Experimental and CFD Evaluation of Debris Transport Augmentation by Turbulence during LOCA

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1. Introduction

The sump clogging issue was designated as GSI-191, and many studies[1,2,3] to resolve this issue have been undertaken. In the determination of the debris transport faction, it is also advised that the turbulent kinetic energy (TKE) distribution is considered to quantify the debris transport fraction as the effect of the TKE has been identified in experimental research. However, the quantification results pertaining to the debris transport fraction during the recirculation phase including debris transport augmentation by TKE were not published in the literature.

2. CFD Analysis

In accordance with NEI[4], a DEGB of a hot leg of the OPR1000 plant was selected without considering multiple breaks. The hot leg break location was selected as the inlet flow boundary. The inlet flow rate was assumed to be 0.40 m^3/sec, which was the sum of the HPSI flow rate and the CS flow rate. For the outlet flow boundary, only one of the two recirculation sumps was assumed to be operable on a conservative basis in the safety analysis. All features of the free-surface motions of the containment floor water are simulated by the FLOW-3D. A transient analysis that forms during 400 sec after the RAS by adopting the VOF scheme. As the analysis results, a strong TKE is observed at the inlet flow region with high flow fluctuation and the open area region under a high velocity. Furthermore, a relatively high TKE is noticed near the structures of the steam generator supports, RCP supports.

3. Experimental Verification of the TKE Effect

The effect of TKE on the augmentation of debris floor transport was observed in several experimental studies[1,2,3]. Its application to the evaluation of the debris transport was highly recommended[4,5].

3.1 Experimental Test Facility and Method

A linear (C-1) flume test facility was created with reference to previous research[2] to measure the tumbling velocities(ITV). The facility was also designed to be modified as sudden-expansion (C-2) and sudden-contraction (C-3) flume test facilities by installing to measure the tumbling velocities under turbulent flow conditions. As the actual debris generated by a LOCA vary in terms of their type, size and shape, it is difficult to conduct direct experiments with them. Therefore, acrylic beads and glass beads are used as surrogates for the debris. The experiment was done while the level of the water in the flume was maintained at 1 m. During the experiments, the flow rate was increased slowly and set constant upon the visual identification of the movement of the beads to determine the exact flow rate.

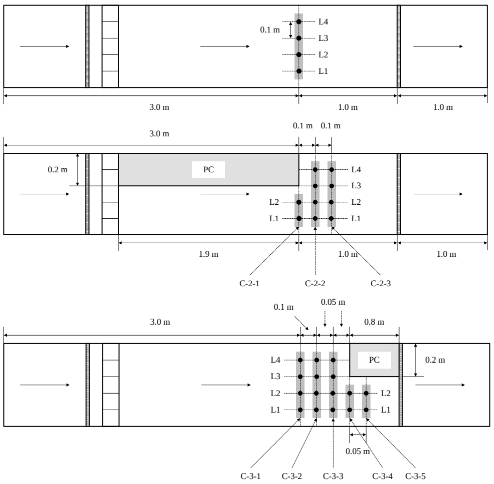

Fig. 1. Locations of the debris specimens and identifications in experimental C-1, C-2 and C-3.

3.2 Experimental Results

Using the measured flow rate at which debris specimens begin to move and the geometrical section area in which the debris is placed, the incipient tumbling velocities for every test location of the various experimental configurations are calculated by Eq. (1).

$$V_I = \frac{Q}{H \times W} \quad (1)$$

As the results, ITV of C-2 and C-3 show relatively low ITVs.

3.3 Supplementary CFD Analysis and Identification of the TKE Effect

Supplementary CFD analyses were performed for the experimental C-2, C-3. The analysis results show that the effective section areas are greatly reduced by the flow recirculation and by flow detachment. Based on these results, the newly determined ITVs (V_I') at all test locations for C-2 and C-3 become closer to the reference values (C-1) for the acrylic beads and glass beads. However, in spite of this improvement, the ITVs remain slightly lower than the reference values.

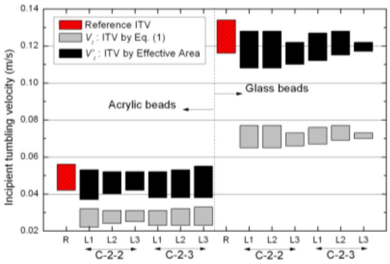

Fig. 2. ITVs based on the effective section area for a sudden-expansion flume.

To verify the turbulence effect, a fluctuating velocity component parallel to the mean flow direction is determined from the TKE, and the algebraic sum of the mean flow velocity and the fluctuating velocity parallel to it is introduced as the effective ITV in the present study[6].

$$V_E = V_I' + u_{rms} = V_I' + \sqrt{\frac{2}{3}TKE} \quad (2)$$

The evaluation result of the above equation using the CFD-calculated TKE is shown in Fig. 3. This plot shows that the effective ITVs of all test locations for various configurations are nearly identical.

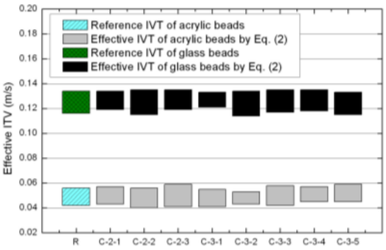

Fig. 3. Effective ITVs for the test locations.

4. Quantification of Debris Transport

Fig. 4 show the change in the area exceeding the reference tumbling velocity depending on the consideration of the turbulence effect. The red area in Fig. 4 represents the area exceeding the reference tumbling velocity for the large NUKON when evaluated based on V_{mean}. This shows that only a part of the exceeded area is linked to the sump suction region continuously and that most of the exceeded area is discontinuous and separated from the sump suction region. The area of which $V_{\max}$ is larger than the reference tumbling velocity is represented by the blue area in Fig. 4. It shows that the exceeded area is enlarged and that the discontinuity to the sump suction region is diminished. The quantitative NUKON debris transport fractions based on V_{mean} or $V_{\max}$ are shown in Tables I for the large NUKON, respectively.

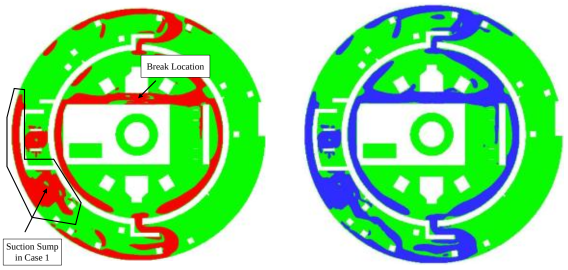

Fig. 4. Excess flow area of large NUKON based on (a) V_{mean} and (b) $V_{\max}$ profiles.

Table I: Fraction of debris transport for large NUKON

EL. (m)	Mean flow velocity	Max. flow velocity
	Fraction of debris transport (%)	Fraction of debris transport (%)
26.61	3.78	16.98
26.81	3.92	17.32
27.01	4.04	17.99

5. Conclusion

Through experiments and supplementary CFD analyses, it was shown that the effective tumbling velocity of debris augmented by the TKE can be represented by an algebraic sum of the mean horizontal velocity and the turbulence horizontal velocity deduced from the TKE. The CFD results for OPR1000 plant showed that a large increase in the debris transport is possible if the TKE is considered in the quantification process. This implies that the effect of TKE on debris transport augmentation should be considered if a conservative debris transport fraction is to be evaluated in resolving the GSI-191 safety issue.

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