Structural Analysis of High Capacity CANDU Spent Fuel Cask under Normal Conditions

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1. Introduction

CANDU spent fuels are loaded into a basket in spent fuel storage pool of nuclear power plant. The baskets are transported to a spent fuel dry storage facility by CANDU spent fuel transport cask. This cask shall have a docking system to transfer the basket into a cask remotely and an upper mechanism for the docking. The purpose of this paper is to identify the type of structural load of the upper mechanism and to establish the design criteria of normal condition for high capacity CANDU spent fuel cask. And in the conceptual design review stage, computational modeling was performed for structural analysis according to the normal condition load.

In this study, it is necessary to evaluate the structural safety of the upper mechanism because the flask stacking and the normal dropping condition that can occur in the normal operation of the spent fuel large capacity transport cask for heavy water reactor should have the safe function of upper mechanism.

2. Concept of upper mechanism and its modeling

The geometrical shape of the upper mechanism was confirmed as shown in Fig.1. Its components include lid lifting screw sets, housings and carriers. Examination of the geometry of the upper mechanism investigated the size, operating function and assembly margin of the lid lifting screw set, housing and carrier, etc., which were the components. In particular, the lid lifting screw set was referenced in the HISTAR-63 safety analysis report.

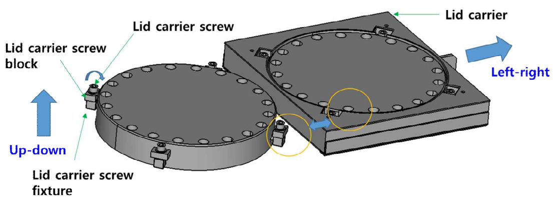

Fig. 1. Upper mechanism of high capacity CANDU spent fuel transport cask

Structural analysis modeling of the upper mechanism of transport cask was made with hexahedral elements or pentahedron elements considering the static and quasi-static load of the flask stacking, the lid bolt preload and drop impact load using the ABAQUS computer codes. The design criteria for the future evaluation of the structural analysis results were determined by considering the elasticity of the analysis results and the assembly margin of the mechanism. In review of the residual deformation, the analysis of the dynamic condition is considered to be an important factor in the occurrence of the maximum instantaneous shock.

The mechanical properties of the applied material are investigated and compiled according to ASME section II parts A and D in order to produce the input data for finite element analysis. The material of the upper mechanism was subjected to elasto-plastic data to predict the residual deformation. The SA240-304 and SA564-630 H1075 were applied for the upper mechanism.

Structural analysis modeling of all cask body was made by 1,184,904 elements such as C3D8 or C3D6 types by ABAQUS computer code. The surface angles of the elements ranged from 10 to 160 degrees and the time increment size was calculated to be 10^{-7}.

Fig. 2. Structural analysis model of high capacity CANDU spent fuel transport cask

3. Applied load and design criteria of structural analysis for upper mechanism

The modeling load of the upper mechanism is subjected to the static load by the weight of the flask in the transport cask, and the quasi-static load of the flask is received by generating from the hoist at the moment of stacking. These loads were converted to pressure to the upper mechanism, and the boundary conditions fixed all translational directions in the bottom nodes of the transport cask. The results of the flask stacking analysis were calculated in terms of the stress and deformation amount for static and quasi-static loads. The design criteria of the upper mechanism are determined by the width of 1 mm and the height of 8 mm, which is the gap between the carrier and the housing. And stress results of mechanism were calculated as the Von Mises stress and compared with the elastic limit. If the stresses remained within the elastic limit and without a residual deformation, the shape and gap should be recovered into the original assembly margin.

The dynamic load of the upper mechanism considered the vertical drop of the lid in the 0.3 m dropping position under normal conditions. The load is the condition that the whole model of the cask collides with the rigid body surface at the initial velocity, and the boundary condition fixes the rigid body surface as a whole. Analysis of 0.3 m dropping condition need to be evaluated in terms of residual stress and residual deformation remaining in the plastic zone for the dynamic load. The design criterion of the residual stress is within the elastic limit, and the residual strain design criterion can be applied within the assembly margin.

4. Structural analysis of static load for upper mechanism

The modeling loads of the upper mechanism were applied with static pressure of 0.472 MPa and 0.745 MPa, respectively, with quasi static load of flask by the hoist at the stacking instant with 28 tons with static load of flask weight.

In the view of stress, the flask stacking stresses were calculated to be 55.3 MPa for the static load and 110.6 MPa for the quasi-static load. The calculated stress was safe to be less than yield stress 207 MPa. The calculated deformations be 0.65 mm for the static load and 1.305 mm for the dynamic load less than 8mm. Normal operation is possible. The modeling including the static load and boundary conditions confirmed that the modeling integrity is maintained through the total reaction force calculation results in the stacking analysis.

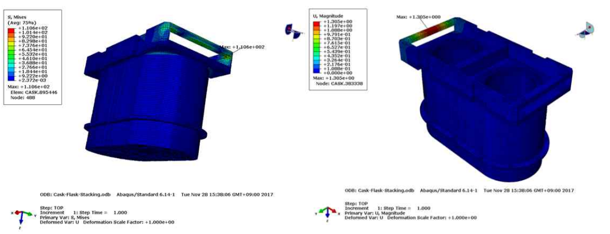

Fig. 3. Stress contour applied static stacking load to upper mechanism

5. Structural analysis of dynamic load for upper mechanism

The upper mechanism of transport cask is analyzed under the normal condition of 0.3 m dropping. Considering load for 1 atm internal pressure and inertia force of basket, the bolt tension load of 268 kN was applied with ABAQUS/Implicit. After that, in ABAQUS/Explicit, the upper mechanism collides with the rigid body surface with an initial velocity of 2.461 m/s in the gravity acceleration of 9.81 m/s^2. The boundary conditions were fixed to the rigid body.

0.3 m drop analysis results showed that the stress generation in the structural carrier was small and the maximum stress was generated in the housing and the maximum residual strain PEEQ was calculated as 1.32E-02 at the edge of the housing. The housing has a residual deformation of 2.7 mm from the viewpoint of deformation amount, and it sustains safe because the maximum deformation amount of collision is 7 mm and the assembly margin is 8 mm or less. Modeling including dynamic loads and boundary conditions confirms that the drop analysis maintains integrity through overall energy retention, kinetic energy, and internal energy changes.

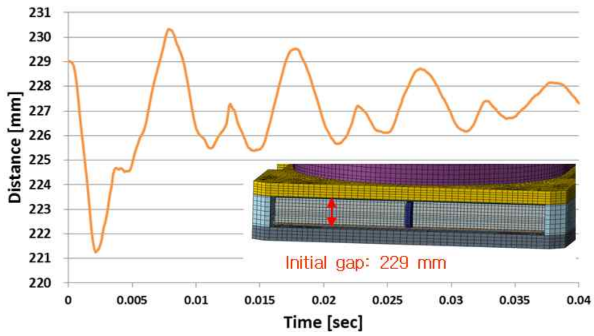

Fig. 4. Residual deformation of upper mechanism housing

6. Summaries

Static analysis acquired a safe stress within elastic limit by static load and had about 1/2 safe factor against a yield stress.

Dynamic analysis for 0.3 m normal condition drop had also the final residual deformation under the housing design criteria gap but at impact moment, maximum deformation is close to the design criteria gap and the stress of housing are beyond the elastic limit.

Therefore, a part of the housing structures shall be reinforced not to exceed its elastic range.

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