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Impact Velocity Estimation of 3×3 Rod Bundle in Water Condition

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1. Introduction

Fuel assembly drop event can be happened accidently during handling in the spent fuel pool (SFP). Once fuel assembly drop accident (FADA) happens, radioactive contaminants would leak because of fuel rod failure. NRC described radiological consequences of fuel handling accident with release of total amount of radioactive material [1-3]. To analyze FADA more realistically, level of rods failure need to be calculated. This rods failure depends on load generated by impact force and impact mode of fuel assembly at the bottom of SFP during FADA. Impact force is a function of impact velocity. The purpose of this study is to calculate impact velocity of short 3×3 rod bundle theoretically and verify the results by CFD analysis. The results show that the theoretical assessment and the CFD results are well matched.

2. Theoretical and CFD method

The model and the methodology of theoretical calculation and CFD is described.

2.1 Simulation Model

The fuel assembly is composed by various components such as top nozzle, bottom nozzle, grids, fuel rods, guide tube, etc. Among these components, fuel rods occupy most of mass and volume of the fuel assembly. Therefore, estimating the drag force of fuel rod bundle is important to evaluate impact velocity. The selected model is 3×3 rod bundle which is 50 cm long (Fig. 1). Drop angle is assumed to remain same as initial angle and drop distance is assumed to be 6.1 m.

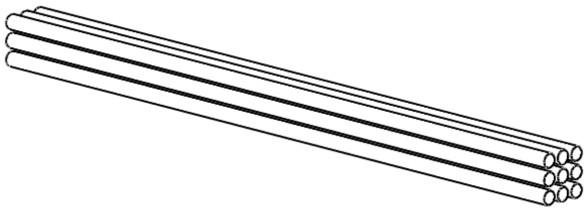
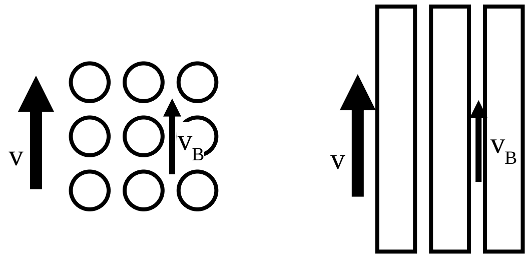


Fig. 1. 3×3 rod bundle model

2.2 Theoretical method

Motion of submerged body can be described by mass, added mass, gravity, hydraulic resistance force and buoyancy. Mass and gravity is constant, and added mass is also considered as a constant for stationary fluid. The hydraulic resistance force can be calculated by pressure balance between leading and trailing of the rod bundle. At the fore of the rod bundle, flow can go through the rod bundle(V_B) or can go around the rod bundle (V) (Fig. 2). Since both path should has same pressure drop, velocity through the rod bundle can be calculated. Drag can divide into two parts which are internal flow drag and external flow drag. The internal drag is shear and form drag of internal flow, and the external drag is calculated by exterior drag coefficient with relative velocity to internal velocity. Known drag coefficients at moderate Reynolds numbers are used. Once the drag is calculated, acceleration of rod bundle can be determined by Newton's 2nd law. In case of inclined drop, combination of horizontal drop and vertical drop can be applied [4, 5]. Temporal discrete is dealt with Euler integration method.



(a) Horizontal Drop (90°) (b) Vertical Drop (0°)
Fig. 2. Flow distribution on rod bundle at drop condition.

2.3 CFD analysis

CFD is used to evaluate drag force of rod bundle at each drop angle and velocity. Ansys Fluent 14.0 is used with RNG k-e turbulent model and enhanced wall function [6, 7]. y+ is kept smaller than 1. The number of mesh is over 8 million. The angle of 0, 30, 45, 60, 90° and the velocity of 0.1, 0.2, 0.5, 1, 2, 5, 10 m/s are selected to be calculated. Since the drop angle is assumed not to be changed during drop, the drag force can be written as a function of the velocity at each drop angle. The methodology to estimate impact velocity except drag is the same as theoretical method.

2.4 Result Comparison

As shown in Fig. 3, theoretical results are close to CFD results. Since drag is related with projected area of the model, the impact velocity decreases as the drop angle increases. Theoretically estimated velocity is greater than CFD velocity. The difference between theoretical and CFD calculation is 3.9~18.8%.

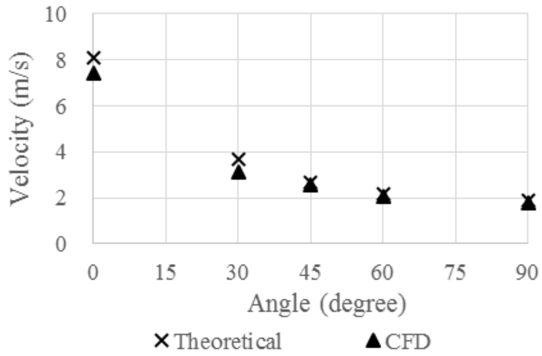


Fig. 3. Impact velocity at each drop angle

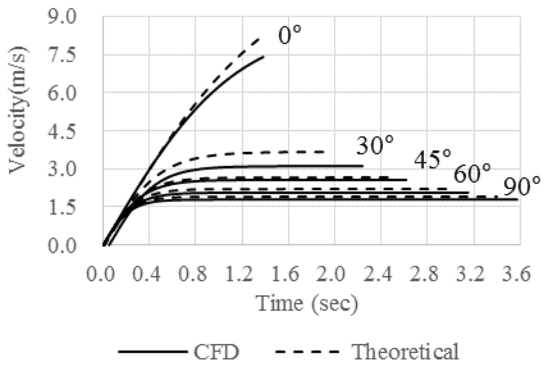


Fig. 4. Velocity profile at each drop angle

3. Conclusions

The impact velocity of 3×3 rod bundle at the bottom of SFP is calculated by theoretical method and verified by CFD method. The results show that the theoretical calculation can be used to estimate rod bundle impact velocity. The methodology will be verified with more realistic model and drag coefficients in future works.

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