Dam Break Analysis - Review of Literature

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Abstract - **Construction of Dams serves various purposes such as power generation, irrigation, flood control, etc. With all the benefits, failure of dam structure can cause tremendous losses by generation of unforeseen floods in the downstream area. To reduce these threats dam break analysis becomes necessary to predict inundation levels and flood prone zones in the downstream area of the dam. Present study gives a literature review of Dam Break Analysis. It covers prediction of breach parameters and Dam break model setup in general. Implementation of Dam break analysis can benefit the people living in the downstream of the dam against floods with the help of inundation maps which can be generated by incorporation of results from dam break analysis with GIS.**

Keywords —Breach parameters, Dam Break Analysis, Dam break model setup, HEC-RAS, Innundation Maping, MIKE 11, Peak Discharge, Saint Venant's Equations.

I. INTRODUCTION

1.1 General

Dams are structures constructed across rivers to serve various purposes. Construction of dams has been in practice since a very long time. With the progression of time, various types of dams were constructed based on the location and prerequisite of society and designs were enhanced with the advancement of technology. The types of dam commonly found are:-

- Earthen/Rockfill dams
- Concrete and Multi-arch dams
- Gravity Dams
- Buttress dams
- Concrete, steel, timber and composite material dams.

With all the benefits, constructions of dams may prompt to tremendous problems on the failure of the dam structure. Dam failure is generally catastrophic and may occur due to many reasons such as piping through the structure, overtopping, design error, heavy rainfall generated runoff, earthquake, etc. There are total 13 causes of failure listed in Hydrologic Engineering Centre (HEC) research document [1]. Whatever might be the reason, the results are devastating. On failure of a structure the energy stored behind the dam can cause a rapid and unexpected flood in downstream of the dam, resulting in loss of life and property. Middlebrooks [2] specified scenarios for dam failure cases. Table 1 shows the causes of Earth dam failures due to various reasons.

As a dam break possess high hazards, dam break analysis is considered very essential. Dam break analysis can be carried out by either Mathematical simulation using the computer or scaled physical hydraulic model.

According to Dam Safety Office, Water Resources Research laboratory Reclamation (1998) [3] methods of analysis are grouped into four categories:-

(i) Physically Based Methods: Using erosion

models based on principles of hydraulics, sediment transport and soil mechanics, development of breach and resulting breach outflow are anticipated.

(ii) Parametric Models: Time to failure and

ultimate breach geometry are assessed utilizing case studies and then breach growth is simulated as a time-dependent linear process and breach outflows are computed using principles of hydraulics.

(iii) Predictor Equation: Using data of case studies, peak discharge is estimated from empirical equations and a reasonable shape of outflow hydrograph is assumed.

(iv) Comparative Analysis: Breach parameters are determined by comparison of dam under consideration and a dam that failed.

Table 1. Causes of Earth Dam Failures 1850-1950

Cause	Source Mechanism	% of Total
Overtopping	Flood	30%

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Piping/Internal erosion of Embankment or Foundation Conduit Leakage Damage/Failure of Upstream Membrane/Slope Paving	Seepage, Piping And Internal Erosion	25% 13% 5%
Embankment Instability Slides	Varies	15%
Miscellaneous	Varies	12%

There are two important parameters of dam breach analysis i.e. Prediction of reservoir outflow hydrograph and routing of that hydrograph through the downstream area. To predict reservoir hydrograph there are some fundamental steps to be followed such as prediction of breach characteristics which includes the shape and size of the breach and rate of breach formation, routing of reservoir storage and inflow through the breach.

1.2 Objectives:-

The following are the objectives of Dam Break Analysis:-

(i) Determination of outflow hydrograph and the peak discharge.

(ii) Estimation of dam breach parameters using appropriate empirical formulae.

(iii) Routing of peak discharge and prediction of hydrograph at different sections in downstream up to the point of consideration.

(iv) Mapping of Inundation levels.

II. LITERATURE REVIEW

Dam break has been a theme of concern and research for a long time. Dam break study incorporates occurrence and proliferation of breach with time and analysis of the subsequent flood. Extensive research has been done in the area of prediction of breach shape and its alteration with time.

There is an immense literature and case histories available about dam break modeling.

Cristofano (19650 [4] considered the angle of repose of given soil as dominant input for the estimation of the process of the breach erosion.

Harris and Wagner (1967) [5] predicted breach flows for a dam breach of parabolic shape while considering some assumptions for breach parameters and sediment properties.

Johnson and Illes (1976) [6] described failure shapes of arch dams, gravity dams, and earthen dams. He explicated trapezoidal and few triangular breach shapes particularly for earthen dams.

Singh and Snorrason (1982) [7] studied 20 dam failures and deduced the variation of breach width from 2 to 5 times the height of the dam. They observed that it will take 15 minutes to 1 hour for the complete failure of the dam and in the case of failure due to overtopping, the maximum depth before failure ranged between 0.15 to 0.61 meters.

MacDonald and Langridge-Monopolis (1984) [8] introduced breach formation factor as the product of breach outflow volume and the depth of water above the breach during failure. They analyzed 42 case studies and concluded that the breach side slope could be assumed to be 1H: 2V in most of the cases, considering the breach shape to be triangular or trapezoidal.

Singh and Snorrason (1984) [9] analyzed 8 hypothetical breached dams and compared the results of DAMBRK and HEC-1. They predicted peak outflows by varying breach parameters using both the models. From the conclusion of their work, they showed that for large reservoirs the change in breach width (B_w) produced large changes in the range of 35 to 87% in peak outflow in comparison of small reservoirs that produced small changes in the range of 6 to 50 %. They also observed that NWS produced smoother and reasonable flood stage profiles than those predicted by HEC. For steep slopes both the models performed well but for mild slopes, HEC model predicted oscillating and erratic flood stages as HEC model is unable to route flood waves in non-prismatic channels.

Petra Check and Sadler (1984) [10] By changing the breach parameters i.e. breach width and breach formation time they studied the sensitivity of discharge, flood levels and flood arrival time. From the results of their analysis, they concluded that both parameters have a reasonable impact for locations close to the dam whereas for locations well downstream of the dam, both peak discharge and flooding levels are insensitive to changes in breach parameters while the timing of flood wave peak can be modified by changes in breach formation time.

Froehlich (1987) [11] analyzed comprehensive case studies of real dam failures. From his analysis, he developed non dimensional prediction equations for the estimation of the average breach width, formation time and average side-slope factor on the basis of data obtained from case studies. By considering all the factors being equal, he also concluded that breaches caused by overtopping are wider and also erode faster laterally in comparison of breaches caused by other means.

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Wurbs (1987) [12] performed numerous scenarios and concluded that breach simulation contains the greatest uncertainty among all aspects of dam breach flood wave modeling. He also mentioned that with the variation of reservoir size, the importance of different parameters also varies. He analyzed that in the case of large reservoirs, the peak discharge occurs when breach attains maximum width and depth, therefore, it is most critical to accurately predict breach geometry. But in the case of small reservoirs, peak discharge occurs before the development of breach and hence, breach formation rate is considered to be a crucial parameter in these cases.

Singh and Scarlatos (1988) [13] analyzed 52 case studies and documented about characteristics of breach geometry and time of failure tendencies. They concluded that the ratio of top breach width to dam height was considerably scattered and found that the ratio of top and bottom breach widths were in the range of 1.06 to 1.74 having an average of 1.29 with the standard deviation of 0.18. In most of the cases, side slopes of the breach were inclined at 10-15º from vertical. They also deduced that most failure times were within 3 hours and 50% of the failures times were within 1.5 hours.

Von Thun and Gillette (1990) and Dewey and Gillette (1993) [14] They developed guidelines for the estimation of breach parameters such as breach width at mid-height, side slopes and time to failure by analyzing data from MacDonald and Langridge-Monopolis (1984) and Froehlich (1987). They suggested that side slopes of breach should be 1:1 except for dams having cores of highly cohesive nature where slopes of 1:2 and 1:3 may be appropriate.

Y. Xu and L. M. Zhang, M.ASCE (2009) [15] studied earth and rockfill dam failure cases of 182 dams among which 50% of dams were having the height above 15 meters i.e. large dams. They came up with a nonlinear regression model by selecting 5 dam and reservoir control variables i.e. dam type, dam height, failure mode, dam erodibility and reservoir shape coefficient and developed empirical relationships between five breaching parameters (breach width, breach top width, average breach width, peak outflow rate and failure time) and also evaluated importance of relativity among each control variables. And dam erodibility factor was found to be most influencing breach parameter.

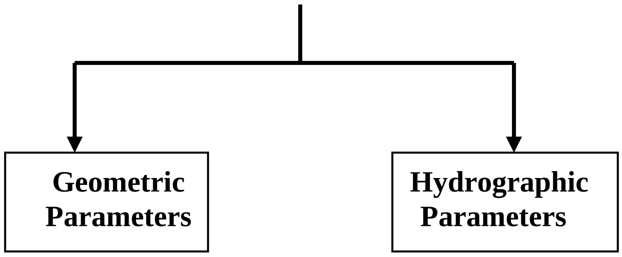
L.Y. Sidek *et al.* (2011) [16] Performed dam break modeling for a saddle dam for breach under Probable Maximum Flood scenario and clear day scenario. From their analysis, they predicted dam breach using Froehlich and MacDonald and Langridge-Monopolis predictor equation.

Rasif Razach (2014) [17] In his study he incorporated flow data and Digital Elevation Model as input in HEC-RAS and created flood plain maps using ArcGIS by importing the output from HEC-RAS.

III. DAM BREAK ANALYSIS

The study involves prediction of reservoir outflow hydrograph and then routing of that hydrograph through the downstream river. According to Sidek [16] formation and shape of breach governs the outflow hydrograph.

3.1 Estimation of Breach Parameters



Breach parameters can be distinguished in two categories:-

Shape and size of a breach are defined by Geometric parameters and peak outflow rate and time of failure comes under hydrographic parameters.

There are three main empirical equations which are mostly used for the prediction of breach geometry:-

(i) Mac Donald and Langridge-Monopolis (1984) [8] :-

$$V_{er} = 0.0261(V_w h_w)^{0.769}$$

$$t_f = 0.0179\, V_{er}^{\,0.364}$$

Where, V_{er} = volume of the material eroded from the embankment (cubic meter)

V_w = volume of water that passes through the breach (cubic meter)

h_w = depth of water above the bottom of the breach (meter)

t_f = failure time

(ii) Von Thun and Gillette (1990) [14] :-

$$B_{avg} = 2.5h_w + C_b$$

$$t_f = 0.015h_w$$

Where, B_{avg} = breach width (meters)

t_f = failure time

C_b = reservoir coefficient

h_w = depth of water above the bottom of the breach (meters)

Value of C_b as a function of reservoir storage can be taken from following table:-

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Table 2 – Value of C_b depending upon reservoir size

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

(iii) Froehlich (1995) [18] :-

$$B_{avg} = 0.1803 K_o V_w^{0.32} h_b^{0.19}$$

$$t_f = 0.00254 (V_w)^{0.53} h_b^{-0.9}$$

Where, K_o = failure coefficient

B_{avg} = breach width

t_f = failure time (hours)

h_b = breach height

On the basis of dam failure in past different empirical formulae have been developed for the estimation of peak discharge through a dam breach.

(i) Mac Donald and Langridge-Monopolis (1984) [8]

$$Q = 1.154 (V_w h_w)^{0.412}$$

(ii) Singh and Snorasson (1984) [9]

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

(iii) Froehlich (1955) [18]

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

Where, V_w is volume stored behind the reservoir at failure in m^3

h_w is height of water above breach invert level h_d is height of dam

1.2 Dam Break Model Setup in General

The core of dam break modeling is hydrodynamic modeling which is based on two partial differential equations given by Barre De Saint Venant in 1871[19]. These equations are:

(i) Conservation of mass (continuity) equation

$$\partial Q/\partial X + \partial (A + A_o)/\partial t - q = 0$$

(ii) Conservation of momentum equation

$$(\partial Q/\partial t) + \{\partial (Q^2/A)/\partial X\} + gA(\partial h/\partial X) + S_f + S_c) = 0$$

Where Q = discharge

A = active flow area

A_0 = inactive storage area

h = water surface elevation

q = lateral outflow

X = distance along waterway

t = time

S_f = friction slope

S_c = expansion contraction slope and

g = gravitational acceleration.

3.3 Cross-sections of Downstream River

The downstream river of the dam is represented in model by taking cross-sections at different intervals up to the point of consideration. These cross-sections can be taken either by surveying of downstream area or with the help of Google Earth. Firmly divided cross-sections are recommended at the area where the geometry of river is changing rapidly.

3.4 Roughness Coefficient

Depending on the bed characteristics of the downstream channel, roughness coefficient is assigned in the model at different sections having changed characteristics. The value of roughness coefficient may be provided by following Chow (1959) guidelines. **[20]**

IV. CONCLUSION

(i) Based on the present literature review it has been found that for almost all types of Dams, HEC-RAS and Mike 11 Software are best for breach analysis.

(ii) HEC-RAS is most preferable as it is easily available.

(iii) Most common shape of breach is trapezoidal.

(iv) For better accuracy, downstream river cross-sections must be taken by surveying.

(v) Different values of roughness coefficient must be assigned at different sections of the downstream river as characteristics of channel keeps on changing from place to place.

(vi) The results from dam break analysis can be incorporated with GIS to make inundation maps and Emergency Action Plans to aware and rescue inhabitants living in the downstream area.

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