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Research article

VERIFICATION OF RESULTS FROM COMPUTER SIMULATION OF A STREAM FLOW ACROSS INFLATED DAM

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ABSTRACT

The aim of this work is to draw a conclusion for the reliability of the calculations by finite element method of an overflow key curve for an inflated dam. The inflated dam is formed by a load bearing membrane with a cylindrical shape, mounted on the bottom of a water flow canal. The calculations provide a link between the overflow water quantity and height of the overflow. Analysis of the formation of the overflow layer is carried out by computer simulation with software ANSYS Workbench CFX. Hydraulic parameters were measured in prerequisite for the rapid flow (Fr> 1) and average level of turbulence. Equations of hydrodynamics are solved by the finite volume type elements with Volume Fraction Fluid. Results were obtained for the pressure and velocity field in the overflow. The overflow height is measured from the graphical representation of the free surface in the cross section of the membrane obtained in the process of simulation.
The verification of the model has been performed on the basis of two criteria:
- small variations of the input variables should cause small changes in the results;
- changes of the mesh size shouldn't provoke changes in the results.

In addition, the influence of the flow and mesh characteristics (turbulence, shape and control spacing) on the output results has been implemented.

Keywords: inflated dam, verification of results, computer simulation

INTRODUCTION

Inflated dams are flexible hydraulic structures made by reinforced rubber and mainly consist of four parts [1] [2]: a dam body made from rubberized fabrics; a foundation; a control room housing mechanical and electrical equipment (e.g. air blower/water pump, inflation and deflation mechanisms); an inlet/outlet piping system (fig.1). The dam body is fixed onto a foundation and abutments by a single or double-line anchoring system. Although the application of such structures in the industry started in the early sixties, their numerical investigation and computer simulation aren't wide-spread in the design activity.

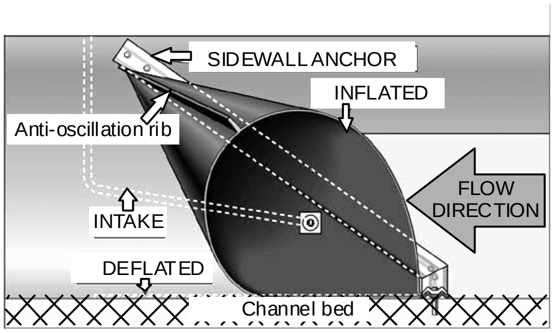

Figure 1: Cross-section of an inflatable dam body

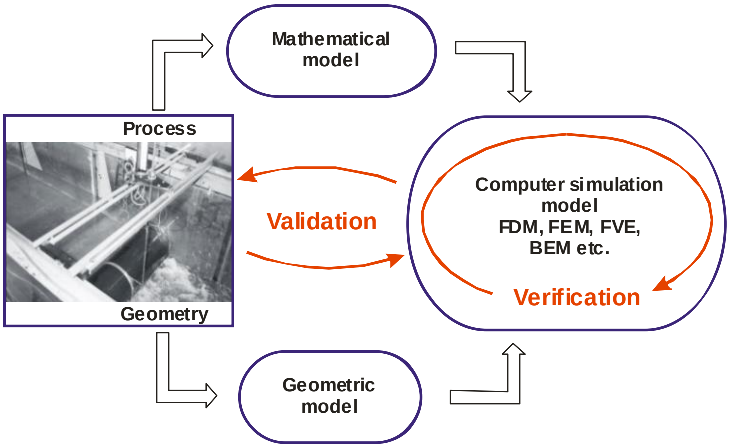

Figure 2: Inflatable dam simulation scheme

As an object for computer simulation, the inflatable dam has two different sides: the hydrodynamic process and the geometry of the hydrodynamic structure (fig.2). In computer simulation system processes are modeled by one of the large spread numerical methods: FDM; FEM; FVE; BEM etc. The geometry is usually modeled by some CAD system, such as AutoDesk Inventor, Solid Works or Ansys Design Modeler. So constructed system can be realized by appropriate software and obtained results can be applied in engineering practice after checking for accuracy. The checking is usually realized by validation and verification of the results. The validation consists of comparing the results with the experimental data while the verification consists of internal system controls, such as small variation control, mesh size control and mesh shape control. These two approaches, which are otherwise widely used, are not well developed for hydraulic inflatable structures. In [3] the numerical example is given without any validation or verification of the results. A comparison between numerical results and experimental results is presented in [4] and [5], but only as a part of a procedure for the model parameters identification. This article presents a verification of numeric results for overflow key curve of a water inflated dam, obtained by computer simulation. The verification has been performed on the basis of small variations of the input variables and the changes of the mesh size. The verification procedure, presented here, can be used in large scale inflatable dam modeling processes.

MATEMATICAL MODELS

The analysis of the overflow stream and dam behavior is based on the Navier-Stokes equations in their conservation form, solved by finite volume technique. The investigated area is divided into small sub-parts, called finite volumes. For each part the equations are discretized and solved iteratively, that leads to approximation values for each variable at the nodes of the finite volume. By these values we can compos the full picture of the pressure and velocity distribution.

List of symbol:

ρ – density; U – vector of velocity; τ – shear stress; T- static temperature; p – pressure; Hu – height of the upstream, Hd – height of the downstream, c_p – specific heat capacity at constant pressure; h – specific enthalpy;

$$step(x)=\begin{cases}1\, for\ x>0\\ 0\, for\ x<0\\ 0.5\, for\ x=0\end{cases};$$

$$\nabla=\left[\frac{\partial}{\partial x},\frac{\partial}{\partial y},\frac{\partial}{\partial z}\right];$$

$$U\otimes V=\begin{bmatrix}U_xV_x & U_xV_y & U_xV_z\\ U_yV_x & U_yV_y & U_yV_z\\ U_zV_x & U_zV_y & U_zV_z\end{bmatrix};$$

$$\nabla\bullet(\rho U\otimes U)=\begin{bmatrix}\frac{\partial}{\partial x}(\rho U_xU_x)+\frac{\partial}{\partial y}(\rho U_yU_x)+\frac{\partial}{\partial z}(\rho U_zU_x)\\ \frac{\partial}{\partial x}(\rho U_xU_y)+\frac{\partial}{\partial y}(\rho U_yU_y)+\frac{\partial}{\partial z}(\rho U_zU_y)\\ \frac{\partial}{\partial x}(\rho U_xU_z)+\frac{\partial}{\partial y}(\rho U_yU_z)+\frac{\partial}{\partial z}(\rho U_zU_z)\end{bmatrix}.$$

Transport equations:

$$\frac{\partial\rho}{\partial t}+\nabla\bullet(\rho U)=0$$ - Mass conservation;

$$\frac{\partial(\rho U)}{\partial t}+\nabla\bullet(\rho U\otimes U)=-\nabla p+\nabla\bullet\tau$$ - Momentum conservation;

$$\frac{\partial(\rho h_{tot})}{\partial t}-\frac{\partial p}{\partial t}+\nabla\bullet(\rho U h_{tot})=\nabla\bullet(\lambda\nabla T)+\nabla\bullet(U\bullet\tau)$$ - Energy conservation.

Incompressible equation of state

$$\rho=\rho_{spec};$$

$$dh=c_p dT+\frac{dp}{\rho};$$

$$c_p=c_p(T).$$

K-epsilon model for turbulence

K-epsilon turbulence model is used here as a model, that has proven to be stable and robust with a well established regime of predictive capability, offering a good compromise in terms of accuracy and robustness [6].

$$\frac{\partial(\rho U)}{\partial t}+\nabla\bullet(\rho U\otimes U)=-\nabla p+\nabla\left[\mu_{eff}\left(\nabla U+(\nabla U)^T\right)\right]$$ - Momentum conservation,

were $\mu_{eff}=\mu+\mu_t$ is an effective viscosity, μ is a molecular (dynamic) viscosity and μ_t is a turbulence viscosity:

$$\mu_t=C_\mu\rho\frac{k^2}{\varepsilon},\ C_\mu$$ - constant.

The turbulence kinetic energy k (variance of the fluctuations in velocity) can be obtained from the differential transport equation for the turbulence kinetic energy:

$$\frac{\partial(\rho k)}{\partial t}+\nabla\bullet(\rho Uk)=\nabla\bullet\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\nabla k\right]+P_k+P_{kb}-\rho\varepsilon,$$

were P_k is a turbulence production due to viscous forces:

$$P_k=\mu_t\nabla U\bullet\left(\nabla U+\nabla U^T\right)-\frac{2}{3}\bullet\nabla(3\mu_t\nabla\bullet U+\rho k).$$

The turbulence eddy dissipation ε (the rate at which the velocity fluctuations dissipate) can be obtained from the differential transport equation for the turbulence dissipation rate:

$$\frac{\partial(\rho\varepsilon)}{\partial t}+\nabla\bullet(\rho U\varepsilon)=\nabla\bullet\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\nabla\varepsilon\right]+\frac{\varepsilon}{\kappa}\left[C_{\varepsilon 1}(P_k+P_{\varepsilon b})-C2\rho\varepsilon\right],$$

were P_{kb} and $P_{\varepsilon b}$ present the influence of the buoyancy forces (don't used in this case).

COMPUTER SIMULATION

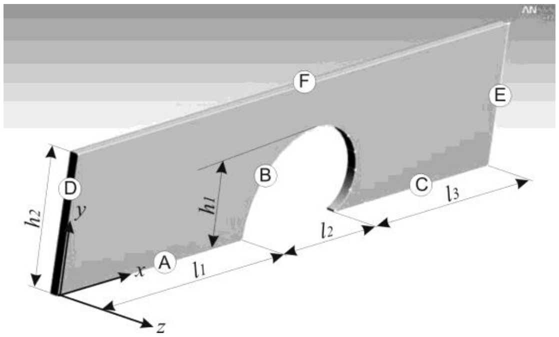

Figure 3: Geometrical model

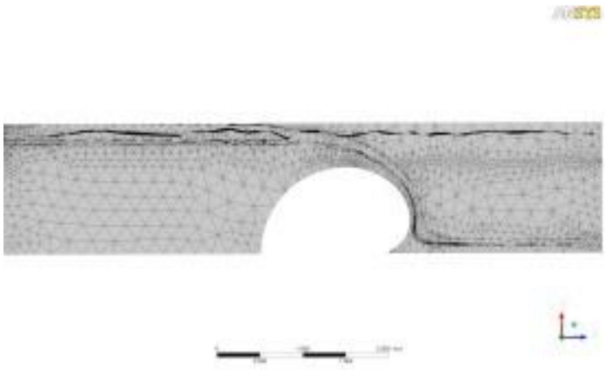

Figure 4: Finite volume mesh with mesh adoption

Computer simulation of the overflow process has been performed by Ansys CFX software on the basis of the described above equations. As the inflatable dam has a cylindrical shape, the analysis has been limited in a plane (in CFX case – in a thin volume) normal to cylinder's axis (fig.3). The boundary conditions are (following notations on fig.3):

A – upstream bottom, no slip wall, U=0;

B – inflatable dam surface, free slip wall, Un=0;
C - downstream bottom, no slip wall, U=0;
D – inlet, Uy=Uz=0, Ux=Uin, $p = \rho(Hu-y)$;
E – outlet, Uy=Uz=0, $p = \rho(Hd-y)$;
F – open area, Uz=0.
In addition the two side vertical layers have been treated as planes of symmetry.

The investigated area has been divided (fig.4) into finite volumes of fluid for simulate a free surface flow. The volume mesh around the interface area between stream water and air has been refined by mesh adoption process to obtain better solution [5]. Initial conditions for air volume fraction (AVF), water volume fraction (WVF) and pressure, applied in the solution, are:
- AVF = step(y – Hu), indicate that the initial water depth is equal to Hu;
- WVF = step(Hu - y), indicate the same state;
- $p = \rho(Hu-y)$, indicate a hydrostatic distribution of the pressure;
- Uy=Uz=0, Ux=Uin, indicate that initial velocity vector is equal to inlet velocity.

With “High Resolution Advection Scheme”, auto time scale factor equal to 1 and RMS residual target equal to 10^{-3}, the process converged after 86 iterations.

RESULTS AND DISCUTION

For verification of the simulation process, a set of calculations has been performed in limits for height of the dam 1 $<h_1<2$, mesh size in square meter $0.1 < m < 0.3$ and velocity in meter per sec. $0.1 < Uin < 1.2$. The results have been obtained for full velocity (fig.5), pressure (fig.6) and air and water volume fraction (fig.7),

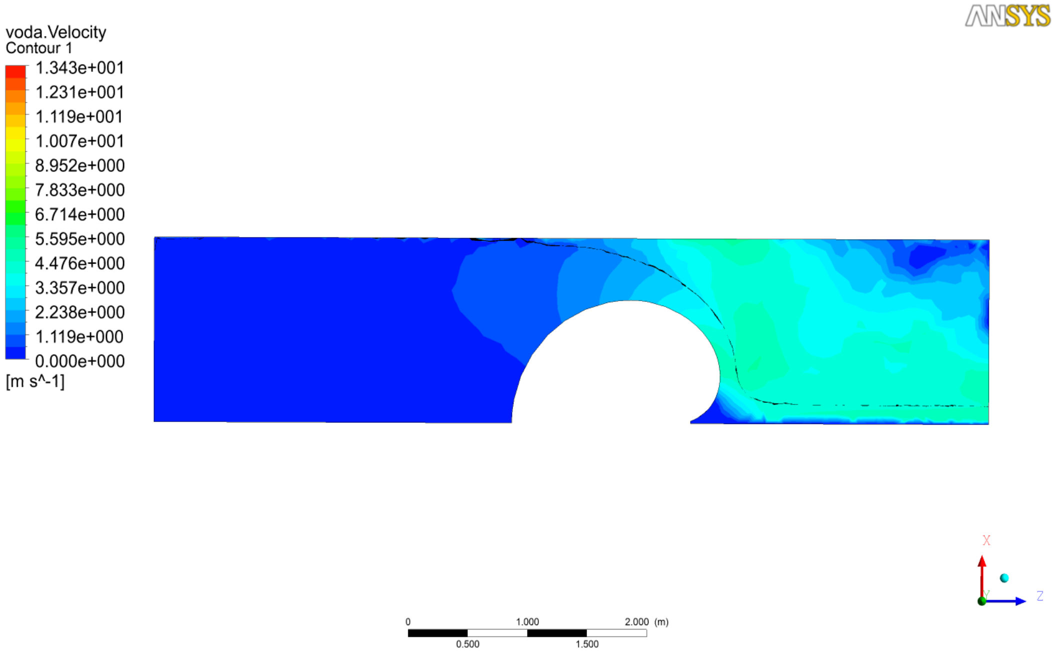

Figure 5: Velocity distribution for h_1=1m, Hu=1.5 m, Uin=0.5 m/s.

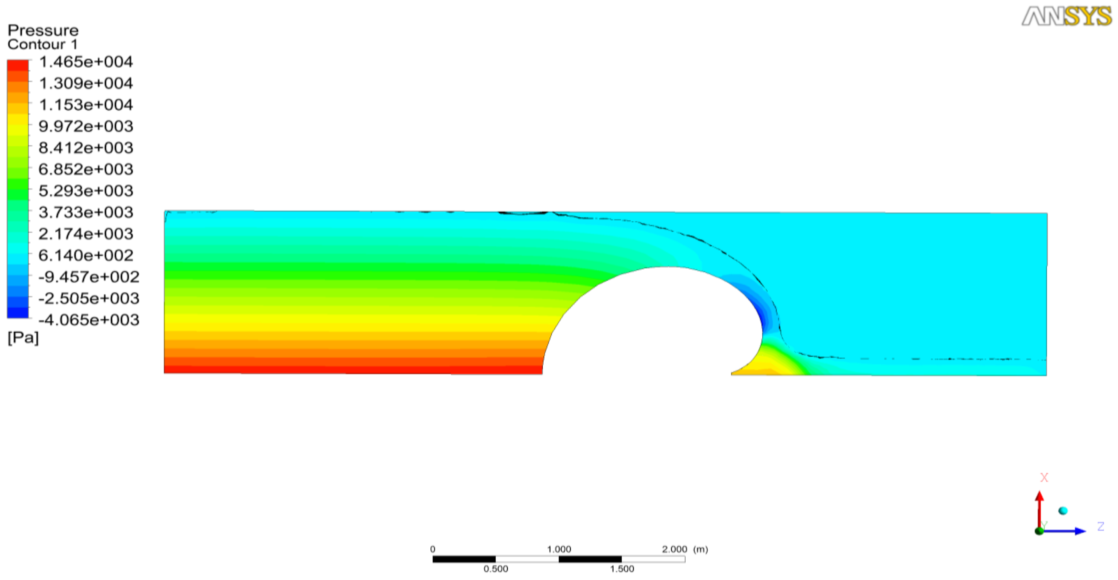

Figure 6: Pressure distribution for h_1=1m, Hu=1.5 m, Uin=0.5 m/s.

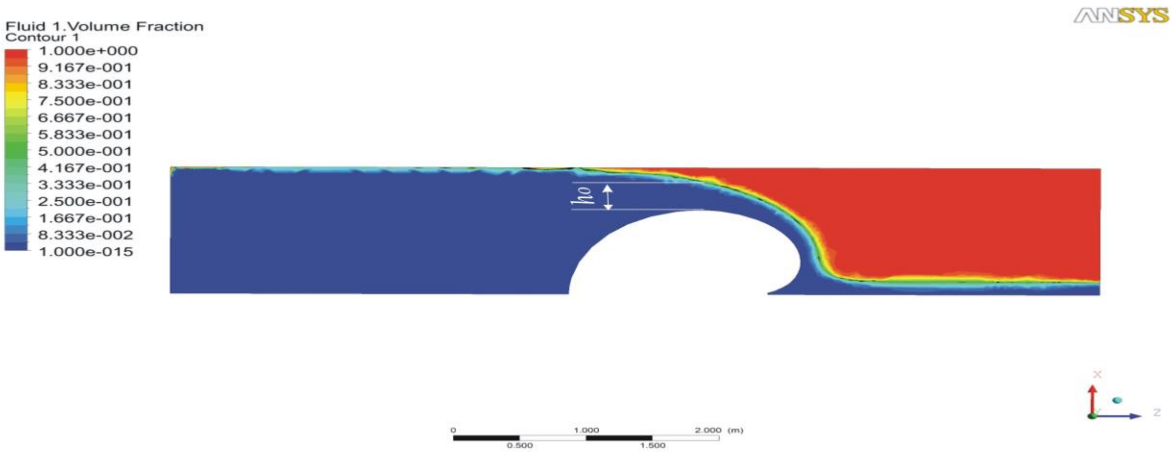

Figure 7: Phase volume fraction for h_1=1m, Hu=1.5 m, Uin=0.5 m/s.

The height of the overflow stream (y_0 in fig.7) has been taken as control parameter during verification. Analysis of results for all elements of the set leads to the next conclusions:

1. Small variations of the input variables should cause small changes in the results.

Figure 8 depicts the results for ±20% change of input velocity. The underlying tendency fit to the awaited one: the increasing of the velocity leads to increasing of the overflow height. The obtained curve is smooth and continues, with control parameter deviation equal to this of the input. The conclusion is that the model, used for computer simulation, is adequate.

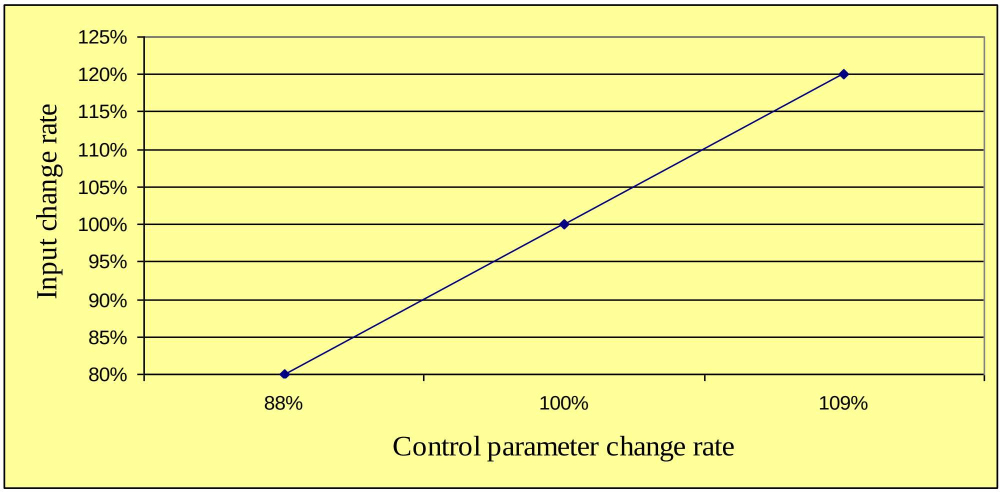

Figure 8: Change rate of the control parameter in ±20% change of the input

2. Changes of the mesh size shouldn’t provoke changes in the results.

Figure 9 depicts the results for mesh size changing. The slope part of the curve shows dependence of the control parameter on the mesh size, which is inadmissible for the model. The horizontal part shows the lack of such dependence, but decreasing the mesh size we also increase the memory and CPU requirements. The conclusion is that the mesh size for adequate model is 0.185 (at the bent).

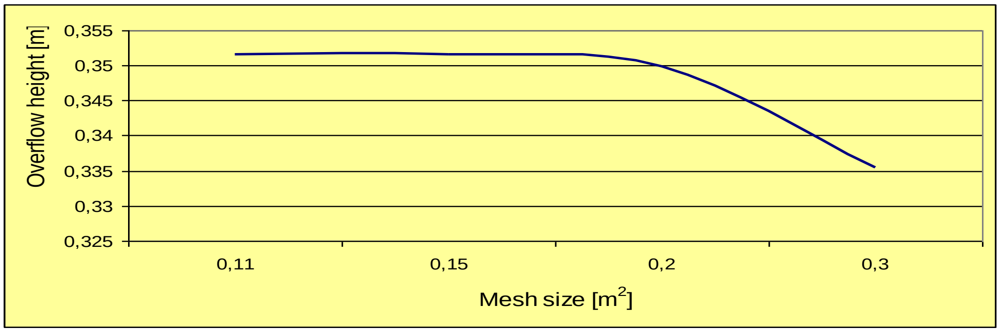

Figure 9: Impact of the mesh size changing on the overflow height fraction for h_1=1m, Hu=1.5 m, Uin=0.5 m/s

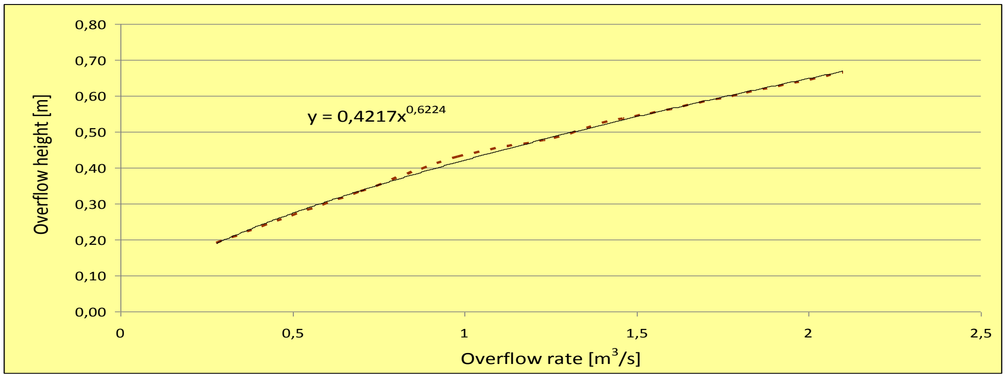

Figure 10: Overflow key-curve for h_1=1m and dam width 1m.

After verification, the model has been used for computer simulation of the overflow process, directed to obtaining of the key-curve of the dam. Figure 10 depicts the typical results for computer simulation. Such results are of great importance for inflatable dam construction and can be used for validation of the models, comparing with nature or physical experiments.

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