Engineering and Technology Journal e-ISSN: 2456-3358
Volume 08 Issue 02 February-2023, Page No.-1974-1980
DOI: 10.47191/etj/v8i2.02, I.F. – 7.136

Estimating Culvert Capacity to Resist Flood Water

Raymundo V. Romero
Partido State University, Goa, Camarines Sur, Philippines

ABSTRACT: Kulasi is one of the main rivers with catchment areas located in eastern part going down Mt. Isarog. The passage of the river crosses important roads and highways within the lower portion of the mountain, made of culverts and mostly were destroyed during the passage of typhoon Ulysses with international name VAMCO. This study describes a situation of the water course crossing after the extreme typhoon event. It derived hydrologic models that will be used to estimate the capacity of the culvert to handle excessive storm water event and it estimated the capacity of the culverts using the derived models. The evidences of culvert failure in different portions were presented. With known data of precipitation, watershed area, river surface slope and other parameters hydrologic modeling was shown to define the discharge capacity of the culvert pipe line at identified portion of the river. The capacity of the culvert pipe line was then computed using the derived hydrologic models. With the presented table, it expressed the capacity that flood water flow be accommodated in terms of actual precipitation and discharge at certain culvert pipe line. The procedure used on this study may be applied in other portions of the river and in other rivers.

KEYWORDS: Kulasi River, culvert, flood, water discharge, hydrologic model

I. INTRODUCTION

Culverts serve as alternatives bridges to small river widths [1]. They are required to be provided under earth embankment for crossing of water course like streams but are not allowed to obstruct the natural water way since it is needed to balance the flood water on both sides to reduce the flood level on one side of road that thereby decrease the water head [2]. Some rivers have lost their former carrying capacity to accommodate all excess water within its active domain due to over siltation and drainage congestion while other recurrent hydrometeorological phenomenon is intensified by the human activities [3]. As essential elements of a highway system, blockage inside culverts are problems of hydraulics engineers that the computational schemes and hydraulic modelling are created in predicting whether culverts may be blocked or opened by floodwater [4] as blockage on culvert entrances can be a hazard in themselves if not cleared appropriately [5]. Culvert failure can occur for a wide variety of reasons such as maintenance, environmental, and installation related failures, functional or process failures related to capacity and volume, and structural or material failures causing culverts to fail due to materials they made [6]. Another cause of failure is when it has not been adequately sized that flood event can overwhelms the materials so that culverts to function without failure depends on proper design and engineering considerations such as load and water capacities, soil analysis, backfill, bedding compaction and erosion protection [7], [8]. As sedimentation and flood risk can exceed natural levels, these issues can transmit geomorphological and hydrological changes on upstream and downstream portion of the rivers [9]. Poor drainage causes early pavement distresses leading to driving problems and structural failures as well as economic hardship on inhabitants of affected communities with devastating effects [10].

Kulasi River is one of the main rivers with catchment areas located within the eastern part going down the foot of Mt. Isarog [11]. However, the passage of the river crosses important roads and highways within the lower portion of the mountain. The road crossings made of culverts were destroyed during the passage of typhoon Ulysses. Typhoon VAMCO was extremely strong in terms of wind speed and precipitation that creates various destruction on road passages made of culvert in upstream and downstream portion of the river.

ll. OBJECTIVES

A. General Objective

This study was conducted to assess if the culvert pipe lines are suited to accommodate extremely flowing flood waters as used as alternative bridge crossing the river.

B. Specific objectives

Specifically, the purposes of this study are:

1. To describe a situation of the culverts as water course crossing in Kulasi River after an extreme typhoon event.
2. To derive a model that will be used to estimate the capacity of the culvert as water course crossing.
3. To estimate the capacity of the culverts using the derived models.

III. METHODOLOGY

The data was be obtained through site visit, field survey and by visiting suitable websites to acquire the needed satellite feed data. The Geometric Information System (GIS) and Digital Elevation Model (DEM) were used in the analysis of the obtained data. Topographic and field surveying were also used to determine the relationship between distance, slope, and elevation. Since the previews days that the data used on this study were showered with vast amount of precipitation, it was presumed that the surface runoff is in full basis which means that all loses is satisfied and rainfall intensity is continued to be greater than infiltration rate. On this case, portion of rainfall enters the stream immediately after touching the ground [12]. The precipitation data that was announced by the Mines and Geoscience Bureau (MGB) [13] shown in Table 3.1 was utilized on this study.

Table 3.1. The daily and accumulated precipitation during Typhoon Ulysses

Date	**Precipitation**	**Accumulated Precipitation**
November 10	12.2	12.2
November 11	282.00	294.20
November 12	13.30	307.5
November 13	1.4	308.90

A. Culvert line

The important parameters looked being considered are the number of culvert lines that may be provided in the road crossing appropriate to accommodate the extreme river flow. Culvert lines are the drain lines that were provided to allow water flow to pass without affecting the road crossing. The culvert lines are illustrated in the figure.

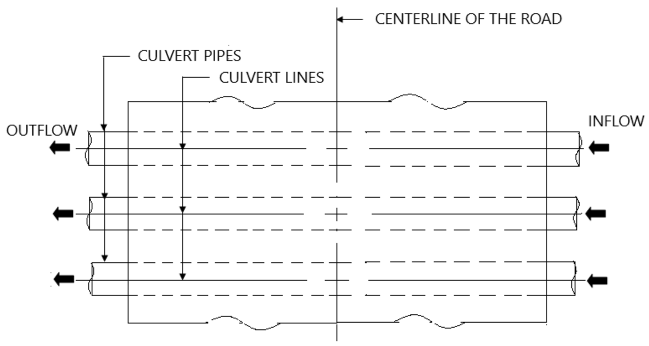

Fig. 3.1. Illustration of the culvert lines

B. Hydrologic model

Hydrologic modeling was used to evaluate the actual stream flow of the river during the extreme weather condition. Hydrological models which are simplified representations of actual hydrological systems allow to study the functioning of watersheds and their responses to various inputs, providing a deeper physical insight into hydrological processes [14] in which hydrologists were able to use indirect method of estimating river discharges by applying channel geometry and hydrological models for estimation of peak discharge due to unavailability of sufficient discharge data for many rivers [15], [16].

C. Manning's Equation

Manning's equation was used to determine the capacity of the culvert lines in accommodating the flood water. The equation below is the equation used to determine the discharge capacity of the single culvert pipe line.

$$Q_m = vA = \frac{1.00}{n} A R^{\frac{2}{3}} S^{\frac{1}{2}}$$

where Q_m is the discharge in m^3/s, n which is the Manning' roughness coefficient on this study is 0.040 for gravel, boulders and cobble, A is the cross-sectional area of the one-meter diameter concrete pipe, which is equivalent to 0.7854 m^2 for one meter diameter concrete pipe, S is the river slope which is equivalent to 2.2% and the hydraulic radius is equivalent to 0.25 m when computed using the equation, with the wetted perimeter value of 3.1416 m when computed using the equation, and r as the radius of the one-meter diameter concrete pipe.

$$R = \frac{A}{P}$$

$$P = 2\pi r$$

In order to settle that the concrete pipe line is sufficient to accommodate the storm water, the equation must satisfy that the capacity of the river to accommodate discharge (Q_m) which is computed through manning's equation must be greater than the actual river discharge (Q_r). Q_r is a hydrologic model which determined on this study. The derived model was used to compute the actual discharge based from the actual precipitation (P_r)

$$Q_m > Q_r$$

IV. RESULT AND DISCUSSION

A. Situation of the culverts after an extreme typhoon event.

Several portions of the Kulasi River were crossed by roads using culverts as the passageway of water. All these culverts were destroyed during the devastation of Typhoon VAMCO (Ulysses). Figure 4.1 shows the location and evidence of devastated culverts on different portions of Kulasi River.

Fig. 4.1. Location and evidences of culverts that were devastated by Typhoon Ulysses

The figure shows that during the extreme typhoon event, most of the culverts that serve as bridge to cross rivers were destroyed. This indicates that the volume of waterflow is at extreme level to be accommodated by the number and sizes of the culverts that cross the river. Although watercourse crossing failure cannot completely be avoided, it can be reduced by careful crossing design that could accommodate water, wood and sediment and eliminate potential failure of the structure [17]. Hence, it is necessary to calculate the sufficiency of the cross-sectional area of the culverts.

Table 4.1. Location and elevation of culverts that were destroyed by Typhoon Ulysses

Culvert Name	Coordinates	Elevation
C-1	13.67767, 123.47428	151.00m
C-2	13.69462, 123.49305	55.00m
C-3	13.69744, 123.49554	52.00
C-4	13.71639, 123.50333	25.00
C-5	13.73431, 123.50346	16.00

Table 4.1 reveals that there are five water course crossings made of culverts that were destroyed by the typhoon at different location and elevation of Kulasi River. Several factors must be satisfied to determine if the culverts are adequate such as estimated peak storm discharge to current and future precipitation conditions at each culvert location and the values can be compared to conservative estimate of culvert capacity [18].

B. The derived model

A mathematical model was derived to estimate the capacity of C-2. The location of C-2 was chosen for it is an important passage of vehicles coming from the bus terminal and the town proper. The first step was done by identifying and measuring the catchment area. It was reminded that it is not just the internal parameters that is important to simulate urban flooding, but also the use of correct inputs from outside the area of study, especially for catchments with a mixture of urban and rural areas [19]. However, catchment classification strategies based on easily available physical characteristics are important for extrapolating hydrologic model parameters and improving hydrologic predictions in ungauged catchments [20]. Figure 4.2 shows the catchment area of C-2.

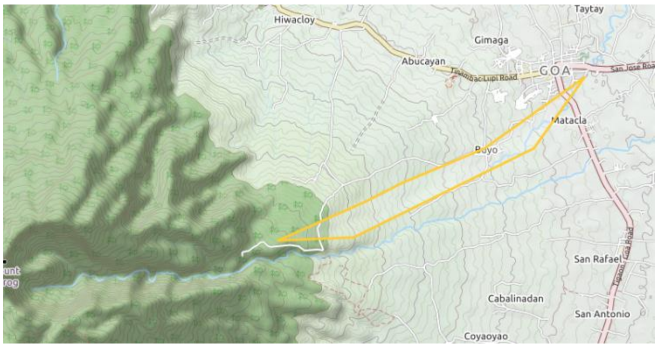

Fig. 4.2. The catchment area of C-2

Using a spatial resolution of satellite images, the catchment area of the river was measured. The derived model was based on the definition of discharge shown below
:

$$Q_r = \frac{V}{t}$$

Where:

Q_r = actual discharge of storm water in m^3/s

V= the volume of the precipitated water in meter (m^3), however considering the catchment area and the amount of precipitation (P_r) in millimeter (mm)

t = time of that precipitation water was accumulated (s)

The equation for volume could be written as:

$$V = A_w P_r$$

with known area of the watershed measured as A_w=3.95km^2, and by applying conversion of units from kilometer (km) to meter (m) and day (D) to seconds (S), the equation could be written as:

$$Q_r = 3.95km^2\left[\frac{1000m}{1km}\right]^2 P_r mm \quad \frac{1m}{1000mm(tD)\left(24\frac{H}{D}\right)\left(60\frac{\min}{H}\right)\left(60\frac{\sec}{\min}\right)}$$

By simplifying the equation, the hydrologic model which can be used for computing the actual discharge of storm water in the river using the actual precipitation data that occurs in the catchment area is:

$$Q_r = 0.046P_r$$

An equation was formed by taking a ratio and proportion between the actual discharge and precipitation compared to the discharge and precipitation that could be accommodated by the culvert pipe line.

$$\frac{Q_r}{P_r} = \frac{Q_m}{P_m}$$

The mathematical model was derived by substituting the previous equation:

$$0.046 = \frac{Q_m}{P_m}$$

or simplified as:

$$P_m = \frac{Q_m}{0.046}$$

The derived mathematical model was used to determine the actual precipitation suited to be accommodated per number of culvert pipe lines.

C. Discharge capacity per culvert pipe line

The discharge capacity (Q_m) of the culvert per line was computed using the Manning’s equation. The result is shown in the Table 4.2, however the derived mathematical model was used to compute the actual precipitation that appropriately be accommodated.

Table 4.2. Discharge Capacity per culvert line

Number of Culvert Pipe lines (x)	Discharge Capacity (Q_m) (m^3/s)	Actual Precipitation (P_m) fitted to be accommodated (mm)
1	1.15	25.00
2	2.30	50.00
3	3.45	75.00
4	4.60	100.00
5	5.75	125.00
6	6.90	150.00
7	8.05	175.00
8	9.20	200.00
9	10.35	225.00
10	11.50	250.00
11	12.65	275.00
12	13.80	300.00
13	14.95	325.00
14	16.10	350.00

The table shows the capacity of discharge that the number of culvert pipe line could accommodate flood water. It is increasing by 1.15 m^3/s for every culvert pipe line that is added in the road crossing. However, with the known . capacity of the first culvert pipe line and with one pipe line represented by N, the capacity of the additional pipe line could be computed by the mathematical model

$$Q_m = \sum_{x=1}^{N} 1.15$$

To determine the amount of precipitation within the capacity of the per number of culvert pipe lines, the mathematical model shown below could be used.

$$P_m = \sum_{x=1}^{N} 25.00$$

The presented models were used to check the results shown in Table 4.3 resulting to similar data. The derived models were also used to check if the culvert pipelines are sufficient to accommodate the flood event brought by typhoon Ulysses using the four days accumulated precipitation data.

Table 4.3. River discharge based from the accumulated precipitation

Number of days	Discharge (m^3/s)	Safe number of pipelines to accommodate the discharge
1	0.562	1
2	13.53	12
3	14.14	13
4	14.20	13

Table 4.3 shows that the first day of storm water accumulation is safe to be accommodated by one (1) culvert pipe line. Two days of storm water accumulation is safe to be accommodated by twelve (12) pipe lines. The third and fourth day of storm water accumulation is safe to be accommodated by thirteen (13) culvert pipe lines. However, all these presumptions are correct unless the floodwater are not mixed with foreign objects like floating debris, plastics and wastes. It is presumed that if the actual number of culvert pipe lines is less than the safe number of pipelines found on this study

could result to overflow of floodwater or destruction of the pipelines within the road crossings. Culvert as the most prevalence means of conveying water from one side of a roadway to another produces burden to be managed and maintained thus there is a need to efficiently design and analyze the quantity of the system [21].

CONCLUSIONS

This study presented evidences of culvert failure in different portions of Kulasi river as remarkable typhoon Ulysses with international name VAMCO affected the area. With known data of precipitation, watershed area, river surface slope and other parameters hydrologic modeling was conducted to define the discharge capacity of the culvert pipe line that was constructed at identified portion of the river. The capacity of the culvert pipe line was then computed using the derived hydrologic models. With the presented table, it expressed the capacity to accommodate flood water flow in terms of actual precipitation and discharge at certain culvert pipe line. The procedure used on may be applied in other portions of the river and in other rivers.

ACKNOWLEDGEMENT

We would like to acknowledge the support extended to the researchers by the PSU administration through the leadership of President Dr. Raul G. Bradecina, Vice President for Research and Extension Patricia Candelaria and Research Director Luisa Lanciso specially when it comes to financial and moral obligation

REFERENCES

1. Mohiuddin Ali Khan, (2015), Modular bridge construction issues, Accelerated Bridge Construction, 2015, 215-256
2. Neha Kolate, Molly Mathew and Snehal Mali, (2014), Analysis and Design of RCC Box Culvert, International Journal of Scientific & Engineering Research, 5(12), 36-41
3. Sandipan Ghosh & Biswaranjan Mistri, (2015), Geographic concerns on flood climate and flood hydrology in monsoon-dominated Damodar River Basin, Eastern India, Geography Journal, vol. 2015
4. M. Kamaka, E. Cheng, M. Teng & C. Matsuda, Analytical and hydraulic model study of highway culvert sand blockages (2007), WIT Transactions on Modelling and Simulation, 36
5. G. Streftaris, N. P. Wallerstein; G. J. Gibson; and S. Arthur, (2013), Modeling Probability of Blockage at Culvert Trash Screens Using Bayesian Approach, Journal of Hydraulic Engineering, 139(7)
6. Chandresh H. Solanki, Jigjisha M. Vashi & Atul K. Desai, Analysis of geotextile reinforced embankment on difficult subsoil condition, (2013), International Journal of Scientific and Engineering Research, 4(5)
7. Azman Kassim, Danial Jahed Armaghani & Koohyar Fazi, (2013), Evaluation of geotextiles on embankment displacement under seismic load, Computers and Geotechnics, 47, 16-27
8. R.K. Rowe & K.L. Soderman (2009), An approximate method for estimating the stability of geotextile-reinforced embankments, Computers and Geotechnics, 33, 153-163
9. J.C. Olson, A.M. Marcarelli, A.L. Timm, S.L. Eggert & R.K. Kolka, (2017), Evaluating the effects of culvert designs on ecosystem processes in Northern Winconsin streams, River Research and Applications, 33, 777-787
10. Michael T. Tiza, Vitalis T. Iorver & Enoch T. Iortyom, (2016), The effect of poor drainage system on road pavement: A review, International Journal for Innovative Research in Multidisciplinary Field, 2(8), 218-225
11. Raymundo V. Romero, Fe B. Romero, Nelson V. Romero, Marijane A. Iglesia, Moriel L. Prado & Alicia Pempena, Hydrologic input-output model of Mt. Isarog watersheds, Asia Pacific Journal of Multidisciplinary Research, 7(4), 27-35
12. A Balasubramanian, (2017), Surface water runoff, Technical Report,
13. Mines and Geoscience Bureau, Landslide Bulletin No. 3 for Typhoon Ulyses, DENR, Region 5, November 11, 2020
14. Chih-Chieh Young & Wen-Cheng Liu, (2015), Prediction and modelling of rainfall–runoff during typhoon eventsusing a physically-based and artificial neural network hybrid model, Hydrological Sciences Journal, 60(12), 2102-2116
15. Raymundo V. Romero, Marijane A. Iglesia, Alice Pempena, Nelson V. Romero and Fe B. Romero, Estimating the channel cross section runoff overflow using fuzzy rule-based system: A hydrologic analysis of Mt. Isarog watershed, Journal of Soft Computing in Civil Engineering, 3-3(2019), 37-46
16. Roy S, Mistri B. (2013), Estimation of Peak Flood Discharge for an Ungauged River: A Case Study of the Kunur River, West Bengal. Geography Journal, 1–11
17. Peter Cafferatta, Thomas Spittler, Michael Wopat, Greg Bundros & Sam Flanagan, (2004), Designing watercourse crossings for passage of 100-year flood flows, wood and sediment. California Forestry Report No. 1, State of California, Department of Forestry and Fire Protection.

18. Allison M. Truhlar & Rebecca D. Marjerison, (2020), Journal of Sustainable Water in the Built Environment, 6(2)
19. Dapeng Yu and Tom J. Coulthard (2015), Evaluating the importance of catchment hydrological parameters for urban surface water flood modelling using a simple hydro-inundation model, Journal of Hydrology, 524, 385-400
20. Yi Jin, Jintao Liu, Lu Lin, Aihua Wang and Xi Chen (2018), Exploring hydrologically similar catchments in terms of the physical characteristics of upstream regions, Hydrology Research, 49(5), 1467-1483
21. Ashton D. Greer, Zachary B. Wilbanks, Leah D. Clifton, Bradford Wilson and Andrew J. Graettinger, (2018), GIS-enabled culvert design: a case study in Tuscaloosa, Alabama, Advances in Civil Engineering, 1-10