DAM BREAK-A Review

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Abstract— *The Dams are essential structures compiling numerous advantages for the development and sustenance of society, on the contrary breaking of dam can prove to be fatal in the same proportion. The study of dam breach and modelling of dam break scenario thus becomes very important for mapping of floods and preparation of emergency action plans. Failure of a dam differs from one type of dam to other. Dam failure may be broadly classified as instantaneous and gradual. The masonry or rigid concrete dams fail instantly due to failure of monolith on the other hand the earthen dam fail gradually by erosion due to overtopping over crest and piping failure beneath the dam structure. With the advancement in computational techniques various types of software are now available which enables simulation of dam break scenarios and help in preparation of inundation maps. This paper reviews the study of dam break scenario and important types of dam breach parameters. Various guidelines regarding dam breach parameters have been compiled and the capabilities of different types of software available for simulation of dam break scenarios have also been discussed.*

Keywords— Breach, Dam Break, Modelling software, MIKE 11, ArcGIS

I. INTRODUCTION

Dam are structures that are constructed across the direction of flow of water with the purpose of confining flow for storage, diversion of flow, mitigating flood, harnessing hydropower etc. Dams are massive structures failure of which can cause human loss, economic loss as well as loss of natural diaspora. A dam break is the partial or catastrophic failure of a dam which leads to an uncontrolled release of water (Fread, 1993).Floods generated due to dam break are perilous as compared to ordinary precipitation generated runoff flood. Dam break may occur due to uncontrolled inflow into a reservoir, erosion of dam material due to seepage, piping, overtopping or due to defects in embankments and foundation. The failure of dam can be gradual or sudden (instantaneous).Sudden failure generally occurs in case of concrete dams which generally fail by either overtopping or sliding. Dam break in case of earthen dams is due to erosion and hence is gradual. The study of dam break is vital for disaster management as well as for development of plains in the vicinity of the dam. Dam break modelling helps in making preparedness plans, issue of emergency warnings and planning downstream development. Dam break modelling entails the following:

i.) Determining the outflow hydrograph and the peak discharge.
ii.) Routing the peak discharge and prediction of hydrograph at different sections downstream up to the point of consideration on the river.
iii.) Mapping of inundation levels.

II. LITERATURE REVIEW

Dam break has been a topic of concern and research since long time. Dam break study involves a detailed study of occurrence and propagation of breach with time and analysis of the resulting flood. Much research has been done in the area of prediction of breach shape and its variation with time. One of the pioneers in this area was Cristofano (1965), he estimated the breach erosion process taking the angle of repose of a given soil as the primary input. Harris and Wagner (1967) considered a parabolic dam breach shape along with assumptions regarding breach dimensions and sediment properties to predict breach flows.

Johnson and Illes (1976) worked on different breach shapes of earthen, gravity and arch dams. He expounded trapezoidal breach shape and few triangular breach shapes for the earthen dams. Singh and Snorrason (1982) with their study of 20 dam failures inferred the variation of breach width from two to five times the height of dam. They observed that the time taken for complete failure of dam, was generally 15 minutes to 1 hour. In their study for overtopping failures, the maximum overtopping depth before the failure ranged from 0.15 to 0.61 meters.

MacDonald and Langridge-Monopolis (1984) proposed a breach formation factor, defined as the product of the volume of breach outflow and the depth of water above the breach at the time of failure. Further, they concluded from analysis of the 42 case studies cited in their paper that the breach side slopes could be assumed to be 1H: 2V in most cases; the breach shape was considered to be triangular or trapezoidal.

Singh and Snorrason (1984) compared the results of DAMBRK and HEC-1 for 8 hypothetical breached dams. By varying the breach parameters they predicted the peak outflows using both the models. In their results they showed that for large reservoirs the change in B_W (breach width) produced larger changes (35-87%) in peak outflow and for small reservoirs the peak outflow (6-50%) were less. They observed that the flood stage profiles predicted by the NWS were smoother and more reasonable than those predicted by the HEC. For channels with relatively steep slopes, the methods compared fairly well, whereas for the channels with mild slope, the HEC model often predicted oscillating, erratic flood stages, mainly due to its inability to route flood waves satisfactorily in non-prismatic channels.

Petra check and Sadler (1984) studied the sensitivity of discharge, flooding levels, and flood arrival time with the change in breach width and breach formation time. Based on their study they concluded that for locations close to the dam, both parameters have reasonable impact whereas for locations well downstream from the dam, the timing of the flood wave peak can be modified significantly by changes in breach formation time, but the peak discharge and flooding levels are insensitive to changes in breach parameters

Froehlich (1987) has performed extensive case studies of actual dam failures. On the basis of data obtained from these studies he developed non dimensional prediction equations for estimating the average breach width, breach formation time and average side-slope factor. Froehlich additionally concluded that, all other factors being equal, breaches caused by overtopping are wider and erode laterally at a faster rate than breaches caused by other means.

Wurbs (1987) on the basis of his study concluded that breach simulation contains the greatest uncertainty of all aspects of dam-breach flood wave modeling. The importance of different parameters varies with reservoir size. In large reservoirs, the peak discharge occurs when the breach propagate to its maximum depth and width. Changes in reservoir head are relatively slight during the breach formation period. In these cases, accurate prediction of breach geometry is most critical. For small reservoirs, there is significant change in reservoir level during the formation of the breach, and as a result, the peak outflow occurs before the breach has fully developed. Hence for such cases, the breach formation rate is the crucial parameter.

Singh and Scarlatos (1988) documented breach geometry characteristics and time of failure tendencies from a survey of fifty two case studies. They found that the ratio of top and bottom breach widths, ranged from 1.06 to 1.74, with an average value of 1.29 and standard deviation of 0.180. The ratio of the top breach width to dam height was widely scattered. The breach side slopes were inclined at 10-50° from vertical in most cases. Also, most failure times were less than 3 hours, and 50 percent of the failure times were less than 1.5 hours.

Von Thun and Gillette (1990) and Dewey and Gillette (1993) used the data from Froehlich (1987) and MacDonald and Langridge-Monopolis (1984) to develop guidelines for estimating breach side slopes, breach width at mid-height, and time to failure. They proposed that breach side slopes be assumed to be 1:1 except for dams with very wide cohesive cores, where slopes of 1:2 or 1:3 (H: V) may be more appropriate.

Y. Xu and L. M. Zhang, M.ASCE (2009) compiled the data of 182 earth and rockfill dam failure cases, half of them were large dams having height above 15 m. A multiparameter nonlinear regression model was devised to develop empirical relationships between 5 breaching parameters(breach depth, breach top width, average breach width, peak outflow rate, and failure time) and selected five dam and reservoir control variables (dam height, reservoir shape coefficient, dam type, failure mode, and dam erodibility). The relative importance of each control variable was evaluated. The most important factor influencing all 5 breaching parameters was found to be dam erodibility.

L Y Sidek et al (2011) conducted a study to specifically model the dam beak of Saddle Dam A located in Keniyr reservoir. He performed dam break modelling for breach under two scenarios Probable maximum flood (PMF) scenario and clear day scenario. They predicted dam breach parameters using Froehlich and Macdonald–Langridge-Monopolis (MDLM) predictor equations. The modelling was done using MIKE 11 -1D hydrodynamic model developed by Danish Hydraulics institute (DHI) using which they simulated peak flows for both the scenarios.

Rasif Razach (2014) extracted geometric data for the Neyyar reservoir from Digital elevation model using ArcGIS for use in the HEC RAS (Hydraulic Engineering Center's River Analysis System) model. Further flow data was incorporated as input. The result from HEC RAS model output were than exported to ArcGIS to create flood plain maps. Anila C. George and B. T. Nair (2015) analyzed Dam Break Analysis of Thenmala Dam of Kerala State, India. The final analysis was done using BOSS DAMBRK software for evaluating the extent of inundation, travel time and velocity of downstream progressing water. They used ASTER digital elevation maps to obtain downstream river cross sections.

III. DAM BREAK ANALYSIS

Dam break modeling involves study of dam breach parameters and using them to predict reservoir outflow hydrograph which is then routed to downstream of river reach. As per Fread (1984) Breach is the opening shaped in the dam as it fails. The formation of Breach in a dam and the resultant shape of breach govern the outflow hydrograph and the downstream relocation of the flood wave. (Sidek 2011).

3.1 Breach parameters

Parameters which are required to characterize the breach are known as breach parameters. Breach parameters can divided into two categories

i.) Geometric parameters

ii.) Hydrographic parameters

The geometric parameters define the shape and size of the breach. The hydrographic parameters include peak outflow rate and time of failure. After the onset of breaching, the outflow through the breach increases until it reaches a peak, Q_p and then decreases until there is no longer any water in the reservoir or the breaching process ceases to develop (Chinnarasri et al. 2004). Failure time T_f is defined as the period from the initiation to the completion of the breaching process (Singh and Snorrason 1984).For estimating the breach parameters such as average breach width (B) and time of failure (T_f) some empirical equations which are in popular use are:

i.) Froehlich's Formulae(1995 B)

$B= 0.1803\ V_w^{0.32}\ h_b^{0.19}$

$T_f =0.00254\ V_w^{0.32}\ h_b^{-0.90}$

Where, V_w is volume of water behind the dam at failure in m^3 and h_b is the height of water above breach invert level.

ii.) Federal energy Regulatory Commission's formulae(FERC 1987)

$B= 2\text{-}4\ h_d$

$T_f =0.1$ to 1 hour

Where, h_d is the height of dam

iii.) Von-Thun and Gillete's formulae (1990)

$B=2.5\ h_w + C_b$

$T_f =0.02h_w+0.25$ for erosion resistant material

$T_f =.015h_w$ for easily erodible material

C_b is a factor that depends on the storage capacity of reservoir as shown below.

Where h_w is the height of water above breach invert level

Table.I: Value of C_b as a function of reservoir storage

Reservoir Size(m^3)	C_b (m)
< 1.23 x 10^6	6.1
1.23x 10^6 - 6.17 x10^6	18.3
6.17 x 10^6 - 1.23 x10^7	42.7
> 1.23 x10^7	54.9

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For estimating the peak discharge through a dam breach different empirical formulae have been developed on the basis of dam failure in past :

i) MacDonald and Langridge-Monopolis(1984)

$Q= 1.154(V_w\ h_w)^{0412}$

$Q=3.85(V_w\ h_w)^{0.411}$ (envelope equation)

ii) Singh and Snorrasan(1984)

$Q_p =13.4(h_d)^{1.89}$

iii) Froehlich (1995b)

$Q_p =0.607(V_w^{0.295}\ h_w^{1.24})$

Where V_w is volume of water behind the dam at failure in m^3 and h_w is the height of water above breach invert level at the time of failure and h_d is the height of dam.

Breach mode for a dam break event may be Linear i.e. breach dimension increases linearly with time. For erosion based failures classical sediment transport formulae is used for calculation sediment transport in the breach. The breach shape may be assumed to be triangular trapezoidal or rectangular.

3.2 Breach selection criteria

As per the UK dam Break Guidelines and U S federal Energy Regulatory commission (FERC) Guidelines, in the case of concrete gravity dams the breach width should be taken between 0.2 To 0.5 times the crest length of dam and full breach formation time may be taken as 0.2 to 0.25 hours. The final bottom level at the dam location should be restricted to reservoir bed level. According to the NWS (Fread 2006) guidelines, earthen dams average breach width varies from two to five times the height of dam and failure time varies from 0.1 to 1 hour.

IV. DAM BREAK MODELLING

Dam break modelling can be divided into three categories, first is Physical based modelling second is the regression analysis using available dam failure data and third is numerical simulation which is done using various computer software. There are a number of simulation software packages which give reasonably accurate results for storage type dams and tailings dams. Simulation mostly involves solution of solve 1-D Saint Venant equations using implicit finite difference models in order to determine discharge and depth variation at different sections with time. Some of the commonly used modelling software are:

i) MIKE 11 1-D Hydrodynamic Model developed by Danish Hydraulics Institute (DHI). It is based on implicit, finite difference computation of unsteady flows in river and estuaries. The formulation can be applied to branched and looped networks and flood plains. Mike Hydro which is a part of MIKE ZERO package can be used to create input geometric features from DEM's for MIKE 11

ii) Hydraulic Engineering Center's River Analysis System (HEC-RAS) uses algorithms to model both overtopping and piping breaches. HEC-RAS uses hydraulic principles through cross sections upstream and downstream of the dam to define how the reservoir drains during the formation of a dam breach. The dam crest is modelled as an inline weir and either a piping failure or overtopping failure is simulated with enlargement of the breach occurring over time as defined by a specified breach progression

iii) DAMBRK was initially developed by the National Weather Service in 1984, it was than Updated by BOSS International. It predicts the dam breach wave formation and its downstream progression. The software allows the user to input geometric and temporal data for the dam break to accurately predict the initial breach wave, including modelling piping and overtopping failures

iv) SMPDBK developed by the National Weather Services as a simpler version of DAMBRK. It Returns virtually the same results as the normal DAMBRK software in simpler cases. Three assumptions have been made in order to simplify the model firstly initial breach has been assumed to be constant and rectangular. Secondly the reservoir surface is assumed to be constant and last that breach time is equal to Peak flow time.

v) BOSS DAMBRK was developed from original NWS DAMBRK code. It was improvement over original as it provided faster calculation and better graphic interface

vi) FLO-2D model developed from a model developed by Jim O'Brien for FEMA called MUDFLOW in 1989. It is helpful in predicting flood hazard, mudflows, and debris flows over alluvial fans. It uses a grid system to determine the layout of the floodplain based on elevation, roughness factor, and flow. It can be used to model both clear as well as sediment flow.

vii) FLDWAV has been developed by the NWS to replace DAMBRK. It adds wave front tracking for more accuracy and better time based models Designed to model rapid flood events from large precipitation events or dam break occurrences.

V. INPUT DATA REQUIRED FOR DAM MODELLING

Numerical simulation of dam break generally requires the following data as input:

i) Elevation area capacity curve of the reservoir

ii) River cross sections downstream of a dam at suitable intervals. The river cross section data can be obtained either from actual survey along the river or extracted through a high resolution Digital elevation map

iii) Rating curve of spillways and sluices

iv) Design flood hydrograph as upstream boundary condition for the dam

v) Rating curve or time series water level for downstream boundary conditions

vi) Salient Features of all hydraulic structures

vii) Details of inflow and outflow of all tributaries and branches for the river reach under study

viii) Manning's roughness coefficient for the site

ix) Construction material properties for the earthen dams(Grain diameter, Density , Porosity)

VI. DAM BREAK MODEL SETUP IN GENERAL

The dam break model includes several channels, reservoirs, dam break structures, spillways sluices etc. The river is represented in the model by cross sections at regular intervals. Most preferably the cross sections should be closely spaced especially where the river changes its flow direction so as to accurately describe the river course. The reservoir is normally modelled as a storage area to describe the storage characteristics by the use of storage volume at different levels. This location will be at the upstream boundary of the model where inflow hydrograph may be specified. The downstream boundary condition will be either stage discharge relation or time series water level as in case of tidal waves etc.

VII. CONCLUSION

The dams are massive structure impounding a large volume of water in the upstream of reservoir. Failure of dam is disastrous to human life as well as property hence dam break analysis is of utmost importance. The most popular and comprehensive software used for Dam break modelling are MIKE 11 and HEC-RAS. Different probable dam break scenarios can be modelled for each dam depending on the critical likely situations. The result of the dam break analysis can be used for preparing emergency action plan and also planning disaster mitigation measures

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