# A Particle Tracking Model to Predict the Debris Transport on Containment Floor

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## 1. Introduction

Debris transport through the containment floor to recirculation sump has been one of the most difficult problems in resolving the Generic Safety Issue (GSI) 191. The complicated hydrodynamic phenomena including break jet flow, water spreading, interaction with structures, free surface flow, etc., are involved. Also debris transport may range from transport of solute to one of particle or rigid body. Due to those aspects, the regulatory requirement was imposed to use a conservative assumption (100% transport) unless the analytical approach was fully justified [1]. One of the feasible approaches is to calculate the hydraulics on containment floor and then to calculate the debris transport using the hydraulic data[2]. Lagrangean particle tracking method or Eulerian method can be used for the latter. Although the fluid-debris interaction is ignored in this approach, the complex and iterative calculation for the interaction can be avoided and the overestimation of transported amount of debris expected.

The present paper is to discuss a particle tracking model for the use of debris transport evaluation. The hydrodynamic flow field was already calculated by the authors [3].

## 2. Particle Tracking Model

Position of particle *i* at time *n+1* in two-dimensional cartesian coordinates can be expressed as follows:

$$\begin{Bmatrix} x_i^{n+1} \\ y_i^{n+1} \end{Bmatrix} = \begin{Bmatrix} x_i^{n} \\ y_i^{n1} \end{Bmatrix} + \begin{Bmatrix} u_i^{n}\Delta t \\ v_i^{n}\Delta t \end{Bmatrix} \quad \text{......(1)}$$

where particle velocity, $u_i$ and $v_i$ can be solved from the equation of motion with fluid velocity $u_f$ and $v_f$,

$$m_i \frac{du_i}{dt} = -D_{x,i} = -A_i C_{Dx} \frac{1}{2}\rho_f \left|u_i - u_f\right|(u_i - u_f)$$
$$m_i \frac{dv_i}{dt} = -D_{y,i} = -A_i C_{Dy} \frac{1}{2}\rho_f \left|v_i - v_f\right|(v_i - v_f) \quad \text{......(2)}$$

Assume the particle be in spherical shape with diameter $d_i$ and density $\rho_i$, then

$$m_i = \rho_i \frac{1}{6}\pi d_i^{\,3}, \quad A_i = \frac{1}{4}\pi d_i^{\,2} \quad \text{......(3)}$$

Inserting eq.(3) into eq.(2), and express the time derivative term in explicit manner,

$$u_i^{n+1} = u_i^n - \frac{3}{4}\frac{\rho_f \Delta t}{\rho_i d_i} C_{Dx}^n \left|u_i^n - u_f^n\right|(u_i^n - u_f^n)$$
$$v_i^{n+1} = v_i^n - \frac{3}{4}\frac{\rho_f \Delta t}{\rho_i d_i} C_{Dy}^n \left|v_i^n - v_f^n\right|(v_i^n - v_f^n) \quad \text{......(4)}$$

Drag coefficient, $C_D$ can be expressed based on Schiller and Neumann correlation [4]:

$$\begin{aligned} C_D &= 24/\mathrm{Re} && \textit{for}\ \mathrm{Re} < 0.1 \\ &= Max\left[(24/\mathrm{Re})(1+0.15\,\mathrm{Re}^{0.687}),\ 0.44\right] && \textit{for}\ 0.1 < \mathrm{Re} < 1000 \\ &= 0.44 && \textit{for}\ 1000 < \mathrm{Re} < 1.2\times10^5 \end{aligned} \quad \text{......(5)}$$

, where Reynolds number was defined as follows:

$$\mathrm{Re}_x = \frac{\rho_f \left|u_i^n - u_f^n\right| d_i}{\mu_f}, \quad \mathrm{Re}_y = \frac{\rho_f \left|v_i^n - v_f^n\right| d_i}{\mu_f} \quad \text{......(6)}$$

To define the fluid velocity, we have to know the cell having the particle, i.e., the hosting cell. To save the time required to search the hosting cell, the method proposed by Martin [5] is introduced. If the particle is located within the cell, then the following condition should be met (Fig. 1(a)).

$$E_1 = \boldsymbol{n_1}\cdot(\boldsymbol{p}_i - \boldsymbol{m_1}) < 0,$$
$$E_2 = \boldsymbol{n}_2\cdot(\boldsymbol{p}_i - \boldsymbol{m}_2) < 0, \quad \text{......(7)}$$
$$E_3 = \boldsymbol{n}_3\cdot(\boldsymbol{p}_i - \boldsymbol{m}_3) < 0$$

If those conditions are not met, the particle will be outside the cell k. For that case, the cell sharing the side *j* related to the maximum of $E_j$ will be searched first. This process are repeated until eq.(7) is satisfied.

An intersection of a particle trajectory with side of a cell can be determined as shown in Fig.1(b). Consider the particle moves from position ***p*** to position ***q*** with intersecting with the side at position ***r***. Assuming ***t*** is unit vector from ***p*** to ***q***, ***C*** is a center of the side, and vector ***r-p*** = $\alpha t$, then

$$(\boldsymbol{r}(\alpha) - \boldsymbol{C})\cdot\boldsymbol{n} = 0 \quad \text{......(8)}$$

From the equations, $\alpha$ can be determined as follows:

$$\alpha = (\boldsymbol{C} - \boldsymbol{p})\cdot\boldsymbol{n}/(\boldsymbol{t}\cdot\boldsymbol{n}) \quad \text{......(9)}$$

If the distance from ***p*** to ***q*** is *d*, $\alpha > d$ means the position ***q*** is inside the cell.

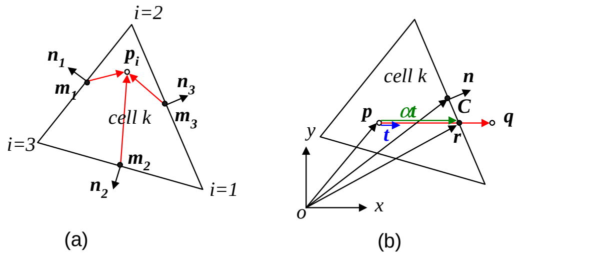


Fig. 1. Host cell criteria and intersection of particle trajectory

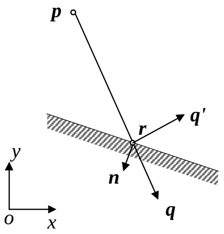


Fig. 2. Treatment of reflective boundary

If the intersecting side is a reflective boundary, i.e., solid wall, the reflection of the particle should be considered (Fig. 2) [6]. From the vector operation, the new position ***q'*** can be determined as follows:

$$\boldsymbol{q}' = \boldsymbol{q} - 2\{(\boldsymbol{q}-\boldsymbol{r})\cdot\boldsymbol{n}\}\boldsymbol{n} \quad (10)$$

For the given mesh system and transient velocities at each cell, the initial positions of particles is inputted, the new positions were calculated by eq.(1) to (7). For the reflective boundary, the new particle position is modified.

## 3. Application to Actual Problem

Two-dimensional transient flow field on the containment floor following a large break loss-of-coolant accident (LOCA) for the APR-1400 was already calculated by the authors [3]. In the present study, the hydraulic calculation was improved using the refined mesh system (Fig.3). The number of cell and nodes were 7228 and 4245, respectively.

Using the geometry and flow field data, the trajectory of particle was calculated. The particle was assumed to be distributed randomly within a circle with center (0, 6.91) and radius of 0.9 m. Total number of particle was 1000 and they were assumed to be present in the circle with a manner decreasing linearly up to 9.5 sec. Totally, 1000 particle trajectories were calculated for 100 seconds. The calculated result at 31 seconds was shown in Fig. 4. In the calculation, the diameter and density of the particles were 0.02 m and 400 $kg/m^3$, respectively.

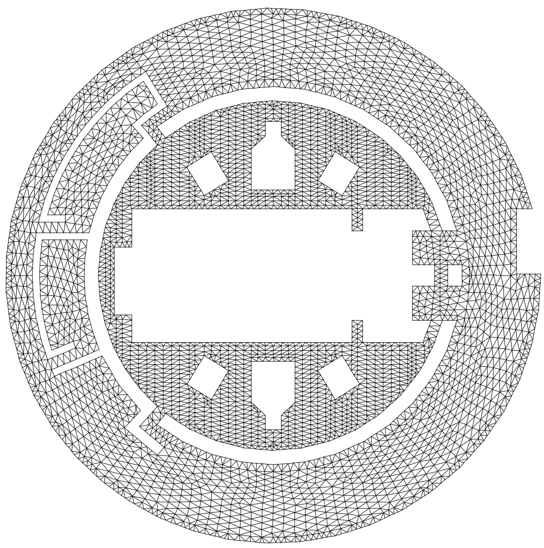

Fig. 3. Mesh system of the containment floor

## 4. Concluding Remarks

A particle tracking model was developed to predict the debris transport on containment floor. Algorithms to find host cell and to correct the position at reflective boundary were implemented. The model still needs a validation with the applicable experiment data, however, the performance of the model is believed to be applicable to the debris transport problem.

## REFERENCES

[1] USNRC, Regulatory Guide 1.82, Revision 3, Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident, 2003.

[2] Atsushi Ui and Fumio Kasahara, Development of a Numerical Method for Flooding Flow and Transport of LOCA-Generatad Debris to Sump Screens, NTHAS5-I004, 5th Korea-Japan Symposium on Nuclear Thermal Hydraulics and Safety, Nov. 2006.

[3] Young S. Bang, et al., Transient Flow Field in Containment Floor Following a LOCA of APR-1400, Transactions of the Korean Nuclear Society Autumn Meeting Pyeong Chang, Korea, October 30-31, 2008.

[4] R. Clift, J. R. Grace, and M. E. Weber, Bubbles, Drops and Particles, Academic, New York, 1978.

[5] Martin, G.D, et al., Particle Host Cell Determination in Unstructured Grids, Computers and Fluids, Vol. 38, pp. 101-110, 2009.

[6] Haselbacher, A., et al., An Efficient and Robust Particle-Localization Algorithm for Unstructured Grids, Journal of Computational Physics, Vol. 225, pp. 2198-2213, 2007.

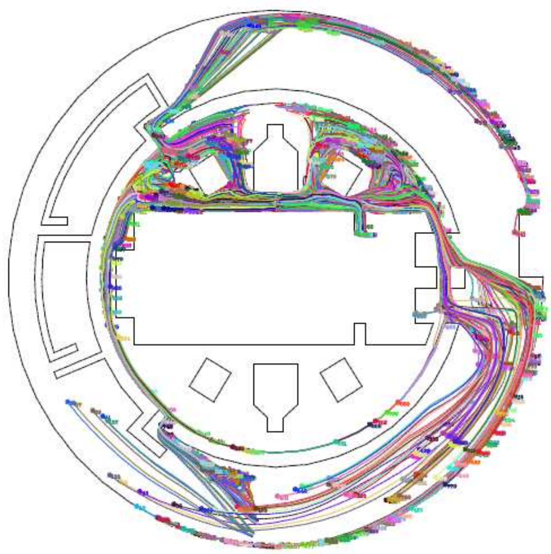

Fig. 4. Trajectories of particles until 31 seconds.