A distorted physical model to study sudden dam break flows

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Abstract

A distorted physical model, based upon Urkmez Dam in Izmir, Turkey, was built to study sudden dam break flows. The distorted model had a horizontal scale of 1/150 and vertical scale of 1/30, containing dam reservoir, dam body and downstream area—from dam body to Urkmez urban area until the sea coast. In the model, the reservoir is approximately 12 m^3, the dam body has a width of 2.9 m and a height of 1.1 m and the downstream area is nearly 200 m^2. The Ürkmez dam is chosen since it has reasonable dimensions and it is located close to Ürkmez village. The features creating roughness such as buildings, roads, plant, etc are also reflected in the physical model.

The dam break problem is investigated for sudden partial collapse which is simulated by a trapezoidal breach on the dam body. The water depths are measured by using e+ WATER L (level) sensors. The velocities are determined by Ultrasonic Velocity Profiler (UVP) transducers. The propagation of the flood is recorded by a HD camera.

The experimental results show that Urkmez area can be flooded in a matter of minutes, at depths reaching up to 3 meters in residential areas. The flood wave can reach in the residential areas in 4 minutes. Flood wave velocities at peak discharge can exceed 55 km/h.

Introduction

Dams, which are crucial hydraulic structures, providing power, irrigation, recreation, fishery etc can have disastrous effects when they collapse. There exist experimental and mathematical dam break studies in the literature. However, these studies mostly involve the investigation of dam failure mechanisms. Few studies investigate flood routing at the downstream section of collapsed dams in two dimensions by physical and numerical models.

The pysical dam break flow experiments have generally involved flume experiments. In a long and large flumes, by lifting of a plate, the flow experiments have been carried out [1]. For example; [6] used rectangular 19.2 m long, 0.5 m wide and 0.70 m high channel and a movable plate. [10] used 2.40 x 2.40 reservoir connected to 8 m long and 0.5 m cm wide rectangular flume. By lifting the plate right at the reservoir, they observed flood propagation in the flume. [2] built 0.35 m wide and 0.37 m high trapeozoidal sand-fill dam body in a flume for experiments. [8] built 6 m high earth—fill dam body in a field, right downstream of a an actual dam to study dam breaching. They also built the same dam in a small scale in a laboratory to carry out dam—break flow experiments.

As seen, we do not see studies that involve physical models replicating actual dams with reservoir, dam body and downstream areas. To do so, one needs to build distorted physical model, which is rarely encountered in the literature due to many complications. This study in this regard an important milestone.

Design of the distorted model

The distorted physical model of the dam with its reservoir and downstream part was designed to investigate two dimensional flood wave as a result of a dam failure. Ürkmez Dam is selected because of settlements on its downstream part. The general view of the studied area is given in Figure 1.

This physical model was designed and built in scope of the research project TÜBİTAK 110M240 titled “Physical and numerical investigation of dam break flood waves - Application to real dams in GIS environment”.

Figure 1 The general view of the studied area [3]

The physical model is designed according to the Froude similarity law since the gravitational force is dominant. The horizontal and vertical scales of the model are selected so that it can be built and operated conveniently and still be big enough to measure flow depths and velocities with sufficient accuracy. According to the available space in the open area of Hydraulics Laboratory within Dokuz Eylül University, the horizontal and vertical scales are selected as ℓ_{xr} : 1/150 and ℓ_{zr} : 1/30, respectively.

The geometric characteristics of Ürkmez Dam (prototype) and its distorted physical model are given in Table 1.

Table 1 The geometric characteristics of the prototype and physical model.

Characteristics	**Prototype**	**Physical model**
Crest length (m)	426	2.84
Crest width (m)	12	0.08
Dam height from base(m)	32	1.07
Lake volume at minimum level (m^3)	375 000	0.556
Lake volume at maximum level (m^3)	8 625 000	12.778
Lake volume at normal level (m^3)	7 950 000	11.778
Lake active volume (m^3)	7 575 000	11.222

The velocity scale for the distorted model in this study becomes $S(V)=\sqrt{1/30}$ and it implies that $V_p = 5.48\ V_m$. For example; measured *10 m/s* velocity in the distorted model would correspond to *54.8 m/s* in the actual field.
As the time is a characteristic parameter, in addition to the Froude number the Strouhal number also must be taken into consideration [11].The time scale for the distorted model becomes $S(T)=\sqrt{30}/150$. In other words, $T_p = 27.38\ T_m$. For example, a flood wave front reaching a downstream in 13 s in the distorted physical model experiment would correspond to about 6 min in the actual field.

Construction of the physical model

The sight of the area of about 300 m^2 which was reserved to the construction of the physical model is given in Figure 2.

Figure 2 The initial sight of the construction sight.

This area was arranged and concrete was poured after the placement of the reinforcing bars. The cross-sections concerning the dam lake were drawn by using the related maps. The sections manufactured from metal (Fig.3). The lake region was filled with granular material after its walls were constructed (Fig.4). The final shape of the dam lake is given in Figure 5.


Figure 3a Manufacturing of the sections


Figure 3b Placing of the sections


Figure 4 Formation of the concrete surfaces


Figure 5 Final shape of the dam lake

The volume-elevation curve of the physical model lake is given in Figure 6.

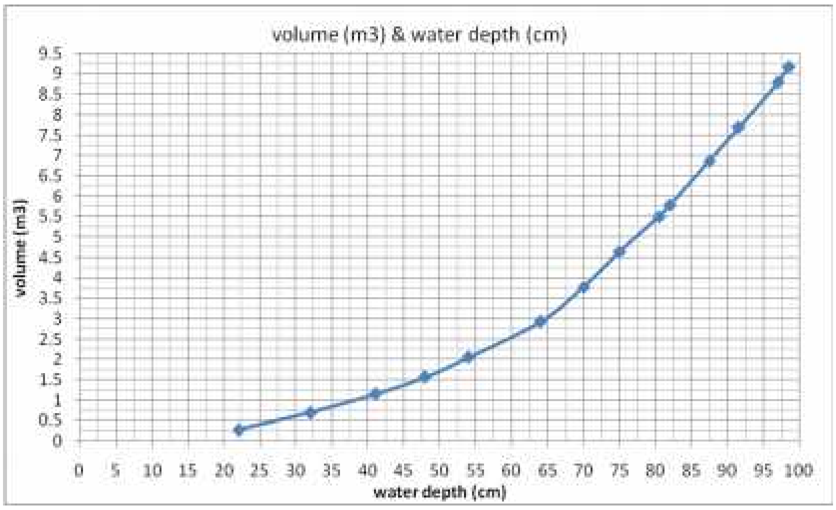

Figure 6 **V**olume-elevation curve of the dam lake of the physical model.

The downstream region was constructed in a similar manner. A view of the downstream part of the model taken before placing the dam body and the roughness elements such as houses, roads is given in Figure 7a. The modeled Seferihisar-Ürkmez highway is shown in Figure 7b.


Figure 7a A general view from the downstream part Figure7b.The highway of Seferihisar-Kuşadası

The final sight of the downstream part of the physical model is given in Figure 8.


Figure 8a A general view from the downstream part Figure 8b Seferihisar-Kuşadası highway

Measurement method

The flow depths are measured by e+ WATER L level sensors (Fig. 9a). These level sensors were distributed over the lake (L1,L2 and L3) and downstream part of the Ürkmez Dam (L4, …,L8). The level measurement values are automatically compensated for variations in air pressure and water density variations due to temperature fluctuations. The velocities are measured by means of UVP (ultrasonic velocity profiler) and its transducers (Fig. 9b).

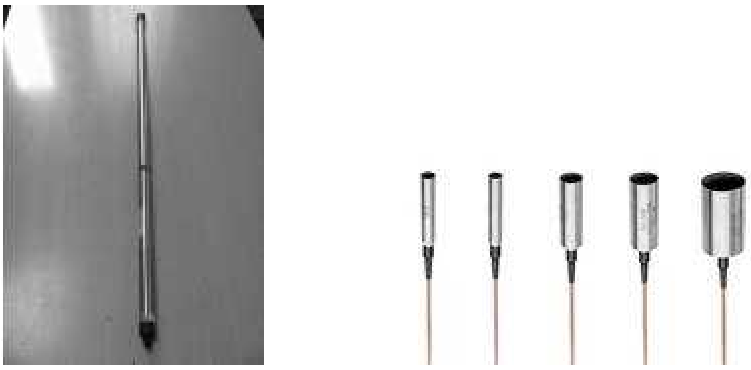

Figure 9 a) e+ WATER L level sensors b) UVP-DUO and UVP transducers

The location of the level meters and UVP transducers are shown in Figure 10.

Figure 10 Locationsof the level meters and UVP transducers

The partial dam break is performed by lifting the trapezoidal shaped part of the dam body (Figure 11).The propagation of the flood is recorded by a HD camera.

Figure 11 The mechanism of the partial dam break

Experimental findings

Flood hydrograph

The flood hydrograph is generated by lifting the trapezoid shaped part of the dam body. The water levels with respect to time in the dam lake are registered by means of the level meter sensor L1. The so measured level values are converted to the volume values by using the prescribed curve given in Figure 6, allowing the determination of the discharge values of the flood hydrograph. The curve obtained from an experiment is depicted in Figure 12.

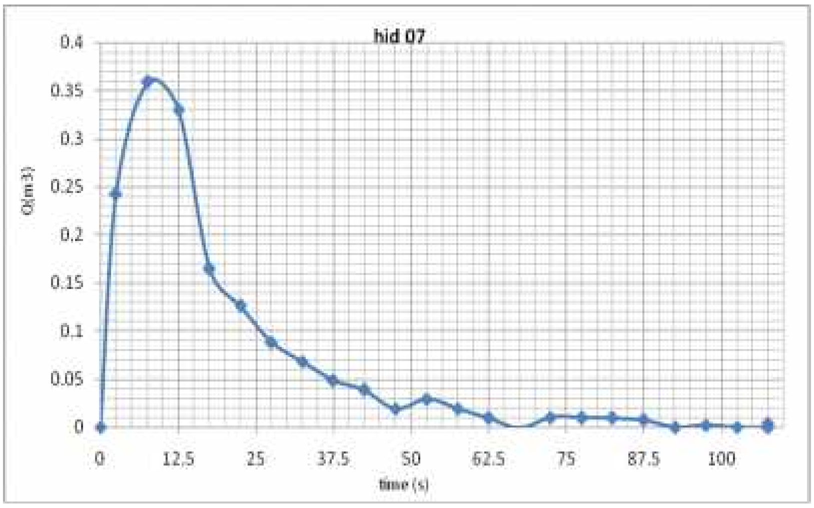

Figure 12 Theflood hydrographs generated during experiments

Water level and velocity measurements

Water level is determined by level rods. 11 level rods were placed in dam area, one of them was positioned at dam lake. Level rod which is in dam lake, sets the falling of water depth at dam lake. Flow hydrograph is obtained based on this information. Other level rods were placed at downstream part. Flow depths are obtained by this way. Also level rods data help the determination of velocity at these points. Here, we shall present some results due to sake of the brevity.

Locations 2, 6, and 10 are on the right hand side of the creek. Figures 13 presents levels on these locations. According to Fig.13, on the right hand side of the creek, the wave front reaches to the first location in 1 min and the last location in 4.5 min. While the rising limbs are sharp, the recession limbs are gradual. The storage effects are not enarmous because the recessions take place in about 20 min in sparse residential areas (Locations 2 and 6) and 35 min in residential area with min level of 30 cm (Location 10).

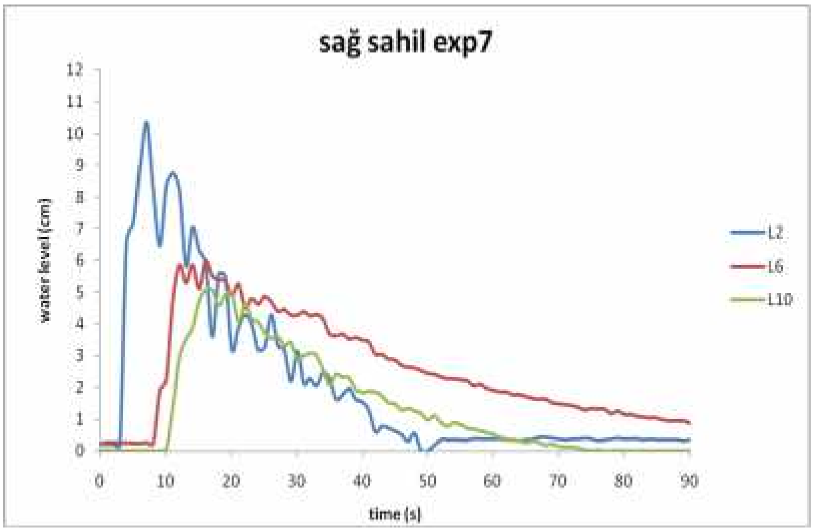

Figure 13 Comparison of levels at locations #2, #6 and #10

Table 2 presents summary of the flow depths, corresponding to the in the prototype. As seen, the depths can reach about 3 m in residential areas.

Table 2 Corresponding water depths (m) at different times (min) at prototype

Time (min)	S2 (m)	S3 (m)	S5 (m)	S6 (m)	S7 (m)	S9 (m)	S10 (m)	S11 (m)
2.2	2.15	**0.72**	0	0.07	0.07	0.10	0	0.09
4.4	**2.51**	0.39	0.52	0.68	0.07	1.83	0.02	0.08
6.6	1.89	0.32	0.78	**1.53**	0.08	**2.60**	1.42	1.55
8.8	0.96	0.26	0.94	1.47	0.74	2.51	**1.49**	**1.81**
10.8	0.98	0.26	0.94	1.46	1.41	2.36	1.12	1.75
12.8	0.94	0.20	0.94	1.29	1.75	2.24	0.86	1.55
14.8	0.68	0.15	**1.00**	1.10	**1.86**	2.00	0.62	1.36
16.8	0.47	0.16	0.99	1.05	1.83	2.03	0.55	1.28

Figure 14 presents flow velocity measurements near Location #2. As seen the velocities measured in the experiment is about 3 m/s, which corresponds to about 4 min in the actual field.

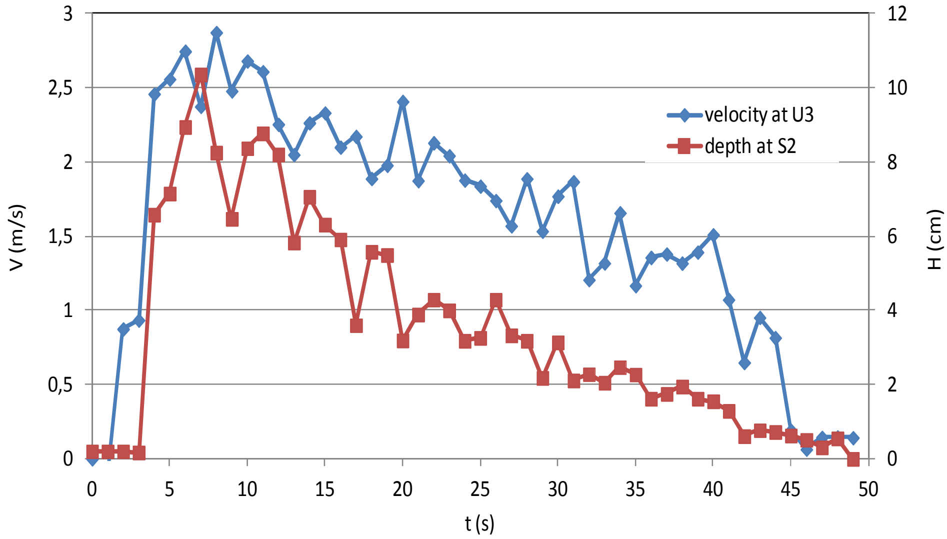

Figure 14 Temporal variations of depths and velocities at Location 2

The propagation of the flood is recorded by a HD camera. The regions to which the flood wave reached at time 2s, 4s and 8s are given in Figure 15.

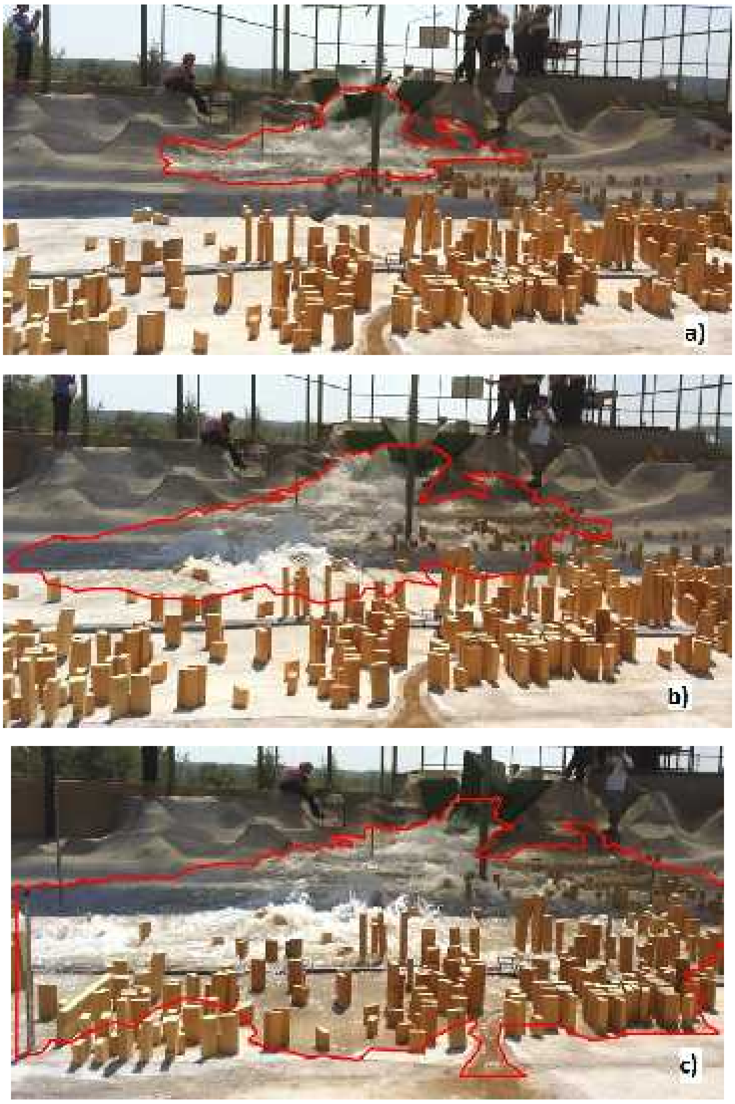

Figure 15 The regions to which the flood wave reached at time (a) 2 s, (b) 4 s; (c) 8 s

Conclusions

What we can summarize from the experimental measured water levels that flow depth exceeds 3 m near downstream of the dam in 3 minutes and reaches 2.5 m depth in the downstream residential areas in about 10 minutes. That means houses and building's first floors would be submerged under the flood flows, causing extensive damage and loss of life in a very short time duration. The storage effects of buildings and highway are clearly observed. In such areas levels can stay around 1.2 m for about 1 hour.

Acknowledgement

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