Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 49(3) (2017) 141-144
DOI: 10.22060/ceej.2016.705

Flow Field over the Rubber Dams Based on Fluid-Structure Interactions

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ABSTRACT: Rubber dams are flexible cylindrical structures, attached to a rigid base, and are inflated with air and/or water. Most of the rubber dams are permanently inflated, however, they have the advantages of deflating and being flat, when they are not needed, and then inflated in a short period of time when they are required. Large deformation of the membrane due to the internal and external loads, makes the governing equations of such problem to be non-linear and complicated. In the present study, three-dimensional behavior of the rubber dams with respect to the boundary conditions of dam and flow was simulated numerically. Dam geometry and flow hydraulics were modeled, using ANSYS software, CFX and transient structural in workbench environment, simultaneously. Flow hydraulic characteristics and deformation of the dam are obtained, considering fluid-structure interaction. Water free-surface was obtained, applying two-phase air-water flow interface. SST turbulence model in CFX was employed for modelling the separation of flow, downstream of the inflatable dams. Due to the flexibility of the structure, large deformation theory was used in the transient structural solution. Consequently, different features of the flow field, including flow streamlines, velocity and pressure profiles are obtained and compared with those of the rigid circular-crested weirs. Results indicated that the flow hydraulic characteristics over the equilibrium shape of the rubber dams is analogous to those of the rigid circular-crested weirs.

Review History:

Received: 2 December 2014
Revised: 10 November 2015
Accepted: 19 August 2016
Available Online: 21 November 2016

Keywords:

Discharge Coefficient
Fluid-Structure Interaction
Large Deformation
Rubber Dam

1- Introduction

Anwar [1] was the first to study the two-dimensional hydraulic and structural aspects of rubber dams, made of flexible but inextensible materials. He has investigated behavior of the rubber dams, inflated with water under hydrostatic condition as well as the rubber dams, inflated with air under both hydrostatic and hydrodynamic conditions. Harrison [2] considered that the rubber dams are made of elastic materials with linear stress-strain relationship. He investigated both the water and/or air inflated rubber dams under hydrostatic pressure acting at both up- and downstream sections. Alhamti et al. [3, 4] applied the Harrison's approach to obtain the equilibrium shape of the rubber dams, which are inflated by air and/or water. However they did not consider the overflow condition. They quantified the influences of internal pressure, upstream head, dam perimeter length, membrane thickness and base length of the dam on equilibrium shape of a rubber dam. Diaz and Gonzalez [5] investigated the characteristics of an inflatable rubber dam, located over a WES spillway, both experimentally and numerically, indicating good agreement between the two sets of the results. Cheraghi-Shirazi et al. [6] investigated the equilibrium shape, pattern of the three-dimensional deformation of the dam and the flow hydraulic characteristics, based on numerical modelling, using ANSYS software. They also presented a design correlation for the determination of the weir discharge coefficient, based on the equilibrium shape of a rubber dam.

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2- Methodology

By assuming finite length for the models of the rubber dams, effects of the dam's lateral supports and the cross flows, that affect the equilibrium shape of the dam, are deliberated. In the present study, the rubber dams were considered to be attached in a channel with 2 m long, 0.45 m height and 0.9 m wide. The membrane perimeter, base width and thickness were 0.275-0.55 m, 0.15-0.35 m and 0.5-2 mm, respectively. Internal pressure was 1-5 kPa and modulus of elasticity was 4.633-40.6 MPa. Based on a trial-error procedure as well as sensitivity analysis, using available experimental data, a special fine mesh was employed for the interface between the dam and flow due to high gradients of hydraulic aspects, dam flexibility and large deformations.

The available experimental data of velocity profiles over the rubber dam's crest and the rubber dam's equilibrium deformation, were applied as the databank. Notably, very fine meshes tend to loss the appropriate solution due to the divergence of the solution algorithm. Consequently, different features of the flow field including flow streamlines, and velocity and pressure profiles were obtained and comparisons were made with those of the rigid circular-crested weirs. Results indicated that the flow over the equilibrium shape of the rubber dams behaves likewise the rigid circular-crested weirs. A comparison between the present numerical results and experimental data is presented in Figure 1. It can be concluded that the maximum discrepancy between the two sets of data is almost smaller than 2%.

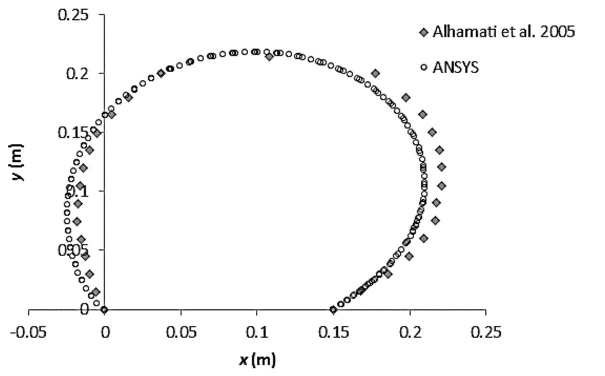

Figure 1. Equilibrium shape of a rubber dam for a flow discharge of 5.25 lit/s and an internal pressure of 4 kPa

3- Results and Discussion

Maximum displacement of a rubber dam relates to the dam crest in the middle section of a 3-D deformed model. For short rubber dams relating to the type of the connection to the channel side-walls, the membrane deforms to a special shape namely "V-notch". Accordingly, the dam height in the middle part decreases, consequently the discharge coefficient increases. According to the present numerical results, by increasing the channel width, for long rubber dams, a 2-D behavior becomes dominant to the fluid-structure interaction. The flow velocity field is a major hydraulic characteristic that affects other hydraulic specifications. Former studies on frontal rigid circular crested-weirs show that the flow velocity is maximum over the weir crest, which decreases from the crest to the free-surface. Comparing the results of velocity distribution obtained in the present study regarding to the equilibrium shape of the rubber dams and those of the rigid circular crested weirs, a meaningful similarity prevails between the two sets of the results (Figure 2). The velocity profiles over the rigid circular crested-weirs belong to Heidarpour and Chamani [7], using model experimentation. Figure 3 compares the pressure profiles obtained in the present numerical modeling with the experimental results of Heidarpour et al. [8]. As shown in this figure, by increasing H_1/R, the pressure profiles deviate from the hydrostatic pressure distribution, leading to the non-linear pressure distribution. By decreasing y/Y2, due to the effects of the deformed rubber dam, and consequently the changes in the hydraulic aspects of flow, major deviations are occurred between the two sets of results.

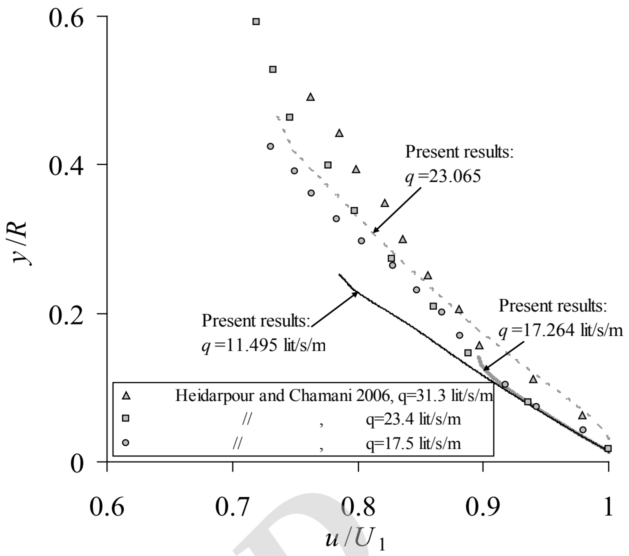

Figure 2. Velocity profiles obtained in the present study compared with those of reference [7]

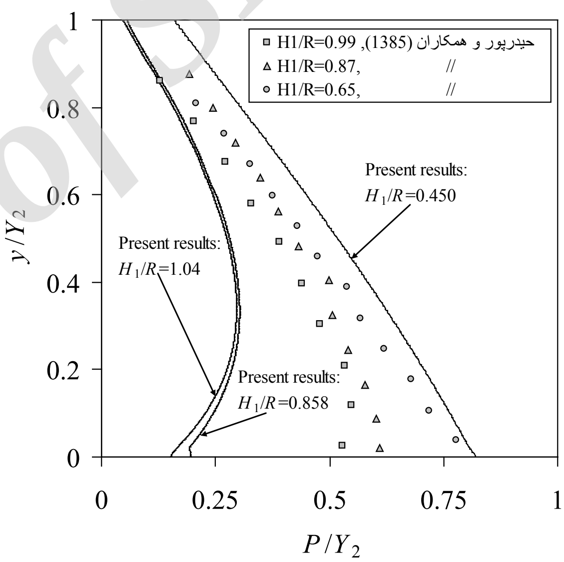

Figure 3. Pressure distributions obtained in the present study compared with those of [8]

4- Conclusions

The major highlights and outcomes of the present study are:

- Dam geometry and flow hydraulics were modeled in ANSYS software using both CFX and Transient structural in workbench environment, simultaneously.
- Due to the flexibility of the rubber dam structures, large deformation theory was used in the transient structural solution
- Different features of the flow field including flow streamlines, velocity and pressure profiles were obtained and compared with those of the rigid circular-crested weirs.
- Flow hydraulic characteristics over the equilibrium shape of a rubber dam perform likewise those of a rigid circular-crested weir.

- By increasing H1/R, the pressure profiles deviate from the hydrostatic pressure distribution, leading to the non-linear pressure distribution

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Please cite this article using:
N. Cheraghi-Shirazi, A.R. Kabiri-Samani, B. Boroomand, “Flow Field over the Rubber Dams Based on Fluid-Structure Interactions”, *Amirkabir J. Civil Eng.*, 49(3) (2017) 477-486.
DOI: 10.22060/ceej.2016.705