Response Spectrum Analysis of Cask Assembly considering Void Swelling

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1. Introduction

One of the most critical issues in nuclear industry is spent fuel management. The current situation requires an economical and compact storage due to limited wet storage capacity. The spent fuel dry storage is an alternative and study of structural assessment for long-term storage is necessary until the final management policy for spent fuel is determined. In this study, effect of the void swelling on a dry storage cask assembly in Korea was investigated. Modal analysis of the integrated assembly was performed based on the previous research[1] and design document[2] to determine individual mode shapes and frequencies. Subsequently, the structural integrity regarding to the earthquake was evaluated through a response spectrum analysis by using output variables of modal analysis and levels of void swelling.

2. Analysis method and conditions

2.1. Analysis model

Fig. 1 depicts a cask assembly consist of cask, canister and basket assembly. The cask comprises a main body made of stainless steel. The canister composes a thick metallic cylinder for containment of radioactive materials and neutron shielding materials. The basket assembly composed of a basket cell, a bearing plate and a disk tie rod. Materials considered in this study for seismic response analysis are SA350 and SA240. The relevant properties at 400°C are summarized in Table I.

Table I: Material properties

Cask (SA350)	Young's modulus	167 GPa
	Poisson's ratio	0.3
	Density	7,850 kg/m^3
Canister, Basket assembly (SA240)	Young's modulus	169 GPa
	Poisson's ratio	0.3
	Density	8,030 kg/m^3

2.2. Void swelling effect

The void swelling among degradation mechanisms due to neutron irradiation may lead to a loss of ductility in austenitic steels. The swelling rate is given by the flowing equation[3].

$$S' = 2\emptyset\emptyset'^{(-0.731)}\exp[22.106 - \frac{18558}{(T+273.15)}] \quad (1)$$

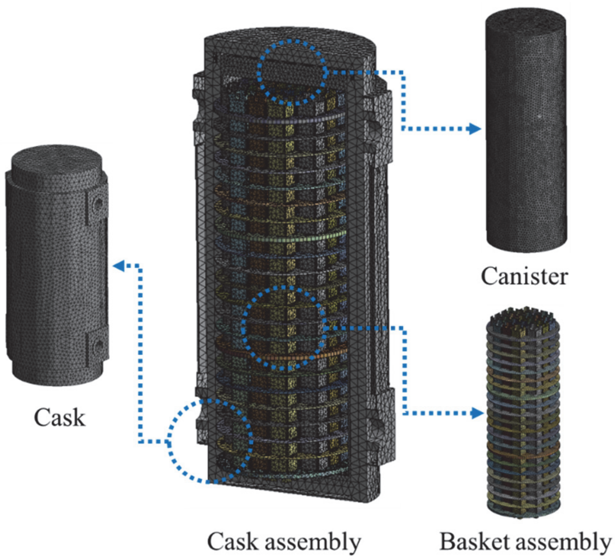


Fig. 1. Numerical model of assembled cask

where $S', \emptyset, \emptyset'$ and T are volumetric swelling rate(%/dpa), neutron dose(dpa), neutron dose rate(10^7dpa/sec) and temperature. The neutron dose was calculated by using total neutron flux[4].

The void swelling affects the temperature dependent elastic modulus as described by the following equation[3].

$$E(T,S) = E(T)/(1+S)^2 \quad (2)$$

where S is volumetric swelling strain. Table II is elastic modulus change with time dependents.

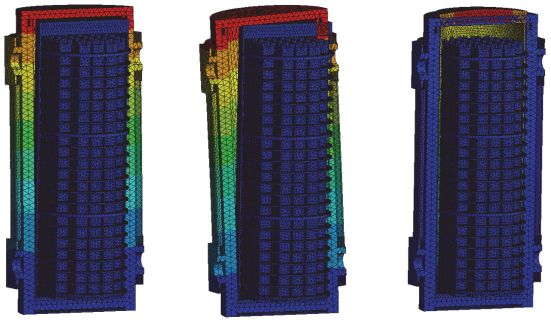
Table II: Time and temperature dependent elastic modulus change

Year	Volumetric swelling strain	Young's Modulus (GPa)
10	4.1e-4	168.86
50	1.0e-3	165.57
100	4.1e-2	155.89
200	1.6e-1	124.58

3. Dynamic analysis and results

3.1. Modal analysis

The modal analysis is necessary to predict dynamic characteristics of components, such as mode shapes and natural frequencies, when it is not available to perform modal test for large-sized real geometry. Block Lanczos method was employed in the modal analysis to determine the values of frequencies, mode shapes and participation factors. The first mode shape of cask assembly occurred at 27.29 Hz on unirradiation condition. Fig. 2 represents typical mode shapes of the cask assembly at the maximum effective mass. Fig. 3 shows frequency of cask assembly on irradiation condition.



(a) 6th mode (48.72 Hz) (b) 5th mode (48.56 Hz) (c) 19th mode (136.36 Hz)

Fig. 2. Typical mode shapes of cask assembly

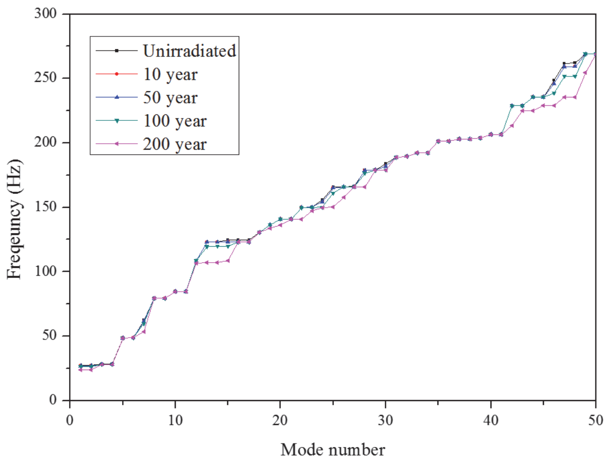


Fig. 3. Frequency of mode number on time dependent

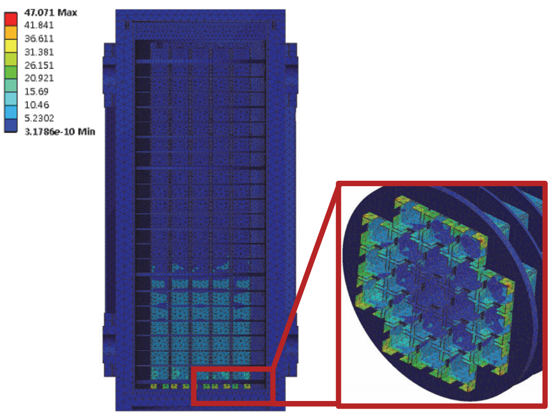
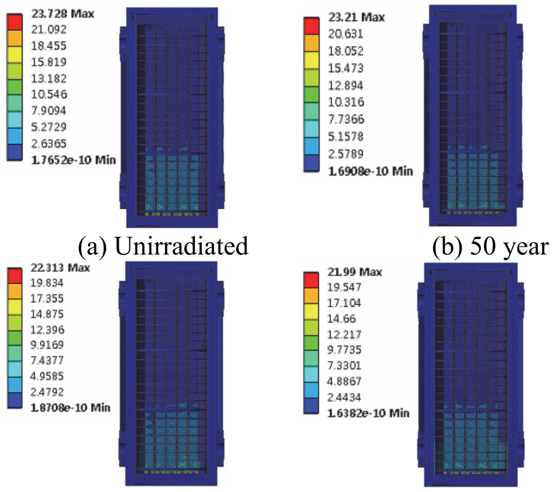


Fig. 4. von Mises stress distribution

3.2. Response spectrum analysis

Structural analysis for earthquake loads can be carried out by either response spectrum method or time history method. In this study, the total response was calculated through the square root of the sum of the squares method for all the individual modal response. Subsequently, the design response spectra[5] was applied at the cask bottom for the response spectrum analysis. Fig. 4 represents resulting stress contour on unirradiation condition. The maximum von Mises stress of 47.07 MPa occurred basket assembly bottom, which satisfied the corresponding allowable criterion. Fig. 5 compares snapshots of resulting Tresca stress distribution. The maximum Tresca stress value obtained from unirradiated model was higher than that of 200 year model and their difference was 7.32 %.



(a) Unirradiated (b) 50 year

(c) 100 year (d) 200 year

Fig. 5. Tresca stress distributions

4. Conclusion

In this study, effects of the irradiation on dynamic response of a Korean cask assembly have been examined and the followings key findings were derived.

1) The first mode shape of cask assembly occurred at 27.29 Hz on unirradiated condition
2) The maximum von Mises stress of 47.07 MPa occurred at bottom of basket assembly.
3) The maximum Tresca stress value obtained from unirradiated model was 7.32% higher than that of 200 year model.

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