

## Flood Risk Analysis of Bridge – A Case Study

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**Abstract:** Depth of flowing water and its velocity through the bridge are critical design parameters for analyzing hydrodynamic load on bridges. Digital Elevation Model is suitable approach to extract cross section profile and elevation data of river and this was used to synthesize the river profile in the present study. Fourteen different profiles for two kilo-meter length of river were considered. HEC-RAS, one dimensional hydraulic model was used to perform hydraulic analysis of river channels. The result of this research shows that bridge is situated at the location of critical flow where velocity is maximum as compare to other profiles of the river. However, depth of water covers only one sixth of height of bridge pier. Also, present study provides the brief procedure to study flood risk on existing and proposed bridges that can be estimated and analyzed accordingly.

**Keywords:** HEC-RAS, flow characteristic, hydrodynamic pressure, bridge

### 1. Introduction

Bridges are the essential links in the transport network in Muscat, Oman, due to its irregularity in topography. Some bridges are at risk to damage by flash flood during aggressive rain-fall conditions [1]. To avoid interruption of the transport network, the adequate performance of the bridges has to be assured by undertaking necessary actions. It is important that such necessary actions are only undertaken on those bridges which actually under high risk of collapse due to flash flood. The meteorological data of last three decade shows that Oman is one of several countries located in an arid zone that is subject to flash flooding. [1] Stated that major flash floods occurred in Oman in 1989, 1997, 2002, 2003, 2005, and 2007. Wadi Adai – Amerat Bridge is situated in Wadi Adai River in Muscat. In order to obtained risk on bridge, river flow analysis needs to be conducted to determine flow characteristics.

River profile can be extracted from Digital Elevation Model (DEM) which is integrated with Google Earth. [2] Stated that it has been integrated with a micro scale meteorological model to improve the system's functionality and ease of use. Almost all the components of the model system, including the terrain data processing, meteorological data gathering and initialization, and displaying/visualizing the model results, have been improved by using this approach.

For river flow analysis, one dimensional computational model in river analysis system, HEC-RAS, developed by hydrologic engineering centre of the US army crops of engineer (UASCE) can be used. It can perform computation of various flow characteristic. [3] Compared laboratory and HEC-RAS simulation of a single step weir and found that it can capture the overall features of the flow profile over the weir with reasonable accuracy. [4], [5] and [6] used HEC-RAS for estimating flow characteristic of river and found it's suitability for river flow analysis.

In the present study, the one dimensional steady flow module of HEC-RAS was used to develop water surface profile, type of flow, depth of water and velocity to evaluate flood risk on bridge. ASCE7-10 [7], FEMA P-85 [8] and ICE (Institute of Civil Engineers) manual for bridge engineering [9] was used to predict flood load on bridge.

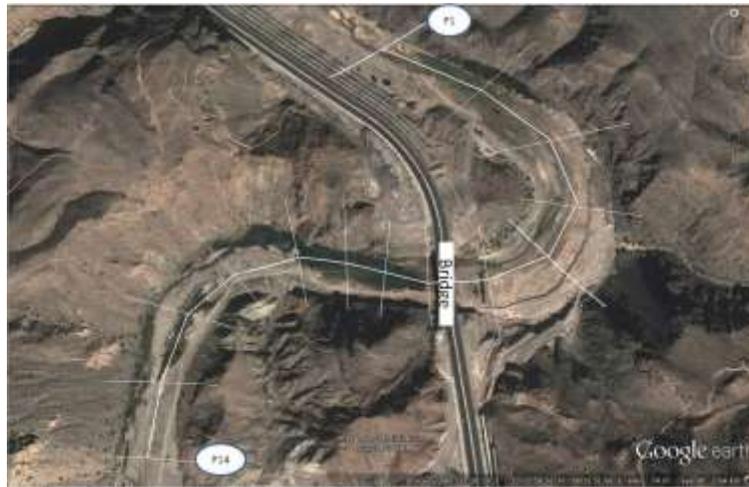


Fig. 1: Location of Wadi Adai - Amerat Bridge, Muscat [10].

## 2. Study Area

Wadi Adai – Amerat Bridge is located in Muscat, Oman and it was selected as the study area for this research. Wadi Adai River is a stream that flows from south through the mountains an upstream tributary to north of Muscat as shown in Figure 1. This bridge has significant role to connect two major area of Muscat, for this reason it has great importance and necessary to find out flood risk on this bridge.

TABLE I: Elevation of different profiles (P1 to P14)

Profile Distance	Elevation in meter for different profiles													
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14
0	50	65	66	59	59	67	89	96	110	108	101	88	75	79
25	48.5	62	63	56	56	62	78.2	89.8	101	98	84	79	66	70
50	46.5	58	59	51	52	58	66.5	79	93	88	72	71	61.5	61.9
75	45	55	56	48	50	51.9	59.8	68	82	77	61	63	58.5	59.9
100	44	54	53	46	48	50.5	58.5	58	72	69	54	59.5	55.1	57.9
125	45.5	52	52	51	47	49.9	56.8	59.9	59	62	53	56	57.9	58
150	48.5	53	53	56	48	49	60	61	58	54.5	54.5	54.5	59.2	60
175	53	60	60	68	49	51	65	64	60	54	57	57	62.2	62
200	60	72	70	76	52	53.9	70	74	62	57	60	59.8	69	68.5
225	67.5	85	90	86	57	58	78	87	70	60	66	64.5	75.5	73
250	77.2	100	114	95	67	64	82	97	79.8	67	71	70.2	81.8	78

Terrain profiles were composed from DEM which are integrated with Google earth. Fourteen profiles across the river were considered for the study. Numbering of river profiles (P1 to P14) is started from downstream to upstream side as per the requirement of HEC-RAS hydraulic model. River profile elevations are given in Table 1. Existing bridge is constructed near to profile P7, i.e. flow data at profile P7 has been used to estimate flood loads on bridge.

### 2.1. Details of Wadi Adai – Amerat Bridge

A simply supported multi-span I-Girder bridge with reinforced concrete hexagonal pier comprised of four lanes. Details of the bridge required to analyze for hydrodynamics load are:

Span length of the I-Girder = 30000 mm

Total number of spans = 6 Number

Cross-section dimension of bridge pier = 5540 mm (perpendicular to the direction of flow)

Area of the pier per meter length (for hydrodynamic loads) = 5540 mm<sup>2</sup>

Total height of bridge pier from pile cap = 48168 mm

Details of longitudinal section, section elevation and cross section of bridge pier are given in Figure 2.

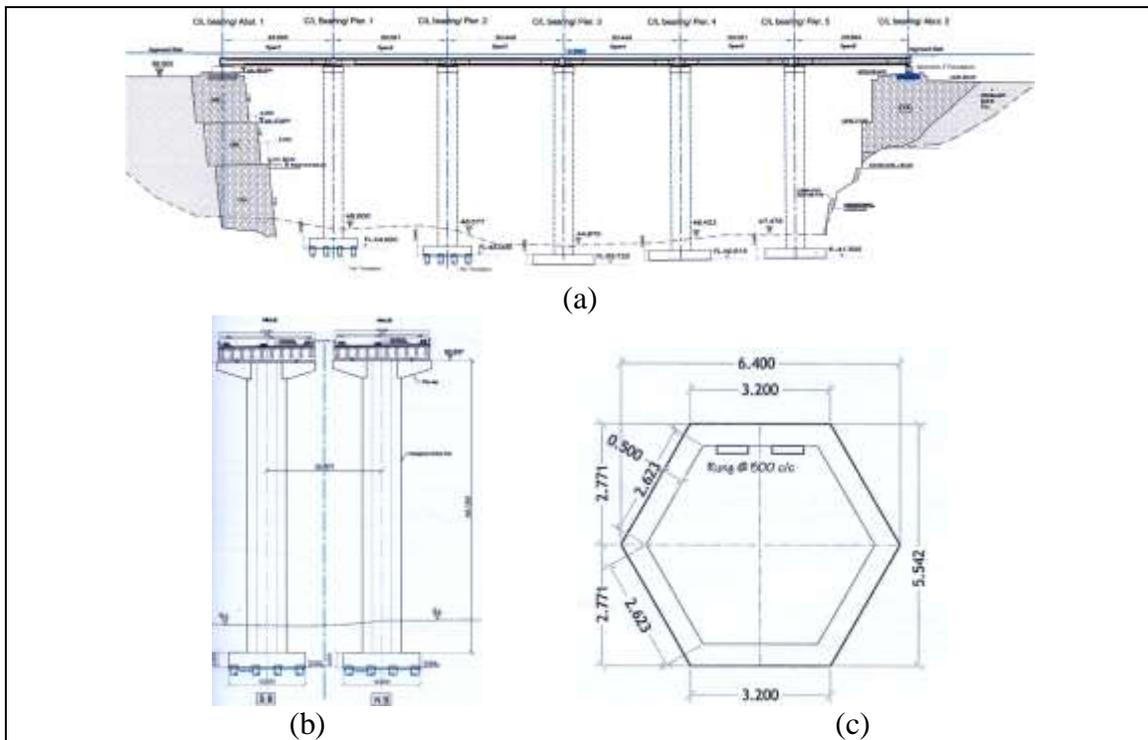


Fig. 2: Schematic diagram of Wadi Adai - Amerat Bridge a) Longitudinal section, b) Elevation detail and c) cross section detail of pier

### 3. HEC-RAS parameters

HEC-RAS requires a number of input parameters for hydraulic analysis of the stream channel geometry and water flow. These parameters are used to establish a series of cross-sections along the stream. In each cross-section, the locations of the stream banks are identified and used to divide into segments of left floodway channel, and right floodway channel (Figure 3). HEC-RAS subdivides the cross-sections in this manner, because of differences in hydraulic parameters. Thus, friction forces between the water and channel bed have a greater influence in flow resistance in the floodway, leading to lower values of the Manning's coefficient. As a result, the flow velocity and conveyance are substantially higher in the main channel than in the floodway. At each cross-section, HEC-RAS uses several input parameters to describe shape, elevation, and relative location along the stream.

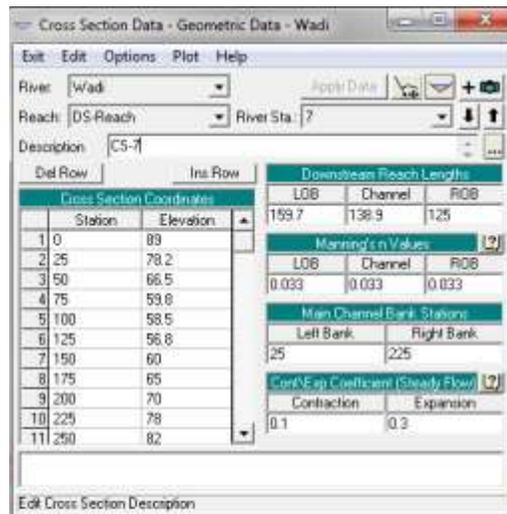


Fig. 3: Geometric data in HEC-RAS for profile P7.

Following parameters are required to analyze the river in HEC-RAS hydraulic model, suggested by [3].

- River station (cross-section) number.
- Lateral and elevation coordinates for each dry terrain point.
- Left and right bank station locations.
- Reach lengths between the left floodway, stream centerline, and right floodway of adjacent cross-sections.
- Manning’s roughness coefficients.
- River contraction and expansion coefficients.
- Geometric description of any hydraulic structures.

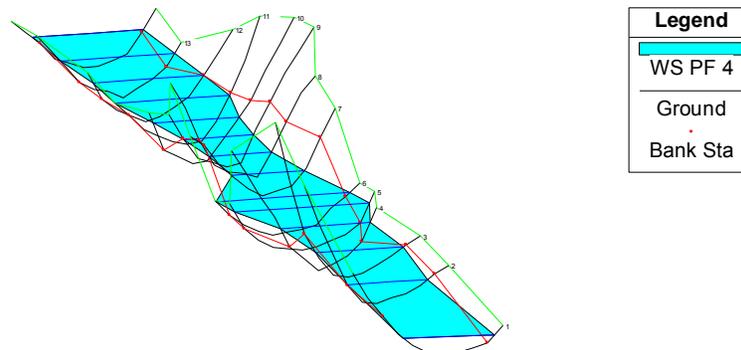


Fig. 4: HEC-RAS x-y-z view of river profile and flood flow.

HEC-RAS assumes that the energy head is constant across the cross-section and the velocity vector is perpendicular to the cross-section (i.e., quasi one-dimensional flow on a two dimensional domain). As such, care should be taken that the flow through each selected cross section meets these criteria. After defining the stream geometry, flow values for each reach within the river system are entered. The channel geometric description and flow rate values are the primary model inputs for the hydraulic computations. Figure 4 shows x-y-z view of river profile and water flow.

### 3.1. Manning’s, contraction and expansion coefficient

Manning’s, contraction and expansion coefficient was assumed based on vegetation and soil roughness available in Wadi Adai River. Following values have been considered for these coefficients:

Manning’s coefficient = 0.033

Contraction coefficient = 0.1

Expansion coefficient = 0.3

TABLE II: Flow results for various profiles of Wadi Adai River

River station	Minimum ground elevation (m)	Water surface elevation (m)	Critical water surface (m)	Energy grade elevation (m)	Energy grade slope (m/m)	Flow velocity (m/sec)	Flow area (m <sup>2</sup> )	Top width (m)	Froude number
14	57.9	71.04	--	71.47	0.000454	2.92	1727.01	191.97	0.3
13	55.1	71.02	--	71.38	0.000312	2.73	1923.02	196.69	0.26
12	54.5	71	--	71.32	0.00027	2.49	2037.45	190.5	0.24
11	53	71.01	--	71.27	0.000187	2.23	2278.74	197.76	0.2
10	54	70.71	--	71.2	0.000407	3.13	1639.14	148.2	0.29
9	58	69.65	--	71.03	0.001904	5.2	961.74	119.39	0.58
8	58	67.55	67.55	70.58	0.00612	7.71	648.47	107.75	1
7	56.8	65.6	65.6	68.34	0.006205	7.34	680.99	124.63	1
6	49	63.58	--	63.86	0.00026	2.34	2182.48	231.16	0.23
5	47	63.64	--	63.81	0.000118	1.84	2781.58	232.52	0.16
4	46	63.3	--	63.76	0.000334	3.02	1719.93	154.26	0.27
3	52	62.23	--	63.55	0.002384	5.11	979.34	150.72	0.64
2	52	60.12	60.12	62.69	0.006374	7.11	703.37	138.46	1.01
1	44	51.42	51.42	53.85	0.006072	6.93	730.38	152.47	0.98

## 4. River flow analysis

The procedure of river flow analysis was followed by [11]. The primary procedure called direct step method had used for computing water surface profiles between cross-sections for steady and gradually varied flow. Iterative solution of the energy equation was used for basic computational procedure. Given the flow and water surface elevation at one cross-section, the goal of the standard step method is to compute the water surface elevation at the adjacent cross-section. For subcritical flow, the computations begin at the downstream boundary and proceed upstream; for supercritical flow, the computations begin at the upstream boundary and proceed downstream. At the boundary, the flow and water surface elevation must be known.

Flow results for various profiles of Wadi Adai River are given in Table 2. Flow properties for profile P7 (Figure 5) were critically evaluated and these properties were used to analyze the bridge.

## 5. Hydrodynamic loads on bridge

ICE manual for bridge engineering [9] discusses the procedure of hydrodynamic load on bridge. It is stated that even under normal conditions, flood waters exert forces many times. Some times the waters top the bridge (negative freeboard) and both the deck and piers are subject to the full force of water and debris. Estimation of the forces involved is complex and unreliable (for example estimating the speed and height of the flood waters), and most countries have their own procedures in place which take into account local topography and experience from previous floods. However, depth of water at profile P7 shows only one sixth of height the pier. Whereas, type of flow is found to be critical at this profile.

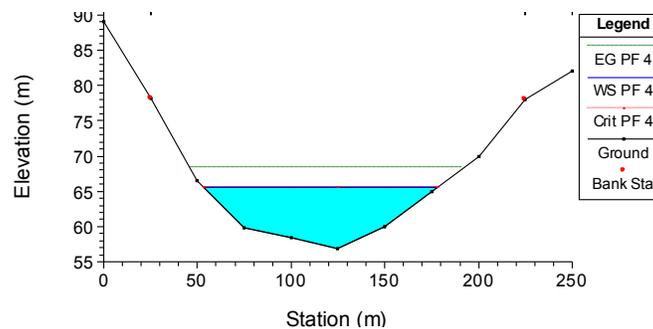


Fig. 5: Flood level at profile P7

According to ICE manual for bridge engineering [9], rivers in flood represent a serious threat to bridges both from the point of view of lateral forces on the abutments, piers and superstructures and the possible undermining of the foundations due to the scouring effect of the water. ASCE7-10 [7] suggests the hydrodynamic forces can be calculated in a similar manner to those due to wind. The hydrodynamic load is calculated by converting it to an equivalent hydrostatic load by increasing the flood depth. The increase in flood depth is referred to as  $d_h$ .

$$d_h = \frac{C_d V^2}{2g} \quad (1)$$

Bridge piers are designed to resist lateral forces from water in normal flow conditions. The forces induced are calculated using the same formulae as for moving air, but with the density of air replaced by that for water. Hydrodynamic pressure as per FEMA P-85 [8] is:

$$p_{hydr} = \gamma \times d_h \quad (2)$$

The total hydrodynamic load ( $F_{hydr}$ ) taken into consideration, the hydrodynamic load is:

$$F_{hydr} = p_{hydr} \times H \times D \quad (3)$$

where  $C_d$  is drag coefficient,  $V$  is the velocity of flow in m/sec,  $g$  is acceleration due to gravity  $m/sec^2$ ,  $\gamma$  is density of water is taken as  $1000 N/m^3$ ,  $H$  is the depth of water in meter, and  $D$  is horizontal dimension of pier in meter:

Selection of the correct value of a drag coefficient (shape factor) will depend upon the shape and roughness of the object exposed to flood flow, as well as the flow condition [7]. As a general rule, the smoother and more streamlined the object, the lower the drag coefficient. Drag coefficients for elements common in buildings and structures (round or square piles, columns, and rectangular shapes) will range from approximately 1.0 to 2.0, depending upon flow conditions. However, given the uncertainty surrounding flow conditions at a particular site, [7] recommends a minimum value of 1.25 be used.

### 5.1. Flood load on bridge pier

Flood velocity and its depth were computed from the HEC-RAS hydraulic model for the maximum discharge of 5000 m<sup>3</sup>/sec. It is found that maximum velocity of flow (V) was 7.34 m/sec and maximum depth of water (H) was 8.8 m due to the maximum discharge. According to ASCE7-10, flood load on the bridge pier was found to be 200 kN. Also, flood loads were calculated for different values of shape factor for the same size of pier. It is found that flood load on the bridge pier varying from 134 to 270 kN for the shape factors varying from 1 to 2 respectively as shown in Figure 6.

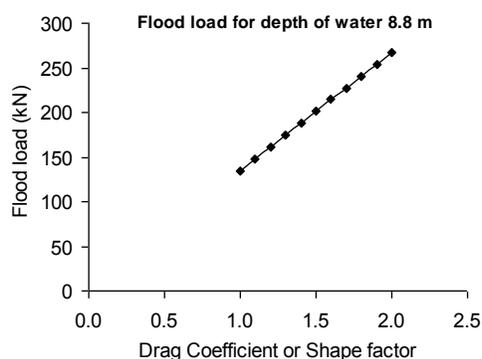


Fig. 6: Flood load on bridge pier for different shape-factors of pier

## 6. Conclusion

This study provides flood risk analysis on Wadi Adai - Amerat Bridge, Muscat, Oman. Digital Elevation Model integrated with Google earth was used to extract river profile data. It is found from the HEC-RAS hydraulic model, for the maximum discharge, flow is critical at the location of bridge pier. Whereas, analysis results for other profile shows behaviour of flow is subcritical. Although, flow is critical at the location of bridge, depth of water is one sixth of height of pier. The procedure adopted for the estimation of flood risk on bridge will be useful to estimate hydrodynamics load on existing or proposed bridge particularly in the arid zone that is subjected to flash flood. Further, it is found that behaviour of hydrodynamic load on pier is linear due to change in drag coefficient between 1 and 2 and values increases from 134 to 270 kN.

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