Development of failure mitigation technologies for improving resilience of nuclear structures (17) Study on mitigation of post-buckling damage of fast reactor vessel during excessive earthquakes

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Buckling and post-buckling characteristics of thin-walled cylinders under severe vibration are studied with combined analyses of Single Degree Of Freedom (SDOF) model and FEM. Nonlinear SDOF model is able to capture global response of the structure while FEM enables evaluation of local behavior. A stabilization diagram against post-buckling damage is obtained, which is applicable to fast reactor vessel under beyond design basis earthquakes.

Keywords: Beyond design basis earthquakes, Fast reactor vessel, Buckling and post buckling, SDOF, FEM

1. Introduction

Severe earthquakes are regarded as Beyond Design Basis Events (BDBEs) in nuclear safety. BDBEs require resilience to mitigate consequences of failures, i.e., to prevent catastrophic failure modes [1]. The main vessel of fast reactor (FRV) is a thin-walled large-diameter cylindrical structure, of which buckling is expected as the critical failure mode during earthquakes [2]. However, much previous research confirmed that no immediate collapse would occur after buckling. Therefore, the objective of safety design of FRV under excessive earthquakes is to achieve a stable post-buckling state.

2. Research method

A FEM model is built on FINAS/STAR to clarify buckling and post-buckling characteristics of thin-walled cylinders under horizontal vibration loading and validated by experimental data. In addition, a nonlinear Single Degree Of Freedom (SDOF) model is built to capture the global response of the structure and verified by FEM analysis results. Then, response obtained by SDOF simulation is used as input to FEM model for static analysis. In this way, time history of response local behavior can be efficiently evaluated.

3. Analysis results

The global dynamic response and local strain characteristic of thin-walled cylinders under the effect of input wave amplitude and input frequency ratio are analyzed. Using the time history of response strain on most dangerous points, a fatigue damage assessment is established. Occurrence conditions of fatigue damage after buckling are clarified based on input energy and input frequency ratio. Thus, a stabilization diagram against post-buckling damage due to horizontal vibration is obtained, which can be applied to fast reactor vessel under beyond design basis earthquakes.

4. Conclusion

In current study, the global dynamic response and local strain characteristic of thin-walled cylinders under vibration is studied by combination of nonlinear SDOF simulation and static FEM analysis. Occurrence conditions of fatigue damage after buckling is clarified based on input energy and input frequency ratio. A stabilization diagram against post-buckling damage is obtained, which is applicable to FRV under excessive earthquakes.

References

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