A 3-dimensional numerical study of flow patterns around a multipurpose dam

Sungyul Yoo, Ph.D.*, Kiwon Hong ** and Manha Hwang, Ph.D.***

* Soft-Tech International, Inc., 15215 NE 72nd Street, Redmond, WA 98052, USA
**STIKorea, Chonghoe Bldg 3rd Fl, Oryu-Dong 115-1,Kuro-Ku, Seoul, 152-100, Korea
***Water Resources Research Institute, Korea Water Resources Corporation
462-1, Jeonmin-Dong, Yusung-Gu, Taejon 305-390, Korea

Abstract This numerical study has been performed to predict the flow patterns and characteristics around Soyang multipurpose dam as the flow of the dam reaches to the flood design capacity or near flooding due to weather changes resulting from the global warming trend. A commercially known software, FLOW-3D®, was applied to numerically solve the Navier-Stokes equations for solution domains which are separated into three regions with overlapping boundaries to efficiently accommodate the grid resolutions; namely, the reservoir, the spillway and the stilling basin. Calculations by using a Pentium (500Mhz) personal computer took typically a few days for the reservoir of up to a half million grid system and less for other domains. The calculated results such as pressure, velocities, flow rate, surface height were compared with the scale model data where available. The reservoir calculation shows 4% more discharge than the operation manual and uneven discharge through each gate due to a complex flow pattern just upstream of the weir. In the spillway calculation reached the maximum velocity to about 43m/sec. Also, the reattachment distance at the stilling basin is in good agreement with the measurement. In conclusion, the results from numerical simulation are generally well agreed with the existing data and flow information such as flow field patterns at increased flow, local flow disturbances, discharge rate and surface height distribution is obtained to be used for engineering design purpose.

Outlines

As the flow at near flooding or flood design capacity was frequently encountered, the design criteria of a multipurpose dam has changed from a frequency basis to the PMF (Probable Maximum Flood) one. This study has been conducted to predict the flow patterns and characteristics due to the flow increase around the multipurpose dam, and will aid the design process of dam structures including the spillway and stilling basin.

In the design process of any large hydraulic structures, hydraulic model tests have usually been employed to verify the design concept with the aid of limited analysis tools. In these days due to the advantage of the computer hardware and software advancement, complicated engineering problems become to have recourse to the new computational approach using numerical methods, which complement the model test in a design process. The merit of numerical simulation is that various probable flow phenomena can be calculated with minor input variations to obtain the data over the calculated domains.

In this paper, numerical simulation using FLOW-3D® is presented for the reservoir, spillway, and stilling basin and their results are discussed and compared with existing data where available.

Hydroinformatics 2002: Proceedings of the Fifth International Conference on Hydroinformatics, Cardiff, UK
 ISBN 1 84339 021 3 (set)

Models of Reservoir, Spillway and Stilling Basin

Based upon the x, y, z location data from GPS, 3-dimensional surfaces in a stereolithographic (STL) CAD format were generated as shown in Figure 1, and subsequently 3-dimensional solid models were constructed using a CAD tool for each region. Table 1 shows the sizes and numbers of meshes for each domain.

Table 1. Domain sizes and meshes

	Reservoir	Spillway	Stilling Basin
X distance :Mesh No.	3300mm(-2000m ~1320m) : 210	80m (-40m ~40m) : 53	350m(-200m~150m) : 90
Y distance :Mesh No.	1850m(-150m ~ 1700m) : 88	304m(-300m~ 4m) : 152	500m(-710m~210m) : 125
Z distance :Mesh No	135m(74m – 209m) : 27	128m(81m~ 209m) : 27	128m(55m~30m) : 25

Assumptions

Although the reservoir level actually rises in two days, the level in the simulation was increased to 203m in 4000 seconds. With the upstream velocities less than 1m/sec, both cases exhibited the subcritical flow patterns, and the flow difference between the two was assumed to be negligible. However, to correct the possible discharge error introduced by reduced time span simulation, a steady state calculation with the upstream level fixed at 198m has been made. By matching the surface heights at the same reference locations, the discharge in difference was corrected.

Boundary Conditions

Currently, the calculation domains are divided into three sequential zones with some overlapping boundaries, which enable the calculations to efficiently make use of meshes as well as to avoid the time step limitations due to high velocity at the spillway. As described in 'Assumptions', inlet conditions of the reservoir were set as mass sources and heights increasing with respect to time, and downstream boundary conditions of the reservoir can be described using a certain surface height lower than the weir crest in order not to disturb the upstream For the spillway simulation, calculated reservoir results with the level of 198m at upstream were used to derive the inflow boundary conditions and for the downstream, continuation conditions were used. Also, the upstream boundary conditions of the stilling basin were derived from the flow field and water heights known from the spillway calculations, along with the sides and top described as pressure conditions and downstream as outflow boundary conditions. For other conditions, no slip conditions are applied for the walls and bottoms when the solid boundaries present, and atmospheric pressure conditions for the top. The table 2 shows the summary of the boundary conditions applied for each domain.

Table 2. Summary of boundary conditions for each domain

	Reservoir	Spillway	Stilling Basin
XMIN	Solid Wall	Solid Wall	Velocity
XMAX	Velocity	Solid Wall	Continuation
YMIN	Pressure	Velocity	Solid Wall
YMAX	Solid Wall	Continuation	Solid Wall
ZMIN	Solid Wall	Solid Wall	Solid Wall
ZMAX	Pressure	Pressure	Pressure

Results and Discussions

In Figure 2, calculated velocity fields in the reservoir are compared with ones from Soyang hydraulic scale model report, because actual measurements were not available. Although, in the hydraulic scale model test, the vortex pattern was not conclusive near the left entrance of the spillway, both calculations of the scale and the real model showed the vortex and the latter with the stronger pattern. The flow pattern just upstream of the spillway in the calculations is quite different from ones from the scale model because the inflow to the model structure comes directly into the spillway region but in reality the inflow will generally pass the spillway upstream and come back after reaching the moorage region at the other end. From this observation, the domain of the scale model test seemed too small for the experiment to predict the correct flow field around the dam but just enough to forecast the discharge, which is determined from the water height at the dam, the width and the characteristic coefficient regardless of the upstream flow pattern. Figure 3 shows the cross sectional flows at the gate and due to non-uniform inflow situation, gates no. 1 and no 5 show quite irregular surface shapes with vortex motion, thus causing the discharge at each gate to be varying.

The discharge curves as a function of height are compared in Figure 4, where the operation manual curve is obtained from the scale model test, the middle curve from actual geometry and the highest curve from the modified fore bay geometry. With only 4% difference in discharge amounts between the calculations and the scale model test, it is noted that the calculations seem to predict the discharge reasonably well and the modified fore bay didn’t impact the discharge rate significantly. Figure 5 shows the surface velocity distributions for the spillway with inlet conditions of 198m at the reference point. The maximum velocity reached 43m/sec in 10 seconds at the spillway bottom and non-uniform flow patterns are observed due to the chute block spacing and the jump is caused by the flip bucket at the chute bottom. Shown in Figure 6 is the reattachment in the stilling basin and the reattachment distance is favourably compared with the scale model test and the hydraulic jump at the reattachment region is predicted in the calculation.

Conclusions

The simulation predicted the velocity fields quite well and showed 4% more discharge than the operation manual. The flow features at gates Nos. 1,2 and 5 showed the very strong vortex motion, resulting in non-uniform discharge through each gate. The fore bay area velocity reaches less than 1m/sec because upstream flow travels to the moorage area and return to the fore bay region, thus increasing the stagnant phenomena before reaching the spillway entrance. The maximum velocity reached around 43m/sec at the downstream of the spillway and the maximum cavitation pressure of about 40,000Pa occurred at a convex curvature location downstream of the gate, suggesting that aeration need to be studied. The reattachment length of about 150m didn't change noticeably when the discharge amount increased and the entering velocity of 40m/sec was reduced to 20m/sec at the exit, which means good energy dissipation at the basin. With this investigation, it is considered that FLOW-3D can reasonably predict the real flow around the hydraulic structures. In conclusion, it is suggested that both the numerical data and the scale model test should serve the design purpose complementing each other.

References

Sicilian,J.M.,C.W.Hirt & R.P.Harper (1987) FLOW-3D:Computational Modeling Power for Scientists and Engineers, Flow Science, Inc. Report FSI-87-00-01

Lee,B.K.,Kim,Y.K.,et al (1970) Report of a Hydraulic Model test on Soyang Multipurpose Dam, National Construction Research Institute, Ministry of Construction

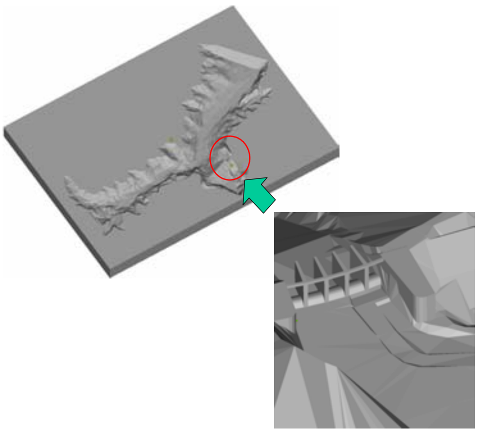

Figure 1. STL geometry for the reservoir, spillway and stilling basin

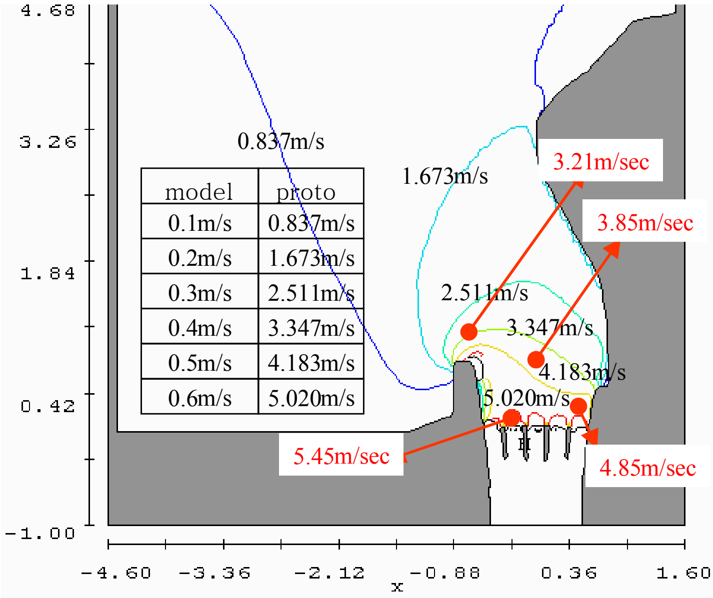

Figure 2. Surface velocity comparison from scale model and calculation

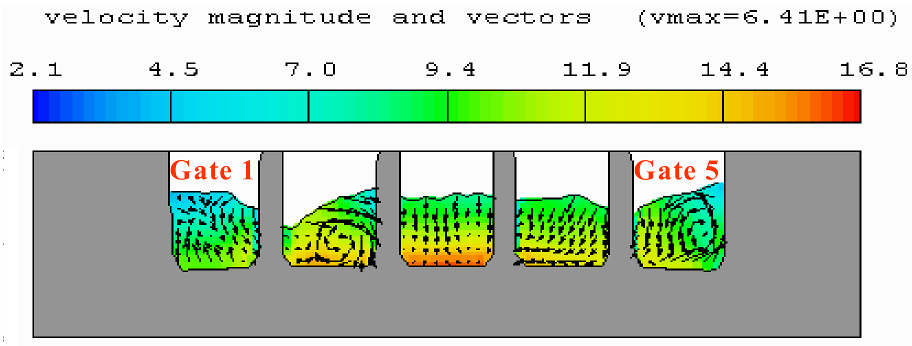

Figure 3. Velocity vectors and surface heights at the weir of the spillway

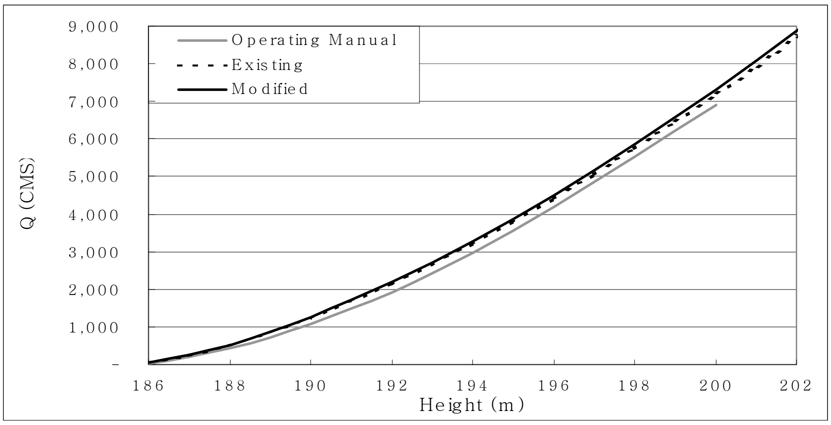

Figure 4. Discharge comparison among operation manual, existing and modified fore bay geometry

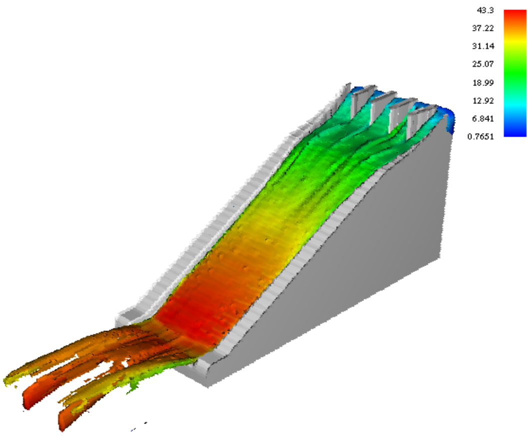

Figure 5. Surface velocity distribution of the spillway flow

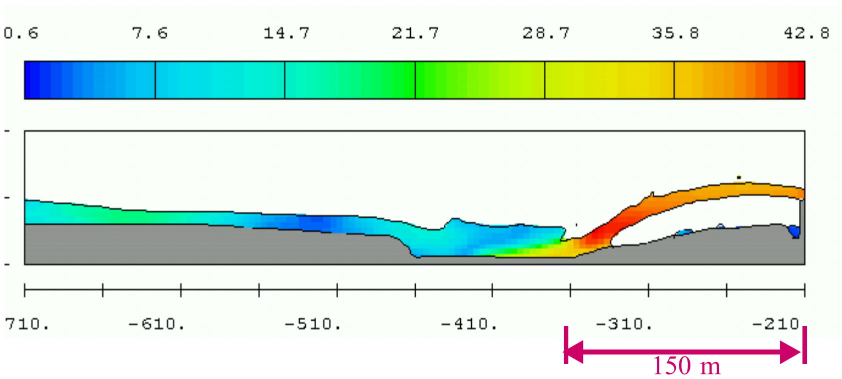

Figure 6. Jump and reattachment in the stilling basin