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Methodologies for Acoustic Induced Vibration Analysis of Reactor Vessel Internals at Fluid-Structure Interfaces

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1. Introduction

For reactor vessel internals, vibration and stress analysis under hydraulic loads is regulated to ensure adequate safety margins through a comprehensive vibration evaluation program [1]. Previous studies used computational models of coolant and fluid dynamics to generate frequency-domain loads for structural analysis. However, these models exhibit limitations in accurately capturing certain dynamic effects, such as eigenvalue shifts induced by the presence of coolant [2]. To overcome these limitations, this study incorporates internal coolant effects into modal analysis and applies mode-based structural analysis to account for dynamic characteristics. By focusing on individual internal structures, the proposed methodology enhances evaluation precision while reducing computational costs. The primary objective is to establish a structural analysis approach that integrates the full vessel assembly's dynamic response, incorporating fluid-structure interactions.

2. Methods and Results

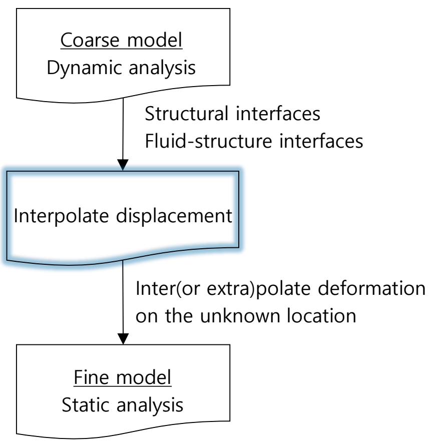

Fig.1 Schematics of dynamic load generation method for a single reactor vessel internal

A time history load on the fluid-structure surface was generated using transient analysis within a reactor vessel assembly, which includes the coolant, reactor, and internal structures [3,4]. The processed load was then applied to the surface of a reconstructed single internal structure through interpolation and extrapolation, as shown in Fig. 1. In this study, the sub-modeling method was adopted to efficiently apply dynamic loads to internal structures, enabling detailed analysis while minimizing computational demands [5].

Fig. 2 shows a comparison of the stress results for the internal structures under different load application methodologies. As illustrated in Fig 2, the blue bar graph indicates that when the fluid-structure interaction is not considered, the internal structures experience a significantly lower stress response. This could lead to a non-conservative analysis, as the actual stress is likely higher than what is observed without the coupling effects. On the other hand, when the coupling load at the fluid-structure interface is incorporated, the stress results match those of the reference case. This demonstrates that even when analyzing only the internal structures, incorporating the fluid-structure interaction load, as derived from reference dynamic analysis, ensures reliable stress response predictions.

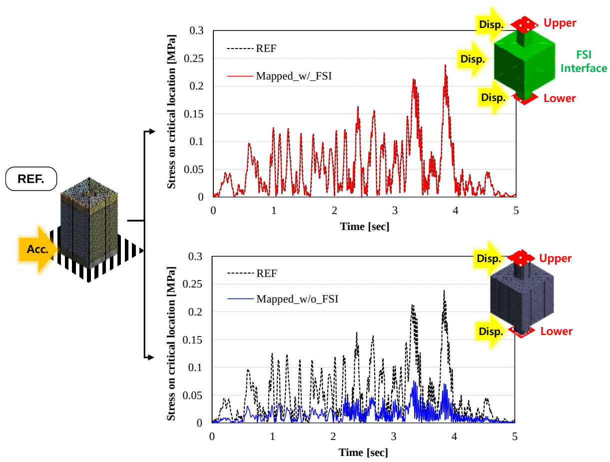

Fig.2 Stress analysis results based on whether or not fluid-structure interaction loads is considered

3. Conclusions

FE simulations were conducted using ANSYS Mechanical Transient Analysis version 19.2. A zoom model for CSB shapes, featuring reduced simplification compared to the assembly model, was developed and analyzed. This methodology was applied with 50 time steps, corresponding to 5 ms per step. The results confirm that deformation remains consistent under identical grid configurations and shape definitions, regardless of the inclusion of external source codes.

Moreover, applying different geometries resulted in a deformation variation of less than 0.2%, validating the robustness of the approach. These findings confirm the effectiveness of the proposed zoom model in accurately capturing the structural behavior of CSB shapes.

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