

Estimating the Maximum Outflow Discharge from Dam Breach using the Scaling Method

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Abstract— *The aim of this paper is to investigate the scaling effect in modeling of the earthen dam breach process during the overtopping or piping. Small scale models are inexpensive but in most cases yield unreal results. In scaling the earthen dam breach phenomenon, the effect of grains detachment should be taken into account. In this article attempt is made to consider the effect of grains detachment in an appropriate way in the scaling method. For this purpose the results of real failed dams are utilized. A number of dams with a high height and a number of dams with low height were selected and it was assumed that the laboratory dams are replaced by the small dams. Then the ratio of their corresponding heights is taken as the scaling factor and the scale of grains detachment is calculated. Calculation of the maximum outflow discharge from dam based on this ratio yields an appropriate estimate of this parameter.*

Keywords— *dam, breach, outflow discharge, scaling, detachment.*

I. INTRODUCTION

Investigation of the dam breach process is mainly performed in the form of estimating the ultimate breach parameters or based on the instantaneous modeling of the process and estimation of the outflow hydrograph from the dam. Various researchers in the past have searched on these two fields. The Soil Conservation Service in 1981 presented some relationships for maximum outflow discharge from the dam breach [1]. MacDonald and Langridge-Monopolis in 1984, using the results of 42 dam failures, and taking advantage of a series of 42 logarithmic diagrams presented the breach parameters values [2]. Singh and Snorrason in the same year, studying 20 failed dams presented some ranges for the breach width and time [3]. Costa in 1985, using the results of 31 failed dams, presented a relationship based on the dam reservoir volume and the height of water behind dam for calculation of the maximum outflow from the breach [4]. FERC in 1987, using the results of damaged dams, estimated a range for the breach width, wall side slope and the breach time [5]. In this respect Froehlich in 1987, United State Bureau of Reclamation (USBR) in 1988, Singh and Scarlatos in 1988, Von Thun and Gillette in 1990, have estimated similar ranges for the parameters of

breach width, breach side slope and breach time [5-9]. Froehlich in 1995 and Webby in 1996, studying the failed dams, presented a relationship for the maximum outflow discharge from a dam breach [10, 11]. Concerning the physical modeling of breaching in the earthen dam, Cristofano in 1965, solved a mathematical model based on the following assumptions: the breach geometric shape is trapezoidal and has a constant bottom width, the side slopes of breach walls depends on the angle of repose of materials, The bottom slope of the breach canal is equal to the internal friction angle of the materials and the model is based on the empirical coefficients [12]. Harris and Wagner in 1967 (HW model), considered the following assumptions: When overtopping happens, erosion takes place and continues till reaching the bed invert. The Schoklitsch sediment transport equation is used, and the breach shape is assumed to be parabolic [13]. Fread in 1977, developed the DAMBRK model using the following assumptions: Breaching starts from the dam crest and uniformly extends to the downstream till the ultimate breach is formed. This model also models the flood routing [14]. Brown and Rogers (BRDSM) in 1981 extended the HW model adding piping failure mode to this model [15]. Ponce and Tsivoglou in 1981, assumed the following: they used Peter-Meyer and Muller sediment transport equations, used the one dimensional unsteady flow and the one dimensional sediment continuity equations, Manning coefficient is used for the discharge flow computations and the breach width is taken variable with respect to the flow within the breach [16]. Singh and Scarlatos in 1987 proposed the BEED model using the following assumptions: they used the Einstein-Brown and Bagnold equations, used the slope stability theory (Chugaev, 1965), considered the failure mode only as the dam crest overtopping and applied empirical coefficients for the outflow discharge from the breach [17]. The SIM1 and SIM2 Flow model was developed in the same year for flood routing at the downstream and also obtaining breach characteristics. Among the main assumptions it could be referred to two of them: it assumes certain shapes for the breach, such as triangular, rectangular, trapezoidal shapes and it uses the Schoklitsch sediment transport equation [18]. Fread in 1988, developed the BREACH model for failure by

overtopping and also piping considering the following assumptions: considered the Smart sediment transport equation. Used the weir discharge formula to predict the maximum outflow discharge, assumed the flow to be quasi-steady. The breach shape was determined according to the slope stability theory. The soil type could be different in the core and shell, lining of the downstream slope could be covered with plantation and the numerical solution does not have the numerical stability problem [19]. V.P.Singh and Scarlatos in 1988 presented an analytic model, which assumed the breach shape as the three geometric shapes of rectangular, triangular or trapezoidal. They assumed the erosion process once as linear and once as nonlinear and obtained for each case the parametric equations with constant coefficients. [8]. Broich in 1998 presented a mathematical model named DEICH. Broich verified his model by an experimental specimen and stated that he needs more specimens. In his model he used the broad-crested weir formula to calculate the outflow discharge. For the breach growth process he used the Exner sediment transport equation and assumed that the ratio of bed slope to that of wall is always constant [20]. Mohamed et al. in 1999, presented a new method for non-cohesive homogeneous earthen dams. They assumed that in the breach process, the bottom portion is eroded and enlarged but the upper portion enlarges only under the slope fall. They verified their assumptions by the experiments and a real case [21]. Kratochvil et al. in 1999 proposed a numerical method for failure due to overtopping. For determining the failure parameters a series of constant unknown coefficients were considered by them and determined using the statistical analysis. They recommended that for application of this model it should be compared to other available methods and models [22]. Tingsanchali and Chinnarasari in 2001 presented a one dimensional model for the earthen dam failure. They have used the Smart sediment transport equation for erosion and the method of slices for stability of the breach wall. They also estimated the outflow discharge from Buffalo Creek Dam with a good accuracy [23]. Ponce et al. in 2003, presented a non-dimensional analytic model. The main aim was to obtain the discharge value at different points of the downstream dam [24]. Wang and Bowels in 2006, formulated a numerical model where their assumptions as: the earthen dam could be of homogenous and non-cohesive materials, the 3D slope stability model of Hunger was used which is the 3D form of the Bishop method. To calculate the flow velocity, the shallow water equations are used. The Smart sediment transport equation is considered. The topography of dam body is taken into account and the dam breach could start from a number of points [25]. The background and assumptions which are assumed by various researchers for simultaneous solution of the hydraulic equations,

slope stability and sediment transport show that an appropriate model is not presented for the issue of earthen dam breach. As Morris et al. implied to this subject in an article entitled "Why there has been no progress concerning the earthen dam breach problem" [26]. The recent research show that considering the river sediment transport equations, results into extensive errors in estimating the outflow hydrograph from the dam breach [27]. To study the dam breach process, studying the laboratory scale is inevitable. The important and basic problem in modeling in small scales is change in the behavior of aggregates. The previous extensive studies have been based on the cohesion and internal friction angle in the soil. In the recent years various mathematical models have been presented for calculation of dam breach parameters and outflow hydrograph, where for each of them the governing equations corresponding to that phenomenon are considered. These equations are: water flow continuity equation, flow dynamic equation, sediment material continuity equation, sediment transport equation and the wall and bottom of breach stability equations. For each of the above mentioned cases there are some uncertainties. For example there is not much error corresponding to the water flow continuity equation while the uncertainty concerning two different sediment transport equations might reach 100%. Therefore use of any certain equation for each of the mentioned cases might divert the problem from its real state. So that experts in this field each have referred to special cases in their models or have used certain equations or assumptions which are justified in their situation but nevertheless none have reached an ideal solution [28]. Among the most important problems associated with these are the assumptions related to the sediment transport process and the corresponding equations. The recent research demonstrate that sediment erosion is not similar to that of the rivers and occurs as detachment. This issue has had significant impact on the breach process and here attempt is made that by focusing on this issue the maximum outflow discharge from the dam be estimated. For this purpose the scaling method is adopted based on the Froude number. For validation of the results and investigating the method's capability, has been used the real dam failure data.

II. SCALING METHOD

In the laboratory investigation of any phenomenon, the most important factor is identification of the effective parameters on that phenomenon and their scaling. Considering that the breach phenomenon in the earthen dam is a free surface flow then the dimensionless number, Froude number, would be effective on it.

$$Fr = \frac{u}{\sqrt{gh}} \quad (1)$$

Where u is the flow velocity, g is the acceleration of gravity, h is the hydraulic depth. Furthermore, regarding the flows with Reynolds number higher than 2000 the viscosity effect would not be effective. Therefore considering the dimensionless number dominating the problem (Fr) in table 1, the scaling parameters values needed are given.

Table.1: Dimensions of the earthen dam breach parameters

Parameter	Fr	h	u	A	Q	V	T
scale	1	L	$L^{0.5}$	L^2	$L^{2.5}$	L^3	$L^{0.5}$

Based on the recent research [29], the amount of erosion is based on the detachment of the grains. Most of the previous models have used the relationships for the sediment transport in rivers. The amount of grain detachment could be calculated considering the Hanson & Cook equation based on expression 2 [30]:

$$\varepsilon = k_d(\tau - \tau_c) \quad (2)$$

ε is the volume of detached grains in the unit of time, τ is the applied shear stress, τ_c is the critical shear stress, k_d and is the detachment coefficient. The τ_c value in the prototype and laboratory models is approximately zero or it could be stated that the difference between τ and τ_c is very much [31]. As the main determining factor in the dam breach is the detachment coefficient, its value should be appropriately scaled so that its value in the laboratory scale becomes larger (more rapid erosion). Table 2 shows this coefficient dimension.

Table.2: Dimension of the grains detachment coefficient

Parameter	τ	ε	k_d
scale	L	$\frac{L^3}{L^2 * L^{0.5}} = L^{0.5}$	$L^{-0.5}$

III. DISCUSSION

Considering a real dam and modeling it in the laboratory scale with the coefficient of 100, indicates that its materials should have a detachment equal to $100^{-0.5}$ (0.1):

$$\frac{L_p}{L_m} = 100, \quad \frac{k_{dp}}{k_{dm}} = \frac{1}{10}, \quad k_{dm} = 10k_{dp} \quad (3)$$

Some researchers investigate the detachment coefficient (k_d) based on the erosion index (I) according to equation 4:

$$I = -\log(k_d) \quad (4)$$

The erosion index (I) varies between 0 and 6, where values close to zero indicate a soil with a high erosion rate. The aim of the present research is application of the estimated k_d and predicting the maximum outflow discharge from a historical damaged dam and estimation of the maximum discharge of another damaged dam based on the scaling method.

A number of dams are selected wherein the height ratio and k_d values are calculated and in case of compatibility,

the outflow discharge is predicted and finally by comparing to its real value the amount of error is measured. Table 3 shows the real and predicted maximum outflow discharge values for a number of sample dams.

Table.3: Estimation of the maximum outflow discharge from the dam and its corresponding error

Dam name	k	H	Q	Da	k	H	Q	H	Q _{si}	Err
	M	M		m	M	H		M/ H _H	m	or
				nam						
				e						
Teton	M	93	65	Sch	H	3	45	3.0	73	+1
			12	aeff		0.	00	49	05	2%
			0	er		5			8	
castl	M	21	35	Kell	H	1	68	1.8	31	-
ewo		.3	70	y		1.	0	4	07	13
od				Bar		6				%
				nes						
swift	M	57	24	Apis	H	3	68	0.9	25	-
		.6	94	hapa		4.	50	8	40	2%
			7			1			1	
swift	M	57	24	Sch	H	3	45	1.8	22	+1
		.6	94	aeff		0.	00	89	05	3%
			7	er		5			6	

The results show that concerning the issue of laboratory modeling in the dam breach phenomenon, contrary to the existing models which calculate the outflow hydrograph from the dam based on the sediment transport in rivers, the dimensions and erosion rate are considered based on k_d .

IV. CONCLUSION

The numerical models mostly estimate the outflow hydrograph from the dam breach based on the sediment transport equations in the rivers. In this research, for estimation of the maximum outflow discharge from the dam the criterion of grains detachment is used for the sediment transport estimation. For this purpose in the scaling method and regarding the dimensional analysis, the grains size is changed based on the detachment coefficient. For validation of the method, the corresponding data of the failed dams are used. The results indicate that this method presents an appropriate estimate of the maximum outflow discharge from the dam.

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