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A CASE STUDY ON FLOOD ROUTING BY HYDRAULIC MODELLING AT UPPER REACHES OF KOYNA RIVER INCORPORATING ST. VENANT EQUATION

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ABSTRACT.

In various zones of India especially near the bank of rivers, flood is a disastrous phenomenon that sometimes appears to be vulnerable to the human lives which is to be taken care of with proper engineering judgment. Flood routing is a scientific approach for forecasting the flood. It incorporates the changing magnitude, shape and rapidity of a flood wave which propagates through a river.

The propagation of a flood wave in a river channel is an extremely intricate phenomenon as the nature of flow in a river is generally unsteady and non-uniform.

Every year Mahabaleswar hill station, in Maharashtra, experiences problems of floods and damages during monsoon. The problems are caused by the release of water from the reservoirs located in the Upper reaches of Koyna River. During these periods, many bridges and sometimes the Mahabaleswar hill station get submerged which results in the disintegration of proper transportation system.

This paper aims to the mathematical approach which is capable of performing one-dimensional water surface profile calculations for unsteady flow for a full network of channels.

The Koyna River reach of length about 130 Km from the upstream of Mahabaleswar hill station was considered for the flood routing studies.

Contribution of discharge from the tributaries and the local catchments was also incorporated.

Studies were also conducted to estimate the changes in the hydrographs under the estimated worst conditions.

Maximum limit for the flood release from Koyna dam could be 1690 cumecs.

KEYWORDS Flood routing, upper Krishna River, Koyna River, Sangli

1. INTRODUCTION

As far as a hydrologic framework is concerned, routing is defined as a process of determining the extent by which the variation in the inflow hydrograph along a watercourse is determined. Flood routing may be defined as the process of computing the progressive time and shape of a flood wave at successive locations along a river. The movement of a flood wave in a river channel is a highly complicated phenomenon of unsteady and non-uniform flow. Thus the analytical solution to the problem becomes quite complicated.

Every year Mahabaleswar hill station, in Maharashtra, faces problems of floods and damages during monsoon. The problems are caused by the release of water from the reservoirs located in the Upper reaches of Koyna River. In 2005 from 23rd July to 2nd August there was consecutive heavy daily rainfall in the catchment ranging from 84 mm to maximum of 462 mm, resulting in major water release from Koyna.

During the analysis of data for the study, it was found that the maximum water released was 2817.40 Cumecs which is @ 73% of the maximum flood release capacity of Koyna Dam at FRL. (3822.70 Cumecs)

Considering this fact, in future there may be probability of releasing more discharges from these Dams.

Flood forecasting is based on statistical correlations between upstream and downstream gauge stations, measured rainfall in the catchment area and gauge/discharge data of tributaries etc.

A one dimensional numerical analysis software is used in this study to calculate the water surface profiles.

Main purpose of flood routing studies is to calibrate the model for water level and discharge hydrographs for specific reach / reaches based on the past data; and to estimate the changes in the hydrographs under the estimated worst scenarios. An unsteady Hydraulic flood model of Upper Koyna river at Mahabaleswar hill station has been prepared for this purpose. Fig: 1 shows the index map of the Krishna River and its various tributaries.

Fig: 1 Index Map showing study area.

2. METHODOLOGY AND MODEL SETUP

2.1 Methodology

The one dimensional equations of unsteady flow derived by Saint-Venant (1871) is the theoretical foundation for flood routing. The St.Venant equations consist of a conservation of mass equation

$$\frac{\partial (Av)}{\partial x} + \frac{\partial A}{\partial t} = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

A conservation of momentum equation

$$\frac{\partial v}{\partial t} + V\frac{\partial V}{\partial x} + g\left(\frac{\partial h}{\partial x} + S_f\right) = 0 \quad \ldots\ldots\ldots\ldots\ldots (2)$$

In which t is a time, x is distance along the longitudinal axis of the water way, A is the cross sectional area, v is velocity, g is the gravity acceleration constant, h is the water surface elevation above a datum, and S_f is the friction slope which may be evaluated using a steady flow empirical formula such as Chezy or Manning's equation.

Due to complexities of the St. Venant equations their solution is not feasible, and various simplified approximations of flood wave propagation continued to be developed. Two possible approaches to the flood routing problems are available to engineers,

• Hydrologic routing also known as lumped routing is based on the conservation of mass and an approximation of the relationship between flow and storage. The hydrologic routing, directly allows computation of the outflow hydrograph at the downstream end of the reach.

• Hydraulic routing also known as distributed routing is based on the conservation of mass and a simplified form of St. Venant conservation of momentum equation. The hydraulic routing requires computation of the discharges along the river in an important number of intermediate points, for every time step, beside the cross sections in these intermediate points, the hydraulic parameters like roughness coefficient are needed. In both cases, the inflow hydrograph at the upstream end of the observed reach is required.

2.2 TYPES OF FLOOD ROUTING MODELS

Basically there are two types of flood routing models:

a) Hydrologic Flood Routing model
b) Hydraulic Flood Routing model

In this paper, we are mainly focusing on the Hydraulic flood routing model and the model analysis is done accordingly.

2.2.1 Hydraulic flood routing models

The hydraulic flood routing models are again classified into

1. Simplified hydraulic models
2. Complete hydraulic models

1. Simplified Hydraulic model

Simplified hydraulic models are based on the conservation of mass equation and simplified form of conservation of momentum equation.

a) Kinematic Wave Models

In some cases, inertial and pressure forces are much smaller than friction and gravity forces. For such cases, Simplified form of momentum equation is $S_o = S_f$, which states that the momentum of the unsteady flow is assumed to be the same as that of steady uniform flow as described by the Chezy or Manning equation. The kinematic wave model is limited to applications where single valued stage-discharge rating exists, and where back water effects are insignificant.

b) Diffusion model

A diffusion model uses the continuity equation and simplified form of momentum equation as $S_f - \frac{\partial h}{\partial x} = 0$the inclusion of water surface slope term allows the diffusion models to describe the attenuation (Diffusion effect) of the flood wave, and accounts for backwater effects. As this models doesn't consider Inertial terms of momentum equation and therefore, is limited to slow to moderately rising flood waves in channels of uniform geometry.

2.3 MODEL SETUP

The Koyna River reaches of length about 130 Km from the upstream of Mahabaleswar hill station was selected for the study. Koyna River originating at Mahabaleshwar, from the topographical point of view the river reach up to Sangli may be divided into 3 reaches.

First reach is from Dhom Dam (Ch.223) to Sangam Mahuli (Ch 178) near Satara, where there isconfluence of Venna with Krishna. Steep slopes, (1:530) deeper channel, and absence of over-bank flows are the typical characteristic features of this reach.

Second reach is from Sangam Mahuli (Ch.223) to Karad (Ch.115) i.e. up to confluence with Koyna. In this reach the rivers like Urmodi, Tarali etc. joins to Krishna, however the flows contributed from these rivers is comparatively less, and the bed gradient of the river is mild than initial reach of @ 1:1100, hence problems of flooding occurs very rarely in this reach.

The third reach is from Karad (Ch.115) to Sangli. (Ch. –10) This is the most vulnerable reach of the river, the bed gradient becomes mild to the extent of @ 1:5700, and the cross section of the river become shallower and wider, and would be subjected to frequent over-bank flows.

Following steps were followed in creating a hydraulic model with HEC-RAS:

Entering Geometric data Using the available cross section survey data, the reach

- River Krishna of length 233 Km from downstream of Dhom Dam to Sangli (Ankali Bridge)
- River Koyna of length 68 Km, from downstream of Koyna dam to Krishna – Koyna confluence at Karad was used.

In the Krishna & Koyna River there are series of Kolhapur Type Weirs, (K.T Weir) and bridges.

During monsoon season there are no needles (i.e. Stop log arrangements) in K.T.Weirs. Hydraulically, the submersible piers of KT weirs will act like piers of submersible bridges. Therefore, these structures were reproduced accordingly.

Entering flow data & boundary conditions

Inflow hydrograph

The data of flood water Release from dams were used as inflow hydrographs at the downstream end of thetwo Dams, i.e. as upstream boundaries

Internal Boundary conditions

Minor river inflows like Venna, Urmodi and Tarali were used only as internal boundary data. These rivers were not reproduced in the topography.

Lateral inflows of local catchments were also used as an internal boundary. Due to limited information available for these items; the lateral inflow from the local catchment was also used as calibration parameter. The values were maintained for all the experimental runs also.

Downstream Boundary condition

Normal depth option was used as a downstream boundary condition at the end of river system station i.e. at Ankali Bridge.

Initial conditions

For high flood runs, the importance of the initial flows is only nominal. They are required only to ensure uninterrupted computations before the high discharges. In the present studies, the initial condition (minimum flow) was used in the model 100 Cumecs.

Performing the unsteady flow calculations

A computation interval of 15 minutes was used for the model runs. Necessary trial runs were made with different time intervals to confirm the accuracy and stability of results.

2.4 Calibration of model

Keeping in mind the limited influence of the resistance of hydraulic structures, Manning's roughness coefficient 'n' was used as principle parameter. The over-bank reaches of river are rougher than the channel, due to trees and agricultural crops. Hence separate values of 'n' are used for within the banks & the reaches beyond the banks. In the model the value of 'n' used for the over-bank was0.05 and 0.023 for the main channel.

The available data namely, River inflows of different rivers, and the gauge –Discharge data at the stations on River Krishna and Koyna, for the floods of year2005 were used for the calibration.

3.0 RESULTS

3.1 Findings of analysis and calibration

Actual Rating curve at gauging site Irwin bridge Sangli and Rating curve obtained by Model are showed vide fig: 2. Actual flood Hydrograph and flood hydrograph obtained by model at Irwin Bridge Sangli, with the inflow at Karad is shown vide Fig: 3.

The actual water level Hydrograph and the same obtained by model is shown vide fig: 4

The available gauge data has been analysed to find out the contribution in flood flow by rivers.

The calibration of the model was taken as satisfactory. Further study runs were made with the calibrated model.

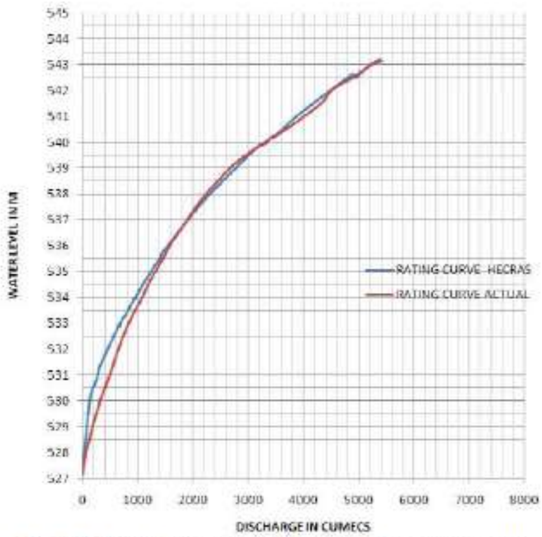

Fig: 2 Rating Curves at Irwin Bridge Sangli

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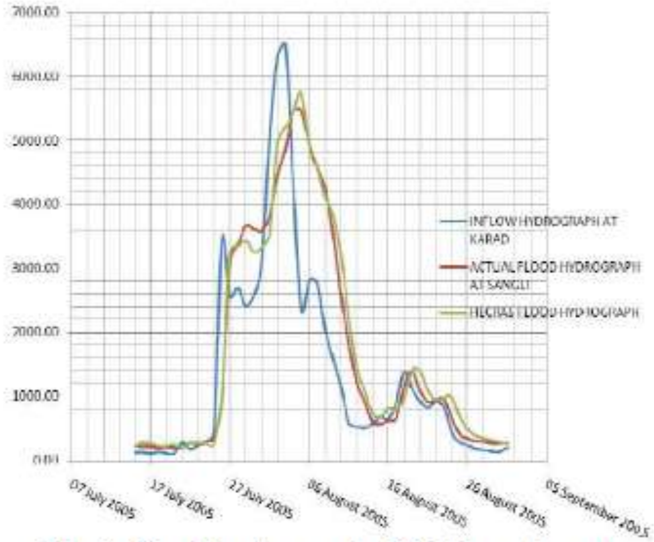

Fig:3 Flood hydrograph of Krishna river at Sangli.

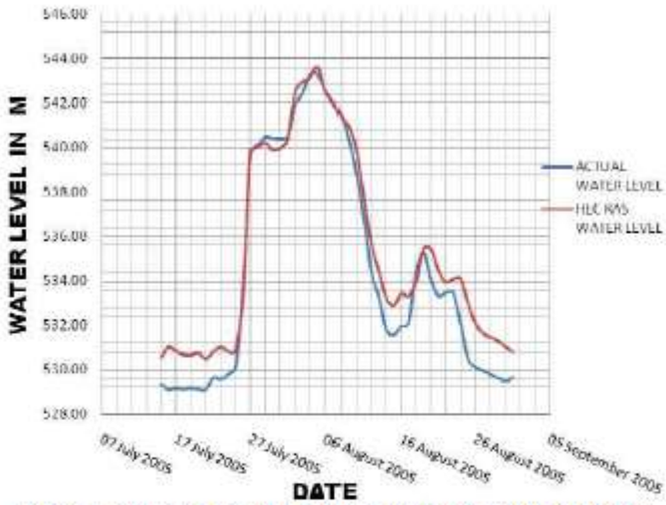

Fig: 4 Water level hydrograph at Irwin Bridge Sangli.

3.1 Findings of Model Run

The calibrated model has been used to evaluate the maximum limit of release to be made from koyna dam to avoid the flood situations at Sangli. It was found that, when flood water release from Koyna dam was of 1690 cumecs, the danger flood level of 540.77 m would reach at Irwin Bridge Sangli.

In order to study the flood sensitivity, the calibrated model was run for

• Peak flood releases from the Dams increased by 10 %

_ Peak flood releases from the Dams increased by 25% and

_ Peak flood releases from the Dams reduced by 10%

For each of the above runs, three scenarios were selected as indicated below:

SCENARIO-I

Only Koyna Dam releases altered

SCENARIO-II

Only Dhom Dam releases altered.

SCENARIO-III

Releases from both Dams releases altered simultaneously

Table No 1 gives details of sensitivity study for thesescenarios.

TABLE: 1 Details of Flood Sensitivity Study

Description	Water release Cumecs	Change in release Cumecs	Peak discharge Cumecs	Contribution of release in peak discharge %	Change in peak discharge Cumecs	Water level m	Change in water level m
SCENERIO I							
2005 FLOOD	2755.89	-	5731.04	48.08		543.65	
Case I (+ 25%)	3444.86	+ 688.97	6609.7	52.11	+878.66	544.68	+1.03
Case II (+10%)	3031.48	+275.59	6223.18	48.71	+492.14	544.20	+0.55
Case III (-10%)	2480.30	-275.59	5701.63	43.50	-29.41	543.54	-0.11
SCENERIO II							
2005 FLOOD	634.92	-	5731.04	11.07	-	543.65	-
Case I (+ 25%)	793.65	+158.73	5770.89	13.75	+39.85	543.70	+0.05
Case II (+10%)	698.41	+63.49	5747.04	12.15	+16.00	543.67	+0.02
Case III (-10%)	571.43	-63.49	5715.26	10.00	-15.78	543.63	-0.02
SCENERIOIII							
2005 FLOOD	2925.92	-	5731.04	51.05		543.65	
Case I (+25%)	3657.40	+ 731.48	6650.59	55.00	+919.55	544.73	+1.08
Case II (+10%)	3218.51	+292.59	6239.58	51.58	+508.54	544.22	+0.57
Case III (-10%)	2633.33	-292.59	5685.59	46.31	-45.45	543.52	-0.13

4.0 DISCUSSION

The forecasting results show that the stage and discharge worked out from the model has a good agreement with observed stage and discharge. Hence the technique provides a reliable stage / discharge profile for the flood forecast.

4.1 Gauge Discharge curves.

Following observations are obtained by comparing the Actual rating curve and HECRAS Rating curve

1. Lot of disturbances to the river basin are observed at village level.i.e. Sand mining, well digging etc. Hence this may lead to constant changes in cross section of the river which may lead to variation in stages and to discharge

2. There is significant obstructions to the river course due to hydraulic structures like Ghats, intake wells etc. which are not represented in the model.

Due to above reasons Gauge discharge values are highly vitiated and therefore less reliable for low flows. Hence only high discharge values were selected for comparison. Actual site gauge – discharge curve and HEC-RAS curve did not matching for low flows, however for high flows the gauge – discharge curve matched well. Moreover our studies were related to high discharge (Flood) only, hence this truncation of rating curve was acceptable.

4.2 Water level and discharge Hydrograph

It was found that water level graph is fairly matching for higher elevation. Also discharge hydrograph is fairly matching for the whole hydrograph. This showed that the results obtained at Irwin Bridge Sangli were largely reliable. From the hydrograph it was estimated that the flood wave time of propagation from Karad to Sangli was about 2 Days (48Hrs)

Hence the model set up could be reliably used for flood routing and other related studies of rivers Krishna and Koyna. Further detailed studies for the estimation of flood levels at Sangli or at any other intermediate station for various releases from the Upper reservoirs.

4.3 River wise flood flow contribution at the study area

At the Irwin Bridge Sangli, it was found that the 56 % flood flow contribution was from Koyna River and 44 % was from Krishna River. Hence flood situation at Sangli depends mainly on Koyna River flow.

4.4 Flood Sensitivity study

SCENARIO-I

Following are the observations obtained from the study

1. At the Sangli, contribution of peak release in peak discharge was found @ 48 %.
2. There was large positive variation between change in peak release and change in peak discharge.
3. The above two observations indicate that theflood situation mainly depends upon the water release from koyna dam.
4. Change in water level for 25% more water release from dam was found @ 1.03 m. In that case maximum water level at Irwin bridge Sangli will be 544.68 m, i.e. 3.91 m above the danger level

SCENARIO-II

Following are the observations obtained from the study

1. At Sangli, contribution of peak release in peak discharge was found @ 12 %.
2. There was large Negative variation between change in peak release and change in peak discharge.
3. This indicates that there was very less effect of water release from Dhom dam on Flood situation at Sangli.

SCENARIO-III

Following are the observations obtained from the study

1. At the Sangli, contribution of peak release in peak discharge was found @ 51 %.
2. There was large positive variation between change in peak release and change in peak discharge.
3. This indicates that the flood situation is mainly depends upon the water release from these dams.

4.5 Limitations of the study

• For carrying out flood sensitivity study, flood release hydrograph for 25% & 10% more flood water release and 10% less flood water release for both Dams has been derived by just numerical extrapolation of flood hydrograph observed in 2005. This assumed hydrograph could be improved by detailed hydrological studies.

• Using the available discharge data of gauging stations for Krishna and Koyna River, and respective dam releases the contribution from free catchment is worked out for each reach of the concern river. These values remained unchanged all the time in the model. The other HEC series software like HEC-HMS can be used for more realistic modelling the free catchment flow. By incorporating the results of these studies, HEC-RAS results can be improved.

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