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ANALYSIS FOR ADOPTING LOGICAL CHANNEL SECTION FOR 1D DAM BREAK ANALYSIS IN NATURAL CHANNELS

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ABSTRACT

The objective of this study was to predict and analyze the dam break flood in a real river valley. A numerical model was developed for simulating dam break flood and applied for analyzing flood situation due to the instantaneous hypothetical failure of the proposed dam in river Dibang, a major Himalayan tributary of the River Brahmaputra. Significant variation in bed slope, bed width and resistance characteristic along the channel length are the typical characteristics of Dibang river. To compute the flood under such dam failure conditions, natural channel is generally represented by a simplified channel. . Such simplification may lead to erroneous estimation of the important parameters such as maximum probable depth, peak arrival, maximum probable velocity and inundated area. Therefore, due emphasis should be given in the selection of an appropriate computational channel while simulating a real dam break flood. Two different approaches for adopting the computational natural channel have been proposed here for predicting the dam break flood. Probable maximum depth of flood, time of peak arrival and the maximum probable flood velocity at different sections up to 63 km downstream of the proposed Dibang dam have been computed . In one approach, the predictions are made by adopting a computational channel, which considers the whole floodplain downstream of the dam when River Dibang enters the plain. The other approach considers only the original simplified river channel of Dibang. The predictions of dam Break Wave Propagation by both the methods have been compared and analyzed. The analysis clearly illustrates the importance of the proper selection of the computational channel in a river valley downstream of the dam to avoid over estimation or underestimation of flood.

Keywords: dam, flood, failure, disaster, channel, river, simulation model.

INTRODUCTION

Floods due to failure of dams induce widespread damages to life and property owing to its high magnitude and unpredictable sudden occurrence. Such flood is required to be simulated to determine the inundated area, flood depth and travel time of the flood waves so that adequate safety measures can be provided. The review of the past works reveals that dam break problem remains a topic of continued interest since Ritter (1892) attempted its first analytical solution for a horizontal frictionless rectangular channel. Investigations are still going on (i) to evaluate performance of different forms of Governing Equations, (ii) for developing analytical solution of these equations for different situations and (iii) for developing better and suitable numerical schemes for addressing complexities of natural rivers. Over the years different investigators have developed both one dimensional (Hicks F. E. *et al*. (1997), Sanders B. F. (2001), Macchione F, Viggiani G. (2004)) and two dimensional models (Katopodes N. D. (1984), Hromadka (1985), Akanbi A. A. *et al*. (1988), Zhao D. H. *et al*. (1996), Sarma, A. K. (1999), Zoppou .C. and Roberts S. (2000)) for simulating dam break flood. Although computation of dam break flood has been a topic of interest for more than hundred years, numerical simulation of dam break flow in relatively simple channels is found more often compared to real river flood simulation. Natural channels with steep slopes and wide flood plains offer numerous complexities and make the computation very challenging. These channels are highly non-prismatic in nature with significant variations in bed width, bed slope and roughness characteristics. In this study dam break flood analysis has been carried out through its' application in natural channel. A hypothetical situation of failure of the proposed dam on the river Dibang, a Himalayan tributary of the river Brahmaputra has been considered. The reservoir extends up to 43,000m upstream of the dam and the channel meets the river Brahmaputra 63,000m downstream of the dam. The elevation of the channel bed changes from 545m to 127m. Manning's roughness coefficients at different sections are taken as 0.03, 0.032, and 0.035 based on the channel and floodplain characteristic of the river.

Computations of the dam break hydraulics in real cases are generally made considering the simplified representation of the original river channel. As, such simplification may lead to erroneous flood estimation, the appropriate selection of the computational cross-sections of the natural channel is quite important for proper prediction of the dam break flood. Two different approaches for selecting the computational natural channel have been proposed here for predicting the dam break flood. In one approach, the predictions are made by adopting a computational channel, which considers the whole floodplain downstream of the dam when River Dibang enters the plain. The other approach considers only the original simplified river channel of Dibang. Probable maximum depth of flood, time of peak arrival and the maximum probable flood velocity at different sections up to 63 km downstream of the proposed Dibang dam have been computed by both the methods .The computed values by both the methods are compared and analyzed .

SIMULATION MODEL

The development of the simulation model under dam failure condition is considered as follows:

Mathematical model:

The movement of the wave in the dam-failure situation is governed by gradually varied unsteady flow equation in open channel, i.e., the Saint-Venant (1871) equations.
It can be represented in matrix form as:

$$\frac{\partial U}{\partial t} + \frac{\partial F(U)}{\partial x} = S(U) \quad \ldots\ldots\ldots\ldots.. (1)$$

Where:

$$U = \begin{Bmatrix} A \\ Q \end{Bmatrix}, \qquad F(U) = \begin{Bmatrix} Q \\ \frac{Q^2}{A} + gI_1 \end{Bmatrix} \qquad \text{and}$$

$$S(U) = \begin{Bmatrix} 0 \\ gA(S_0 - S_f) + gI_2 \end{Bmatrix}$$

x = direction parallel to the river, t= time, A = cross-sectional flow area, Q = discharge, V = Depth averaged flow velocity, g = acceleration due to gravity; S_0 = bed slope; and S_f = friction slope.

$$I_1 = \int_0^{h(x)} [h(x) - \eta] b(x, \eta) d\eta \quad ,$$

$$I_2 = \int_0^{h(x)} [h(x) - \eta] \left[\frac{\partial b}{\partial x}\right]_{h=h_o} d\eta$$

I_1, I_2 = cross-sectional moment integrals; η = integration variable representing the vertical distance to the bottom of the section; b = cross-sectional width at height η; h = water depth above the bottom.

Numerical scheme formulation:

First order "Diffusive Scheme", which has been found to be advantageous for practical application due to its simplicity and ease of implementation (Sarma and Saikia, 2006) is used here for solution of the governing equations. By applying diffusive scheme (Chunge *et al*. 1980) to equation (1), the flow parameters at any time step "n+1" can be represented in terms of the known values at time step "n" as:

$$U_i^{n+1} = \alpha U_i^n + (1-\alpha)\frac{U_{i+1}^n + U_{i-1}^n}{2} - \frac{\tau}{2}(F_{i+2}^n - F_{i-1}^n) + \Delta t S_i^n$$

Where α = Weighting coefficient in diffusive scheme and $0 \le \alpha \le 1$, $\tau = \frac{\Delta t}{\Delta x}$

Macchione *et al.* (2003) found in their numerical investigation that diffusive scheme gives increasingly accurate results as the value of coefficient α increases. Hence α = 0.75 have been considered here. Stability is assured by the Courant–Friedrichs–Lewy condition as follows:

$C_r = \frac{\max(|v| + c)}{\Delta x / \Delta t} \le 1$ Where Cr is the Courant number, v is the velocity, c is celerity = $\sqrt{gh}$ and $\max(|v| + c)$ stands for the maximum value over the whole range of grid points.

SIMULATION APPLICATION

The hypothetical flood due to the failure of the proposed dam in a Himalayan river Dibang has been considered.

Salient features:

The salient features of the dam are as given below:

Location of the dam:

(Location map is presented in Figure-1)
Country: India
State: Arunachal Pradesh
District: Lower Dibang valley district
Dam Site: Latitude: 28°20' 7" N and
Longitude: 95°46' 38" E
Height of the Dam: 288m.

Hydrology:

Catchment area: 11276 km^2
Location of Catchment:
Latitude: 28°11' 50" N to 29°25' 59" N
Longitude: 95°14' 47" E to 96°36' 49" E
Average annual rainfall: 4405 mm

Reservoir:

Maximum water level: EL 548 m
Full reservoir level: EL 545 m
Length of reservoir: 43km

Field data:

For proper prediction of the simulation model the topographical data base is one of the important factor .The basic field data required for the flood analysis are: (i) Terrain profile – for the bed elevation and channel breadth, (ii) Topographic characteristic of the downstream area – for using appropriate value of resistance parameter, (iii) Height of the Dam.

Topographic characteristics:

The topographic characteristic varies significantly within the computation domain. The river Dibang passes its course from hills of Arunachal to the plains of Assam. The river passes through deep gorges, terrains with pebbles and boulders and then through alluvial plains. Most of the portion on the downstream of the dam lies in the plains. In the plain, multiple stream channels namely Deopani, Iphipani, Gango, Siba, Sisiri and Siang are flowing there in the terrain near by the main channel of river Dibang as shown in the detailed downstream (Figure-2). The cross section data obtained with the help National Hydro Power Corporation (NHPC) and National Productivity Council

(NPC) of INDIA was used to compute the flow profile. The input data in the programme is given in the form of regularly spaced grids. To accomplish it, the actual data acquired at convenient chainage points on the riverbed is linearly interpolated. The total channel reach is represented with a total number of 1000 grid points.

THE NON-PRISMATIC COMPUTATIONAL CHANNEL CONSIDERED FOR COMPUTATIONS

Two methods have been proposed here for selecting the computational channel in a natural river valley for predicting the dam break flood.

Computational channel considering the simplified channel of river Dibang:

The computational channel considered here is a parabolic non-prismatic channel. After analyzing the river channel of Dibang, a simplified, parabolic, non-prismatic river channel for dam break computations has been adopted as follows: The linear regression of the available data has been done and the straight centre line has been fitted. Then to get the breadth of the river channel at a particular section downstream the dam, distance of the extreme bank (right or left bank whichever is at far distance from the centerline) from the assumed centre line is taken. Equal distance is considered perpendicularly from the centerline and the opposite bank is fixed for that section as shown in Figure-3. Than to get the parabolic channel, the available terrain data for that section within that breadth has been taken and the parabolic least square curve for those data is fitted. The ground elevation for that particular section is taken as the elevation of the centre point of the channel. For example, the equation for the parabolic least square curve to fit the available terrain data, to get the simplified river channel section, 52km downstream the dam is $y = 9E - 07x^{-2} - 0.0371x + 492.85$. The bed elevation considered for this section is 125.500 (m).The cross-section considering the computational channel by this approach, at 52km downstream the dam (Figure-6).

Computational channel considering the detailed terrain downstream the dam:

The non-prismatic channel taken in the computations is a parabolic channel. After analyzing the field data for the downstream of the dam, it has been observed that when instantaneous failure of the dam will take place, the flow of the huge quantity of water will not confine only to the original channel of Dibang but it will spread out to the nearby land areas and also to the different streams flowing parallel to Dibang. Hence the whole terrain downstream as shown in Figure-4 is considered for computations. To get the parabolic channel cross section at a point downstream of the dam, the available terrain profile data has been taken and the parabolic least square curve for those data is fitted. The ground elevation for that particular section is taken as the elevation of the centre point of the channel. For example: At 52 km down stream the dam the channel taken for computations is as shown in the Figure-5. The equation for the parabolic least square curve to fit available terrain data in the sections is $y = 3E\text{-}08x^{-2}\text{-}.0014x + 145.91$. The bed elevation considered for this section is 126.000 (m).

ANALYSIS OF THE FLOOD DUE TO THE INSTANTANEOUS FAILURE OF THE DAM IN RIVER DIBANG

The maximum probable depths and their time of occurrence, maximum probable velocities, obtained from the simulation model have been shown in Figures 7, 8, and 9, respectively. When the simplified river channel approach is considered the water level at 52km downstream will be as shown in Figure-6. The maximum predicted water level is 138m which is 10m higher than the top elevation of the bank of river Dibang. Hence it is obvious that flow will follow its' own path where the channel will comprise of the original channel of Dibang as well as the nearby area to some lateral distance at that section depending on terrain elevation. On the other hand if the predicted depth by the simplified river channel for a particular section downstream the dam is assumed as the maximum probable depth for that entire lateral terrain in that channel cross-section then the inundated area will be also over predicted. The prediction of maximum water level and the lateral inundation, at 52km down stream the dam (Figure-6), when the entire terrain in the plain, is considered in the computational channel.

Comparison of the maximum probable flood depths shows that the computed depth significantly reduces as the river Dibang enters plain. As observed from Figure-7, reduction in the maximum probable depth of the Dibang dam break flood starts from 11km downstream the dam. Significant high predictions have been observed from 32 km downstream, when the flood is simulated in the channel, where the simplified channel of river Dibang is only taken into account. For example, depths are over predicted as, 220.125%, 306.818 % and 248.185 % at 32km, 52km and 62 km downstream the dam, respectively by this approach compared to the computed maximum depths considering the whole terrain downstream the dam.
While analyzing the time of peak arrival (figure 8) similar observations are made. As soon as the river Dibang enters the plain the time of peak arrival starts increasing remarkably, when the whole terrain is considered in computation compared to the simplified river channel. For example, The peak arrival time increases 23.701% at 32 km downstream and the increment rises to as high as 63.802 % in 62 km downstream.

The comparison of the maximum probable velocity shows that the predicted value is highly overestimated in the simplified river channel. When the river enters in plain region, in 12 km downstream the velocity is predicted as 65.916% higher when the computational channel is considered as the simplified river channel of Dibang. Another observations made from the plot of maximum velocities is that the significant difference in the prediction of the maximum value for velocity at any section cross-section downstream. The simulation results with simplified river channel predicts the maximum velocity possible downstream of the dam as 62.342 m/second at 12000.00m downstream where on the other hand the simulation of the flood in the channel which comprises of the whole floodplain predicts it as 42.376 m/s at 6035.29m downstream .The over prediction of the maximum velocity increases continuously towards the downstream after 32km downstream the dam.

CONCLUSION

A simulation model has been developed and used to predict the flood due to the hypothetical failure of the proposed dam on the river Dibang, a Himalayan tributary of river Brahamaputra. Two different approaches have been tested for appropriate representation of channel downstream of the dam when the river enters the plain. In one approach, the flood was predicted considering the entire downstream terrain as a one-dimensional non-prismatic parabolic channel and the other considers only simplified parabolic river channel. To get the parabolic channel cross section at any point downstream of the dam, the available terrain profile data has been taken and the parabolic least square curves for those data are fitted. The possible extent of submergence of the river basin has been analyzed. The various important factors such as maximum probable depth of flood, maximum probable velocity and time of peak arrival, under the instantaneous dam failure conditions are obtained for the sections downstream.

It has been observed that, the adoption of the simplified river channel as the computational channel over predicts the maximum flood depth, velocity and under predicts the time of peak arrival at the downstream sections when the river enters the plain.. The computed maximum probable depths are highly estimated when the flood is simulated in the simplified channel of river Dibang compared to the channel where entire downstream terrain is considered. The overestimation is quite significant after a distance 32km downstream the dam, with a maximum at 52 km downstream, which is 306.818% higher compared to the computed maximum depth considering the whole terrain downstream the dam. The time of peak arrival starts increasing remarkably after a distance 14400m downstream, when the whole terrain is considered in computation compared to the simplified river channel. The comparison of the maximum probable velocity shows that the predicted value is highly overestimated in the simplified river channel for the entire downstream sections. In the simplified river channel the maximum velocity possible downstream the dam is predicted as 62.342 m/s at 12000.00m downstream where the maximum predicted velocity is 42.376 m/s at 6035.29m downstream when the flood is simulated on the channel which comprises of the whole floodplain.

Hence it has been observed that the consideration of the original river channel over predicts the flood depth, velocity and under predict the time of peak arrival. It is also not logical to consider that the instantaneous dam failure flow will confine only to its original channel in case of such a high dam. Once the depth of flow crosses the depth of the original river channel, it will start flowing to the nearby floodplain. The proper prediction of the possible extend of inundation downstream of the dam is quite important, as it consist of villages, roads, dense forest etc. and therefore, for such practical purposes, for proper prediction of the dam break flood, it may quite realistic and logical to select the computational channel in such a manner that it takes into account the wide floodplain when the river enters the floodplain.

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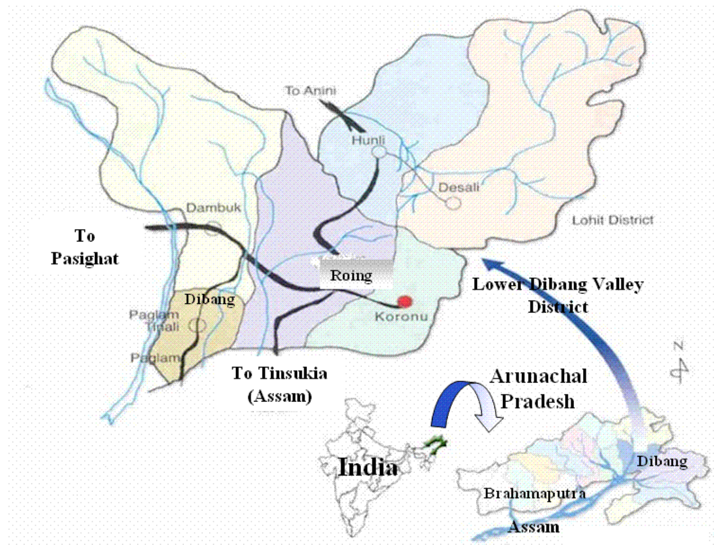

Figure-1. Location Map of the Study area

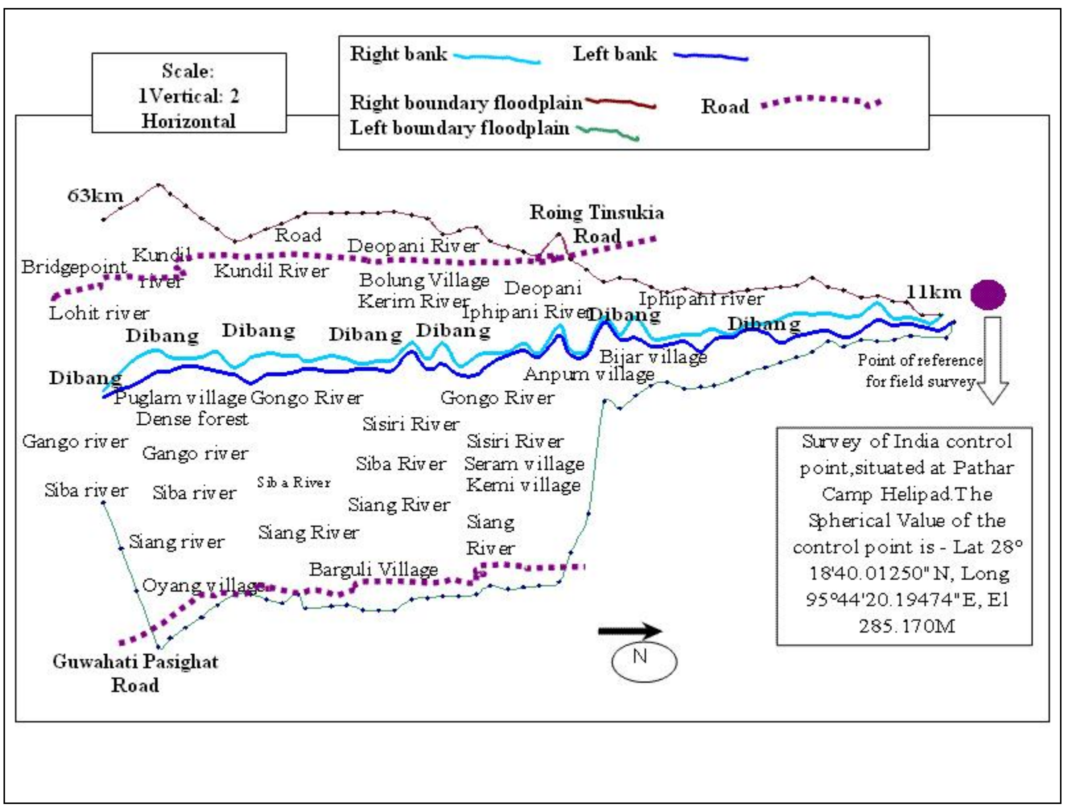

Figure-2. The detailed terrain downstream the dam when the River Dibang enters Wide Flood Plains

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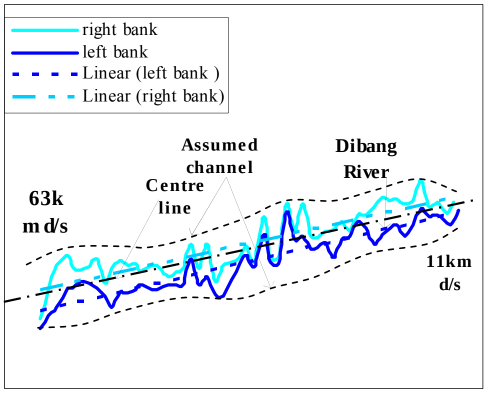

Figure-3. Computaional Channel considering the simplified River Channel of Dibang

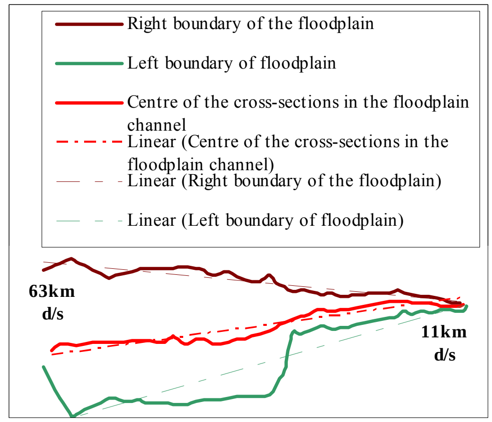

Figure-4. Computaional Channel considering the whole Floodplain downstream of the dam of River Dibang

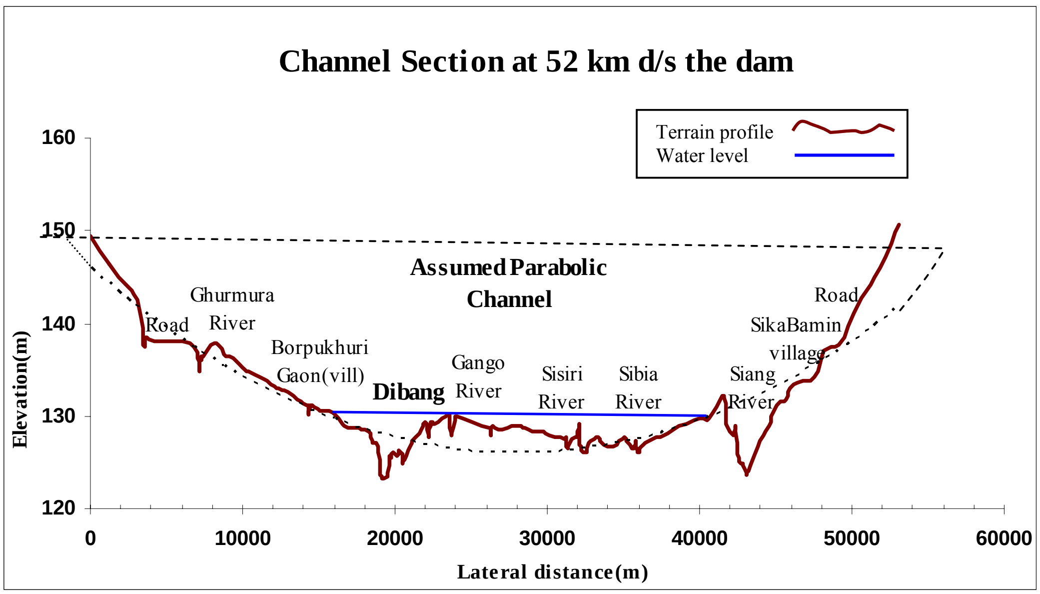

Figure-5. Computational Channel cross-section considering the whole Floodplain downstream the dam of River Dibang

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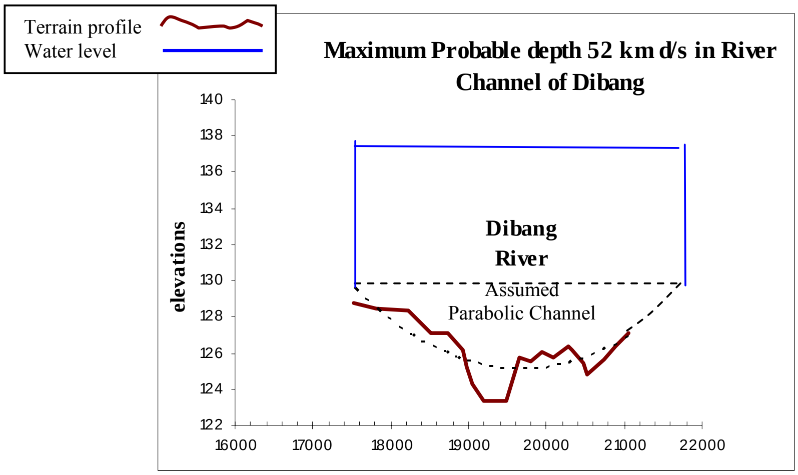

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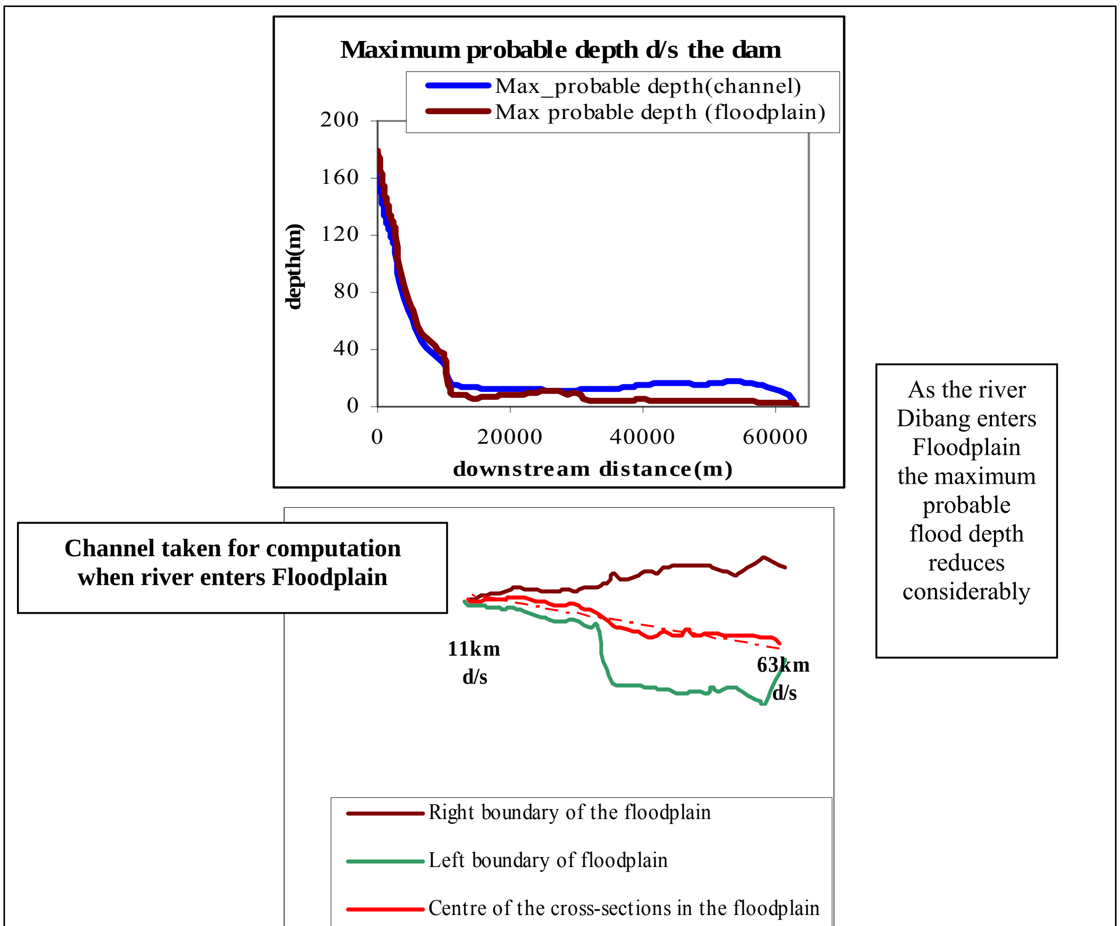

Figure-7. Comparison of the predicted maximum flood depths

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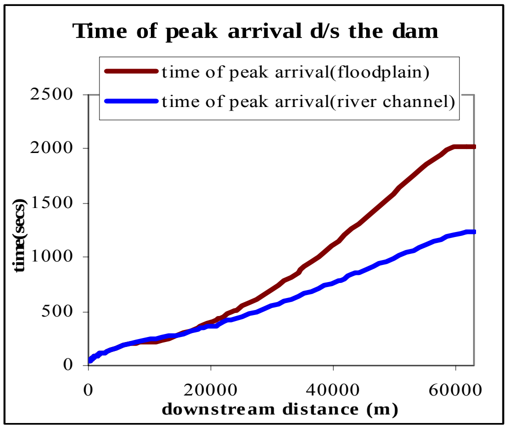

Figure-8. Comparison of the time of peak arrival

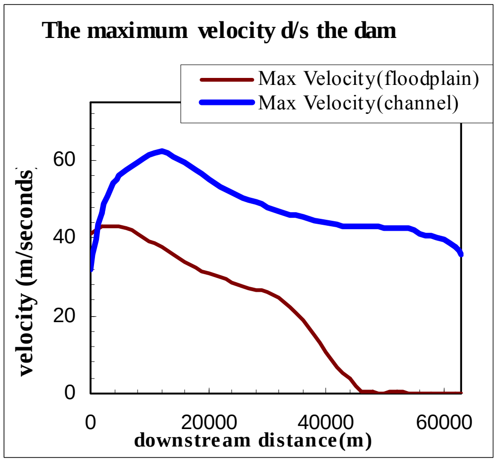

Figure-9. Comparison of the maximum velocity