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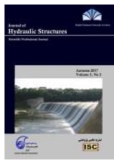

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Investigating the vulnerability downstream area of Taleghan dam due to dam failure

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Abstract

Due to the immense damage caused by dam failure, especially dams constructed near large cities, it is necessary to consider the breaking phenomena as well as studying and designing different parts of the dam. For this purpose, the hydrograph of the outflow due to dam failure must be identified according to size of the fracture and then flood routing, and flood zone must be determined based on the downstream topography and morphology. The integration of hydraulic models and geographic information system is used to achieve this objective. In this research the effect of breaking Taleghan storage dam due to the slip of a pile of reservoir abutment and the creation of current wave toward the dam body as well as the vulnerability analysis due to the breaking of the dam on downstream lands was studied. At first, Taleghan dam failure for five different scenarios was modeled using the FLOW-3D numerical software and then the geometric data of the river was extracted using the ArcGIS software and modeling the flood due to dam failure was conducted in Hec-GeoRas model. Then, the risk analysis was performed for each break scenario of Taleghan dam. The results indicated that the maximum amount of inundation would occur in Razmian city at an approximate distance of 45 kilometers from Taleghan dam site.

Keywords: Dam breaking, Inundation, Vulnerability, Risk analysis, Taleghan dam.

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1. Introduction

Dams are always considered as a potential threat for their downstream areas because of creation of large water reservoirs. Dam designers attempt to lower vulnerability potentials by applying safety factors; however, natural and non-natural factors like floods, piping phenomenon, foundation weakness and exploding can cause a dam to break [1]. The problem of dam failure and effects of surges on downstream areas attracted many scholars and experts' attention, after several important dams like Teton were broken [2]. To reduce the effects of a large reservoir dam failure, it is important to know the changes of hydraulic parameters due to break in dam, such as depth, speed, flow, and the time when the wave forehead reaches the downstream area and finally to determine the border and designing the flood zone in order to reduce the financial losses and casualties. In this regard, in the last few decades, different researchers have done numerous theoretical and practical studies in order to determine the mechanism of dam failure and the trends of hydraulic parameters as a function of time and space [3]. One of the most important methods for erosion control in rivers in these situations is ston masonery and riprap. A general dimensionless equation for the prediction of maximum particle size of stable riprap into the tributary channel at river confluences has been developed by Ghanbari Adivi et al. [4]. Their results showed that the stability number of riprap into the tributary channel increases with increasing the ratio of tailwater depth to particle size.

Fliervoet et al. [5], Lim [6] and Chiew [7] found that during flooding, the emergence of various forms such as Ripple and Dune and live bed is natural. These processes, despite the intersectional structures, can cause inconstancy in these structures. Andam [8] investigated the changes in speed and number of landing by using HECGeo-RAS model in a research entitled as the comparison of river regime inside and outside of forest area, and compared the influence of vegetation on the physical behavior of the flow. He concluded that using the HECGeo-RAS model can offer researchers suitable numbers to study the diet and other hydraulic characteristics of river flow. Sholtes [10] used HEC-RAS software to route flood dynamics in rural and urban areas of Northern California and concluded that the decrease in slope and increase in roughness of floodplain and river have more influence on flood attenuation. Nagy et al., [11] investigated the sand grinding attrition and meanders evolution in an answer to Tisza River engineering in Hungary and found that due to severe attrition in the area and human intervention (performing engineering projects), this river has reached a balance by shortcuts in its route. However, the purpose of this article is to investigate and determine the flood plain area. Then the amount of vulnerability risk over all path of the river for five different scenarios of dam break and for wave arrival times of 30 and 120 minutes were identified.

2. Methodology

The conducted research is presented in details in this section.

2.1. Study area

Taleghan dam at 135 km of north west of Tehran with longitude of 50˚, 37' to 51˚, 10' and latitude of 36˚, 5' to 36˚, 25' is built on Taleghan river in Roshanabdar rural area. Figure 1 shows the study area, including dam, river, and the topography of area.

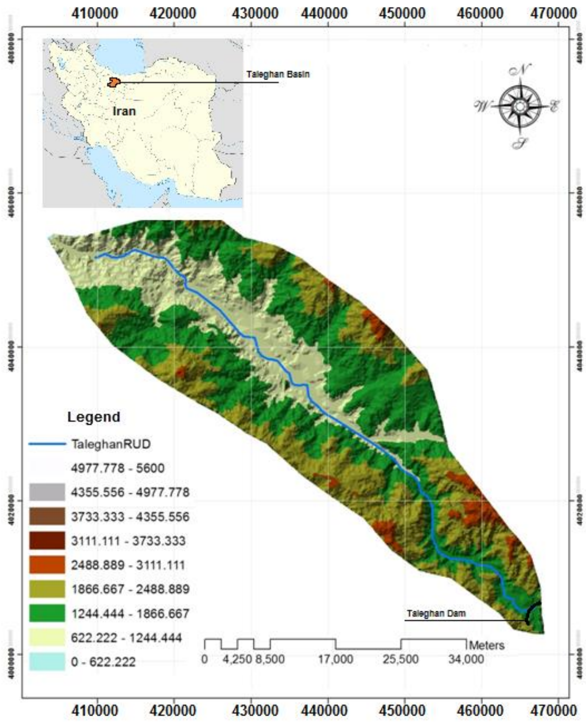

Figure 1. Map of Taleghan river in Taleghan dam downstream

2.2 Physical characteristics of Taleghan river in Taleghan dam downstream

In order to perform the model, it is necessary to determine the river characteristics such as the left and right bank, riverbed, and roughness coefficient of each section. Therefore, after several field studies and inspections, the required data were determined and entered the model. Then using the Arc-GIS, the cross sections were provided and entered the model. Considering the high length of the study area, the distance of cross sections in straight parts of the river was chosen about 4000 meters and 1500 meters in sudden intersections and arches. Among the factors affecting the manning coefficient are the grading substrate material, the rippling degree of river, the relative effect of obstacles, the density of vegetation and morphology form of the river. Therefore, in order to determine and estimate the manning coefficient in a part of river, it should be divided to three main parts including the mainstream and flood plains of right and left banks. Because of the important role of roughness coefficient, the model were calibrated using this parameter.

2.3 Determining boundary conditions

In order to predict the characteristics of the flow in the study period, real boundary conditions are needed. Boundary condition is in fact representative of the output and input status of the downstream and upstream flows. It is obvious that expecting the exact characteristics of flow includes offering correct data in boundaries. In the current research, the introduced boundary condition for hydraulic model to simulate the hydraulic flow of Taleghan river in downstream of Taleghan dam, used the normal depth condition in upstream and also normal depth boundary condition in downstream. The HEC-RAS model can calculate the normal depth using Manning's equation and the slope of river. After simulation, the hydraulic model identifies the slope and suitable level of water in upstream.

2.4 Discharge inflow

Five scenarios are defined to investigate embankment dam failure resulting from overtopping. Inflow volume to the reservoir is different in each scenario. Based on the reviews, minimum flood volume that overtops and damages the dam body is about 5 MCM. In addition, maximum flood volume that fully destroys the dam body is about 25 MCM. In the range of 5 to 25 MCM, flood volumes of 7.5, 9 and 13 MCM have been considered. The charecteristics of scenarios have been presented in Table 1. ([12])

Table1. Flow modeling conditions for five states of overtopping in Taleghan dam

Scenario	Water Height in Reservoir (m)	Storage (MCM)	Flood Volume (m3)	Flood Discharge (cms)
1	82	420	5.0	54,269
2	82	420	7.5	59,390
3	82	420	9.0	78,913
4	82	420	13.0	89,129
5	82	420	25.0	97,054

2.5 The risk taking theory due to dam failure

The researchers consider the three parameters of escape time, velocity, and depth of flooding as the appropriate criteria of dam failure risk. Considering the importance of the escape time in reducing life loss of downstream areas, the 30 to 120 minutes after the beginning of dam failure are selected as the risk criteria of these areas over time [13].

The flow velocity and depth of flooding is considered simultaneously in assessing the consequences of dam failure. In this regard, the flooding area along the river and flood plains and risk index HR are assigned to the grid cells according to the following definition [14].

$$HR=D(V+0.5) \quad (1)$$

Table 2. Flood risk levels based on risk amount and risk description [14](Vrouwenvelder et al., 2003.)

HR	Flood risk level	Sign	Risk description
<0.75	Low	R1	Warning: flooded area with shallow running water with deep water remain
0.75 – 1.25	Average	R2	Dangerous for some people (For example children): flooded area with deep or fast flowing running water
1.25 – 2.5	High	R3	Dangerous for most people: flooded area with deep and fast flowing water
>2.5	Very high	R4	Dangerous for everyone: flooded area with deep and fast flowing water

Where, in the above equation D is the depth of flood flow in meters and V is the flow velocity in meters per second. In general, risk areas are classified into four levels of low, medium, high and very high-risk areas that flood risk levels based on the amount of risk and the descriptions of each level are provided in table 2.

3. Results

Using the HEC-RAS model and geographic information system GIS, modeling the flow of Taleghan river in the downstream of Taleghan dam and caused by the dam break was investigated. Using the topographic data of Taleghan river basin in the downstream of the dam, TIN layer and raster maps of the mentioned area were obtained. Then, using the Hec-GeoRas in the GIS environment, various layers of the river route, banks and river cross sections were prepared. It should be noted that the above data are among the requirements of flow modeling due to dam failure in the HEC-RAS model. After preparing the geometric model of the river, the necessary information was inserted into the HEC-RAS model and flow modeling was carried out after editing the information and peocessing the data.

Modeling the flow for discharges of 54269, 59390, 78913, 89129 and 97054 cubic meters per seconds was conducted. Considering the importance of model calibration after the model simulation, the results for the maximum discharge (scenario 5) and minimum discharge (scenario 1) were calibrated in accordance with the roughness coefficient values. So that the minimum, medium and maximum roughness coefficient values for the right and left side of the river were considered to be respectively as 0.035, 0.040, and 0.045. The minimum, medium, and maximum roughness coefficient values for the riverbed were respectively considered as 0.030, 0.035, and 0.040.

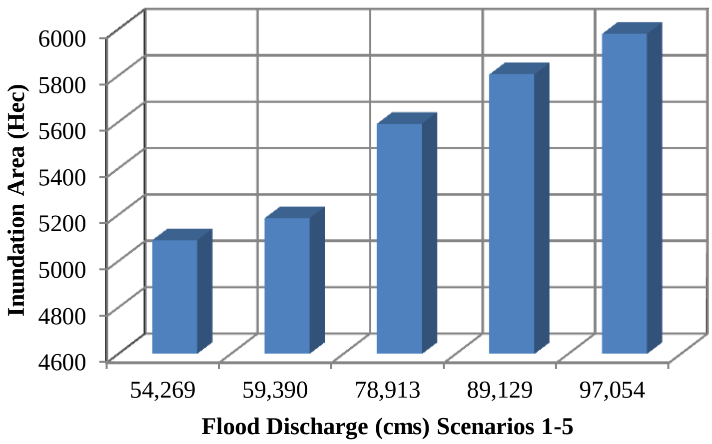

Figure 2. The inundation area due to flooding scenarios 1 to 5 along Taleghan River because of dam breaking

The results indicated that in all studied sections, the amount of water level difference for maximum and minimum roughness coefficients was less than 5%. Therefore, the roughness coefficient values with sufficient accuracy was considered as equal to the average roughness coefficient, that is over the two sides of the river as equal to 0.040 and the river bed as 0.035.

After modeling the flow in HEC-RAS, the data of the flow was exported into the Arc-GIS and the inundation area for each scenario is provided in Figure 2.

Then, the values of HR index for the escape times of 30 and 120 minutes after the dam break was calculated and provided in figures 3 and 4. For the escape time of 120 minutes and 30 minutes, the sections with high flood risk level (HR> 2.5) are respectively provided in tables 3 and 4.

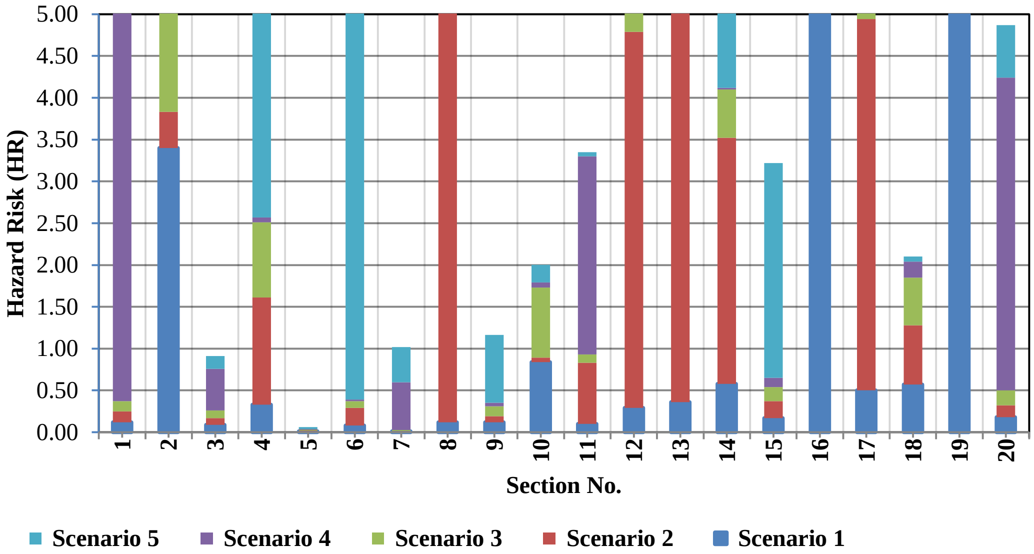

Figure 3. Risk index values for the escape time of 120 minutes in all sections of the river and different dam failure scenarios

Table 3. Sections with very high-risk levels for the escape time of 120 minutes and different dam failure scenarios

Dam failure scenario	Sections with very high risk levels (HR>2.5)																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1		×														×			×	
2		×						×				×	×	×		×	×		×	
3		×		×				×				×	×	×		×	×		×	
4	×	×		×				×			×	×	×	×		×	×		×	×
5	×	×		×		×		×			×	×	×	×	×	×	×		×	×

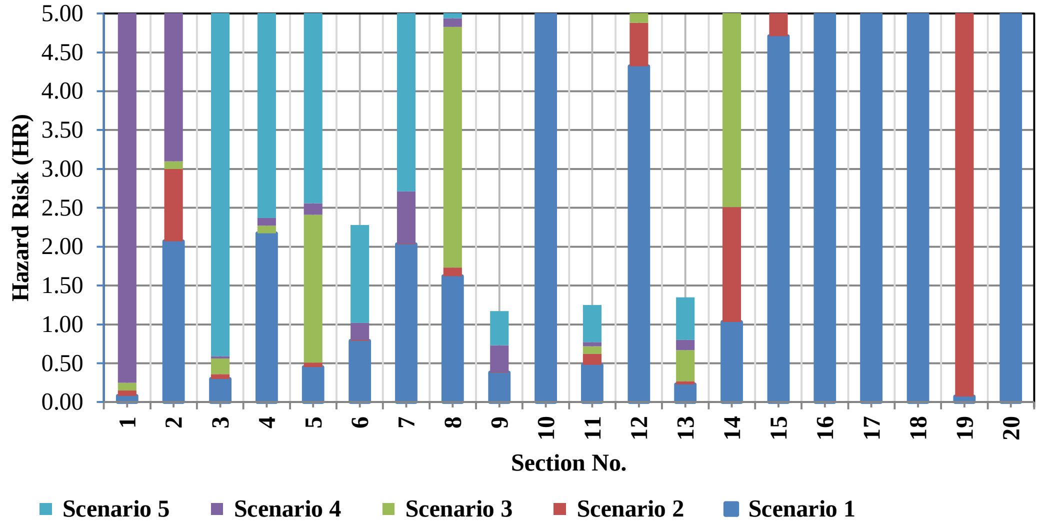

Figure 4. Risk index values for the escape time of 30 minutes in all sections of the river and different dam failure scenarios

Table 4. Sections with very high-risk levels for the escape time of 30 minutes and different dam failure scenarios

Dam failure scenario	Sections with very high risk levels (HR>2.5)																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1										×		×			×	×	×	×		×
2		×								×		×		×	×	×	×	×	×	×
3		×						×		×		×		×	×	×	×	×	×	×
4	×	×			×		×	×		×		×		×	×	×	×	×	×	×
5	×	×	×	×	×		×	×		×		×		×	×	×	×	×	×	×

4. Conclusion

Flood plains and areas adjacent to rivers are suitable regions to carry out economic and social activities due to specific conditions. The effect of break and the risk of flooding due to Taleghan dam failure in the downstream area of the dam were investigated in the present study.

Flood zoning due to Taleghan dam failure with discharges of 54269, 59390, 78913, 89129, 97054 cubic meters per second on Taleghan river and the downstream of the dam were investigated. For modeling the study river, HEC-GeoRAS hydraulic model was applied. In the downstream of Taleghan dam, a total of 80 km of the river from the dam site located in the Alborz mountain was modeled. After zoning the areas with a high risk, the vulnerabilities were identified. Through calculating the risk index (HR) in any sections of Taleghan river after dam failure, the risk of the flood caused by dam failure in the downstream area was quantified. Therefore, we can easily classify high-risk areas. Observed zoning maps indicate that a great flooding can occur in Razmian city at an approximate distance of 45 kilometers from Taleghan dam site and due to dam failure and also indicate the necessity of adopting special measures to deal with this risk.

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