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Fluid Flow over Inflatable Stopper in Penstock

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Extended Abstract

In this article the interaction between fluid flow and rubber inflatable stopper is described on the basis of the computer simulation in an ANSYS Workbench project environment. The stopper is composed by a load bearing rubber membrane, fixed on the wall of a trapezium-shaped penstock in the way to form a cylindrical dam. As a totally flexible media, rubber membrane accepts the form, defined by the pressure and internal membrane forces. The two-dimensional geometry of the stopper cross-section in XoY plain is generated in a MAPLE environment on the basis of the equations for equilibrium of the infinite small element of the membrane under free surface flow:

$$
\begin{aligned}
x &= \left(\frac{2T}{H_0} - H_0\right) F\left(k,\psi\right) + H_0 E\left(k,\psi\right) \\
y &= H_0 - \sqrt{H_0^{\ 2} + 2T\left(\cos\varphi - 1\right)}
\end{aligned} \quad , \qquad (1)
$$

were H_0 is an internal pressure of the stopper, T – internal force of the membrane, φ - angle between tangent to the element and horizontal direction, F and E – elliptic integrals of first and second order with $k = \sqrt{4T / H_0^2}$ and ψ=0,5φ. The coordinate set is included in AutoCAD for constructing a graphical spline, which is taken as a basis for the 3-D stopper geometry. The fluid is homogeneous turbid water with density between 998 kg/m^3 and 1150 kg/m^3 and dynamic viscosity between 0.001 Pa.s and 0.01 Pa.s. 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 by CFX software in ANSYS Workbench environment. The stream has low turbulence modeled by a standard k-epsilon model. The boundary conditions for the velocity at the inlet and the pressure at the outlet are set as first-type boundary condition (Dirichlet boundary conditions). The verification of the model is 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. The investigation of the interaction process is realized using various values for the fluid characteristics (density and viscosity). The results for the pressure and the velocity are compared with the results obtained from free surface flow simulation in similar conditions. While during free surface flow the increasing the velocity arouse increasing of the external pressure, in penstocks the same causes decreasing, due to negative velocity pressure. In this case the internal pressure considerably differs from this, formed by free flow, most often in the uppermost section of the stopper. The different pressure impacts on the geometrical formation of the dam and on the mechanical behavior of the stopper in general. On the basis of the obtained results, the recommendations for modification of the existing calculation procedure for free surface fluid flow in the way to use it for fluid flow in a penstock is given in the conclusion.