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A Study on Assessment System for the Integrity of Spent Nuclear Fuel under Normal Conditions of Transport

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1. Introduction

Due to the imminent saturation of the spent nuclear fuel storage capacity in the wet storage facilities of the Gori, Hanbit, and Hanwool nuclear power plants in Korea, the transportation of spent nuclear fuel to on-site storage facilities or interim dry storage facilities is expected to become a reality in the near future. In addition to maintaining the structural safety of the transport cask itself, there is increasing interest in the integrity of the spent nuclear fuel during the normal transportation process, and regulatory agencies are addressing this issue as a key issue in their review process.

Several studies have been conducted to evaluate the integrity of spent nuclear fuel during normal transportation. A recent study is the Multi-modal Transportation Test (MMTT), a collaboration among the U.S. DOE, Spain, and Korea in 2017 using commercial spent nuclear fuel transportation cask. The U.S. subsequently conducted a 30-cm drop test, which is included in normal transportation conditions, to evaluate the loads on the fuel assemblies. In Korea, road and sea transportation tests and excitation shake table tests were conducted from 2020 to 2022 to obtain sufficient test data under transportation conditions considering Korean conditions.

2. Road and Sea Transportation Test and Analysis

The road transportation test was conducted by simulating various road conditions such as passing speed bumps, accelerating, braking, avoidance and changing lanes. Driving tests were also conducted that ran eight laps on the 4.5 kilometer road. In most cases, peak accelerations of less than 1 g occurred and the maximum strain was less than 48 με. The maritime transportation tests were conducted under normal cruising conditions, as well as rotating, braking, acceleration and water depth impact assessment conditions. In most cases, the maximum acceleration was less than 1 g, and the maximum strain was less than 32 με.(Figure 1~3)

The vibration shake table test was conducted to evaluate the more detailed behavior of fuel assemblies based on road and sea transportation test data. The rolling test identified the conditions under which the ship rolls due to waves and it causes fuel assemblies to slip and collide with the canister lid or bottom. Consequently, under all conditions, no load has occurred enough to cause damage on the fuel assemblies.

Fig. 1. Korean road and sea transportation tests

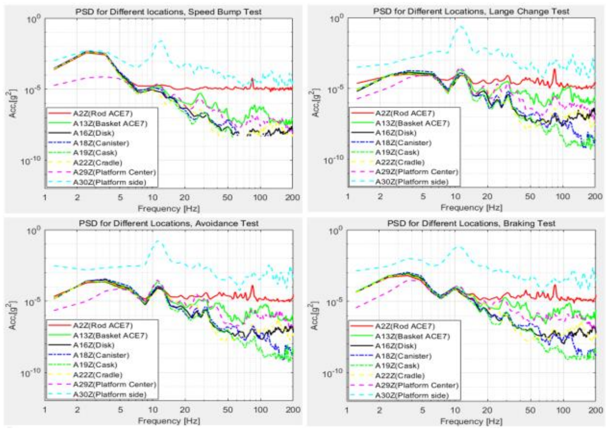

Fig. 2. Analysis of data from road transportation test

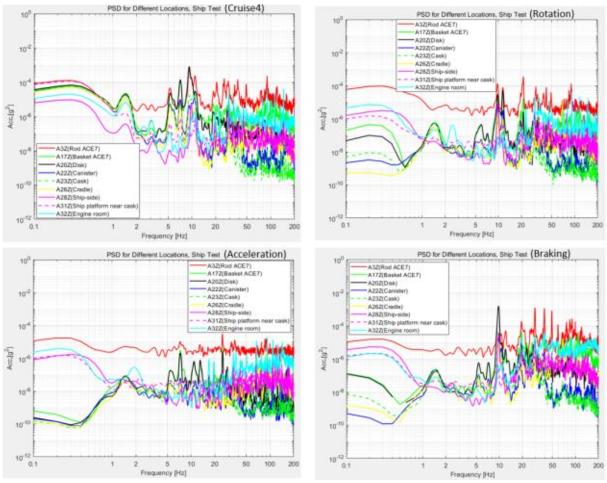

Fig. 3. Analysis of data from sea transportation test

Fig. 4. Shake table test and rolling test

In order to build an analytical method for evaluating the integrity of spent nuclear fuel under normal conditions of transport(NCT), a methodology was developed that combines a multibody dynamics model with a finite element-based model as shown in Fig. 5. This is because it is difficult to fully simulate the effects of the complex geometry and nonlinearity of the transport cask and transport system using only finite element-based analysis, and the analysis time is very large, making it impossible to perform vibration analysis for the entire model.

Therefore, transportation systems such as transport trailers and ships were analyzed using multibody dynamics techniques, and the load on the trunnion was provided as an input to the finite element analysis. The finite element analysis calculated the response of the fuel assemblies along the load path.

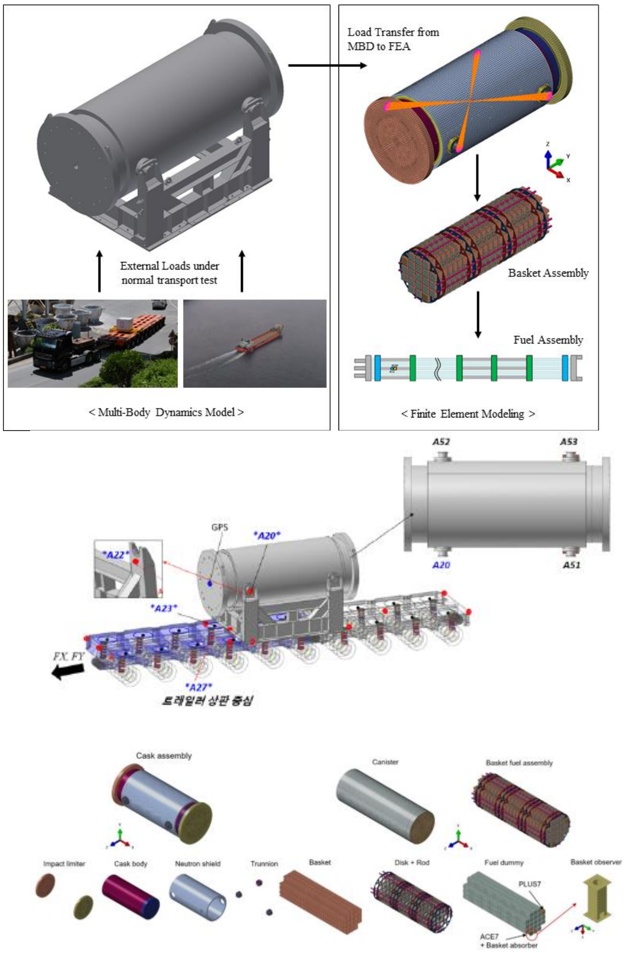

Fig. 5. Schematic drawing for coupled analysis technology

By comparing the results of the test and analysis, it was found that the maximum error of the maximum acceleration and maximum strain was less than 0.136 g for acceleration and 0.34 με for strain.

Based on the road and sea normal transportation tests and the evaluation using the developed analysis method, it was tentatively concluded that the integrity of spent nuclear fuel under conditions of road and sea normal transport is satisfied with a large margin.

However, when the storage business is realized and the transportation of spent nuclear fuel becomes visible, regulators may require storage and transportation operators to demonstrate that spent nuclear fuel remains safe under NCT, in accordance with regulatory requirements.

Transporters may use casks and transport systems with different specifications than those used in the tests conducted in this study. In such cases, it is not appropriate to perform additional expensive tests to demonstrate the integrity of the spent nuclear fuel. Therefore, design basis loads were calculated that can be used by transporters based on these tests and analytical evaluations from this study.

The design basis loads have been produced with a conservative approach to allow for differences in the specifications of the transport cask or transport system. In addition, since the applied location of the design basis loads must be specific, the evaluations were performed on various structures (baskets, internal structures, etc.) within the load transfer path. Finally, the design load was presented as a load input to the basket in the form of a PSD shown in Fig. 6.

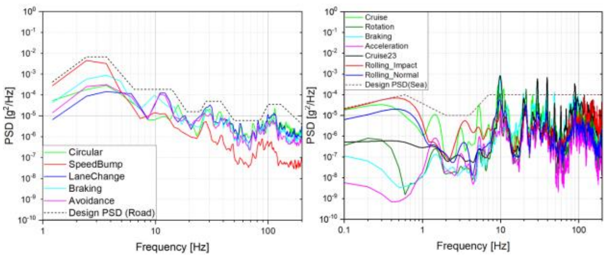

Fig. 6. Design basis PSD for NCT

3. Conclusions

Various tests were conducted to verify the integrity of fuel assemblies under NCT and coupled analytical method were developed. Design basis loads in the form of PSDs were derived. The magnitude of acceleration and strain generated in the fuel assembly under NCT is quite small and it proved that the integrity of spent nuclear fuel is maintained under NCT.

REFERENCES

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[2] J.H. Lim, W.S. Choi, 'Preliminary data analysis of surrogate fuel-loaded sea transportation tests under normal conditions of transport,' NET. (under review).

ACKNOWLEDGMENTS

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