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Modification of the dynamic motion model in MARS for marine reactor thermal-hydraulic analysis

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1. Introduction

At sea, the ship moves in several directions by the waves. These movements can cause additional accelerations in the system and equipment of the marine reactor, affecting performance and safety standards. Especially, in the case of fluid, a change in the thermal hydraulic parameter due to the movement is expected. Therefore, in designing a marine reactor and evaluating its performance and stability, a thermal hydraulic safety analysis code is necessary to take into account the thermal hydrodynamic effects of ship motion. In particular, MARS (Multidimensional Analysis of Reactor Safety) code developed by Korea Atomic Energy Research Institute (KAERI) [1] implements a dynamic motion model that can reflect ocean conditions.

In the previous research [2], the mathematical modeling of dynamic motion in MARS code was confirmed and verified through analyzing conceptual problems. It was revealed that MARS could predict fluid behaviors under the ocean condition with reasonable accuracy.

In this study, we have modified the dynamic motion model of MARS from two viewpoints. First, a user-supplied table was implemented to allow MARS to handle arbitrary motion input for simulating realistic ocean conditions as well as ideal sinusoidal motion. Secondly, the inclination change of the pipe by the motion was reflected in determining the flow regime map. Afterwards, a conceptual problem was analyzed for the compound translational and rotational motions that may occur when the ship is submerged under abnormal conditions.

2. Modification of dynamic motion model in MARS

2.1 Implementation of user-supplied table

In the MARS input file, as a boundary condition for ship motion, the user can select two options: a sinusoidal function and a user-supplied table. A sinusoidal function includes the acceleration values of the translational motion and the angular ones of the rotational motion expressed in equations (1) and (2), respectively,

$$\text{Acceleration} : a_{x,y,z} = \mathrm{A}\sin\left(\frac{2\pi t}{T} + \phi\right) + a_0, \quad (1)$$

$$\text{Angle} : \theta° = \mathrm{A}\sin\left(\frac{2\pi t}{T} + \phi\right) + wt + \theta_\circ, \quad (2)$$

where A is the amplitude of oscillation, T is the period of oscillation, ϕ is the phase angle for acceleration, a_0 and θ_0 are the initial acceleration and angle and w is the initial angular speed. In the other options, one can use the user-supplied table to set a time-dependent acceleration value for six motions, as shown in Table 1.

Table 1: User-supplied table form

Time (s)	Angular acceleration (rad/s^2)			Translational acceleration (m/s^2)		
	Rolling	Pitching	Yawing	Surging	Swaying	Heaving
…	…	…	…	…	…	…

While the sinusoidal function has a certain period and amplitude, the user-supplied table has an advantage that the user can input arbitrary acceleration with time and can simulate an irregular motion in real sea. However, since the current version of MARS code has just an acceleration input environment for the user-supplied table, it does not reflect the angular velocities, the angles, the calculated coordinates, and the body forces in the momentum equation. Therefore, we added a few steps of calculation procedure in MARS code. Firstly, the acceleration values of the current time step (*timehy* in Eq. 3) are interpolated using user-supplied table data ($\ddot{\theta}$ in Eq. 3). Secondly, the velocity and angle are calculated (Eq. 4 and 5) by integration. Lastly, those values are reflected in coordinate calculation and body forces of the momentum equation.

$$\text{acc. } \ddot{\theta} = \frac{\ddot{\theta}(i+1) - \ddot{\theta}}{t(i+1) - t(i)} * \big(timehy - t(i)\big) + \ddot{\theta}(i), \quad (3)$$

$$\text{vel. } \dot{\theta} = \dot{\theta} + \ddot{\theta} * dt, \quad (4)$$

$$\text{ang. } \dot{\theta} = \dot{\theta} + \ddot{\theta} * dt\ , \quad (5)$$

where *timehy* indicates the current time step, $\ddot{\theta}(i)$ and $t(i)$ are the i-th acceleration and time, respectively.

The verification was conducted by reproducing the calculation result using sinusoidal function using the user-supplied table option. The test problem was the manometer rotation problem illustrated in Ref. [2] and as shown in Fig. 1, the result shows good agreement with the maximum error 0.044 m (1.7%).

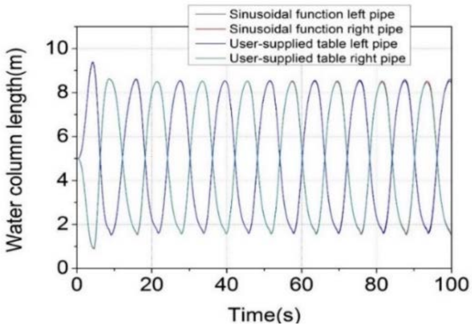

Fig. 1. Verification result of user-supplied table

2.2 Calculation of pipe inclination information for flow regime map selection

When the dynamic motion model in MARS is working, the inclination of each node changes in the case of rotational motion. At this time, the code should reflect the change of boundary conditions as the inclination changes.

For example, the flow regime map varies with the inclination. MARS has a flow regime map for both horizontal and vertical cases. If the inclination of the pipe is 45 <| ϕ | ≤ 90 degrees, a vertical flow regime map is applied and for the 0 ≤ | ϕ | ≤ 45 degrees, horizontal flow regime map is applied [3]. For example, if a horizontal pipe in a two-phase flow state rotates 90 degrees to be vertical one, the code should calculate flow regime by changing the flow regime map from horizontal one to vertical one to reflect the inclination change. This situation was checked by the two-phase flow conceptual problem shown in Fig. 2. In this problem, water and steam are inserted into a horizontal pipe of which pressure is 150 bar and length is 10 m to make a steady state for two-phase flow, then the pipe rotates for 60 s to make vertical inclination. After that, the calculated flow regime is compared with that of vertical steady case from the beginning. The user-supplied table is adopted to simulate this motion.

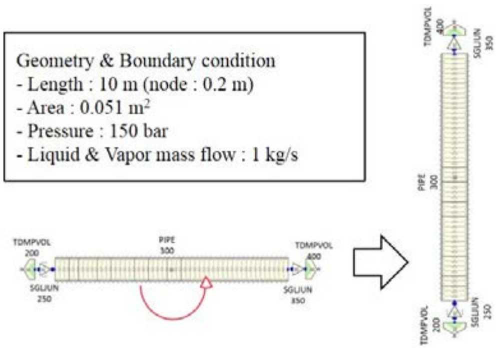

Fig. 2. Concept of horizontal pipe to vertical pipe

As the results shown in Table 2, it was confirmed that the flow regime map did not change, remaining 'HST', even if the inclination changed from the horizontal pipe to the vertical pipe. That is, in the current version of the MARS code, the change of the pipe inclination due to the dynamic motion is not reflected in the flow regime map selection.

Table 2: Result of flow regime change

Condition	Flow regime of horizontal pipe	Flow regime of vertical pipe
Stationary state	HST	SLG
Horizontal → Vertical	HST	HST
HST: Horizontal stratified flow SLG: Slug flow		

The reason is that the pipe inclination used in determining flow regime map is checked only once in the initialization process. Thereafter, the inclination change due to the dynamic motion is not reflected. To solve this problem, we modified the MARS code to calculate the inclination information of the pipe at the every time step when using dynamic motion model and to reflect it in determining flow regime map. In order to confirm the modification result, the conceptual in Fig. 2 was retested. The verification was intended to check whether the pressure at the inlet and the void fraction at the outlet are identical between the vertical case from the horizontal one and vertical stationary case from the beginning. In result, as shown in Fig. 3, before the MARS code modification, the values converges to an value different from the stationary vertical case. After the modification, the values with the inclination change converges to the identical values.

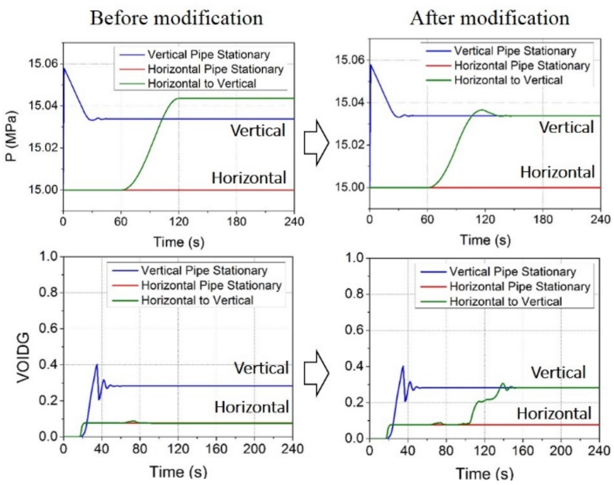

Fig. 3. Result of MARS code modification

In addition, the case that two-phase flow was developed using heat structure was checked. The test conditions are shown in Table 3, including boiling and condensation, and the heat flux is applied as boundary condition. For each case, we confirmed the two cases, the first one where the inclination was changed from the horizontal pipe to the vertical pipe (case 1) and the second one where the inclination was changed from the vertical pipe to the horizontal pipe (case 2).

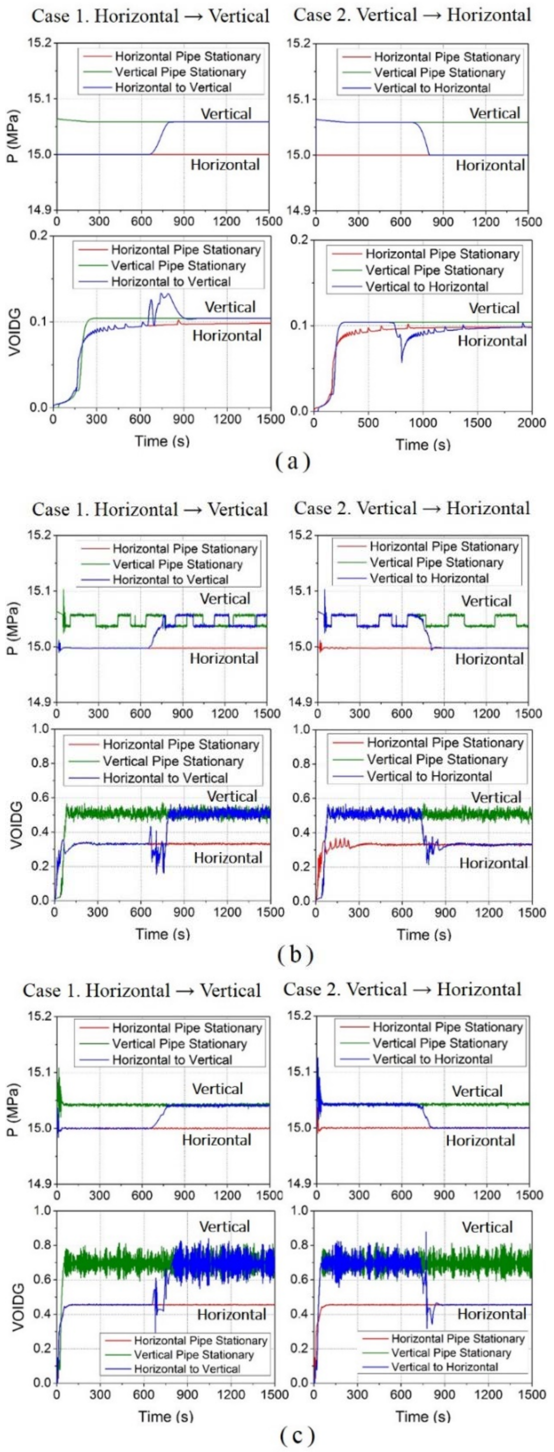

Fig. 4. Verification results of modification in boiling (a) Void: 0.1 (b) Void: 0.5 (c) Void: 0.7

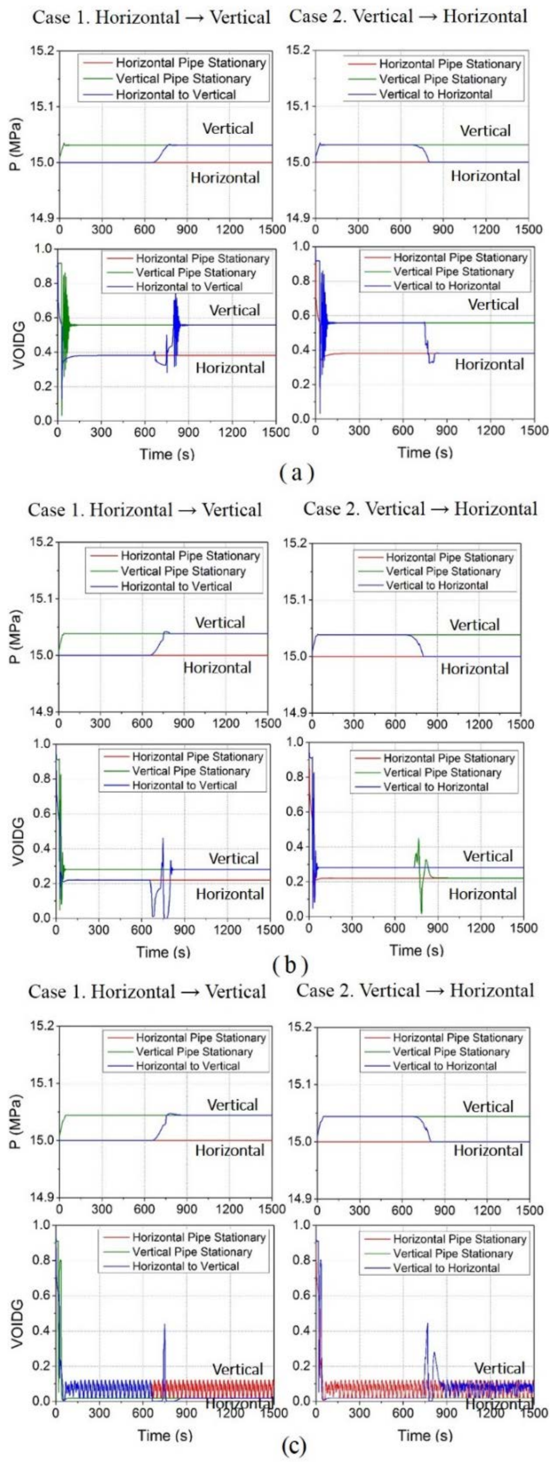

Fig. 5. Verification results of modification in condensation (a) Void: 0.4 (b) Void: 0.2 (c) Void: 0.0

Table 3: Boundary conditions of verification

Boiling	Condensation
▪ Mass flow rate: 1 kg/s (liquid) ▪ Heat flux(kW/m^2) : 25, 100, 230 ▪ Outlet void fraction : 0.1, 0.5, 0.7	▪ Mass flow rate: 1 kg/s (gas) ▪ Heat flux(kW/m^2) : -1, -50, -100 ▪ Outlet void fraction : 0.4, 0.2, 0.0

In both cases, as shown in Figs. 4 and 5, the converged values after the inclination change matched the values with stationary case from the beginning.

3. Analysis of conceptual problems for compound dynamic motions with MARS

In the previous research [2], it was confirmed that the MARS code had the calculation capability for dynamic motion model by solving the conceptual problems. On the other hand, since the tides and waves are generated in actual sea, the translational motion and the rotational motion are simultaneously generated. Therefore, the calculation capability for compound ocean motion is important in evaluating the safety of marine reactors. In this study, the conceptual problem was analyzed for simultaneous rotational and translational motions.

The concept problem is similar to manometer oscillation, but with translational acceleration is added. As shown in Fig. 6-(a), when the manometer receives translational acceleration in the horizontal direction, the water level difference occurs in the left and right pipes. At the same time, the manometer rolls periodically as shown in Fig. 6-(b). Then water levels of the each pipe show the compound effects of translational and rotational motions.

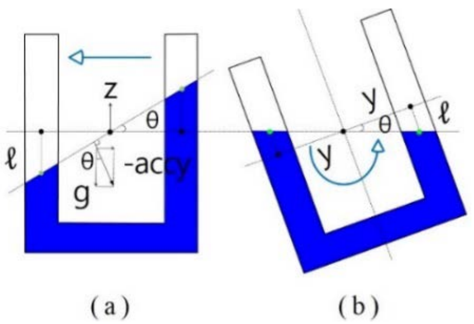

Fig. 6. Concept to calculate water lever under (a) translational motion and (b) rolling motion

The details of the boundary conditions for dynamic motion are summarized in Table 4. For comparison with analytical solution, it was assumed that there was no wall friction and energy loss.

Table 4: Boundary condition of conceptual problem

Parameters	Manometer	
Length & diam.	10 m (5 m for water), 0.254 m	
Pitch	4.5 m	
Pressure & temp.	Atmospheric, 323 K	
Motion Option	Rolling motion - Amplitude : 10 ° - Period : 600 s	Translational motion - Acceleration : 10 m/s^2

In analytical solution (Eq. 6 and 7), one can calculate the water level difference due to translational acceleration. In this problem, X-direction is zero, Y-direction is '-accy' and Z-direction is '-g' for gravity. The maximum water level difference is 5.6002 m for 10 ° inclined position.

$$\mathrm{Xdx} + \mathrm{Ydy} + \mathrm{Zdz} = 0, \tag{6}$$

$$-\mathrm{accydy} - \mathrm{gdz} = 0, \;\; \mathrm{dz} = -\frac{accy}{g}dy, \tag{7}$$

On the other hand, the analytic solution of oscillating amplitude by rolling motion is ± 0.397 m. Then, the analytic solution of the total water level difference is sum of the water level differences by the two motions. As a result, the variation of water level difference in the analytic solution ranges from 3.218 m to 6.394 m, respectively. The results of the MARS calculation are from 3.216 m to 6.586 m, as shown in Fig. 7. In conclusion, the compound dynamic motion was simulated well within an error of 0.06 % ~ 2.92 % in this conceptual problem.

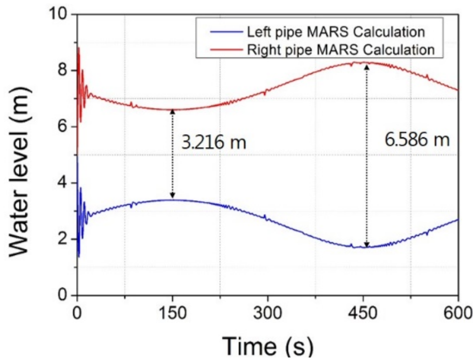

Fig. 7. Result of MARS calculation

4. Conclusions

Two modifications were made in relation to the dynamic motion model of MARS. First, a user-supplied table is implemented to enable simulation of irregular motion such as actual sea. Second, using this method, we modified the MARS code to reflect the inclination change when determining flow regime. In addition, the conceptual problem under compound motion was analyzed.

It is expected that the present modification can contribute to enhance the capability of the MARS dynamic motion for future application as irregular compound ocean motions are expected to occur due to waves and external events.

REFERENCES

[1] J.J. Jeong, K.S. Ha, B.D. Chung, W. J. Lee, Development of a multi-dimensional thermal-hydraulic system code, MARS 1.3.1., Annals of Nucl. Energy 26 18 (1999) 1611–1642.

[2] H.K. Beom, G.W. Kim, G.C. Park, H.K, Cho, Verification of dynamic motion model for ocean condition in MARS using conceptual problems, KNS Autumn(2017).

[3] RELAP/MOD3 Code Manual Volume I: Code Structure, System Models, and Solution Methods, U.S. Nuclear Regulatory Commission, NUREG/CR-5535 (1998).