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Application of Submodel Method for the Structural Analysis of Integral Reactor Internals

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1. Introduction

The structural analysis of reactor internals generally consists of multiple stages to prove the integrity of each component in terms of stress criteria[1]. The stages comprise several steps to construct analyses model and diverse analyses to define design loads. The main reason of hiring such a complicated process comes from the complexities in structures, operating loads, the detail policy of proving structural integrity and even engineering tools in use. Obviously, the minimization of stages is crucial to reduce engineering efforts and to exclude inherent uncertainties from assumptions made in each stage. The main obstacles in squeezing analyses stages are the structural complexity of primary components and engineering tool. For example, the loop type reactor shall have huge amount of degrees of freedom due to its geometrical arrangement when one tries to apply single step analysis with shell or solid elements. In case of an integral reactor, a simplified arrangement of primary structures may give less number of degrees of freedom even though one tries to apply ideas upon it. The introduction of high performance computer makes it easy to treat big sized finite element problems but the efficiency of selected solution method still produces issues. In this study, an integrated structural analysis based on submodel technique is presented to squeeze the stages adopted for the verification of structural integrity.

2. Methods and Results

The main activities of structural analyses include preparation of models for system analysis and subsequent analyses prior to review stress criteria. Since structural complexities and arrangement of a reactor hinder the direct simulation of detailed characteristics of primary components and relevant boundary condition through a single model, a simplified model representing the general behavior of whole system is preferred to prepare the input for subsystems. If the subsystem is not simple to adopt the characteristics of system analysis results directly, the remaining procedure requires additional procedures to utilize the system analysis results. We could imagine extra conservatism and uncertainty during the additional stages.

2.1 Introduction of submodel

Fig.1 indicates a typical example of submodel application to the nozzle junction. The submodel is based on St. Venant's principle, which states that if an actual distribution of forces is replaced by a statically equivalent system, the distribution of stress and strain is altered only near the regions of load application. The principle implies that stress concentration effects are localized around the concentration. If the boundaries of the submodel are far enough away from the stress concentration region, accurate results can be calculated [2].

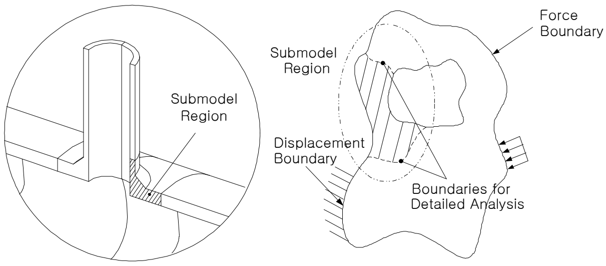


Fig .1 A typical example of submodel

2.2 Application to integral reactor internals

The structural analysis methods applicable to internal structures may differ according to design feature of components, loadings applied, and general procedure for the validation of structural integrity, engineering tools. The thermal and dynamic loading generally requires different model for the convenience of analyses. In case of thermal loading, solid elements are preferred and the application of shell elements could introduce the minimized works in dynamic analysis. Then, a shell to solid submodel technique offered by ANSYS[2] is adopted to develop a dual purpose model for both loadings. Fig. 2 indicates the basic concept of the shell to solid submodel technique available.

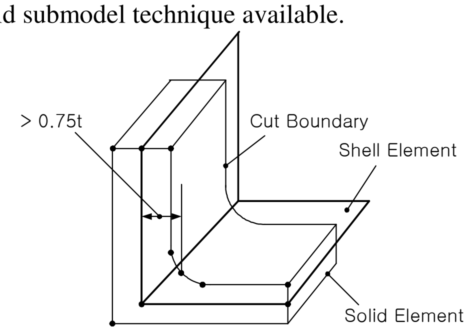


Fig. 2 Concept of shell to solid submodel

Though there is some limitation in treatment of thickness dimension, the direct transfer of displacements from shell to solid submodel saves lots of analysis efforts.

To review the validity of current method, mechanical and thermal loading are applied to a core support barrel (CSB) assembly. Fig. 3 indicates CSB model with shell elements and submodel of flange area with solid elements. Then, total two stages of analyses are required to get stress criteria under specified loading. Fig. 4 shows another application of submodel to localized stress area such as perforated plate or near small openings. When direct application of finer mesh over localized area seems not to be practical, introduction of another shell to shell submodel could provide additional room in treating localized area.

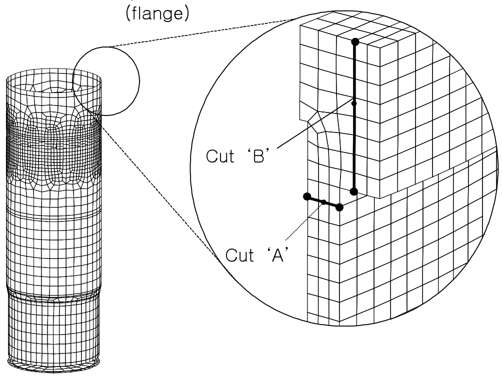


Fig. 3 Shell to solid submodel at CSB flange

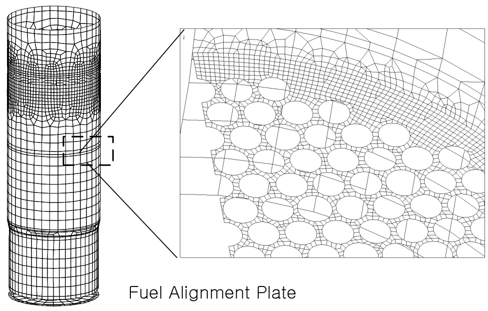


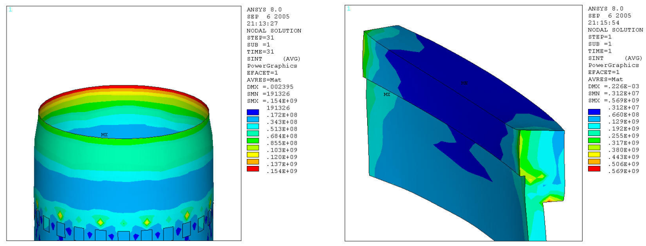
Fig. 4 Shell to shell submodel at FAP

2.3 Results of stress analysis

To review the validity of submodel technique, the final stress results at CSB flange are compared in Fig. 5 and Table 1. The system model result, Fig. 5(a), is complicate to classify the exact order of stress over flange area. The submodel, Fig. 5(b), shows a stress contour along the 3D flange profile, and local stress concentration is monitored along cutoff boundaries. Table 1 shows quite close numbers of stress intensity for both models. Since the stress level of system model is not clear at specific location, the highest stress levels are listed in Table 1. The flange stress is directly referred from stress lines, as shown in Fig. 4 (cut A & B), on the cross section taken by cutting the center of flange toward longitudinal direction. Then, Fig. 3 and Table 1 could prove the validity of submodel method.

Table 1 Comparison of stress intensity

Location	System Model (shell)	Submodel (solid, linearized)
Cut A	137 MPa	131 MPa
Cut B	154 MPa	189 MPa



(a) Global model (b) Submodel

Fig. 5 Comparison of stress at flange region

3. **Conclusions**

Submodel technique is adopted to abridge the structural analysis stages of an integral reactor internals. Shell to solid and shell to shell submodel are introduced to pick up stress indices from a system model and the results show a good agreement in both models in terms of quantitative sense. The proposed method is also proved to be convenient to define stresses criteria but some attentions should be paid to guarantee reasonable results.

Since typical stress concentration at cutoff boundaries is expectable, the location to pick up stresses should be far enough away from the cutoff boundaries. This might cause an increase in problem size. As the permissible distance of geometric discontinuity is limited within range of 0.75t (see Fig. 2), cases with highly localized geometrical discontinuity may be excluded. Finally the direct application of submodel for dynamic analysis based on direct integration is impossible but response spectrum analysis could share the advantages discussed.

ACKNOWLEDGMENT

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