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Geomorphic Channel Design and Analysis Using HEC-RAS Hydraulic Design Functions

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ABSTRACT

This paper presents a preliminary design for physical enhancement of the reach of the Tapi River located near the confluence of Arabian Sea and the Tapi River in Surat City, Gujarat. In this paper designing of stable channel has been done using the Copeland method which has been included in the Army Corps of Engineers Hydraulic Engineering Center River Analysis System (HEC-RAS). This method requires the bottom width, depth, and side slopes of a representative cross-section from a stable, upstream reach as input. A flood in river Tapi affects Surat city and surrounding regions.

KEYWORDS: HEC-RAS Hydrodynamic model; Flood Event; Tapi River Gujarat

Introduction

Flood forecasting and inundation mapping has become easier due to advance computing facilities. In flood warning discharge and stage are used for flood warnings. The discharge, stage and hydraulic properties are interrelated and depend upon the characteristics of channel roughness. Channel roughness is a highly variable parameter which depends upon number of factors such as surface roughness, vegetation, channel irregularities, channel alignment, channel slope etc.

Tapi, one of the largest west-flowing rivers of India, is 724 km long and having its origin in Madhya Pradesh. It then flows through Maharashtra, Gujarat and ultimately meets the Arabian Sea in the Gulf of Cambay which is approximately 20 km west of Surat. In the last reach, at downstream of Ukai, the river enters the flat and fertile land of Gujarat. The Tapi River receives several tributaries on both the banks and there are 14 major tributaries having length more than 50 km. On the right bank, 4 tributaries namely Vaki, Gomai, Arunavati and Aner join the Tapi River. On the left bank, 10 important tributaries namely the Nesu, Amaravati, Buray, Panjhra, Bori, Girna, Waghur, Purna, Mona and Sipna drain into the main river channel. The drainage system on the left bank of the Tapi river is, therefore, more extensive as compared to the right bank area. The Purna and Girna, the two important left bank tributaries, together account for nearly 45 % of the total catchment area of the Tapi River.

The Sardar Bridge to Magdalla Bridge area is taken for study purpose. This paper begins with studying of existing channel cross-sections and then attempt has been made to identify various problems in existing system. As already mentioned, a flood is high flow in river with a high stage when water usually overflows from the banks, it inundates the adjoining areas and spreads over the flood plains and many cause havoc and loss of life and property. In the present paper using past flood data, carrying capacity of river sections along which water enters in the city and remedial measures in the form of raising bank on either side of bank by constructing retaining wall or embankment bund are studied using HEC-RAS software.

The enhancement study reach is shown in Fig.16 It is located between Sardar bridge and Magdalla bridge, and is approximately 11km long with 49 cross sections (Fig. 16).

The Surat city, being coastal city, had been seen susceptible to major floods and undergone with huge damage in the past. The river reach selected for this study is extremely important as on the either side of the bank, 80% of total populations are settled. Major businesses Centre for diamond, one of the world's raw diamond processing industry and India's largest textile industry are within 1km radius of the study reach. Not only that the major industrial Hazira area is at the downstream of the study reach which is directly affected by carrying out any change in river morphology

Objectives

The objective of thesis is to analyze the stability of a segment of lower Tapi river reach between Sardar bridge and Magdalla bridge by evaluating its capacity and stability in response to discharge and sediments.

HEC-RAS software

Originally designed in 1995, the United States Army Corps of Engineers Hydrologic Engineering Centers River Analysis System (HEC-RAS) is "software that allows you to perform one-dimensional steady and unsteady flow river hydraulics calculations, sediment transport-mobile bed modelling, and water temperature analysis."

Model Input Parameters

HEC-RAS uses 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 (overbank), main channel, and right floodway (overbank). HEC-RAS subdivides the cross sections in this manner, because of differences in hydraulic parameters.

At each cross-section, HEC-RAS uses several input parameters to describe shape, elevation, and relative location along the stream:

- River station (cross-section) number
- Lateral and elevation coordinates for each (dry, un flooded) terrain point
- Left and right bank station locations

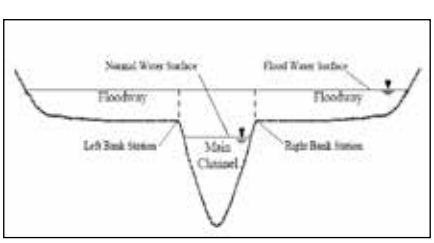


Figure 1- Schematic daigram of stream channel

- Reach lengths between the left floodway, stream centerline, and right floodway of adjacent cross-sections (The three reach lengths represent the average flow path through each segment of the cross-section pair. As such, the three reach lengths between adjacent cross-sections may differ in magnitude due to bends in the stream.)
- Manning's roughness coefficients (may vary horizontally or vertically)
- Channel contraction and expansion coefficient.

Geometric Data

Surat Municipal Corporation (SMC) has provided the geometric data of the reach for present study as contour map in Auto CAD (.dwg file) format. The cross-section data at different locations were extracted from aforesaid map for the river under consideration. The study reach is about 1080m long and has very mild slope. The effect of meandering has been neglected as there is no reasonable curvature seen in study reach by providing expansion and contraction coefficient as 0.3 and 0.1 respectively. Total 49 cross-sections at various important locations on the river have been used. The detailed configuration of study reach was respectively collected from Surat Municipal Corporation (SMC) and Surat Irrigation Circle (SIC), Govt. of Gujarat, India in the hard map format.

Cross-section Profile

The cross section of a natural channel depends on basin run off, sediment input, and boundary soil and vegetation. Usually the average cross section a channel does not change under natural conditions over a period of years. Most of the alluvial stream channels are found to be relatively wide and shallow. If the channel is deep and narrow, the banks become unstable due to higher velocities and the consequent higher shear stresses along the sides. The material that is eroded from the sides drops on the bed and thus a narrow and deep channel tends to widen until the velocities near the side are too low to cause further erosion

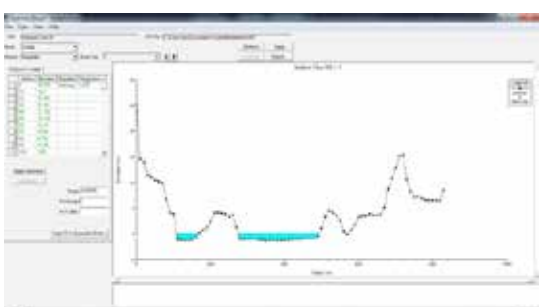
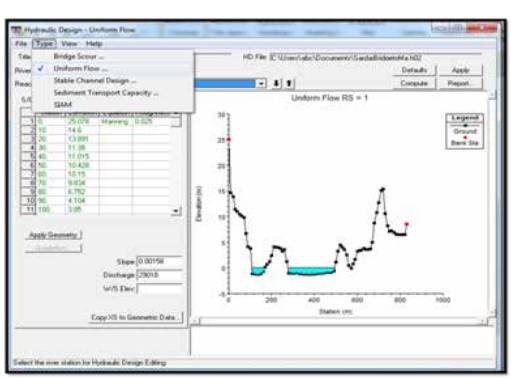


Figure 2- Cross section data



Steady flow data

Once the geometric data is entered, the necessary flow data can be entered. Steady flow data consist of:

- the number of profiles to be computed
- the flow data
- and the river system boundary conditions

In steady flow data three equations are used namely: Continuity, Energy and Flow resistance. Three losses are occurred in this analysis namely: Minor loss, Friction loss and Energy loss. Minor losses includes contraction and expansion along a reach and the value of contraction and expansion depend upon of the type of flow.

After inputing all the data of cross section in software using flood data compute the uniform flow computation and check whether the section is sufficient or not, or check whether section is critical or not critical

Hydraulic Regime

For evaluation of flood performance, past flood data reported by the Surat Irrigation circle, Surat were used. The flood frequency analysis results were based on data which coincides with the upstream limit of the project reach. Major flood event took place in the year 1883, 1884, 1942, 1944, 1945, 1949, 1959, 1968, 1994, 1998, 2002 and 2006. The effective waterway of river Tapi is reducing day by day with respect to width and depth due to silting and encroachment due to urbanization which affect the carrying capacity of the river. The summary of the floods is given in the Table 1

Table 1- Flood History

Sr. No.	Flood Event (Year)	Discharge (Cumecs)
1	1883	28480
2	1884	23974.5
3	1942	24371.2
4	1944	33552
5	1945	29018.7
6	1949	23861.1
7	1959	36670.2
8	1968	43924.2
9	1994	25116.74
10	1998	29817.27
11	2006	25788

Sediment Regime

The bed and bank material composition within the project reach evaluated by collecting samples from the study reach. The grain size distribution of bed material collected downstream of Sardar bridge near Magdalla bridge and indicated that d50 = 3.1mm, d84= 7.4mm and d16= 0.91mm. This data was used to simulate a stable channel design and using Copeland, regime of HEC-RAS software. The modeled channel section rating assumes uniform flow with a slope S = 0.00842.Therefore, a project reach cross-section that was considered most representative of the reach upstream was selected to represent its geometry.

Hydraulic Geometry

The Copeland (2001) was employed to estimate the preferred hydraulic geometry of the bank-full channel. Hydraulic geometry theory is based on the concept that a river system tends to develop in a way that produces an approximate equilibrium between the channel and the inflowing water and sediment load. Chang method which is a rational was developed specifically for active gravel bed channels, as opposed to threshold channels that have no significant transport at bank-full discharge. It predicts the width B, depth D and Slope S of the bank-full channel for a given water discharge Q , particle size d50, and side slope z. The water discharge Q = 25788 m3/s, the particle size d50 = 3.1 mm, and the side slope z = 1. The resulting hydraulic geometry channel is a trapezoidal section with a side slope z = 1, a top width B = 800m, bottom width b = 540 m and depth D = 12.34 m. The minimum slope S = 0.00842. Comparison of this idealized section with surveyed cross-sections in the project channel indicated very good agreement in the upper portion, indicating stability, but poor agreement in the enlarged cutoff reach downstream, which indicates that this lower enlarged reach will be aggrading over time.

Design Channel

The enhancement design channel includes recommendations for the following: (1) The channel planform; (2) The longitudinal profile, including morphology and the average slope; (3) The cross-

sectional profile, including a low flow channel, a bank full channel, and a flood conveyance channel; Guidelines for designing these features of the enhancement channel are based on the foregoing analyses.

Data Analysis

Step 1- Field Reconnaissance

Perform a cross section survey at a stable upstream riffle or infection point. Determine the slope of the upstream section from riffle to riffle. Estimate the bankfull stage by geomorphically observation or some other method. Sediment samples were gathered from the Tapi River between Sardar Bridge to the Magdalla Bridge during November, 2012. Samples were collected within the channel, upstream and downstream of bridges. Sediment was gathered by wading into the river by hand into Ziploc bags. This test is performed to determine the percentage of different grain sizes contained within a soil. The sieve analysis is performed to determine the distribution of the coarser, larger-sized particles, and the hydrometer method is used to determine the distribution of the finer particles. Sieve analysis helps to determine the particle size distribution of the coarse and fine aggregates.

After doing sieve analysis, following values obtained by plotting semi-logarithmic graph between grain size and percent finer:

D16 = 0.91mm,D50 = 3.1mm,D60 = 4.54mm,D84 = 7.4mm

Step 2- Choose a Manning's n-value for the channel side walls and bed

Step 3- Designing of river reach section

- **Uniform flow**

After collecting all the data of study reach, input all the data which are require for designing of river reach section in uniform flow, also using past flood event and are computed using HEC-RAS software.

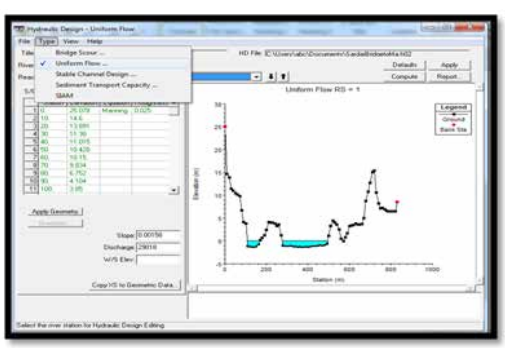


Figure 4- Uniform flow computation

Before computing this cross-section, first run the steady flow analysis by using past peak flood as shown in Table-1. After this, input that discharge while computation of uniform flow which results whether section is critical or not. If it is critical then at that particular section retaining wall or embankment may be constructed for minimizing the flood.

Results

For Flood 2006- Discharge 25788cumecs

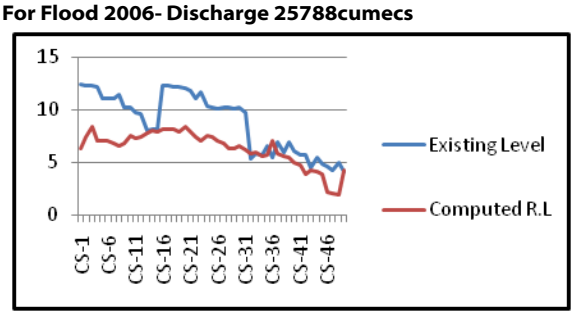


Figure 5- Comparison graph of computed and existing level

For Flood 1968- Discharge 43924cumecs

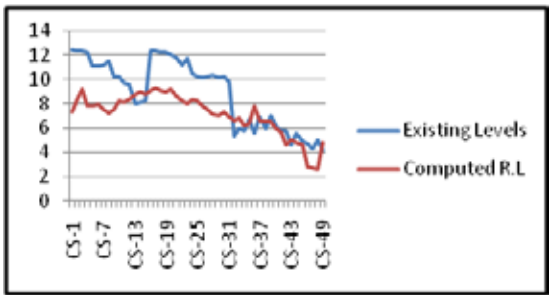


Figure 6- Comparison of computed and existing level

Following are the graphs which shows the comparison of computed and existing levels of study area:

In flood 2006: CS-11, CS-13, CS-24, CS-34, CS-44, CS-49 are the critical sections for preventing or minimizing this, suggest to construct embankment or levee or retaining wall at particular section. (Fig-5)

In flood 1968: CS-2, CS-3, CS-11, CS-12, CS-13, CS-14, CS-15, CS-24, CS-25, CS-27, CS-32, CS-33, CS-34, CS-35, CS-37, CS-38, CS-43, CS-44, CS-45 CS-49 are the critical sections for preventing or minimizing this, suggest to construct embankment or levee or retaining wall at particular section.(Fig-6)

Following are the figures of critical sections which are computed using HEC-RAS software and past flood data:

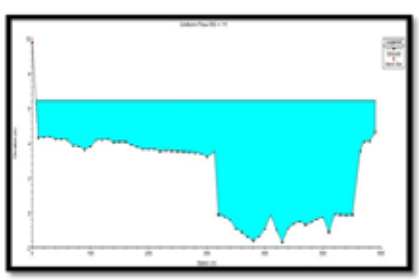


Figure 7- CS-11 of flood event 2006

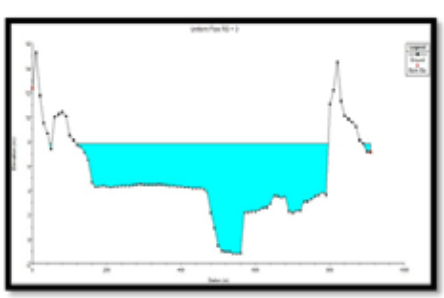


Figure 8- CS3 of flood event 2006

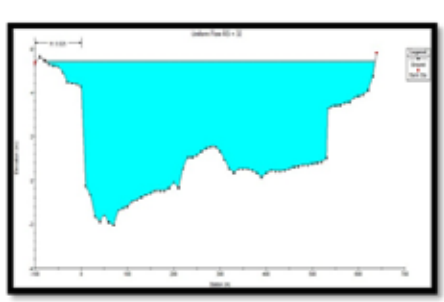


Figure 9- CS32 of flood event 2006

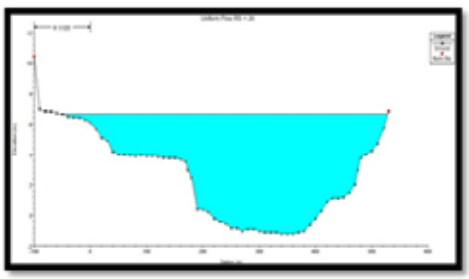


Figure 10- CS24 of flood event 2006

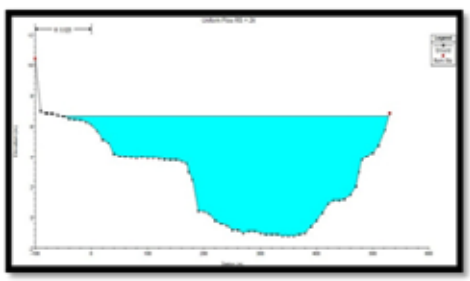


Figure 11- CS10 of flood event 1968

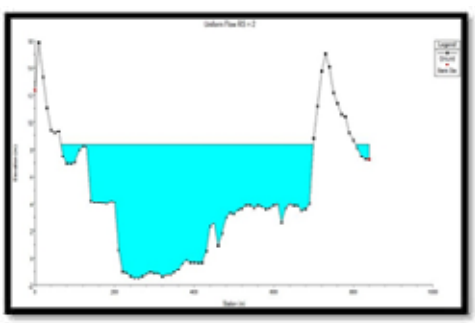


Figure 12- CS2 of flood event 1968

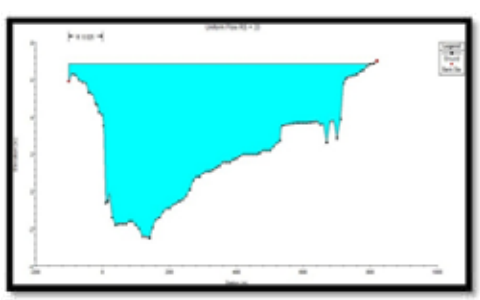


Figure 13- CS33 of flood event 1968

Conclusion and Recommendations

- It is strongly recommended that the sections, which water overtop over the existing embankment or retaining wall need to be raised.
- It is strongly recommended that the entire storm drain outlet should be provided by flood gates to prevent entry of flood water in the study area.
- It is strongly recommended that the sections found critical in the present study require restoration work/design and needs to be raised as per requirement.
- It is strongly recommended that the width of the river in no case be encroached as already sections are sensitive to high floods, encroachment will result flooding of study region.
- It is strongly recommended that no new construction is allowed in flood plain area.
- It is strongly recommended that from either side of bank of river no encroachment is made up to 300m.



Figure 14- Map of India



Figure 15- Study Area



Figure 16- Cross sections in Study Area

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