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Structural Assessment Method of Spent Fuel Assembly under 0.3 m Horizontal Drop Condition of Transportation Cask

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1. Introduction

In general cask drop analysis is focused on structural integrity of its containment boundary of cask body. Currently, an importance of the evaluation of fuel assembly is increased gradually under normal transportation condition. A fuel assembly has a complex structure of fuel rods, guide tubes, nozzles and spacer grids. Specially, it is difficult to simulate springs/ dimples of spacer grid that have a nonlinear elastic characteristic. The fuel assembly and transport cask are simulated using by ABAQUS code to confirm the structural integrity. The purpose of this paper is to present the structural assessment method of spent fuel assembly under 0.3 m horizontal drop condition of transportation cask.

2. Modeling of Fuel Assembly and Transport Cask

The drop analysis is divided to two stages as shown in Fig. 1, which first stage is to perform cask drop analysis with simple fuel assembly model and second stage is to perform impact analysis of detailed fuel assembly model by using the acceleration of simple fuel assembly model obtained from the results of first analysis.

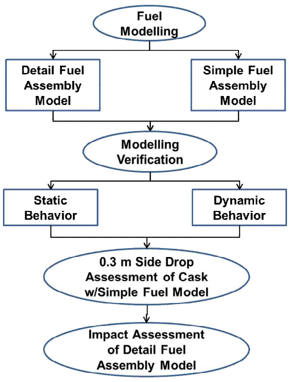

Fig. 1. Structural assessment procedure of spent fuel assembly with transport cask under 0.3 m drop condition.

2.1 Detail Spent Fuel Assembly Model

ABAQUS model of detail fuel assembly consists of three parts based on WE 17x17 fuel as shown in Fig. 2; the first part as a skeleton includes a top nozzle, a bottom nozzle and 25 guide tubes. The second part has 264 fuel rods. The third part has 12 grids. Beam elements type pipe for fuel rods and guide tubes, solid elements for top/bottom nozzle and shell elements for grids were used respectively. The density of beam elements for fuel rods was calculated considering the ratio of the mass of fuel clad and UO_2 to the volume of fuel clad and was decided to 36073.17 kg/m^3. These mechanical properties were applied according to the reference.[1] These springs/dimples have the different force-displacement properties according to the translation and rotation axis.[2] The connector elements in ABAQUS code were applied for the springs/dimples, which have a nonlinear-elastic properties dependent on the translation and rotation axis.[3]

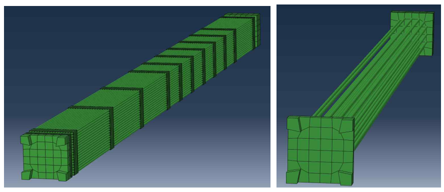

Fig. 2. Detail simulation model of PWR WH 17x17 fuel assembly.

2.2 Transportation Cask Model Including Simple Spent Fuel Assembly Model

This cask consists of a cask body, double lids, impact limiters, which can accommodate 21 PWR spent fuel. This model of transportation cask included solid elements for simple fuel assembly, as shown in Fig. 3.

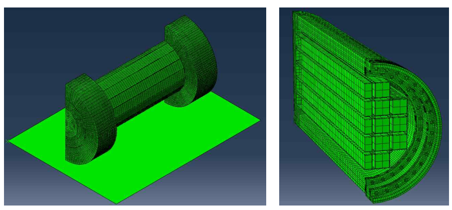

Fig. 3. Transportation cask model with simple fuel assembly

3. Structural Assessment of Spent Fuel Assembly and Transport Cask

3.1 Static and Dynamic Behavior of Detail Spent Fuel Assembly

In order to confirm the suitability of one fuel assembly model, that static load was applied to one detail and simplified fuel assembly model. A load of 30

kg_f was applied to a side of the 6^{th} grid from a bottom nozzle. The Fig. 4 shows the displacement according to 4 load directions of detail fuel assembly model. The calculated displacement of about 4.17 mm has a little difference with about 2 mm from the experiment result of reference [4].

Natural frequencies were extracted from solving eigenvalues by Lanczos method. It was requested in ABAQUS/Standard that maximum eigenvalues were 50 and maximum/minimum frequencies were 50 Hz and 0.1 Hz, respectively. Mode shapes that have the largest participation factor are shown in Fig. 5. Effective mass possesses 85.6 % of mass of one fuel assembly as show in Table I.

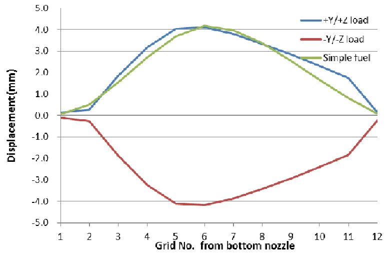

Fig. 4. Displacement of detail and simple fuel assembly model.

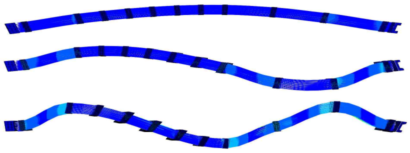

Fig. 5. Mode shape of detail of fuel assembly model.

Table I: Natural Frequency and Effective Mass of Detail Fuel Assembly Model

Mode	Natural Frequency(Hz)	Effective Mass
1^{st}	2.2	496.42
2^{nd}	6.8	0.17
3^{rd}	11.8	44.40
Total		540.94

3.2 Structural Assessment of Transportation Cask under 0.3 m Drop Condition

Horizontal drop analysis of 21 PWR spent fuel transportation cask under normal condition was performed shown in Fig. 6. The X-axis presents an analysis time during 50 ms and the Y-axis presents Energy that its unit is mJ. Total energy of whole model has about 1.6E+05 Joule. Kinetic energy is minimized at about 20 ms from the initial impact moment and plastic dissipation energy is maximized at the same time. Therefore, a maximum acceleration time of transportation cask or fuel assemblies is estimated after 20 msec. The acceleration data extracted from one fuel assembly of bottom right side. Acceleration loads during impact moment obtained from simple fuel model was applied to the gravity load of detail fuel model. Fig. 7 shows the stress and strain contours of the detail fuel assembly model at impact moment.

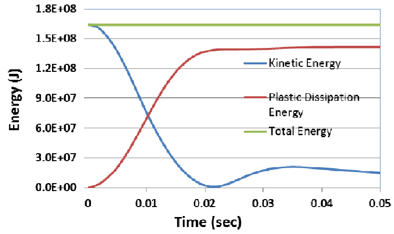

Fig. 6. Energy time history at 0.3 m drop impact moment

3.3 Structural Assessment of Spent Fuel Assembly

The maximum stress results of fuel clad made by Zircalloy-4 are calculated as 154.2 MPa. As this value is lower than yield stress of 569 MPa, the results mean only 27.1 % of elastic limit. The structural integrity was satisfied in the view of stress limit. Zircalloy-4 cladding strain limit is 0.011 % . Maximum principle strain of fuel rod during impact acceleration shows 0.1918 % at 79.2 ms. Maximum calculated strain is just 17.4 % of strain limit. The fuel clads of spent fuels sustain the structural integrity during impact moment inside the transportation cask under 0.3 m drop condition.

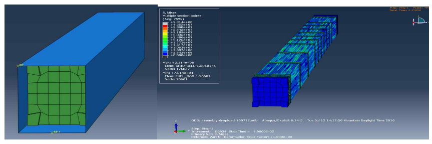

Fig. 7. Detail fuel assembly model loaded by acceleration of 0.3 drop impact

3. Conclusions

The drop analysis is divided to two stages, which separates the cask drop analysis with simple fuel assembly model and the impact analysis of detail fuel assembly model. Structural assessment method of spent fuel assembly under drop condition was presented, which have reliability through static and dynamic behavior of detail fuel assembly model.

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