of 10 culverts in the study area. Figure 2 shows pictorial view of some of the analyzed culverts located within the study area

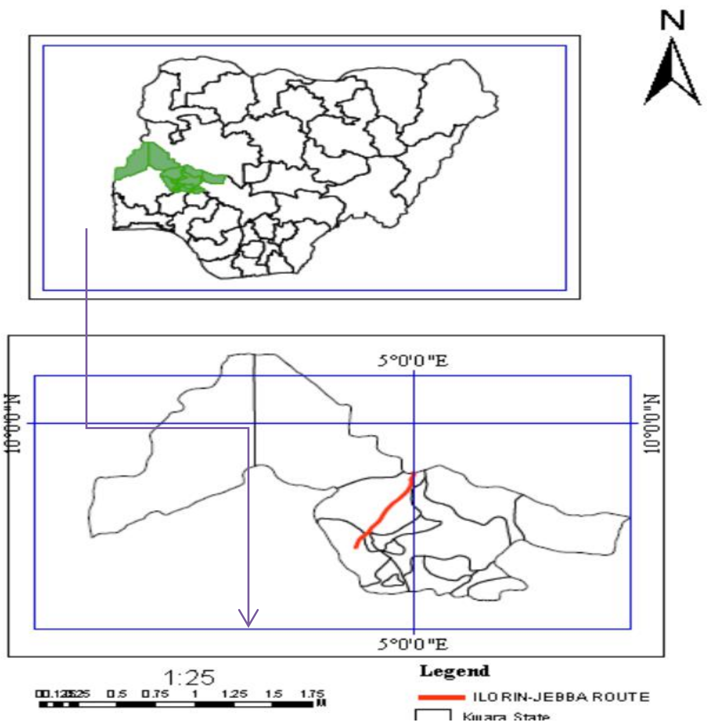


Figure 1: Map of Nigeria showing the location of the Study Area

Figure 2: Some of the analyzed culverts located within the study area

2 Materials and Methods

2.1 Selection and Description of HY-8 Software Package

Hy-8 is a culvert hydraulic modeling tool developed by Philip Thompson and were provided to the Federal highway Administration (FHWA), USA for distribution in early 1980s. Since the period the hydraulic model was developed, understanding of culvert hydraulics has increased significantly leading to development of more acceptable modeling techniques. Various organization and government departments have adopted the usage of the model in designing and analyzing culverts along roadway. The package was selected for the study area because of its ease of use and efficiency as reported in some literatures (Nwaogazie and Agiho, 2019; FHA, 2019) Also, HY-8 tool has been recommended by the Ministry of works and Transport (Nigeria) in volume IV, Drainage Design Manual for culvert analysis which includes inlet control, outlet control and calculation of water profiles (FMW, 2013). Some other deliverable of the software includes the estimation of tailwater downstream of the culvert based on the channel dimension and slope. The software also makes it possible to determine the flow regime and water surface profile in the culvert.

2.2 Hydrological Data and Analysis

Hydrological data Analysis of the drainage catchment was performed using the rational formula for the computation of design discharges for the cross culverts. The rational method (Equation 1) has been widely used and formed the basis of most road drainage designs (Raghunath, 2006).

$$Q = \frac{C*I*A}{360} \quad (1)$$

Where: Q is the Runoff (m^3/s), C is the Coefficient of Runoff, I is the Intensity of Rainfall (mm/hr) and A is the Area of water shed (km^2).

The rational method was applied to estimate the design discharge of each selected hydraulic culverts based on the assumptions as stated in the FMW (2013). Also, the Rainfall Intensity (I) was estimated using the relationship developed by Oyebande (1982) as written in Equation 2.

$$I = \beta + y(1/\alpha) \quad \text{in mm/hr} \quad (2)$$

Where: I =Rainfall intensity (mm/hr) , α and β are the scale and location parameters and are chosen from Table 4.8 and 4.9 of the FMW (2013) for hydrological zone 2 where the study area belongs. y is a parameter obtained from relationship involving the return period or frequency of

Corresponding author's e-mail address: gbengailori@unilag.edu.ng

occurrence of rainfall in the zone as described in equation 3. Coefficient used for each of the culvert locations was chosen based on the guidelines as stated in Table 1 and 2 of Highway Design Manual Vol.VI.

$$y = \ln(T_r) - \frac{1}{2T_r} - \frac{1}{24T_r^2} - \frac{1}{8T_r^3} \quad (3)$$

The catchment area of each of the analysed culverts was estimated using the Digital Elevation Model (DEM) of the study area and Geographical Information System (GIS) tool in MapwindowGIS software. The appropriate Runoff Coefficients for each culvert location were chosen from FMW (2013). The time of concentration, which is defined as the time required for runoff to travel by the longest available flow path to a particular location was estimated using the Kerby's formula as stated in Equation 4. For the hydrological analysis of the culvert, a 50 Year return period was adopted as recommended for lesser or minor culverts (Table 4, Federal Ministry of work, Drainage Design Manual, Volume IV)

$$Tc = 0.604\left(rL/\sqrt{S}\right)^{0.467} \quad (4)$$

Where: Tc = time of concentration (hours), r = roughness coefficient, L = Hydraulic length of catchment measured along flow path from the catchment boundary to the point of interest or where flow enters a defined watercourse, whichever is shorter (km) and S is the slope of the catchment (elevation difference divided by length of flow path) in m/m.

2.3 Model Input Parameters

The application of Hy-8 tool for hydraulic analysis of culverts involved the collection of range of data which serve as input data before the running of model. These data defined the culvert barrels and the surrounding site condition at each of the analyzed crossing. A crossing is defined as the location where a channel crosses a road way, floodplain or another embankment. HY-8 allows for definition and modeling of up to six culverts at each crossing. Data requirements include Discharge Data, Tailwater Data, roadway and Culvert Data. These data were collected using procedures as described Nwaogazie and Agiho (2019) and Kang et al., (2009) using varieties of equipment such as GPS Garmin 600, Total Station, and measuring tape.

The Discharged data was obtained from the hydrological analysis of the watershed using the rational formula as described in FMW (2013). Tailwater Data which includes the channel type, slope and the channels invert elevation were all obtained on the field through observation and direct measurement. The tailwater data are used to define the water surface profile downstream of the channel crossing. Information on the Roadway Data which include the crest length and crest elevation of the road and surface condition of the road (paved or gravel) were collected by measurement and direct observation at each of the culvert location. Culvert Data were acquired by measuring the span of the selected rectangular box culverts and diameter of the pipe culvert. Also, the shape of the culverts were recorded and used as input file at the culvert data section. .

2.4 Model Run and Analysis

All the parameters necessary to define crossing and culvert information are done using the culvert data window (see Figure 3). This is followed by the hydraulic analysis of the culvert including the balancing flow through multiple culverts and over the roadway. The analysis of the culverts involves the necessary hydraulic computation after which the overtopping table will be generated and displayed. At this stage, it is possible to view the water surface profiles as well as a customized table made up of any parameters computed during the analysis. In the case of overtopping of culverts after analysis, the culvert can be re-analyzed after increasing the size of the hydraulic culvert or by increasing the number of barrels until the design flow is fully accommodated.

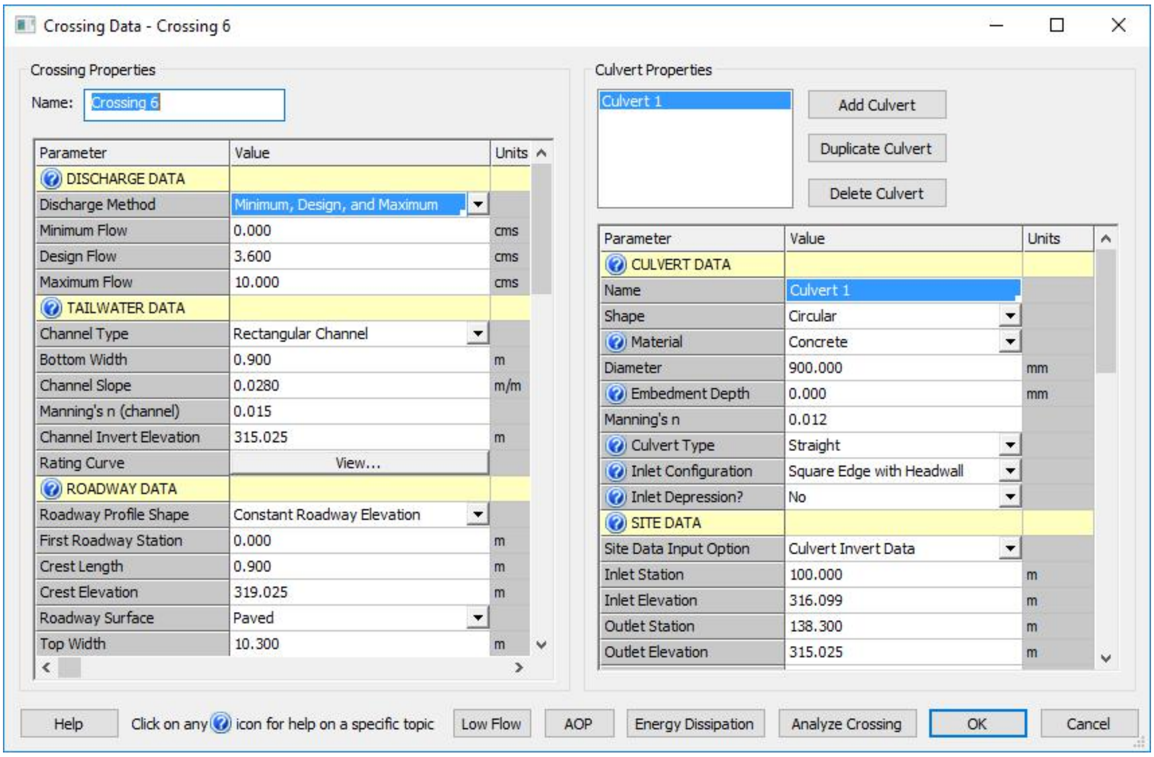


Figure 3: Typical Culvert Crossing Data Window in HY-8 Modelling Tool

3.0 Results and Discussion

3.1 Validation of Model Results

The results of the hydraulic analysis of selected culverts were checked against results obtained using manual calculations based on the inlet control principle for the sizing and checking the adequacy of the cross culverts. The outcome showed that the model results were adequate and in line with the manual calculation results.

3.2 Hydrological Analysis

Summary of the hydrological analysis of selected culverts are as presented in Table 1. The table gives details of the chainages, existing culvert size, the estimated catchment area, computed design discharge (m^3/s) on each of the analyzed culverts. From the Table, it was found that the discharge of the culverts varied from the lowest value of 1.55 m^3/s (culvert located at 10+375 km) to 9.09 m^3/s for culvert located at Km 11+775. Also, the largest catchment area was obtained as 0.71 km^2 for culvert located at Km 11+775 km while the smallest catchment area was estimated as 0.12 km^2 for culvert located at 13+375 km.

Corresponding author's e-mail address: gbengailori@unilag.edu.ng

Table 1: Summary of Hydrological Analysis of Selected Culverts Using HY-8 Modeling Tool

S/N	Chainages	Existing Culvert Size (m)	Culvert Type	Catchment Area (km^2)	Intensity (mm/hr)	Design Flow (m^3/s)
1	1+400	2(0.9)	Pipe (Double cell)	0.27	163.8	2.97
2	2+825	1.5x1.5	Box (Single cell)	0.28	188.77	3.11
3	3+300	2(0.9)	Pipe (Double cell)	0.24	148.75	1.80
4	5+475	2(3.0x3.0)	Box (Double cell)	0.32	158.16	3.40
5	7+500	3.0x3.0	Box (Single cell)	0.30	158.16	2.39
6	9+125	0.9	Pipe (Single cell)	0.48	148.75	3.60
7	10+375	2(2.5x2.5)	Box (Double cell)	0.36	153.62	1.55
8	11+775	2(2.5x2.5)	Box (Double cell)	0.71	142.86	9.09
9	12+875	0.9	Pipe (Single cell)	0.18	188-78	4.44
10	13+375	0.9	Pipe (Single cell)	0.12	142.86	2.78

3.3 Hydraulics Analysis

3.3.1 Hydraulic Status of Culverts

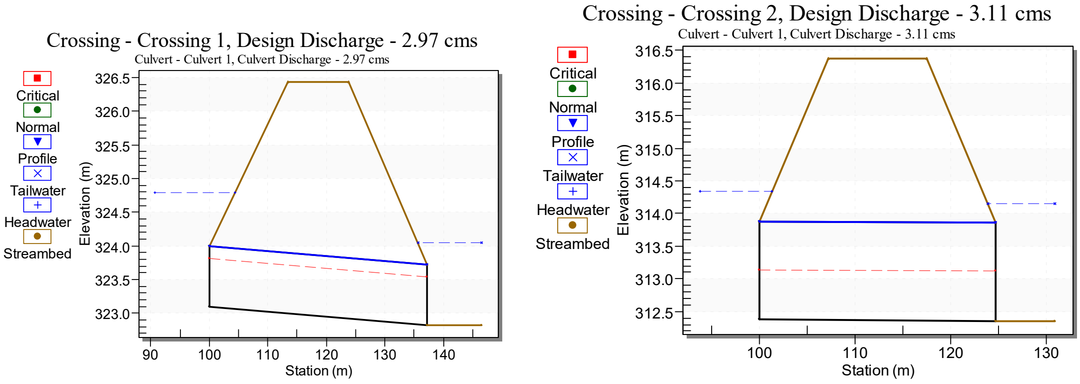
The results of the hydraulics analysis of the culverts are as presented in Table 2. The table contains details such as the sizes of existing and proposed culverts with their locations. Also, the status column in the table provides information on adequacy or inadequacy of the analysed culvert to convey the design flow. Those culverts found to be inadequate were further re-analysed by increasing the size of the existing culvert to accommodate the design flow. Overall, three culverts were found to be inadequate as against seven culverts that have adequate capacity to accommodate the design flow.

Table 2: Summary of Hydraulics Analysis of selected Culverts Using HY-8 Modeling Tool

S/N	Location (Chainage) (km)	Existing Culvert Size (m)	Status	Type of Proposed Culvert (m)
1	1+400	2(0.9)	adequate	2(0.9)
2	2+825	1.5x1.5	adequate	1.5x1.5
3	3+300	2(0.9)	adequate	2(0.9)
4	5+475	2(3.0x3.0)	adequate	2(3.0X3.0)
5	7+500	3.0x3.0	adequate	3.0X3.0
6	9+125	0.9	not adequate	2(0.9)
7	10+375	2(2.5x2.5)	adequate	2(2.5X2.5)
8	11+775	2(2.5x2.5)	adequate	2(2.5X2.5)
9	12+875	0.9	not adequate	1.5X1.5
10	13+375	0.9	not adequate	2(0.9)

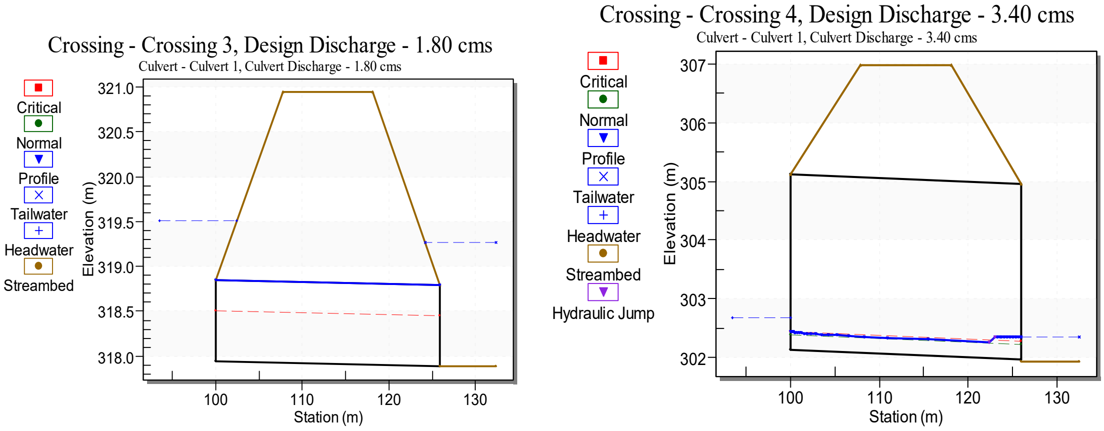
3.3.2 Water Surface Profile of Analyzed Culverts

HY-8 tool was used to plot the water profile using the direct step method in each direction and the sequent depth associated with each of the steps. If the sequent depth associated with the forward profile matches the depth along the backward profile through the culvert, a hydraulic jump occurs and the length of the jump is calculated from that location. Once a profile is selected, the user may then plot and view the profile. Figures 4-8 displayed the water surface profiles of the selected culverts.



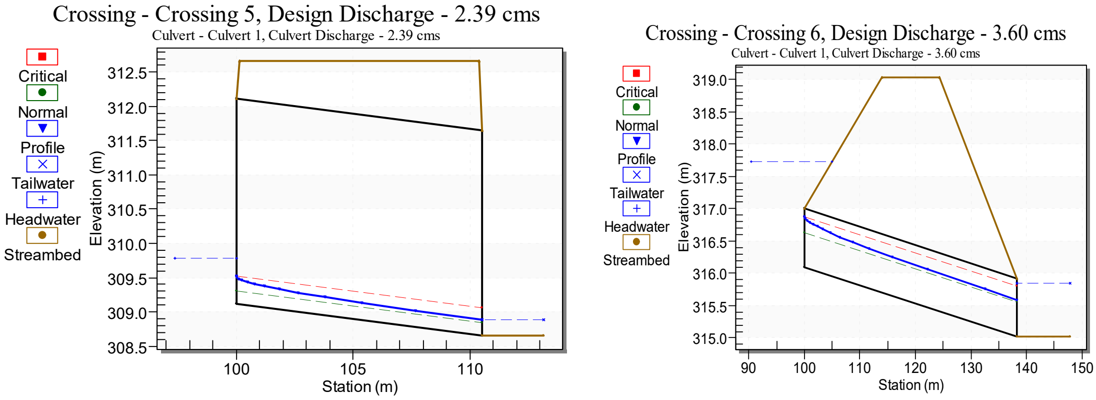
(a) (b)

Figure 4: Water Surface Profile generated for Culverts located at (a) Km1+400 and (b) Km 2+825



(c) (d)

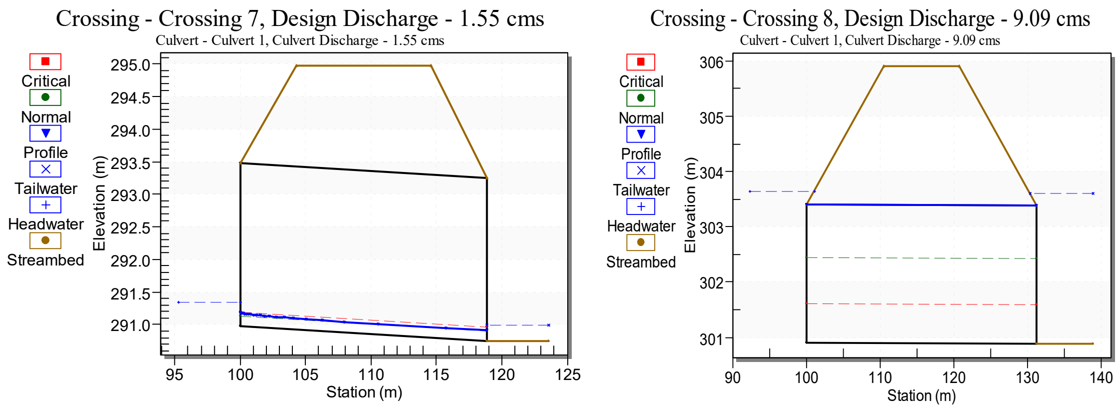
Figure 5: Water Surface Profile generated for Culverts located at (c) Km3+300 and (d) Km 5+575



(e) (f)

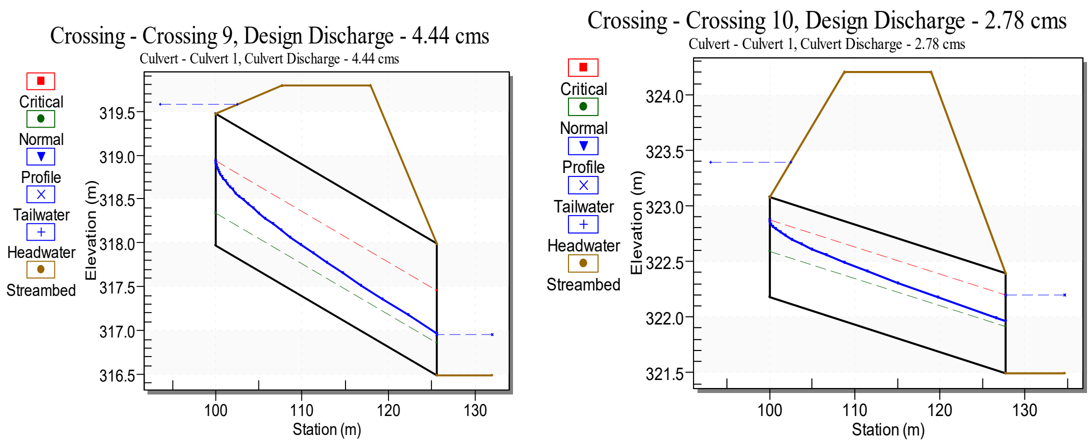
Figure 6: Water Surface Profile generated for Culverts located at (e) Km 7+500 and (f) Km 9+125

Corresponding author's e-mail address: gbengailori@unilag.edu.ng



(g) (h)

Figure 7: Water Surface Profile for Culverts located at (g) Km10+375 and (h) Km 11+775



(i) (j)

Figure 8: Water Surface Profile for Culverts located at (i) Km12+875 and (j) Km 13+375

4.0 Conclusion

In this study, hydraulic analyses of selected culverts were carried out using HY-8 Tool. Prior to the analysis, appropriate design flows for each culvert was evaluated using rational method while other site data necessary for the modeling of the culverts were collected in-situ on site. Based on the outcome of this study, the following can be concluded:

The design flow of the selected culvert varied from the minimum values of 0.77m^3/s for culvert located at to a maximum value of 1.55m^3/s for culvert located at Km

Three pipe culverts each of diameter 900mm were found to be inadequate to convey the estimated design flow. This is evident on their surface water profiles with a head water elevation which is above the roadway elevation. To prevent overtopping the road way, larger sizes have been recommended for the pipe culverts and redesigned.

This study has confirmed the efficacy of HY-8 tool in its ability to size and resize culverts during the hydraulic design of road infrastructures and can also be used to address issues relating to inlets control of culverts.

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Corresponding author's e-mail address: gbengailori@unilag.edu.ng