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A physical model to study dam failure flood propagation

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Abstract: Dam break flood propagation was investigated using a physical model having a horizontal scale of 1/150 and vertical scale of 1/30 of the actual dam with its reservoir, dam body, and downstream area. All major features of Urkmez dam, Izmir, Turkey downstream floodplain such as topography, houses, roads, and bridges were represented in the model. The flood propagation was investigated for a sudden partial collapse of the dam. The water depths were measured by using e+ WATER L (level) sensors. The experimental results showed that the residential area is flooded in a matter of minutes, at depths reaching up to 2.5 meters.

Key words: dam-break, Urkmez dam, physical model, flood propagation.

1. INTRODUCTION

Dam can collapse due to many reasons such as insufficient spillway capacity, piping, overtopping, and earthquakes (Molu, 1995; Bozkus, 2004; Yanmaz and Beser 2005). Residential areas located right downstream of dams can make such failures very disastereous. For example; the collapse of an earthfill dam due to intense rainfall in 2009 in Indonesia resulted in more than 100 fatalities. According to wikipeadia source, so far, about 60 major dam failures occurred since 1900 (http://en.wikipedia.org/wiki/Dam_failure).

Dam flood propagation has been extensively studied in the literature (Lauber and Hager, 1998; Leal et al., 2002; Frazao 2007; Cagatay and Kocaman, 2008; Tsakiris et al., 2010; Tsakiris and Spiliotis, 2013; and Bosa and Petti, 2013). Majority of experimental studies have mostly concentrated on dam failure mechanisms while few investigated flood propagation at downstream section by flume experiments (Palumbo et al., 2008; Frazao and Zech, 2007; Yochum et al., 2008; LaRocque et al., 2013). It is interesting to note that in order to study flood propagation mostly numeical models are used. However physical modelling can be used as an additional supprtive way for flood hazard mapping (Bellos, 2012). Flood hazard maps, according to the EU Directive on floods are maps presenting the inundation area with maximum depths and velocities (Tsakiris et al, 2009). Large scale physical model experiments are quite rare in the literature, such as the work of Morris et al. (2008) who built 6 m high earthfill dam body, right downstream of a an actual dam. Dam break flood propagation over varying topography was also attempted in the literature, such as the work of Testa et al. (2007) who carried out laboratory dam break flows in a simplified urban district. LaRocque et al. (2013) investigated urban flooding by a levee breach.

The study presented in this paper investigates flood propagation due to partial dam break by a distorted model which simulates the actual reservoir and the downstream urban area. It does provide data set on a complex free surface flow in an urban area for validating numerical models.

2. BUILDING THE PHYSICAL MODEL

Urkmez Dam (Figure 1), located in Izmir, Turkey, was chosen for the study because of the settlements located in its downstream area. The physical model was designed according to the Froude similarity law. According to the available space in the open area of Hydraulics Laboratory in Dokuz Eylül University, the horizontal and vertical scales were chosen as l_{xr}: 1/150 and l_{zr}: 1/30, respectively. The geometric characteristics of the Urkmez Dam (prototype) and its distorted physical model were summarized in Table 1.

Figure 1. Urkmez Dam (http://maps.google.com).

Table 1. The geometric characteristics of the prototype and model

Characteristics	Prototype	Model
Crest length (m)	426	2.84
Crest width (m)	12	0.08
Height from base (m)	32	1.07
Reservoir volume at minimum level (m^3)	375 000	0.556
Reservoir volume at maximum level (m^3)	8 625 000	12.78
Reservoir volume at normal level (m^3)	7 950 000	11.78
Lake active volume (m^3)	7 575 000	11.22

The model was constructed in 300 m^2 area which was first arranged and then concrete was poured after the placement of the reinforcing bars (Figure 2).

The cross-sections of the dam reservoir were drawn by using the related maps. The sections manufactured from metal were placed in place. The reservoir region was filled with granular material after its walls were constructed (Figure 3).

Figure 2. Concrete and reinforcing bars.

Figure 3. Metal cross sections and walls.

The downstream area was also constructed in a similar fashion (Figure 4). The dam body which was constructed by screwing the metal sheets had a breach section (Figure 5).

Figure 4. Construction of downstream area.

Figure 5. Construction of dam body.

The roughness elements such as houses, road, and bridge were built in their respective locations (Figure 6).

Figure 7 presents the final version of the constructed physical model with its reservoir, dam body, trapezoidal breach section, and the downstream area.

Figure 6. Residential area including the highway.

Figure 7. Final version of the physical model.

3. EXPERIMENT

The partial dam break was carried out by lifting the trapezoidal part of the dam body (Figure 8) by a motor.

The flow depths were measured by e+ WATER L level sensors (http://en.eijkelkamp.com) whose measurement values were automatically compensated for variations in air pressure and water density due to temperature fluctuations. Figure 9 shows the sensors placed in downstream area and within the dam reservoir.

The model lake volume-water depth curve was obtained by measurements from level meter placed in the reservoir, just next to dam body (see Figure 9). Measured values were converted to the volume by using the curve, allowing the determination of the discharge values of the hydrograph. Figure 10 shows such obtained hydrograph from an experiment carried out on 20.09.2012.

Figure 8. Moment from an experiment.

Figures 11 and 12 show measured water depths corresponding to the discharge hydrograph presented in Figure 10. According to Guney et al (2013), the velocity scale for the distorted model is $V_p = 5.48\ V_m$ and the time scale is $T_p = 27.38\ T_m$. According to Figure 11, the wave front reaches to the last location in about 5 min. While the rising limbs are sharp, the recession limbs are gradual. The storage effects are not significant because of sparse settelments. On the other hand, the storage effects are dominant in dense residential areas. According to Figure 12, the decrease in general takes about 50 min and stays at 1.2 m levels in dense residential area. Table 2 presents summary of the flow depths, corresponding to the ones in the prototype. As seen, the depths can reach 2.5 m in residential areas.

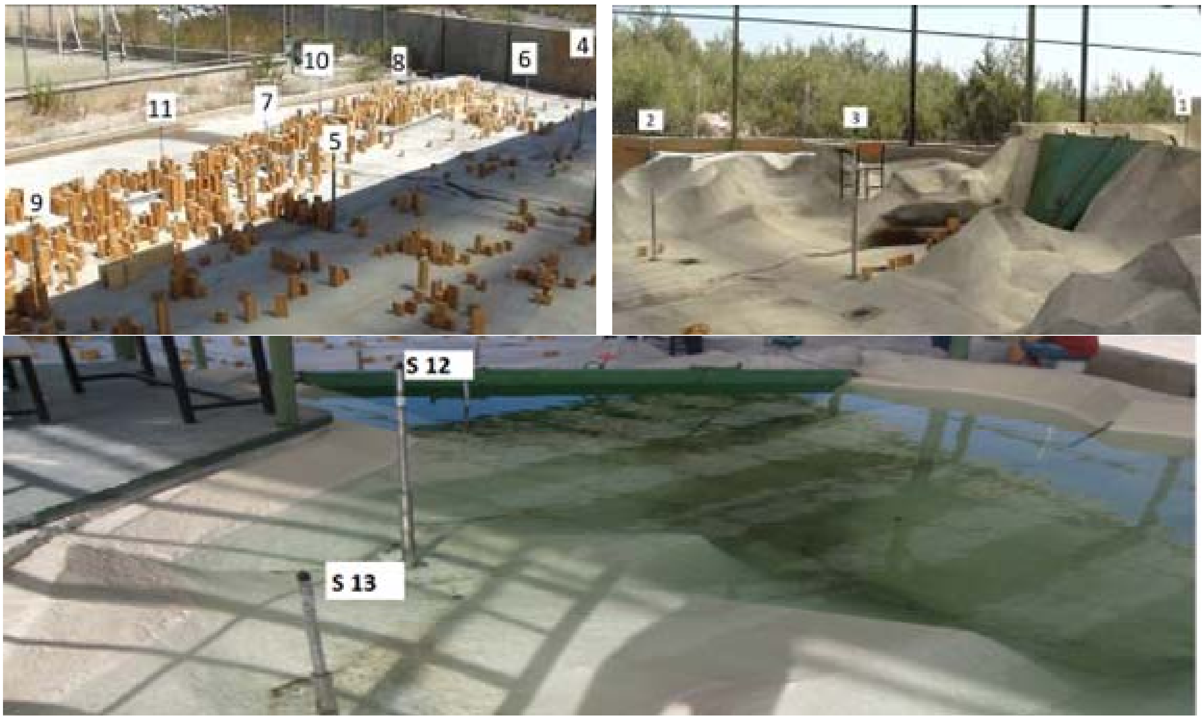

Figure 9. Water level sensors in downstream area (upper) and in the reservoir (bottom).

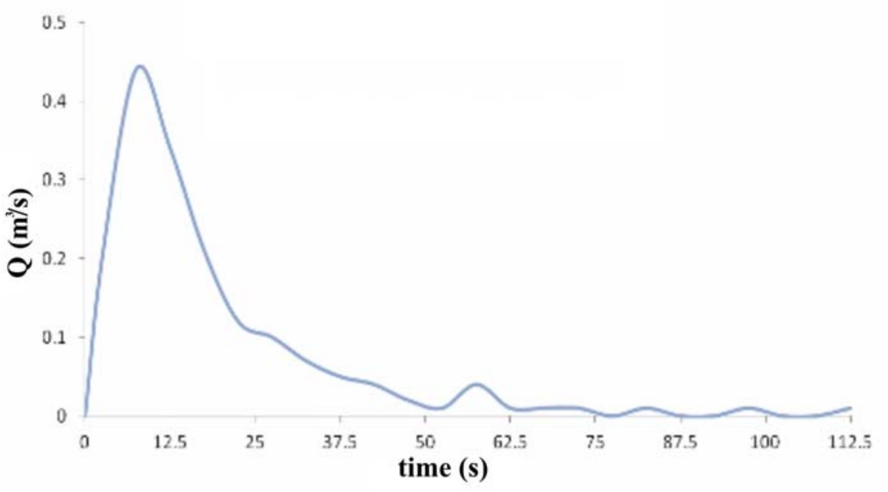

Figure 10. Discharge hydrograph.

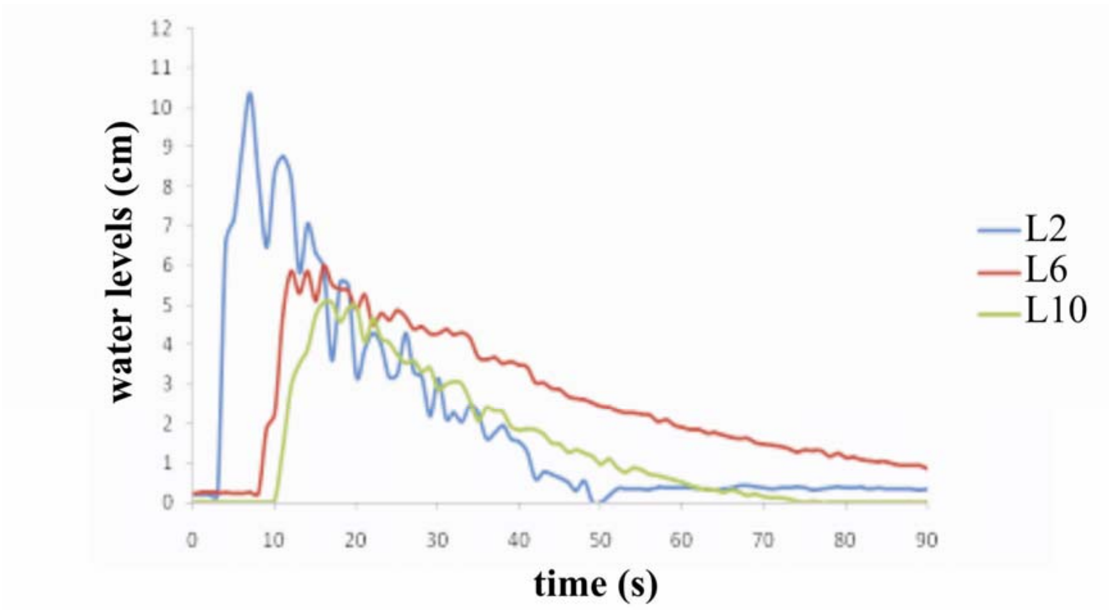

Figure 11. Comparison of levels at locations 2, 6 and10, of the flood field

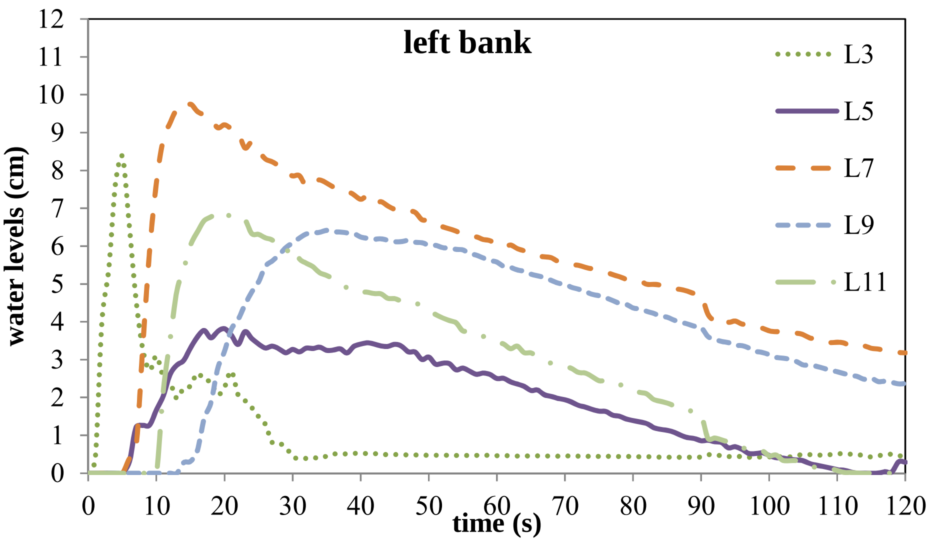

Figure 12. Comparison of levels at locations 3, 5, 7, 9 and 11, of the flood field

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

Time (min)	S2 (m)	S3 (m)	S5 (m)	S6 (m)	S7 (m)	S9 (m)	S10 (m)	S11 (m)
2	2.2	**0.7**	0	0.1	0.1	0.1	0	0.1
4	**2.5**	0.4	0.5	0.7	0.1	1.8	0	0.1
6	1.9	0.3	0.8	**1.5**	0.1	**2.6**	1.4	1.6
8	1.0	0.3	0.9	1.5	0.7	2.5	**1.5**	**1.8**
10	1.0	0.3	0.9	1.5	1.4	2.4	1.1	1.8
12	0.9	0.2	0.9	1.3	1.8	2.2	0.9	1.6
14	0.7	0.2	**1.0**	1.1	**1.9**	2.0	0.6	1.4
16	0.5	0.2	1.0	1.1	1.8	2.0	0.6	1.3

4. CONCLUSION

A distorted physical model of Urkmez Dam in Izmir, Turkey was designed and built in order to study the flood propagation due to hypothetical dam failure resulting from a trapezoid shaped breach. The water depths were measured by e+ WATER L level sensors. The experimental results showed that maximum water depths can reach 2.5 m which can cause serious damages in Urkmez town, located downstream of the dam.

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