The Evaluation of Dynamic Impact Behavior on SNF Shipping Cask for Korean Standard Nuclear Power Plant

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The structural safety of spent fuel shipping cask is considered very stringent because serious effect can be brought to both mankind and environment in case of radioactive material leakage by the accident occurred during transportation. According to the IAEA Safety series, 10 CFR 71 and Regulatory Guide 7.8, the spent fuel shipping cask must be able to withstand 9m free drop impact onto an unyielding surface and 1m drop impact onto a mild steel bar in a position causing maximum damage.

In this study, a structural safety evaluation was carried out for the conceptual design of SNF (Spent nuclear fuel) shipping cask for Korean standard nuclear power plant. Three dimensional dynamic structural analyses was executed using ABAQUS/Explicit code and dynamic impact behavior was analyzed to ensure the integrity of cask.

The structural dimension of designed cask was obtained from criticality and shielding analyses. The cask is capable of loading 21 PWR CE-type spent fuel assemblies with a burn-up of 55,000 MWD/MTU and a cooling time of 7 years. The loaded cask weighs about 91.3 ton maximum. The whole cask system consists of cask body, cask lid, neutron shielding, outer shell and impact limiters. The cask dimension and conceptual drawing are shown in Fig. 1.

In accordance with ASME section III Division 3, elastic material properties were used for all the cask component. However, since the claddings of the impact limiters rely on large plasticity to absorb the energy and mitigate impact, elastic-perfectly plastic properties were applied.

Figure 1. Cask Dimension & Conceptual Drawing   Figure 2. 3D-FEM Model for cask system

The drop analysis of the shipping cask was performed using 3D finite element method considering nonlinearity and dynamic behavior. 3-D FEM model was meshed into 104,096 elements (124,541 nodes) as shown on Fig.2 and a nonlinear dynamic 3-D FEM code, ABAQUS/Explicit, was used. ABAQUS/Explicit applied explicit time integration method is a very effective algorithm for solving a wide variety of nonlinear solid and structural mechanics problem.

As the analytical conditions, 1m side puncture, 9m vertical drop and 9m side drop cases were considered.

For a 1m side puncture condition, it was assumed that the above-mentioned model is dropped from height of 1m onto a mild steel bar in a horizontal position with the initial velocity of 4.43m/sec at the moment of contact with the bar. For the evaluation of dynamic behavior, several dynamic response data such as the time histories of energy, maximum stress, impact force and velocity and the distribution of maximum stress and deformation of the model were analyzed. The maximum stress of 213 MPa occurred at the vicinity of direct impingement on the C/S cask body as shown Fig.3 was well below the stress limits of 2.4Sm(385.4 MPa).

For a 9m vertical drop condition, it was assumed that the whole cask system is dropped from height of 9m onto an unyielding surface in a vertical position with the initial velocity of 13.29m/sec. The maximum stress, 108 MPa occurred at the cask lid part was well below the stress limits of 2.4Sm (385.4 MPa).

For a 9m side drop condition, it was assumed that the whole cask system is dropped from height of 9m onto an unyielding surface in a horizontal position with the initial velocity of 13.29m/sec. The maximum stress of 121 MPa occurred at the adjacent part of direct impingement was quite low against the stress limits of 2.4Sm(385.4 MPa).

[1m side puncture condition]   [9m vertical drop condition]   [9m side drop condition]
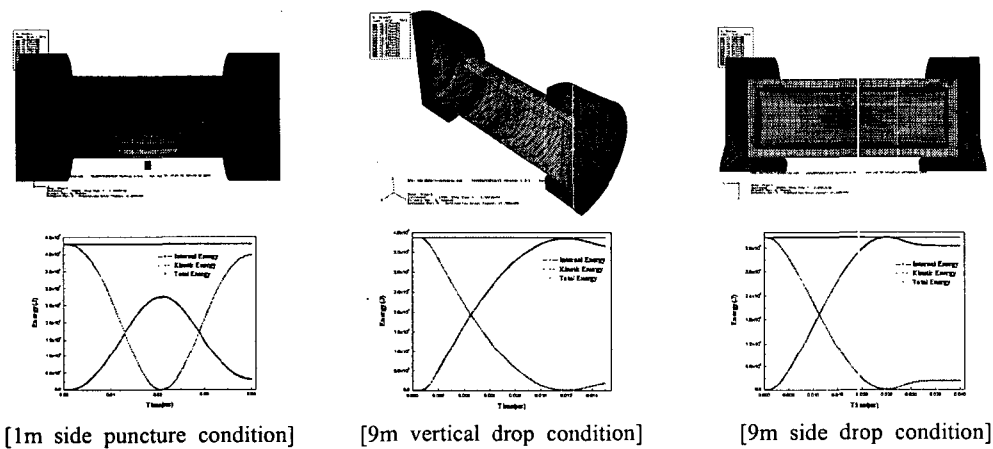
Figure 3. Stress distribution & Energy time history

As the results of drop analysis, the structural integrity of SNF shipping cask was guaranteed for all the evaluated cases.

References

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