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The Calculation of Flooding Level using CFX Code

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1. Introduction

The plant design should consider internal flooding by postulated pipe ruptures, component failures, actuation of spray systems, and improper system alignment. The flooding causes failure of safety-related equipment and affects the integrity of the structure. The safety-related equipment should be installed above the flood level for protection against flooding effects. Conservative estimates of the flood level are important when a DBA occurs.

The flooding level can be calculated simply applying Bernoulli's equation. However, in this study, a realistic calculation is performed with ANSYS CFX code. In calculation with CFX, air-core vortex phenomena, and turbulent flow can be simulated, which cannot be calculated analytically.

2. Flooding Level Analysis

The flooding level is determined by internal flow sources, occurring with pipe ruptures, component failures and drain capacity. (Q_i) is defined as the quantity of the inflow rate for the internal flood sources due to the postulated piping. (Q_o) is defined as the outflow rate through an outflow path using an appropriate formula.

If a pipe rupture occurs in the isolated room with the drain and the inflow rate is assumed to be constant, the flood level rises until the outflow rate is equal to the inflow rate. The flood level is defined as follows:

$Q_i = Q_o(\triangle h)$

The assumptions in this calculation are as follows:

- Inflow rate: $0.03\ m^3/sec$
- The room size: 5m×5m
- Pressure: 1 atm.
- Drain diameter: 10cm
- The length of drain: 3m

Figure 1 shows the schematics of the flooding analysis for a flooding room.

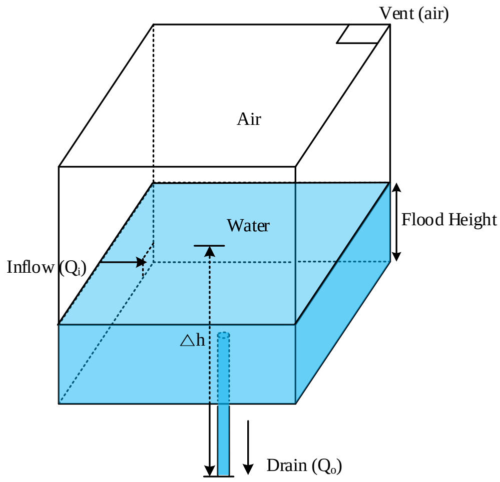

Fig. 1 The schematic of flooding analysis

2.1 Analytical Calculation

The flood level can be calculated with Bernoulli's equation as the following:

$$\rho g \Delta h + \frac{1}{2}\rho v^2 + P = C \quad (1)$$

The outflow velocity is derived from eq. *(1):*

$$v = \sqrt{\frac{2g\Delta h}{k}} \quad (2)$$

$Q_i = Q_o(\triangle h)$; therefore, the flood level is calculated as follows:

$$\Delta h = \frac{k}{2g}\left(\frac{Q_i}{A}\right)^2 \quad (3)$$

$$\Delta h = \frac{4.92}{2\times 9.8}\left(\frac{0.03}{0.0078}\right)^2 = 3.71m$$

Where,

k : Pressure loss coefficient	$\frac{0.5\times 3}{0.3045} = 4.92$
g : Gravitational acceleration	*9.8m/sec*
A : Flow area	$0.0078m^2$
Q_i *: Inflow rate*	$0.03m^3/sec$

Δh is evaluated as 3.71m, and the flood height is approximately 0.71m.

2.2 CFX Analysis

For a realistic evaluation, a CFX Analysis is performed. In the analysis, an air-water flow can be simulated. This simulation evaluates the flood level in the steady-state.

The 5 governing equations are used in CFX because 2 fluids, air and water, in a three-dimensional space. Thus, 2 mass conservation *(eq.4)* equations and 3 momentum conservation *(eq.5)* equations are solved simultaneously at each node.

$$\frac{\partial \boldsymbol{u}}{\partial \boldsymbol{x}}+\frac{\partial \boldsymbol{v}}{\partial \boldsymbol{y}}+\frac{\partial \boldsymbol{w}}{\partial \boldsymbol{z}}=0 \qquad (4)$$

Where,
u : Fluid velocity in the x direction
v : Fluid velocity in the y direction
w : Fluid velocity in the z direction

$$\rho\left(\boldsymbol{u}\frac{\partial \boldsymbol{u}}{\partial \boldsymbol{x}}+\boldsymbol{v}\frac{\partial \boldsymbol{v}}{\partial \boldsymbol{y}}+\boldsymbol{w}\frac{\partial \boldsymbol{w}}{\partial \boldsymbol{z}}\right)=-\frac{\partial \boldsymbol{p}}{\partial \boldsymbol{u}}+\mu\left(\frac{\partial^2 \boldsymbol{u}}{\partial \boldsymbol{x}}+\frac{\partial^2 \boldsymbol{v}}{\partial \boldsymbol{y}}+\frac{\partial^2 \boldsymbol{w}}{\partial \boldsymbol{z}}\right)+\rho \boldsymbol{g}_x \qquad (5)$$

Where,
ρ : Fluid density
μ : Fluid viscosity
g : The gravitational acceleration

A CFX Model setup is presented in Fig.2. Water and air fluid is applied in the CFX model. An inlet is modeled for a flooding source, and outlets are modeled for drainage of the flooding source and ventilation of the air.

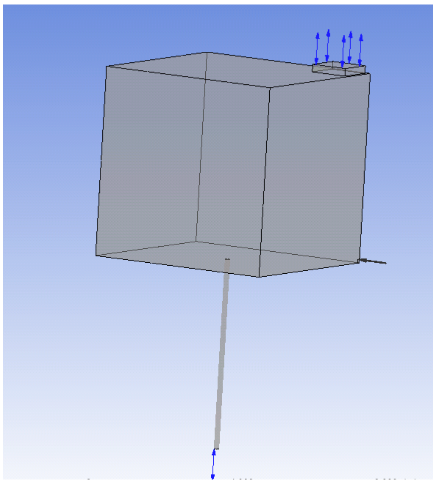

Fig. 2 CFX modeling

K-epsilon model is selected for turbulence modeling. K represents the energy carried by the turbulence, while ε represents the length scale of the turbulence. And a free surface model is applied between air and water.

Figure 3 shows the water volume fraction at steady-state. The flood level is evaluated as approximately 1.1m.

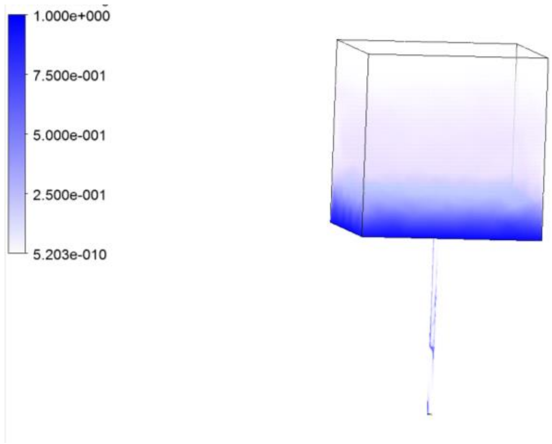

Fig. 3 The result of water volume fraction

Figure 4 shows the water velocity of the drain. The velocity distribution in the drain indicates irregularity due to the turbulent water flow with air.

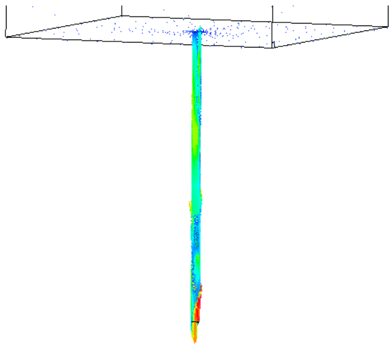

Fig. 4 The result of drain water velocity

Figure 5 shows the air volume fraction in the drain where air is mixed with water. Consequently, water drainage rate is reduced.

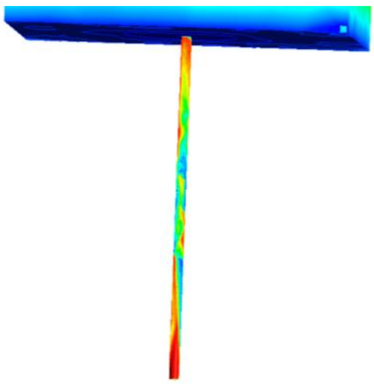

Fig. 5 The result of air volume fraction

3. Conclusion

The flooding level is evaluated by analytical calculation and CFX analysis for an assumed condition.

The flood level is calculated as 0.71m and 1.1m analytically and with CFX simulation, respectively.

Comparing the analytical calculation and simulation, they are similar, but the analytical calculation is not conservative. There are many factors reducing the drainage capacity such as air-core vortex, intake of air, and turbulent flow.

Therefore, in case of flood level evaluation by analytical calculation, a sufficient safety margin should be considered.

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