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# Dam Break Modeling for Large Earth and Rock-fill Dams

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## ABSTRACT

**Dam break analysis plays a very important role in the risk assessment of dams. Large dams pose significantly higher risks to the people and property downstream of the dam as compared to smaller dams. So the flooding risk due to the possible failure of large dams is more crucial. In this study, dam break modeling for very large dams has been focused. For this purpose, Mangla dam, located on Jhelum river in Pakistan, has been taken into consideration. With a height of about 125 m (after raising), Mangla dam is one of the largest earth and rock fill dams in the world. The Erosion based overtopping failure of Mangla dam with raised conditions has been analyzed by using MIKE 11 dam break module. The parametric approach has been used to estimate the breach geometry and simulate the breach growth as a linear process in order to determine the breach outflows. Different cases of dam breach have been considered for dam break simulations. The failure outflow hydrographs have been computed for different breach cases. Moreover, the time to failure and the breach erosion rate have also been determined for the considered breach cases. The maximum outflow for the worst case of dam failure is about 160,000 m$^3$/s which is about 2.5 times the maximum design flood for Mangla dam. This study would be useful for the dam break analysis and the risk assessment of existing & planned dams in Pakistan as well as in other parts of the world.**

## KEYWORD

**Mangla dam, Dam break, Breach geometry, Overtopping failure, MIKE 11**

## INTRODUCTION

The findings of dam break modeling are helpful in the risk assessment of dams. The flooding risk could be quite high due to the failure of large dams. This study elaborates the dam failure analysis of a very large earth and rock-fill dam. As a case study, Mangla dam in Pakistan has been considered. Mangla dam completed in 1967, is one of the largest earth and rock-fill dams in the world. The original height of the main dam is about 115.85 m above river bed [1]. The raising of the dam by about 9.15 m started in 2004 and it was planned to be completed by 2009 [2]. For this study, Mangla dam has been considered with raised conditions. The crest length of the main dam is about 2561m [3]. The original catchment area of the reservoir is about 33360 km$^2$ & water surface area (at conservation level) is about 253 km$^2$ [1]. Fig.1 shows the location of Mangla dam on the Jhelum river.

In this study, dam failure modeling has been carried out for the Mangla dam with raised conditions by using the MIKE 11 dam break module. An erosion based overtopping failure has been analyzed with respect to the estimated breach geometry. Different breach cases have been considered for the dam break simulations. Failure outflow hydrographs have been determined for different failure scenarios. Further, the time to failure and the breach erosion rate have also been computed for the considered dam breach cases.

## ESTIMATION OF BREACH PARAMETERS

The breach parameters have been estimated by using different available relations based on case studies. Two cases of dam breach have been considered for the computation of the breach geometry. (Tab. 1)

Tab. 1: The estimated breach parameters

| Case 1 | Case 2 |
|---|---|
| Z = 1.4 (Overtopping) | Z = 1.4 (Overtopping) |
| $d_{ovtop}$ = 0.61 m | $d_{ovtop}$ = 0.61 m |
| $h_w$ = 62.92 m | $h_w$ = 41.95 m |
| $h_b$ = 62.31 m | $h_b$ = 41.34 m |
| HB = 323 m asl | HB = 344 m asl |
| $B_{bot}$ = 185.34 m | $B_{bot}$ = 139.54 m |

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Fig. 1: Location of Main Pakistani dam sites [4]

Following is the description of parameters: [5, 6]

$h_d$ = Height of dam (m) (in this case, 125 m after raising)

CL = Crest level of dam (m) (in this case, 385.37 m asl after raising)

Z = Breach side slope factor (Z horizontal: 1 vertical); 1.4 for overtopping [7, 8 and 9]

$d_{ovtop}$ = Maximum overtopping depth (m) (0.15 to 0.61 m); 0.61 m considered in this case [10,11]

$h_w$ = Hydraulic depth of water at dam at failure, above breach bottom (m), [12,13]

$h_b$ = Height of breach (m), ($h_w$ - $d_{ovtop}$)

HB = Breach bottom level (m), (CL – $h_b$)

$B_{bot}$ = Breach bottom width (m), by $B_{avg} = 2.5h_w + C_b$ where $B_{avg}$ is the average breach width and $C_b$ is a function of reservoir storage [14, 15], and $B_{top}/B_{bot}$ =1.29 where $B_{top}$ is the breach top width and $B_{bot}$ is the breach bottom width [16]

Fig. 2 shows the main parameters of the breach in an idealized way. In large reservoirs, the peak discharge occurs when the breach reaches its maximum depth and width [5,6 and 17]

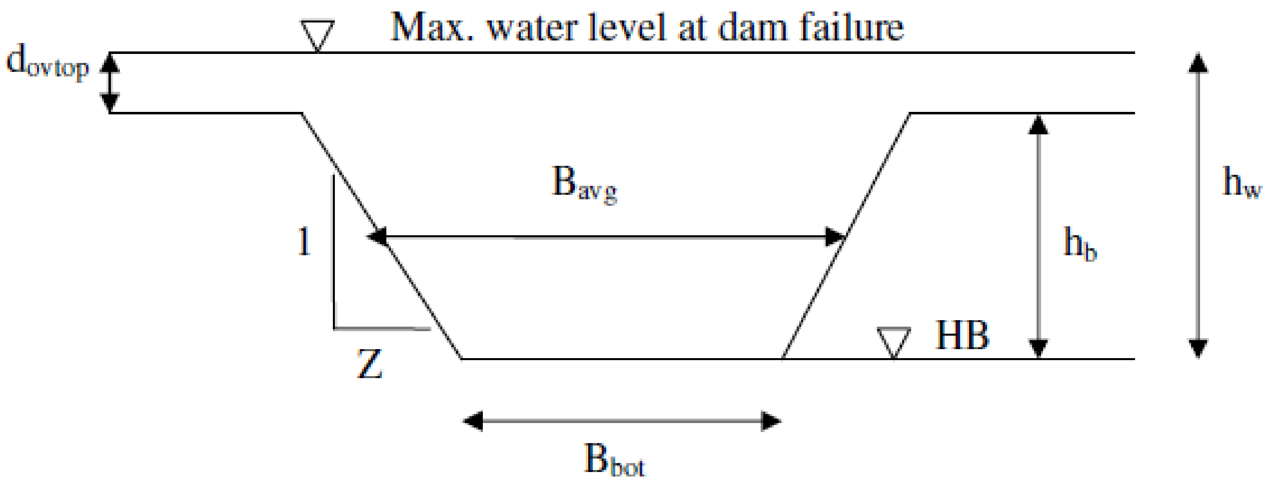


Fig. 2: Parameters of an idealized dam breach [18]

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## DAM BREAK MODELING IN MIKE 11

An erosion based overtopping failure of Mangla dam with raised conditions has been analyzed. Depending on the available data, the parametric approach has been used to estimate the breach geometry and simulate the breach growth as a linear process in order to determine the breach outflows.

### A) Theoretical background in MIKE 11

In MIKE 11, an erosion based breach development is modeled only by the energy equation. The initial and the final breach shape must be specified. During the development of the breach the trapezoid increases in size and changes the shape in a linear way as shown in Fig. 3.

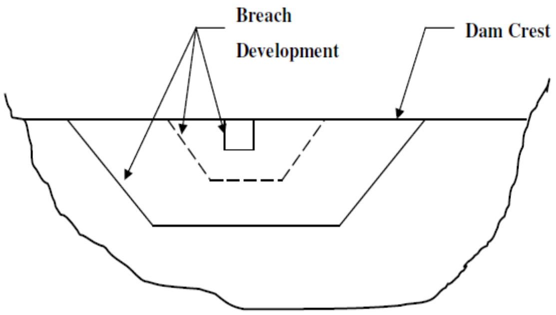


Fig. 3: Linear development of the breach [18]

The increase of the breach during a time step is calculated from the actual prevailing conditions in the breach itself. The sediment transport formula is used to compute the sediment transport in the breach [19].

The flow resistance is calculated as the total dimensionless shear stress, based on the Engelund formulation for flow resistance, *q-q´* relationship [20].

The sediment transport rate ($q_t$) is calculated from the Engelund-Hansen formula in terms of $m^2/s$ per meter-width of pure sediment. By application of the sediment continuity equation in the breach, the change in breach level ($dH_b$) in a time interval ($d_t$) is given in equation (1), [20]

$$\frac{dH_b}{d_t} = \frac{q_t}{L_b(1-\varepsilon)} \qquad (1)$$

Where
$H_b$ = breach level (m)
$q_t$ = sediment transport rate ($m^2/s$)
$\varepsilon$ = porosity of the sediment (%)
$L_b$ = breach length in the direction of flow (m)
$t$ = time

Modeling the variation of the breach width perpendicular to the flow direction is more difficult to relate to the classical theories of sediment transport. This is why for the development of a wall boundary layer along the often very steep side walls of the breach the theories for bed load and suspended load do not apply. As an approximation, the sediment transport at the sloping walls is assumed to be proportional to that in the central part of the breach. The coefficient of proportionality *SE* (side erosion index) relates the increase in breach width ($W_b$) to breach depth ($h_b$) as shown in equation (2), [20]

$$\frac{dW_b}{dh_b} = 2.SE \qquad (2)$$

Where
$W_b$ = breach width (m)
$h_b$ = breach depth (m)
*SE* = side erosion index, generally the side erosion index (*SE*) is in the range of 0.5-1.0

### B) Dam Break Setup in MIKE 11

The reservoir is modeled as a water level point in the model. This point also corresponds to the upstream boundary of the model where the inflow hydrograph is specified. So the surface storage area of the dam is expressed as a function of the water level. The dam break structure is located at the discharge point with the reservoir. Depending on the available data, the dam geometry and different material properties were defined [21, 22]. According to the available options in the model, an overtopping failure setup was made according to the following conditions [23].

1) When the water level in the reservoir exceeds the dam crest level (385.37 m), failure will initiate

2) The volume of water in Mangla reservoir at overtopping should be about 1.15 E+10 $m^3$ (max. storage capacity at crest level by the extrapolation of available data)

No sufficient information was available for the exact estimation of the side erosion index (*SE*) required in the model. The erosion increases with the increase in *SE* and vice versa. So two cases of erosion with respect to the side erosion index were considered for different dam failure cases, *SE*: 0.75 (mean value) and 0.6.

The estimated breach parameters (Tab. 1) were inputted accordingly in the model for different failure cases with respect to the two erosion cases as above mentioned. Finally, the model was run with unsteady flow conditions for an erosion based overtopping failure.

## RESULTS OF DAM BREAK SIMULATIONS

According to the breach parameters for different cases and dam break setup, simulations were run for the failure cases in order to determine the outflow hydrographs after failure. Fig. 4 and 5 show the computed failure outflow hydrographs with respect to the two erosion cases. The maximum outflow for the worst case of failure is close to 160,000 $m^3/s$ which is about 2.5 times the maximum design flood for Mangla dam i.e. 62,000 $m^3/s$.

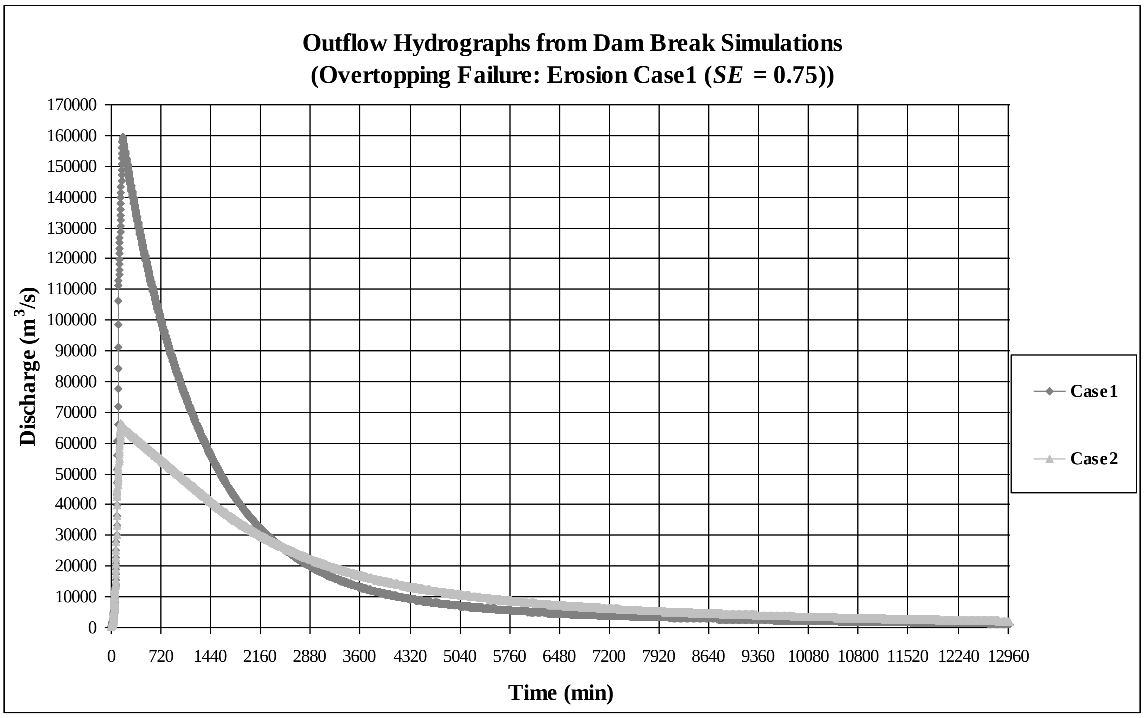


Fig. 4: Outflow hydrographs from dam break simulations (Erosion case1: *SE* = 0.75)

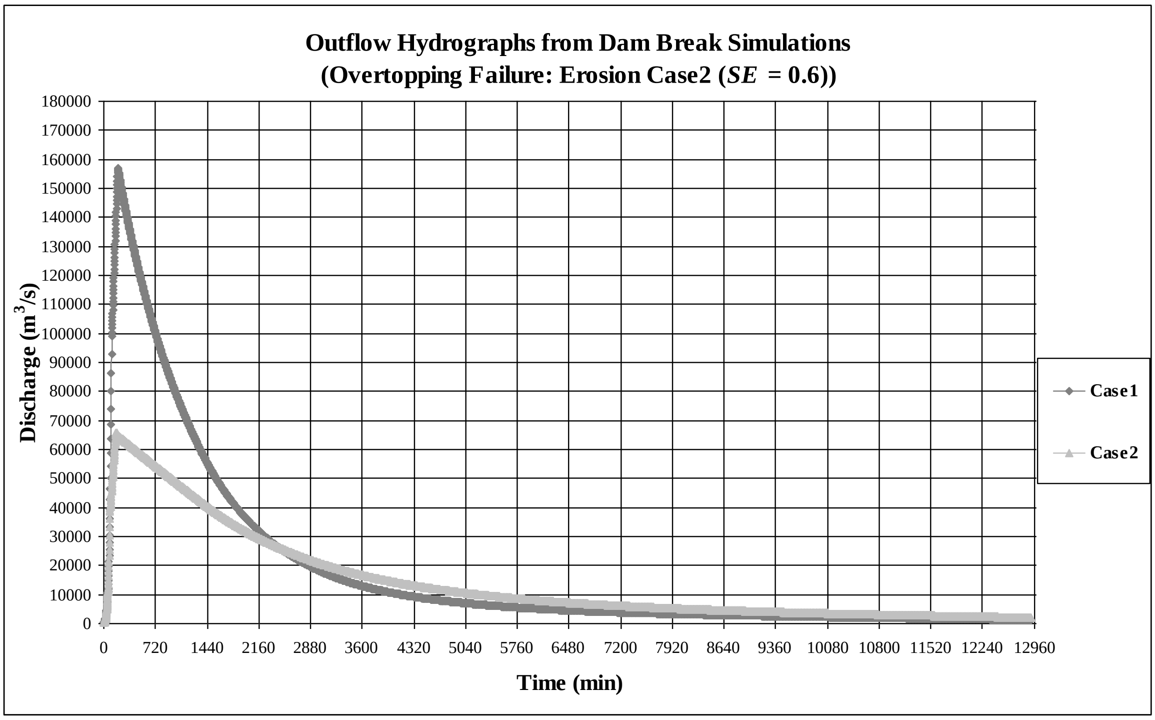


Fig. 5: Outflow hydrographs from dam break simulations (Erosion case2: *SE* = 0.6)

## CONCLUSIONS

This paper presents the dam break modeling of a large earth and rock-fill dam in Pakistan . Different scenarios of an

Erosion based overtopping failure for Mangla dam have been analyzed in MIKE 11 with respect to the considered breach cases. In different breach cases, the breach parameters have been estimated by using various relations based on case studies. The outflow hydrographs have been determined for different failure scenarios. Further, time to failure and the breach erosion rate have also been computed. The maximum outflow for the worst case is about 160,000 $m^3/s$ which is about 2.5 times the maximum design flood for Mangla dam i.e. 62,000 $m^3/s$. It was also found that with increase in erosion, the time to failure decreases and the breach erosion rate increases. The outcomes of dam break modeling are very important for the risk assessment of dams. MIKE 11 is a useful tool to model dam break scenarios with the variety of options. There could be some uncertainties in the estimated breach parameters because they are related to different case study relations. The results could be helpful in flood safety management of the areas downstream of Mangla dam. This study would also be useful for the dam break analysis and the risk assessment of existing & planned dams in Pakistan as well as in other parts of the world.

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## REFERENCES

[1] ***WAPDA*** *Mangla Dam Raising Project, Feasibility Study Report Volume I: Main Report; Pakistan: 2001.*

[2] **WAPDA** *Mangla Dam Raising Project; Pakistan: 2007. (http://www.wapda.gov.pk/htmls/ongoing-index.html)*

[3] ***WAPDA*** *Mangla Dam Raising Project, Tender design Report Volume I: Section 3, Embankment Dams; Pakistan: 2004.*

[4] ***Pakistan Water Gateway****- Key Water Information, Mangla Dam.*

*(http://www.waterinfo.net.pk/fsmd.htm)*

[5] ***Wahl TL.*** *Prediction of embankment dam breach parameters, A Literature review and needs assessment (DSO-98-004), Dam safety report; U.S. Department of the Interior, Bureau of Reclamation, Denver: 1998.*

[6] ***Wahl TL.*** *Uncertainty of predictions of embankment dam breach parameters, Journal of Hydraulic Engineering; 130: 389-397. 2004*

[7] ***Froehlich DC.*** *Embankment-Dam breach parameters,Hydraulic Engineering, Proceedings of the 1987 ASCE National Conference on Hydraulic Engineering;Williamsburg, Virginia, 1987. pp. 570-575.*

[8] ***Froehlich DC.*** *Peak outflow from breached embankment dam, Water Resources Engineering, Proceedings of the 1995 ASCE Conference on Water Resources Engineering; San Antonio, Texas, 1995a. pp. 887-891.*

[9] ***Froehlich DC.*** *Embankment Dam Breach Parameters Revisited, Journal of Water Resources Planning and Management; 121: 90-97. 1995b.*

[10] ***Singh KP.*** *Snorrason A. Sensitivity of outflow peaks and flood stages to the selection of dam breach parameters and simulation models, SWS Contract Report 288, Illinois Department of Energy and Natural Resources, State Water Survey Division, Surface Water Section at the University of Illinois; 1982.*

[11] ***Singh KP.*** *Snorrason A. Sensitivity of outflow peaks and flood stages to the selection of dam breach parameters and simulation models, Journal of Hydrology; 68: 295-310. 1984.*

[12] ***U.S. Bureau of Reclamation.*** *Downstream Hazard Classification Guidelines, ACER Technical Memorandum No. 11, Assistant Commissioner-Engineering and Research; Denver, Colorado: 1988.*

[13] ***Johnson FA, Illes P.*** *A classification of dam failures, International Water Power and Dam Construction; 28: 43-45. 1976.*

[14] ***Dewey RL, Gillette DR.*** *Prediction of embankment dam breaching for hazard assessment, Proceedings, ASCE Specialty Conference on Geotechnical Practice in Dam Rehabilitation; Raleigh, North Carolina. 1993.*

[15] ***Von Thun JL, Gillette DR.*** *Guidance on breach parameters, internal document; U.S. Bureau of Reclamation, Denver, Colorado: 1990.*

[16] ***Singh VP, Scarlatos PD.*** *Analysis of gradual earth-dam failure, Journal of Hydraulic Engineering; 114: 21-42. 1988.*

[17] ***Wurbs RA.*** *Dam-Breach Flood Wave Models, Journal of Hydraulic Engineering; 113: 29-46. 1987.*

[18] ***Ehsan S.*** *Evaluation of Life Safety Risks Related to Severe Flooding; Institute of Hydraulic Engineering, Universität Stuttgart, Germany: 2009, Vol. 180, ISBN: 978-3-933761-84-2.*

[19] ***Engelund, F, Hansen, E. A****. monograph on sediment transport in alluvial streams, Teknisk Forlag, Copenhagen, 1967.*

[20] ***Reference Manual*** *MIKE 11. A modeling system for rivers and channels, 2004.*

[21] ***WAPDA,*** *Pakistan: Mangla Dam Raising Project, Feasibility Study Report, Volume 3: Geotechnical, 2001.*

[22] ***Tingsanchali, T, Khan, N.*** *Prediction of flooding due to assumed breaching of Mangla dam, Proceedings of 3rd International Conference on Hydroscience & Engineering, Bradenburg University of Technology, Cottbus,* Germany, 1998.

[23] ***User Guide*** *MIKE 11. A modeling system for rivers and channels, 2004.*