Risk Assessment of A Dam-Break Using GIS Technology

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Abstract
Flood disaster cause massive losses of human lives and immense damages to the infrastructure and economic activities not only in Turkey but also all over of the world. The governments consider several long-term and short-term precautions for the flood control. The numerical simulation of dam-break problems could be accomplished with geographic information systems and innovation maps. Spread of the flood wave after a dam break can be predicted using these enabling technologies. This kind of advanced modelling technology is becoming an inevitable tool for decision-making process. Using data produced by GIS is used initial value for FLDWAV. ArcView GIS has been used to produce Digital Elevation Model and visualization of dam-break effects and propagation of possible flood wave. Using GIS technique and hydrologic modelling software, possible effects and damages of a dam-break flood have been investigated and results were simulated to show significant importance dam break effects on the region.

Keywords

GIS; Dam break; Flood; Risk assessment

INTRODUCTION

Istanbul, which is located on two continents, is the largest city of Turkey with a population of over 12 million. It is a combination of a very rich historical background and a modern appearance (Seker, et al. 2001). Water demand of Istanbul is supplied from 7 lakes and reservoirs, which are in service. In this study one of these reservoirs, Alibeykoy Dam has been selected for the case study. In rapidly developing cities such as Istanbul, settlement areas extend enormously at an unexpected rate. This out - of -control situation causes new problems. As the planned structures take long time to build or the regulations are not applied and political decisions interfere, settlement areas are mostly developed within the dam areas.

In such cases, the risks caused by breakage of the dams, which have been constructed for a number of purposes such as provision of drinking and irrigation water as well as generation of electric power, could reach serious proportions. Most of the dams constructed so far are earth-fill dams. Breaking mechanism of such structures could be one or more of numerous reasons like intake flow at unforeseen level, inadequate foundation works, different settling, landslides, earthquakes or improper project design. Past experiences show that the time between the occurrence of a breach and discharge of the dam reservoir ranges from 15 minutes to 5 hours. Therefore, it is necessary to make again the risk assessment and accordingly the plans of rescue and evacuations for the dams, which remain within the settlement units during their economic lifetime.

On the other hand, it is estimated that the overflow characteristics change due to global climate change. This development, which is beyond control, poses itself to be another reason for risk assessment of the existing dams. Terrorism is regrettably another fact of the 21st century. While mankind considers measures against such inhumane activities, especially after the events on September 11th, dams, too, have to born in mind within the sphere of such extensive measures. Concrete dams, which usually are less susceptible to collapse, compared to the earth fill dams must be dealt with in this assessment.

In risk assessment of a dam surrounded by settlement units, main objective is the use of contemporary techniques producing and using healthy data together with classical methods. To be more precise, compilation in digital media of the topographic, demographic and socio-economic data partitioning to the area in the upstream and production of data to be used in geographical information systems and classical methods as well as evaluation of the results thus obtained again in GIS in order to produce risk maps must be considered as one of the contemporary methods.

In order to provide this kind of risk maps and applying early warning systems, we need to find the time and water elevation of cross sections during the dam failures, obtaining main data and the damages of dam breach flood. In this study solution techniques for dam breach formation that causes failure of dam and the routing of flood waves were investigated.

STUDY AREA

The selected project area of this study is Alibeyköy Dam area, which is a typical example for the situation mentioned in the previous section. When the construction of dam started in 1966, the area was completely a rural area. In 1983, after the construction was completed, human settlement started in this area. Today settling density of area is higher than before. Flood created by the Alibeyköy dam failure may cause large amounts of property damage and, large losses of human life.

In the failure scenarios of Alibeyköy Dam, different probabilities were taken into consideration. In this study the overtopping failure examined with the worst - case scenario, which is the flood and closed spillway gates while the reservoir water elevation is equal to crest of the dam elevation.

Construction of Alibeyköy dam on the Alibey Stream in Istanbul started in 1966 and in 1968 it started to retain water temporarily. It was taken into full service in 1983. For the purpose of using in the application, apart from the data given in the Table 1, 1000-year Flood hydrograph, area – elevation curve of the dam reservoir and the spillway discharge curve have been obtained from DSI (State Waterworks of Turkey) and used in this study.

METHODOLOGY

In this study “Breach” model for breach formation, and Fldwav model for flood routing were used with the computer programs having the same names (Fread, 1978, Bellos and Sakas, 1987). The necessary cross-sectional data were obtained from numerical area model of ArcView GIS by using the digital maps of Istanbul Municipality. At the end of the study the time of flood reaching to the cross sections and the peak values of water elevations at this cross sections were calculated and the time of maximum water elevation at the last cross section flood wave reaching to the furthest cross section from the dam of the worst scenario was estimated. It is seen that the arrival time of maximum water elevation value at the last cross section allows enough time to evacuate the settlement areas.

Table 1. Data about Alibeyköy Dam

GENERAL DATA	
CHARACTERISTICS	
Drainage Area	160 km ^{2}
Annual Mean Precipitation	800 mm/year
Annual Mean Flow	280 mm/year
Predicted Flow	160 km^2 * 280 mm/year
RESERVOIR	
Maximum Water Level	32.00 m
Maximum Capacity	65*10^6 m^3
Maximum Reservoir Area	4.76*10^6 m^2
Maximum Operation Level	26 m
Minimum Operation Level	10.50
Minimum Operation Area	0.426*10^6 m^2
Dead Volume	0.487*10^6 m^3
Active Volume	35*10^6 m^3
Flood Peak	1000m^3/sn
Downstream River Capacity	80 m^3/sn
BODY	
Type	Eartfill
Volume	2.00x10^6 m^3
Crest Level	34.00 m
Crest Weight	15.00 m
Crest Length	6.00 m
Talveg Level	6.00 m
Height above Talveg	28.00 m

Numerical model of dam breach

Formations of a breach in earth-filled dams occur gradually in the course of time. When examples of many destructed dams are examined, it is seen that the breach reached as far as the foundation of the dam body by means of attrition after the first occurrence of the breach. In the meantime, examination of some other failed dams revealed that formation of the breach stopped also somewhere in the middle of the dam body. Dimensions of the breach are defined in terms of width and the depth of the breach. Dimensions of the breach and the speed of its formation are the factors determining the shape and size of the overflow hydrograph coming out of the breach. Therefore, it is very important that the engineers and hydrologists would determine the dimensions and formation speed of the breach so that the overflow hydrograph coming out of the breach can be accurately ascertained.

Fread first developed the Breach model used in this study, which is among the models used also today to determine the breach that can occur in a dam and the characteristics of the breach, in 1977. The model got its latest shape in 1991 after having gone through a number of modifications (Sakkas and Strelkoff, 1976, Fennema and Chaudry, 1987, Fread, 1998). Breach model is a mathematical model used to determine the dimensions, duration of occurrence of the breach and the overflow hydrograph coming out of the breach. Breach model is physically based on hydraulic principles, carriage of solid substances, surface mechanics, dam geometry, properties of the dam material, features of dam reservoir and the amount of inflow entering the reservoir depending on the time.

The main difference of the Breach model developed by Fread from the previous versions is the absence of a parametric approach unlike the previous ones; that is to say, ampirical conclusions were not drawn taking the failed dams as basis. Latest Breach model depends on the use of qualitative parameters of the dam that can be estimated or measurable. However, one has to mention that even though measurable parameters are used, there is a likely distribution among the parameters. This distribution affects the size of the overflow hydrograph coming out of the breach and the duration of breach formation. Therefore, hydrologists and engineers must carry out sensitive analysis and measurement in areas where the dam material is most critical.

If the dam body to be studied does not consist of homogeneous material, features of the materials that have to be considered for Breach model are shown in Table 2. This table shows the parameters of the materials in both the outer section of the body and the inner core as well as the characteristic data that have to be considered for the model. Apart from the specified characteristics of the materials, if the surface of the upstream is sprouted, then the quality of the grass is to be taken into consideration.

Table 2. Features of the Materials to be considered in Breach Model

Parameters related to the material	Characteristics related to the structure
a) Internal friction angle	a) Downstream and upstream slope of dam
b) Cohesion stress	b) River bottom slope
c) Mean grain diameter (D_{50})	c) Crest level and weight
d) Density	d) Spillway level and capacity level
	e) Inflow hydrograph
	f) Reservoir surface-area curves
	g) Initial surface level

In the destructions caused by overflow of water over the body, water surface spot height of the reservoir must exceed the top spot height of the body without any attrition. In such failures, formation of a breach starts in the upstream side of the dam first and the breach that is formed progresses towards the downstream side along the crest width of the dam. In the used model, water coming out of the breach is obtained by means of sluice formula and the width of the formed breach is assessed as dynamic. The changes occurring in the reservoir during the formation of the breach is dealt with the principle of protection of the mass.

Numerical model for flood routine

Overflow flood routine model FLDWAV used in modelling the overflow wave occurring upstream after the collapse of the dam was developed by NWS (National Weather Service). FLDWAV includes not only the combined properties of the former DAMBRK and DWOPER overflow flood routine models but also the new hydraulic simulation properties.

Risk Assessment by means of GIS

River basin and coastal management relies on an appreciation of the complex nature. Clear understanding requires the modelling of these processes, which in turn calls upon a large number of disparate data sets. The most effective way to model these data, facilitate analysis, and allow clear visualisation, is by geographical position. This paper describes a system, which improves the efficiency and applicability of coastal process in support of shoreline management decision.

In connection with territorial management activities, potential risk to the population, and risk for costly material damages need to be assessed. Risk assessments are also sometimes carried out as part of the design of new facilities. Various types of risk assessment may be carried out using GIS and conventional modelling techniques together. In this study one of the possible risks, flood prediction is assessed. An emergency management needs of planning and training activities. GISs are nowadays widely used by authorities at regional and municipal levels. When such systems are taken into full use, basic registers are connected to GISs and thereby all population, building, tenement and property information can be managed directly from the map. In the area of emergency management, planning and training risk assessment calculation form the basis for decision making. When the calculation are linked to geographical information, it is much easier to rescue people who are under the risk (Heino and Kakko, 1998).

Geographic Information System provides an extensive approach to evaluate map characteristics that explain the spatial distribution of study area. GIS have the capability of spatially representing data on the land surface and linking additional data related to this spatial depiction through tables and charts as well as maps. In this study a decision support system was developed for dam break. In this study together with hydrologic model linked geographic information system to simulate possible dam break and its effect on the area.

APPLICATION

In Fldwav model, certain topographic data about the area where the dam is located and the upstream bed of the dam are needed. Topographic data in the form of 1/5000-scale digital maps have been obtained from the Istanbul Metropolitan Municipality. Using digital elevation data and by means of ArcView Geographical Information System, digital terrain model was formed. As seen in Figure 1 totally 10 cross-sections along the valley lying in the upstream of the dam were obtained on this model.

Distance of the first cross-section to the dam is 0.273kms and the last one is 5.162 kms. As a sample section, is also given in figure 1 shows the section that is 1.045 kms away from the dam. Manning coefficients used in cross-sections have been determined by going around the upstream of the dam and making use of table of manning values according to Chow’s surface features.

Scenario of the Dam Collapse due to Overflowing of Water over the Dam Body

Before examining the scenario of the Dam Collapse due to Overflowing of Water over the Dam, it was studied to see whether the full sluice capacity was adequate or not for different water levels at the reservoir when there is an overflow with 1000-year return period. During the first stage, when we examined the case of water level spot height in the reservoir at 26m and the spillway hatches are open, it has been observed that the water level did not exceed the dam body therefore no breach was formed. Later on, when the same process was repeated under similar circumstances but at different water levels for 28m, 30m and 32m respectively, no breach formation was observed at the body of the dam. Even in case the water level in the reservoir is at the maximum, spillway capacity is found to be adequate.

In order to see the consequences of overflowing of water over the dam body, case of water level in the reservoir to be 34 meters and spillway hatches to be closed was examined as an extreme case.

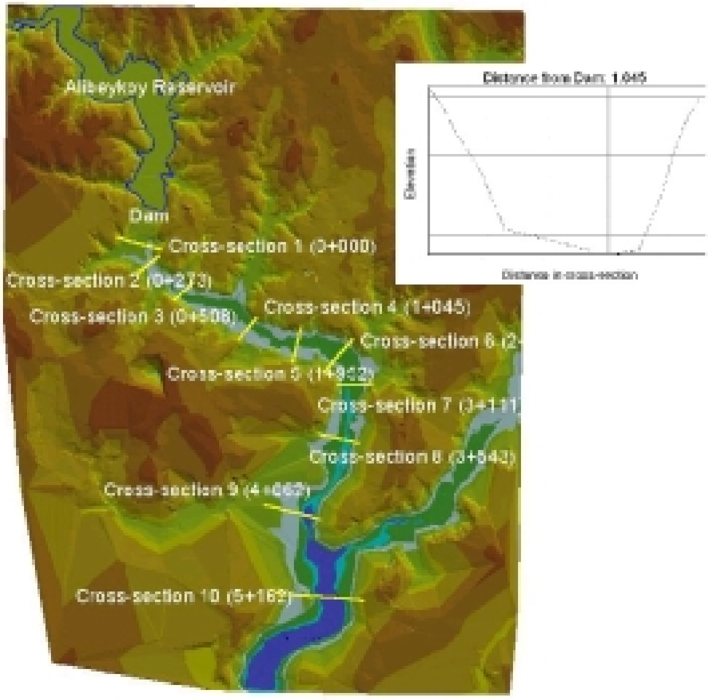

Figure 1 Digital terrain model produced by means of GIS and the cross-sections taken on it and cross-section 1.045 kms away from the dam

Table 3 Water levels on the cross-sections after dam break

Time (hour)	1	2	3	4	5	6	7	8	9	10
2.74	34.16	8.18	7.43	5.96	5.51	4.8	4.13	3.4	2.9	1.37
2.80	34.15	9.47	8.53	6.19	5.55	4.83	4.15	3.42	2.92	1.38
2.85	34.12	10.75	9.71	7.15	5.66	4.85	4.17	3.44	2.94	1.38
2.90	34.06	12.11	10.97	8.68	6.38	4.88	4.18	3.47	2.96	1.39
2.95	33.95	13.62	12.39	10.35	7.9	5.14	4.2	3.5	2.98	1.41
3.0	33.78	15.3	13.95	12.07	9.69	6.32	4.32	3.52	3.01	1.42
3.05	33.54	17.02	15.53	13.88	11.63	8.05	5.47	3.63	3.03	1.43
3.10	33.2	18.7	17.06	15.67	13.41	10.14	7.48	5.3	3.19	1.45
3.15	32.76	20.41	18.62	17.39	15.03	11.92	9.74	8.1	5.93	1.47
3.20	32.2	22.11	20.17	19.01	16.5	13.45	11.78	10.93	9.24	1.79
3.25	31.51	23.76	21.65	20.53	17.84	14.93	13.9	13.11	11.61	5.46
3.30	30.68	24.95	22.85	21.84	19.07	16.53	15.71	14.89	13.49	8.64
3.35	29.86	24.65	22.85	22.04	19.55	17.62	17.07	16.31	13.83	10.73
3.40	29.09	24.2	22.56	21.72	19.57	18.03	17.57	16.92	15.9	12.05
3.45	28.36	23.7	22.19	21.4	19.5	18.15	17.73	17.13	16.19	12.56
3.50	27.68	23.21	21.82	21.08	19.34	18.11	17.69	17.11	16.22	12.73
3.55	27.02	22.75	21.45	20.74	19.11	17.94	17.53	16.98	16.11	12.76

When calculating the breach characteristics of the Breach model, it has been assumed that the formation of the breach started once the water level in the reservoir reached 34.16. In lower values, it has been assumed that the water exceeded the dam body without causing any harm to the body of the dam. Breach characteristics thus obtained were; 0.63 hour as the duration of breach formation, 240 meters as the top width of the breach and 25 meters as the base width, respectively. In Fldwav model used for the overflow flood routine occurring as a result of breach formation, 1000-year overflow hydrograph was taken as upstream border condition.

When calculating the duration of breach formation, time interval was selected to be Δt=0.01hour and distance interval to be Δx=0.01 km. The results obtained for the scenario of water exceeding the dam body, water surface spot heights in the sections used at the application for t=2.74 hours and t=3.55 hours time intervals are given in Table 3. As a result of the calculations, it has been observed that the water level in the dam reservoir reached the level of 34.16 meters since the beginning after t=2.74 hours and the peak value of the output overflow coming out of the breach was t=3.30 hours. As a result of this failure scenario, maximum water level spot height in section which is farthest from the dam (5.162 kms) reaches the value of 12.76 at the time of t=3.55 hours. As the total duration of 1000-year overflow hydrograph is 72 hours, observation period was selected to be 100 hours when analyses were made. Maximum surface spot height was calculated as 3.84m at the time of t=20.57 hours in the section which is the farthest from the dam.

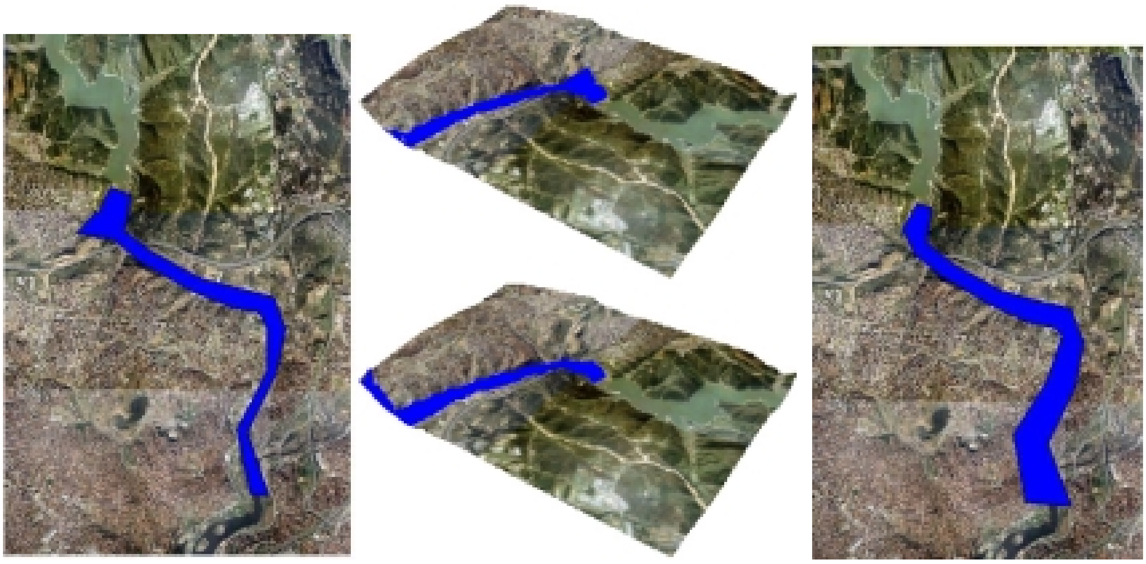

Figure 2 Distribution of water on the upstream side of the dam at the time of t=3.05 hours and of t=3.55hours of the flood due to overflow of water over the dam body

CONCLUSIONS

In this study, the breach and the hydrograph of the overflow out of the breach occurring in case of an overflow of water over the body of an earth-filling dam have been determined and flood routine of this overflow in the upstream bed was made numerically and risk maps were obtained with the integration of new methods.

By using ArcView software, water distribution in the upstream for the times of t=3.05 hours and t=3.55 hours, are calculated and results given in Figure 2. Distribution of water is also given in middle as 3D view of the study are, which draped with the aerial photograph of the same area. As it can be understood from the figures and the tables, in the event of an overflow of water above the dam body, the areas lying on the upstream side of the dam will quickly be under water. Therefore, as mentioned above, such studies have to be carried out for all the dams in order to determine urgent prevention plans and flood maps.

- It has been shown that Geographical Information Systems can be widely and successfully used in determining the risk maps
- They can further be used in setting up early warning systems. It can be said that cost of setting up an early warning system in all the dams throughout the country would be less than the cost that would incur after a dam failure.
- As by means of overflow routine calculations, change in output of the flood and water level can be calculated, dimensions of the flood prevention structures can be safely determined.
- When the overflow hydrograph entering the lake is known, output leaving through the Spillway can be calculated by flood routine. As a result of these studies, size of the spillway, height of the cofferdam, highest water level in the dam lake, height of the dam and the soil that will submerge under the dam lake are determined.
- Besides being rather costly structures**,** the dams, when destructed, would lead to large-scale material and moral loss. Therefore, such calculations should be applied to all structures.

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