Dam Break Analysis - A Review

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Abstract – This review paper is mainly focused the methods used for dam break analysis. The said analysis is very useful in estimation of flood after dam break. Also, there are other advantages of dam break analysis which are important from planning point of view on downstream side of the dam for assessment of emergency facilities.

Index terms – Dam-Break Analysis, Dam Breach, Methods for Dam-Break Analysis

I. INTRODUCTION

1.1. Dam Break Analysis:-

Dam break analysis is characterization and identifying of potential dam failures are post effects of resulting floods from dam breach. The classification of dams is to be made for the threat to public safety and also the standard of care, safety and maintenance of dam. The requirement to prepare an emergency action plan, requiring preparation of inundation maps predicting the dam breach flood depths and arrival times at critical locations. The population associated along with the critical section are located in close vicinity of downstream of a dam, details of the breaching process and the calculated peak discharge may have little effect on the results. The breach parameters like breach width, depth, and rate of development are more crucial to analyse especially when the locations of population centres are near to the dam. The estimated cost and assumptions increases if the breach parameters cannot be predicted with reasonable accuracy. A recent query of the dam safety engineers within the Colorado Dam Safety Branch determined that there is currently no consensus nor up-to-date guidance regarding the state-of-the-practice procedures for performing dam breach analysis. They have formed the committee of dam safety engineers to perform a literature review of the current state-of-the-practice, research available methods, and develop a guidelines for use within the Branch and for engineers working on dam [i]. This study can also estimate high flood level and, to fix the flood control lines on downstream side of the dam, estimation of wave pressure after dam break. This study also focus on to understand the hydraulic characteristics and breach shape, understand the flow of huge debris from upstream as well as downstream which will be carried away with flow after dam break, study the erosion of dam after dam break, it give important information for embankment on the downstream sides of the river. It also helps to avoid erosion of soil along the embankment of downstream.

1.2. Need for Dam-Break Analysis:-

Two major consequences of a dam failure are:-

1. Life loss: This loss occurs if the villages and the residing families are washed away by the flood resulting from dam-break.

2. Economic: Economic loss is calculated in terms of revenue which will be required to rebuild the washed away villages in terms of infrastructure, and other allied facilities.

The dam break analysis will make possible to estimate the flood and flood affected areas at downstream due to breach. This enables the cost estimation in case of rehabilitation. The study sees the possibilities of precautionary measures which can be taken to completely avoid the dam break which avoid or minimize damage.

This study will help the town-planner decide on the no development zone, flood control lines within certain limit after the embankment along the river.

1.3. Significance of Dam break analysis [ii] :-

The dam break analysis study will help us:

1) Estimate the flood, high flood level and flood affected areas near the dam.
2) To fix the flood control lines on downstream side of the dam.
3) Estimation of wave pressure after dam break.
4) It helps to understand the hydraulic characteristics and breach shape.
5) Understand the flow of huge debris from upstream as well as downstream which will be carried away with flow after dam break.
6) It will also help us study the erosion of dam after dam break.
7) It will give important information for embankment on the downstream sides of the river. This will help avoid or minimize damage.
8) It will also help avoid erosion of soil along the embankment of downstream.
9) This study will help the town planner decide on the no development zone within certain limit after the embankment along the river. It means no residential buildings will be allowed but the land can be used for irrigation with low cost crops.
10) It also helps town planner to plan city or village (taking into consideration the flood control lines) based on the results of this study.
11) In case of dam break, what safety measures are required to be taken in place?
12) It will also help in disaster management & planning in case of dam break.
13) This will help estimate the cost required for rehabilitation or flood affected villages.

II. METHODOLOGY

In dam-break analysis, it is important to understand the critical breach parameters. There are four such critical parameters:
1) Breach parameter estimation (breach size/shape and time of failure).
2) Breach peak discharge and breach hydrograph estimation,
3) Breach flood routing, and
4) Estimation of the hydraulic conditions at critical locations.

For understanding the concept, the same can be explained as shown in the following Figure [vi].

Various methods are described in guidelines framed by State of Colorado department of natural resources division of water resources for Dam break analysis.

2.1 Comparative analysis:-

Comparative analysis is the simplest approach to dam break flood estimation. As it is name of this method makes a comparison between the dams which is under study with the database available from a well-documented dam failure cases in history. The comparison begins with finding similarity between the dam under consideration and the list of similar sized dam that have failed in the past. The dam’s geometry, height, slope angles and reservoir area and volumes are compared in order to find similarity. Once a similar dam is identified, then the dam breach parameters and peak discharge values reported from the failure case history are directly applied to the dam being analyzed.

2.2 Empirical equations:-

The Empirical methods are utilized to several parameters related to dam break. These parameters include, time to failure, breach geometry. It also helps to predict peak breach discharge, The empirical approach relies on statistical data which is analyzed from the history of documented failures.

The four most widely used and accepted empirically derived enveloping curves and/or equations for predicting breach parameters are:
1) MacDonald & Langridge – Monopolis (1984)[iv],
2) USBR (1988),
3) Von Thun and Gillette (1990)[v] and

The predicted values using these methods when compared to the actual values; a very good correlation was found. The most basic statistical process generally involves plotting data for variables extracted from the dam failure dataset such as volume of embankment removed, volume of water released, height of water behind the dam, and development time of the failure. In few of the cases other variables like Breach Formation Factor (BFF) are derived based on the products of these variables. The best fit curve or envelope is developed by plotting these variables and factors against each other on log-log plots and least squares. Since these curves are based on actual data, they can then be used for prediction of hypothetical dam breach cases. MacDonald & Langridge-Monopolis method (1984) is a perfect example of an empirical method which estimates the embankment volume removed the development time and the peak discharge of a breach; and it does so by using a reserved volume and height.

2.3 Models:-

Models are being used in Dam break analysis. Various models are described below:-

2.3.1 Physically-Based Models:-
A physically-based model (also referred to as a "process" or "causal" model) utilizes generally accepted relationships based on physical principles to establish the framework of a model. For a given input the model then attempts to solve those relationships. It is relatively a very simple concept. But can become complex if the input is changing time to time. Now, as the dam erodes during breach, both the input and physical constraints are changing with time. This happens as the reservoir evacuates. Although several physically-based models have been reported as being in the development stage for research purposes, the National Weather Service’s BREACH program (NWS BREACH or BREACH) is currently the only widely available model. BREACH predicts the development of a breach and the resulting outflow using an erosion model based on principles of hydraulics, sediment transport and soil mechanics. The very first development happened in 1987, and it went under significant upgrades in 1988, 1991 and 2005. Several components of dam and reservoir such as area versus elevation, dam dimensions, and soil properties of the dam, and tail water effects downstream which are not considered in empirical methods are taken into account in this method. It is relatively simple to run and is widely used within the United States. Unfortunately, BREACH is no longer supported by the National Weather Service and significant advances in the understanding of the complex mechanics of a dam failure have not been incorporated (Wahl, 1998). Also, the model has only been calibrated with a very limited number of cases.

2.3.2 Parametric Models:-

Parametric models like HEC-1, HEC-HMS and HEC-RAS estimate peak discharge and breach hydrographs from dam breaches based on parameters. These parameters are breach geometry and breach development time and are provided by the user. The flood routing of the hydrograph downstream can also be calculated using these computer models, and, in the case of HEC-RAS, can be used to estimate the hydraulic conditions at critical downstream locations.

2.3.3 Hydrologic Models:-

Hydrologic routing employs the continuity equation and an analytical or an empirical relationship between storage within the reach and discharge at the end (USACE, 1994). The hydrologic routing models offer the advantages of simplicity, ease of use and computational efficiency (USACE, 1994) in the absence of significant backwater effects. Hydrologic routing models provide attenuated flow hydrographs at locations of interest, but do not provide useful information on water surface elevations or flow velocities. HEC-1 and HEC-HMS are the most widely used hydrologic models for dam safety analysis, and both contain a parametric dam breach routine that calculates the breach hydrograph.

2.3.4 Hydraulic Models:-

Hydraulic models, in general, are more physically based than hydrologic models since there is only one parameter to calibrate that is the roughness coefficient. The full unsteady flow equations have the capability to simulate the widest range of flow situations and channel characteristics.

The basic data requirements for hydraulic routing techniques include:

1) Flow data
2) Channel geometry
3) Roughness coefficients and
4) Internal boundary conditions

Hydraulic modeling is further subdivided into steady flow analysis and unsteady flow analysis. In unsteady flow, time dependent changes in flow rate are analyzed explicitly as a variable, while steady flow analysis models neglect time all together (USACE, 1993). Steady flow analysis can determine a water surface elevation and flow velocity at a given cross section for a given flow using Manning’s equation under the assumption of gradually varied flow conditions. Downstream attenuation of the flood wave can be evaluated using unsteady flow analysis. This provides a more accurate Guidelines for Dam Breach Analysis February 10, 2010 9 estimate of flood magnitude and velocity at critical locations. HEC-RAS is the most widely used hydraulic model for dam safety analyses in the United States and can be utilized for steady and unsteady flow analyses. The latest versions of HEC-RAS (since version 3.0) have a parametric dam breach routine that can calculate a breach outflow hydrograph within an unsteady flow simulation. NWS DAMBRK model is another hydraulic model which is very widely used for unsteady flow analysis. A graphical user interface (GUI) has been added by BOSS Corporation. However, the same numeric algorithm is maintained. This made the model more user-friendly. This version is called BOSS DAMBRK. The model is based upon the same basic unsteady routing hydraulic principles as HEC-RAS, but DAMBRK was specifically developed for modeling dam failures. The cross-section input requirements for routing dam break floods require the same number of points to represent every cross section, which limits its usefulness.

2.4 The Graham Method:-

The Dam-break analysis can also be done by another empirical method known as Graham method [ix]. This method is discussed as below.

DSO-99-06 is an empirical life loss estimation tool developed with the following inputs.

- Every U.S. dam failure that resulted in more than 50 fatalities and every dam failure that occurred after 1960 resulting in any fatalities.
- Using a data set which totaled approximately 40 floods which were caused by dam failure.
The procedure is composed of 7 steps:

1) Determine dam failure scenarios to evaluate.
2) Determine time categories for which loss of life estimates are needed.
3) Determine when dam failure warnings would be initiated.
4) Determine the area flooded for each dam failure scenario.
5) Estimate the number of people at risk for each dam failure scenario and time category.
6) Apply empirically based equations or methods for estimating the number of fatalities.
7) Evaluate uncertainty.

2.5 Emergency Action Plan (EAP):

In India, Dam break analysis was started in 2006. The guidelines are framed and Emergency Action Plan (EAP) is prepared i.e. (Guidelines for Development and Implementation of Emergency Action Plan (EAP) for Dams, Govt. of India, 2006) is a formal Emergency Action Plan (EAP) document that identifies potential emergency conditions at a dam and specifies preplanned actions to be followed to minimize property damage and loss of life. The EAP contains procedures and information to assist the dam owner in taking necessary actions in time to moderate or alleviate the problems, in addition to issuing early warning and notification messages to responsible emergency management authorities, viz., District Magistrate/Collector, Armed forces, Paramilitary forces, Project Authorities and other Central/State Agencies. It also contains inundation maps to show the emergency management authorities of the critical areas for necessary relief and rescue actions in case of an emergency. In a nutshell, it outlines “who does what, where, when and how” in an emergency situation or unusual occurrence affecting the dams.

In India, there are about 4050 completed large dams and another 475 are under construction (as per National Register of Large Dams – 2002). Emergency Action Plans are, however, not available for most of the completed large dams. The National Water Policy, 2002, recognizing this deficiency, has stressed for preparation of EAP for all large dams.

Dams store large amount of water. Uncontrolled or excessive release of such a huge amount of water has great potential for loss of life and damage to property in the downstream areas due to excessive flooding. Such situations can occur due to several reasons, such as, breach of dam on account of earthquake, landslide and/or sabotage; excessive release of water on account of extreme storm events, etc. The EAP specifies actions the dam owner should take to moderate or alleviate the problems at the dam site as well as in the areas downstream of the dam. It contains procedures and information to assist the dam owner in issuing early warning and notification messages to responsible emergency management authorities, viz., District Magistrate/Collector, Armed forces, Paramilitary forces, Project Authorities and other Central/State Agencies. It also contains inundation maps to show the emergency management authorities of the critical areas for necessary relief and rescue actions in case of an emergency.

2.5.1 Scope:

Emergency Action Plan (EAP) is intended to help emergency officials, save lives, minimize damages to property, structures and inhabitations and also to minimize environmental impacts in the event of flooding caused by large releases from the dam, dam failure or in other such events that present hazardous conditions. The EAP will guide the dam operation supervisory personnel in identifying, monitoring, responding to and mitigating emergency situations. It outlines “who does what, where, when and how” in an emergency situation or unusual occurrence affecting the dams.

Certain causes such as heavy floods or dam failure may create emergency conditions at the dam site as well as in the areas downstream of the dam that will require warning, evacuation of the population at risk or other response actions. The EAP is intended to interface with the emergency operation plans of other Local, District and State agencies to ensure effective and timely implementation of response actions.

2.5.2 Inputs:

The following are the main inputs for preparation of an emergency action plan:

1) Probable Maximum Flood (PMF) / Standard Project Flood (SPF) / 500 / 100 years return period Flood hydrographs for the dam;
2) Flood hydrograph due to combination of PMF / SPF coupled with dam break;
3) Inundation maps under different situations, viz., Dam break, PMF, SPF, 500 / 100 years return period Flood, etc.;
4) Assessment of safe carrying capacity of the downstream channel and the safe levels;
5) Assessment of potential damage to lives and properties at the dam site as well as in the areas downstream of the dam; and
6) Assessment of resources for relief & rescue measures.

III. CONCLUSION

Various methods are used in analysis of Dam break. Dam break analysis is very important tool in context of estimation of flood in case of dam break and designing downstream side. It is very difficult to estimate the loss due to dam break i.e. human, financial, social etc. for the
given dam. The care should be taken for regular maintenance of dam.

ACKNOWLEDGEMENT

I hereby take opportunity to give my sincere thanks to Dr. S. K. Ukarande and Prof. Seema A. Jagtap for their guidance and constant encouragement and support in this paper. I truly appreciate the value and their esteemed guidance and encouragement which would be remembered lifelong.

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