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Sensitivity of Debris Transport on Containment Floor in Particle Tracking Model

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1. Introduction

Debris transport through the containment floor to recirculation sump in pressurized water reactors (PWR) has been one of the most important areas in resolving the Generic Safety Issue (GSI) 191 [1].

For the regulatory supporting purpose, the authors have developed a hydraulic solver to calculate the flow field on containment floor [2] and a Lagrangean particle tracking model to trace debris particle using the pre-determined flow field following a loss-of-coolant accident (LOCA) [3]. The flow field was calculated by Finite Volume Method (FVM) with unstructured triangular meshes for two-dimensional Shallow Water Equation (SWE). The method has been successfully applied to Advance Power Reactor 1400 containment. In the plant specific evaluation of the GSI-191, it was found that sensitivity study was needed to investigate the reliability and accuracy of the model, especially in terms of the transport fraction (TF). Also the characteristics of the TF are requested for the various sizes, densities and other properties of debris.

The present paper is to discuss reliability and sensitivity of the transport fraction calculated by the author's model. [3].

2. Particle Tracking Model

Position of a particle i at time n+1 in two-dimensional cartesian coordinates can be calculated during time interval Δt_P as follows:

$$\boldsymbol{x}_i^{n+1} = x_i^{n+1}\boldsymbol{i} + y_i^{n+1}\boldsymbol{j} = \boldsymbol{x}_i^n + \boldsymbol{w}_i^n \Delta t_P \quad \text{.........................(1)}$$

particle velocity, $\boldsymbol{w}_i = u_i\boldsymbol{i} + v_i\boldsymbol{j}$, can be solved from the equation of motion with fluid velocity $\boldsymbol{V}_f = u_f\boldsymbol{i} + v_f\boldsymbol{j}$,

$$m_i \frac{d\boldsymbol{w}_i}{dt} = -\boldsymbol{D}_i = -A_i C_D \frac{1}{2}\rho_f \left|\boldsymbol{w}_i - \boldsymbol{V}_f\right|(\boldsymbol{w}_i - \boldsymbol{V}_f) \quad \text{..................(2)}$$

In this equation, interactions of debris-fluid and debri-debri were not considered in conservative point of view to maximize the particle velocity. Assume the particle be in spherical shape with diameter d_i and density ρ_i, then

$$\boldsymbol{w}_i^n = \boldsymbol{w}_i^{n-1} - \frac{3}{4}\frac{\rho_f \Delta t_p}{\rho_i d_i} C_D^{n-1}\left|\boldsymbol{w}_i^{n-1} - \boldsymbol{V}_f^{n-1}\right|(\boldsymbol{w}_i^{n-1} - \boldsymbol{V}_f^{n-1}) \quad \text{......... (3)}$$

The reason for the spherical shape was in simplicity and conservatism in resulting in small drag force. Drag coefficient, C_D can be expressed based on Schiller and Neumann correlation [4]:

In solving the eq.(3), the position of particle and the cell having the particle, i.e., the hosting cell, should be determined. To do this, the method proposed by Martin [5] was incorporated, which was to save the time required in searching the hosting cell. And a scheme of Haselbacher [6] was adopted to determine the reflected positions from the solid wall.

Actually the transport fraction over a specified time period is calculated by eq.(1) and (3), it may be affected by several parameters including physical property. Those effects including density and size were studied in the present study.

3. Base Calculation

The method described above was applied to the debris transport problem on containment floor following a large break LOCA of APR1400. Fig. 1 shows a computational domain of APR1400 containment. The domain has structural walls including containment inner wall, secondary shield wall, etc. The Hold-up Volume Tank (HVT) was surrounded by three pieces of HVT shield structures allowing four entrances.

The solution domain was discretized by unstructured triangular meshes as shown in Fig. 1. The number of cells and nodes were 7228 and 4245, respectively. Two-dimensional transient flow field for the APR-1400 was already calculated [3].

Base calculation was conducted for the particle whose diameter and density were 0.02 m and 900 kg/m^3, respectively. The particles were assumed to be initially within a circle whose center and radius are (0, 6.5151 m) and 0.9 m, respectively. They were randomly

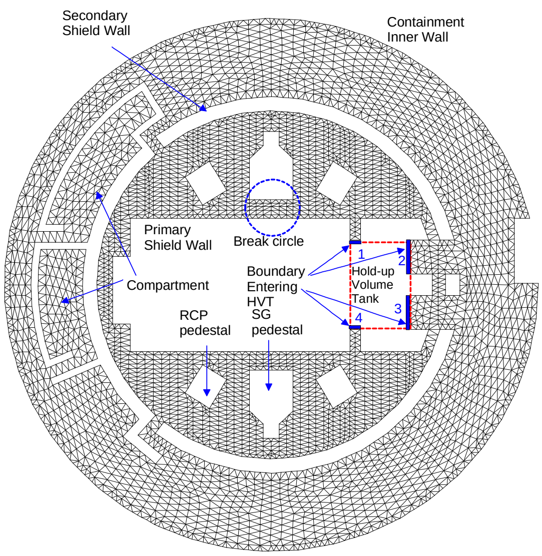

Fig. 1. Calculation domain and meshes

distributed within the circle. The particles were added to the circle such that the number of particle decreased linearly from 98 at zero seconds to 2 at 9.5 seconds. The time step Δt_P was 0.01 sec.

Fig. 2 shows the predicted particle trajectories until 10 sec. The number of particles transported to HVT was 120 among 1000 particles (0.12 of transport fraction).

4. Sensitivity Calculation

To confirm the calculated TF is reliable with the change of time step size and number of particle injected, calculations were conducted for the case Δt_P =0.001 seconds and for the cases with particles of 200~2000. Fig. 3 shows a comparison of the TF behavior up to 100 seconds. As a result, it was shown that the identical value of TF can be obtained for time step less than 0.01. And the cases with the number of particles more than 1000 can provide a reliable TF within 10^{-3} order level.

To investigate the effect of particle size and density, additional calculations were done for d_i=2 mm ~ 5 cm and ρ_i,=400~1300 kg/ kg/m^3, respectively. Fig. 4 shows comparison of the result with the base calculation. It was shown that the smaller sizes and density the more particles to HVT. The TF ranges from 0.12 to 0.22 for the range of parameters investigated.

5. Concluding Remarks

The reliability and sensitivity of the transport fraction calculated by the particle tracking model proposed by the authors was investigated. Time step size less than 0.01 seconds and number of particles injected more than 1000 under the current mesh system were confirmed to provide a reliable value. It was also found that the smaller particle size and density the higher transport fraction in the APR1400. The calculated transport fraction was ranged 0.12 to 0.22.

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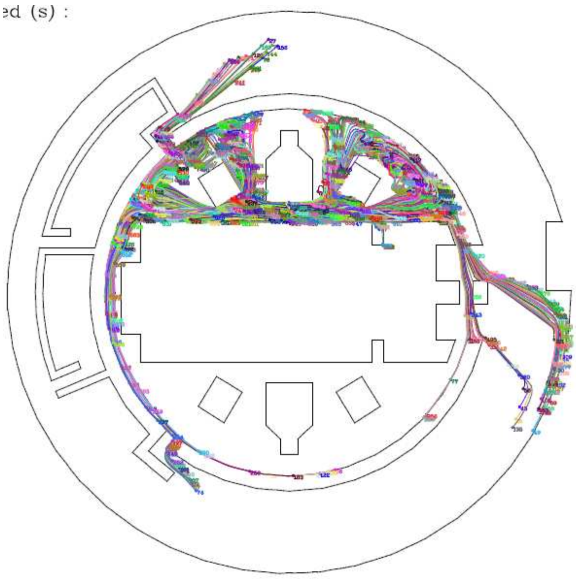

Fig. 2. Particle trajectories at 10 seconds

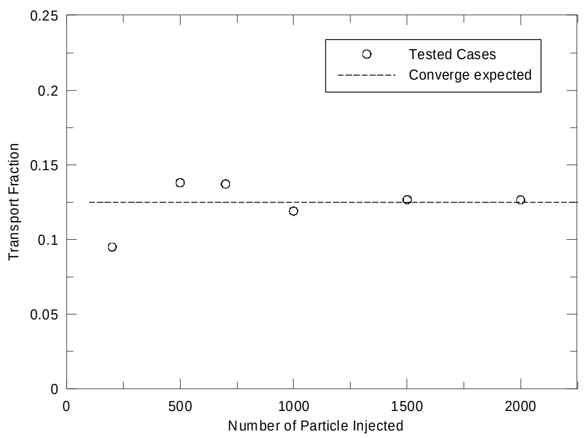

Fig. 3. Convergence of transport fraction with number of particles

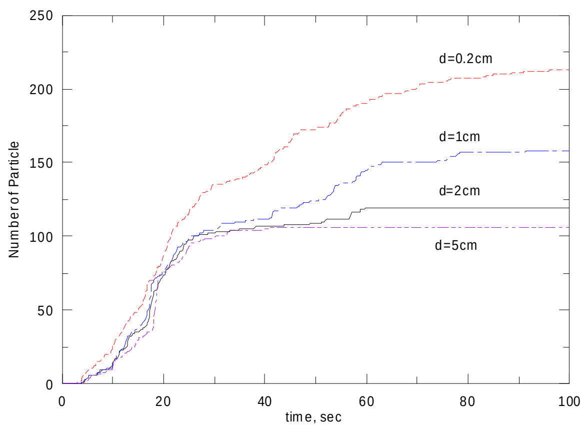

Fig. 4. Comparison of number of particles entered HVT (effect of size)