Flood Damaged Bridges in Papua New Guinea

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1. INTRODUCTION

The climatic effects against the road infrastructure such as a bridge, are so prevalent that it requires deeper engineering and technological intervention to address these ever-present phenomena. Papua New Guinea has been experiencing frequent bridge failures and collapses due to flooding rivers in the recent past. According to the records from Papua New Guinea Department of Works, it has shown that over Two Hundred and Eighty (280) bridges, fords (causeways) and major culverts were damaged by flood action alone in the last Five years.

Richard Davies, a News Reporter for Floodlist Asia, published on 16th October 2016, that Papua New Guinea is vulnerable to both inland and coastal flooding. The country has suffered from severe coastal flooding in 2008 as many as 75,000 people were displaced from eight (8) different provinces. In 2016, around 10,000 people were affected by flooding in West New Britain Province with thirty-five (35) houses, bridges, roads and agricultural farms were damaged across both provinces of Gulf and Southern Highlands.

Therefore, this study is so eminent to address the problem of flood-damaged bridges. Most of these damaged bridges have not been maintained and are still waiting for funding from the government since they were damaged. The cost of reconstruction is very high and with economic crisis faced in the country due to a decrease in the world market prices, this is now a dilemma for poor local people.

2. FIELD INVESTIGATION WORKS

Field investigations were carried out in Papua New Guinea at twenty-one (21) flood-damaged and affected bridge sites. The bridges that were investigated were all constructed over natural river crossings in three distinctive provinces in the country. These bridges are part of six (6) major road networks in the country that support the socio-economic development. The investigations were undertaken in Madang, Morobe and New Ireland Provinces along Wau Highway, Highlands Highway, Ramu Highway, Boluminski Highway, West Coast Road and Lanzarote Road in Papua New Guinea.

The field investigation works gathered field data such as, river channel width, bridge dimensions, river cross-sections, flow depth, scour depth, flow angle, clearance height (freeboard), debris and log sizes. Inspections were carried out on superstructure and damages the floods have caused on the bridge. These bridges have fallen victim to flooding having major structural damages while several bridges were destroyed by flood as discussed in the following chapters.

3. RESULTS AND DISCUSSION

Scouring of bridge abutments and piers, flood debris and log impact and embankment erosions were observed to be the main leading cause of bridge damages as summarised in Figure 2. All rivers have natural banks with no bank revetment or scour protection measures. These bridges were constructed for accessibility convenience; hence no adequate investigation works were undertaken. This was proved with no design record.

3.1 Flood Estimation

The Papua New Guinea Flood Estimation Manual (SMEC, 1990) provides a standard guideline for the estimation of floods in Papua New Guinea. This manual is intended for general use in the planning and design of small to medium-sized engineering works for the planning and design of bridges, culverts, small dams, drainage works and flood mitigation works in the country.

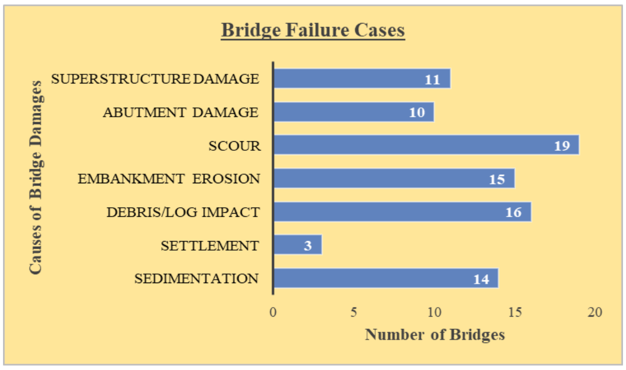

Figure 2 Summary of Bridge Failure Cases

Therefore, it is important that the flood estimation methods of this manual were used for design flood discharges in which Regional Flood Frequency Method (RFFM) was used for flood estimation using Eq. (1), Eq. (2) and Eq. (3). The results of the flood assessments are as presented in Figure 3.

$$Q_2 = 0.028 * AREA^{0.70} * P_2^{1.12} * KS \quad (1)$$

$$Q_{20} = Q_2 + 0.62(Q_{100} - Q_2) \quad (2)$$

$$Q_{100} = 0.059 * AREA^{0.65} * P_2^{1.12} * SLOPE^{0.11} * KS \quad (3)$$

Q_2 is the two-year return period or the base flood, Q_{20} is the twenty-year return period and Q_{100} is the one-hundred-year return period which is known as Annual Recurrence Intervals (ARI) or return periods. The AREA represents the area of the catchment size in km^2, P_2 is the two-year daily rainfall data taken from flood estimation manual, the SLOPE is the mean slope of the river channel and KS is the swamp adjustment factor of the main catchment and 0.62 is the regression factor for Q_{20} return period.

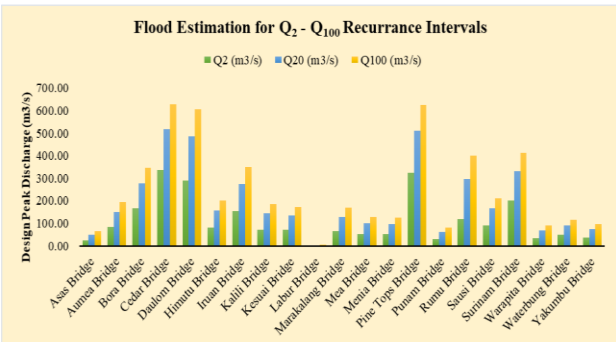

Figure 3 Flood Estimation for Q_2, Q_{20} and Q_{100} ARI

3.2 Scour Estimation

Many researchers have undertaken considerable studies providing design guidelines, procedures and methods of scour at bridge piers and abutments. In this study, FHWA Scour Estimation method for General Scour and CSU method for Local Scour were used for scour estimation as given in Eq. (4), (5) and Total Scour in Eq. (6).

$$\frac{y_u + d_g}{y_u} = \left(\frac{W_U}{W_B}\right)^{k_1} \quad (4)$$

$$d_l = y_u . 2.0 k_1 k_2 k_3 k_4 \left(\frac{W_p}{y_u}\right)^{0.65} Fr^{0.43} \qquad (5)$$

$$d_t = d_g + d_l \qquad (6)$$

The d_g is the general scour depth, d_l is the local scour depth, d_t is the total scour depth, y_u is the upstream flow depth, W_U is upstream main channel width, W_B is the constriction channel width at bridge location, W_p is the pier width, F_r is the Froude Number which is a function of gravitational acceleration (9.8 m/s), flow velocity (U) and flow depth. The $k_1 – k_4$ are correction coefficient factors for pier nose shape factor (k_1), angle of incidence flow factor with respect to pier axis (k_2), the correction factor for bed conditions (k_3) and (k_4) which is the correction factor for armoring effects. Using these equations and the field measurements the total scour depths were calculated for each bridge as analyzed in Figure 4 below.

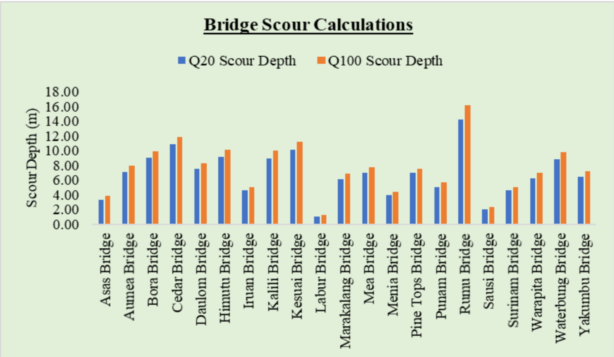

Figure 4 Total Scour Depth Calculation of Q_{20} and Q_{100}

3.3 Hydrodynamic Loads

Bed aggradation due to high sediment deposition reducing high water level clearance (freeboard) created an opportunity for log and debris impact in flood event which damaged Aumea Bridge, Asas Bridge, Kesuai Bridge, Surinam Bridge, Waterbung Bridge, Punam Bridge and Wara Pita Bridge. Huge logs were observed to be part of the flood debris generated from heavy logging, subsistence farming, landslide and plantation agricultural activities along the coast.

The hydrodynamic flow pressure (P) was calculated using the AASHTO formula while Drag Force (F_d) and Lift Force (F_L) were analyzed using the Australian Bridge Standard AS5100 specified Eq. (7), (8) and Eq. (9) as given below respectively.

$$P = 0.51KU^2 \qquad (7)$$

$$F_{du} = 0.5C_d V_u^2 A_d \qquad (8)$$

$$F_{Lu} = 0.5C_L V_u^2 A_L \qquad (9)$$

K is the pier shape adjustment factor, U is the flow velocity, C_d is the drag force coefficient, C_L is the lift force coefficient, V_u is upstream flow velocity, A_d and A_L are projected areas of the pier with respect to the flow angle.

The results in Figure 5 shows that as the flow velocity increased, the magnitude of hydrodynamic loads was increased. The projected area and angle of incidence and pier or abutment shapes and sizes contributed to high impact forces. Therefore, it is very important to undertake accurate assessments of the hydrodynamic loads during the design stage of the bridge. As presented in Figure 2, debris and log impacts accounted for a lot of bridge superstructure damages and even causing bridge failures. Hence, more research is required to improve the debris and log impact forces on bridges constructed over natural river crossings.

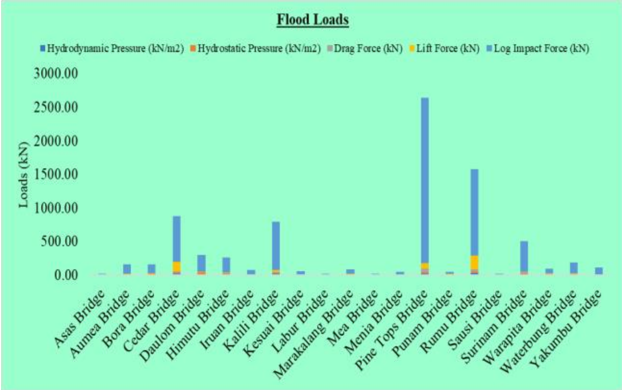

Figure 5 Flood Loads in Ultimate Limit State

4. CONCLUSION

According to Figures 2 and 4, it has proved that scouring is a major cause to bridge failures in Papua New Guinea. Therefore, as a flood-resistant measure against scouring, this research has proposed Eq. (10) for use in bridge design, where Z_d is the designed bed elevation, Z_0 is the natural bed elevation, d_t is the total scour depth and 1.0m is the conservative depth as a scour countermeasure.

$$Z_d = (Z_0 - d_t) - 1.0m \qquad (10)$$

The second most cause of bridge failure in this study is flood debris and log impact. Hence, as design countermeasure, Eq. (11) is recommended to use for estimating flood levels and determining bridge superstructure elevations.

$$F_b = 0.5H_{100} + 1.0m \qquad (11)$$

Where F_b is the freeboard, H_{100} is the flow depth at the 100-year flood and 1.0m is the safety margin for bridges prone to flood debris or log impact. Bridges built over rivers require multi-disciplinary inputs, and it is often advisable for the bridge engineer to involve hydraulics engineer, environmentalist and geotechnical engineer at planning and design stage.

The selection, location, and design of countermeasures are dependent on hydraulic and geomorphic factors that contribute to stream instability, as well as costs and construction and maintenance considerations. One of the countermeasures to be incorporated at the planning and design stage is the use of Eq. (12).

$$L = W + (F_p) + 12.0m \qquad (12)$$

Where L is the required bridge length, W is the river channel width from bank to bank, F_p is the floodplain width parallel to the bridge along the road alignment and 12.0m is the safety margin for bridges estimated to experience overtopping in a 100-year flood. If the bridge is not located in a floodplain then the designer can neglect the floodplain width.

REFERENCES

1. Australian Bridge Design Standard AS5100, Standards Australia International Ltd, Sydney, Australia, (2004).
2. Scottish Design Manual for Roads and Bridges, The Design of Highway Bridges for Hydraulic Action, Volume 1, Section 3, Part 6, (1994).
3. U.S DOT FHWA, Evaluating Scour at Bridges, 5th Edition, (2012), Washington DC, USA.
4. U.S DOT FHWA, Hydraulic Design of Bridges, (2012), Washington DC, USA.
5. US DOT FHWA, Bridge Scour and Stream Instability Countermeasures, Volume 1 and 2, HEC-23, (2009), Washington DC, USA.