Extension of MARS-KS Motion Model to MULTID Component Modifying Volume Connection Information for Marine Reactor Simulation

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1. Introduction

Marine reactors are being developed by several domestic institutions [1, 2, 3]. Since it can supply small-scale electricity to coastal areas or be used as an energy source for seawater desalination, the demand for marine reactors has become increasing. With the development of marine reactors, it is necessary to develop a safety analysis code applicable for marine reactors. The code is required to calculate the external force and thermal-hydraulic characteristics caused by the ocean environment. To develop the safety analysis code for marine reactors, MARS-KS motion model has been modified in our previous studies [4, 5, 6]. Those works made improvements on implementation of user-supplied table for motions, flow regime determination algorithm, and motion model for cross-junction [4, 5, 6].

However, modifications of the MARS-KS motion model were limited to a one-dimensional component and its applicability to the MULTID component has not been tested. Since the movement under motion condition takes place in three-dimensions and multi-dimensional flow is dominant in some components of marine reactors, it is necessary to extend the calculation capability of MARS-KS motion model to the multi-dimensional component. In this study, the modification for extension of MARS-KS motion model to the multi-dimensional component was performed by modifying volume connection information. This model can be used for both one-dimensional component and multi-dimensional components as it considers the external forces on junctions based on general position information. The improved code was verified by solving the conceptual problems under motion condition.

2. Extension of motion model to MULTID component

In this section, the modifications in the motion model are described in detail. At first, the automatic production algorithm for volume direction unit vector was implemented. Subsequently, the MARS-KS motion model was changed adopting the modified volume connection information. Through the modification of MARS-KS motion model, the six-volume problem could be analyzed successfully using one-dimensional PIPE components, which could not be solved before the modification. Then, verifications with conceptual problems of the MULTID were carried out.

2.1 Auto-generated Volume Direction Unit Vector

The original MARS-KS motion model had a limitation in producing the volume direction unit vector which indicates the flow direction of the volume. In the motion model, a user should produce it manually for all volumes with coordinates for two points of a volume: the center of the volume and the top face of the volume as shown in Fig. 1. In other words, a user had to input the coordinates for center and top points of all volumes to produce volume direction unit vectors. This manual-generation is not user-friendly and requires tedious calculations.

For this reason, the calculation procedure for the volume direction unit vector was added into the model. This unit vector is generated automatically by using rotation matrix and the coordinates for center point of the volume. In the rotation matrix, the angle of inclination and azimuth of the volume are used, provided by MARS-KS input data. Fig. 2 shows the calculation procedure. This procedure simplifies the user's vector calculation procedure by removing manual input of top volume position. It helps users to reduce input preparation time and human errors in the input file generation.

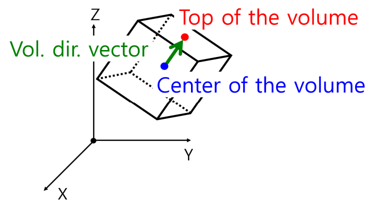


Fig. 1. Definition of volume direction vector

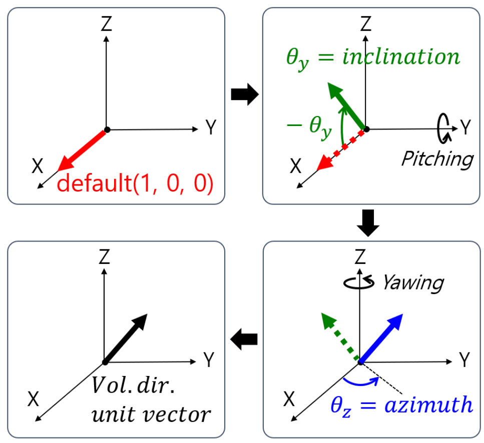


Fig. 2. Procedure for production of auto-generated volume direction unit vector

2.2 Modification of MARS-KS Motion Model Modifying Volume Connection Information

In our previous works, Beom et al. [4, 5] added a procedure for non-flow directional faces, numbered from 3 to 6, into the motion model. The procedure adds the external forces to cross-junctions including the gravity calculation according to the height difference between two connected volumes. Afterwards, Park et al. [6] improved the model in order to overcome its limitations in simulating horizontal pipes and their translation. They extended cross-junction connection to horizontal pipes and translational motion. The modified code was verified by the conceptual problems including four vertical pipes connected using cross-junctions under translational motion and two horizontal pipes connected using cross-junctions under rotational motion.

However, the cross-junction connection of these studies was restricted to coordinates of a non-inertial reference frame, as shown in Fig. 3. Therefore, it was difficult to freely connect the volumes regardless of the angles between two cross-junction connecting one volume. In addition, the previous modification of MARS-KS motion model was a constraint on multi-dimensional application. Thus, it was necessary to improve the MARS-KS motion model applicable to both one-dimensional component and multi-dimensional component.

To resolve this issue, the procedure evaluating the volume connection information was improved in the present work as shown in Fig. 4. The distances between connected volumes are used for calculating the gravity. Detailed process of modification is as follows. Firstly, a calculation subroutine was added for updating the junction property such as inclination or flow regime of the junction at every time step. The distance vector between two connected volumes under motion condition for X, Y, and Z axes in the Cartesian coordinates is also updated. Then, the distances are divided by the ratio of the length of connected volumes. These procedures are repeated at every time step.

2.3 One-D Verification: Hexagonally Placed Six Pipes Connected using Cross-junction

Verification of the modification for one-dimensional component was performed with six pipes connected using cross-junction placed hexagonally under rotating condition. Before modification, the pipes can be connected using cross-junctions if only the angle between the two cross-junctions connecting one volume was 90˚ or 180˚ only. After modification, the limitation on direction of connection using cross-junction has been removed. The problem, as shown in Fig. 5, is to simulate the single-phase six pipes connected using cross-junctions under rolling condition. Each of pipe has divided to six nodes and fully filled with water to check the changes in pressure head due to motion. The amplitude of the rotation along the X axis called rolling is 90˚ and the period is 600 s. The pressures of each node should be changed as the positions of nodes are changed due to the motion condition.

The verification result of the problem is shown in Fig. 6. The pressures of Volume 100 under rolling condition are compared with analytical solution. The simulation results are agreed well with those of analytical solution within maximum error of 0.3 %. The modified code well predicted the pressure change due to motion in hexagonally connected pipes using cross-junctions.

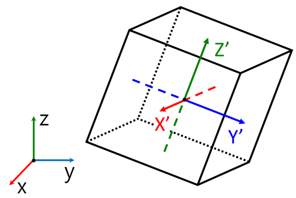


Fig. 3. Cross-junction connection based on a non-inertial reference frame

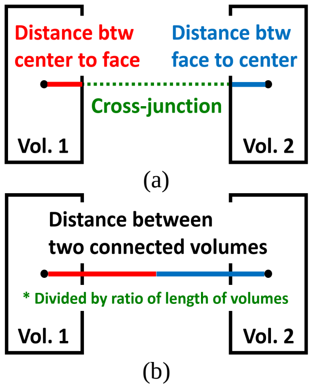


Fig. 4. Modification of the volume connection information (a) before modification (b) after modification

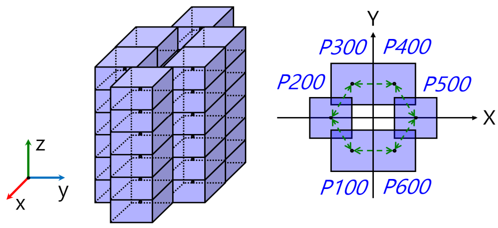


Fig. 5. Figure of six pipes connected using cross-junction placed hexagonally in one-dimensional component

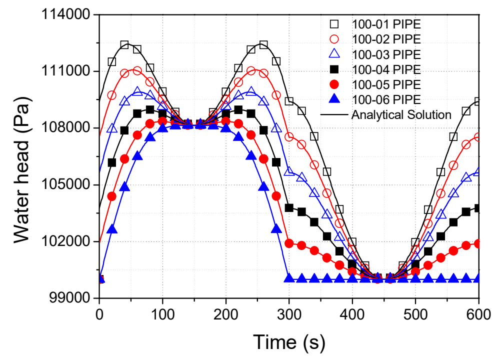


Fig. 6. Simulation result of six pipes connected using cross-junction placed hexagonally under rolling motion

2.4 MULTID Verification: Two-dimensional Slab Modeled by MULTID Component

Verification of the modification for multi-dimensional component was performed with two conceptual problems. The first problem, as shown in Fig. 7, is to simulate a single-phase two-dimensional slab consisted of 100 volumes with rotational and translational motions. The slab is fully filled with water to check the changes in pressure. The amplitudes of the rotation along the X axis called rolling are 30˚, 60˚, 90˚ and their periods are 600 s. The accelerations of the translational motion along Z axis called heaving are 2 m/s^2, 5 m/s^2, 10 m/s^2, respectively, and their periods are 600 s. The pressures of the volumes should be varied according to their position changes due to the motion condition.

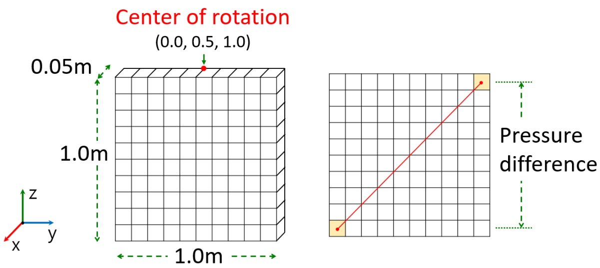
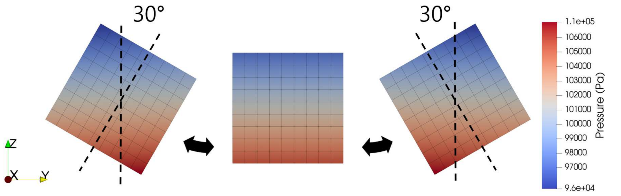


Fig. 7. Figures of three-dimensional slab in the multi-dimensional component

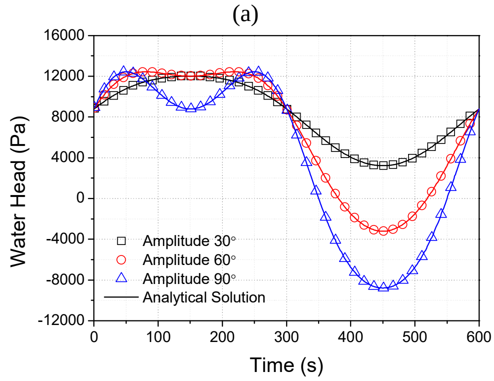
The verification results of the first problem are shown in Fig. 8. Fig. 8-(b) shows the pressure differences between two volumes, depicted in the right side of Fig. 7, under rolling condition. The simulation results are compared with analytical solutions and agreed well with those of analytical solutions within maximum error of 0.6 %. Fig. 8-(c) shows the pressure differences calculated in MARS-KS under heaving conditions. The results are compared with analytical solutions and showed error less than 0.1 %.

The second problem is to simulate the same domain for a two-phase condition under rolling condition. The slab is partially filled with water to check the movement of water. The motion conditions are the same as the rolling conditions of the previous single-phase problem. The pressure differences and water level of volumes should be varied according to the flow in the slab due to the motion condition.

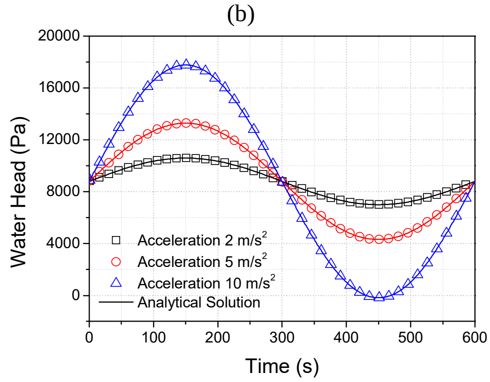
The verification results of the second problem are shown in Fig. 9. Fig. 9-(a) shows the pressure differences between two volumes, depicted in Fig. 7 calculated in MARS-KS under rolling condition. The simulation results are compared with analytical solutions and agreed with those of analytical solution. Fig. 9-(b) shows the water level of the slab calculated in MARS-KS under 30˚ amplitude rolling. The water level of the slab calculated in MARS-KS shows reasonable results with the inclination of the slab.



(a)

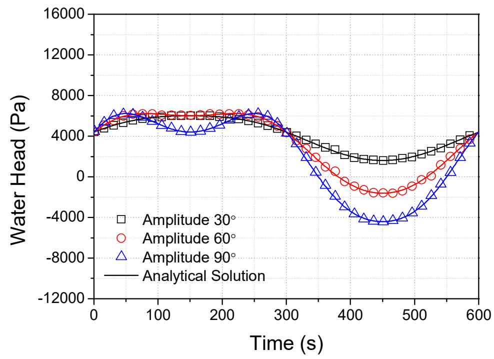


(b)

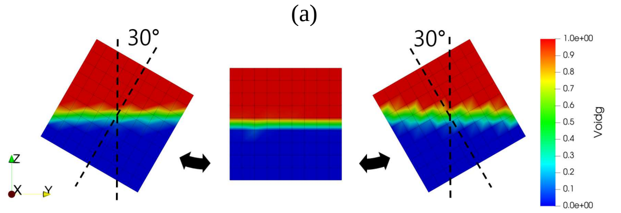


(c)

Fig. 8. Simulation results of single-phase conceptual problems (a) 30˚ amplitude rolling condition (b) rolling condition (c) heaving condition



(a)



(b)

Fig. 9. Simulation results of two-phase conceptual problems (a) water head under rolling condition (b) water level of the slab under 30˚ amplitude rolling condition

3. Conclusions

The present work improved the dynamic motion model of MARS-KS for marine reactor analysis. At first, the user-friendly volume direction vector calculation routine was added. Then, volume connection information was modified in order to more generalize the dynamic motion model. With this feature, the motion model was extended to MULTID component with minor additional modification. The simulation of cross-junction connected pipes with arbitrary angles became feasible with this.

The modifications were verified by conceptual problems. A conceptual problem for one-dimensional component includes single-phase six PIPEs connected using cross-junction with 60˚ angle. Two conceptual problems for MULTID used a single-phase and two phase slab geometry. The verification results showed good agreement with analytical solutions under motion condition.

This model improvement merely covers the implementation of the external force models under motion conditions. Thus, in the future, the physical models on the motion model needs to be reviewed and implemented into the code, if necessary. More verification and validation are required with various geometry such as a cylindrical or annulus geometry for more practical applications.

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