# ANALYSIS METHOD ON THE 9M DROP IMPACT OF SPENT FUEL SHIPPING CASKS USING ABAQUS AND LS-DYNA3D

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## ABSTRACT

Various analysis codes have been used for the 9m drop impact analysis of nuclear fuel casks, and analysis results are usually compared with the experimental results of scale model casks. Due to the complexity of mechanical behaviors, the results depend on how users apply the codes and it can cause severe errors during analysis. In the present study, ABAQUS/Explicit and LS-DYNA3D are implemented; we have investigated the analyzing technique for the drop impact test of the cask and found several vulnerable cases to errors. The analyzed results were compared with each others. Conclusively, we have suggested a reliable and relatively simple analysis technique for the drop test of nuclear fuel casks.

## INTRODUCTION

To design and to analysis a spent fuel shipping cask we use scaled model test and analysis code. It is getting popular to use commercial finite element codes rather than experiments because of the problems of time and cost. There can be a different result depending on the boundary conditions and engineer's ability in analysis codes. In this study, we research what characteristic each analysis codes display to reduce such a difference, resulted in shipping cask impact analysis of the hypothetical accident condition. LS-DYNA3D[1] and ABAQUS/Explicit[2] were used as analysis codes and we choose the KSC-4 shipping cask as analysis model (Figure 1). KSC-4 shipping cask is the equipment which can transport 4 PWR spent fuel assemblies and consists of the cask body, the impact limiters, a lid and tie-down devices. Resin and lead radiation shielding materials are made from resin and lead. Balsa wood and red wood are used for the impact limiters. The weight of empty KSC-4 shipping cask is about 34 tons and that of KSC-4 shipping cask with 4 spent fuel assemblies is 37.4 tons. In addition, the whole length of the cask is 5.6 m, the cask body length is 4.8 m and width is 1.2 m. Table 1 shows the materials and dimensions of the KSC-4 shipping cask.

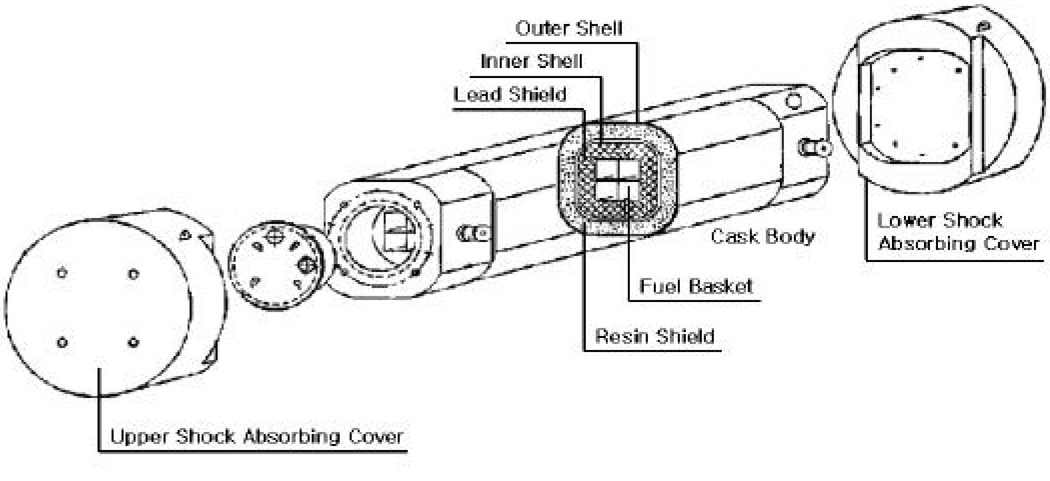


Figure 1, The KSC-4 shipping cask

## FEA MODEL

We make half model in Figure 2 with symmetric condition of the KSC-4 shipping cask. To simplify, we don't make the part of skin steel shell and upper part is made equal to lower part of the cask. Bolting components are modeled to perfectly bonding condition. And we assume that impact limiters are isotropic material and ignore the friction coefficient. Generated finite elements include eight nodes solid element. The number of element is 13254 when the lead is perfectly combined to cask body; the number is 25064 in case that there is contact condition. Table 2 shows the material properties for the component of the cask. Dynamic material properties are used because strength of stainless steel and lead increase as strain rate increase especially when it is under the dynamic loading condition [3].

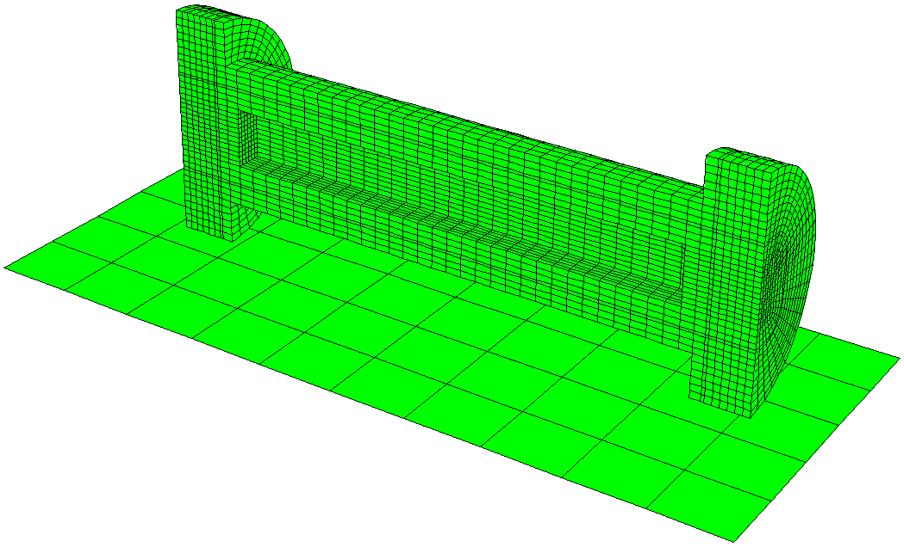


Figure 2, Half-model for finite element analysis

Table 1, Materials and dimensions of the KSC-4 shipping cask

| Components | Materials | Dimensions | | |
|---|---|---|---|---|
| | | Thickness (mm) | Height (mm) | Weight (ton) |
| Inner shell | SA 240 Type 304 | 25.4 | 4,740 | 2.82 |
| Outer shell | SA 240 Type 304 | 10.0 | 4,750 | 1.51 |
| Resin | NS-4-FR | 150.0 | | 4.00 |
| Lead shield | ASTM B29 ch. Gr.<br>99.9% Pb, Casting | Side 160.0<br>Bottom 175.0 | | 20.8 |

## BOUNDARY CONDITIONS

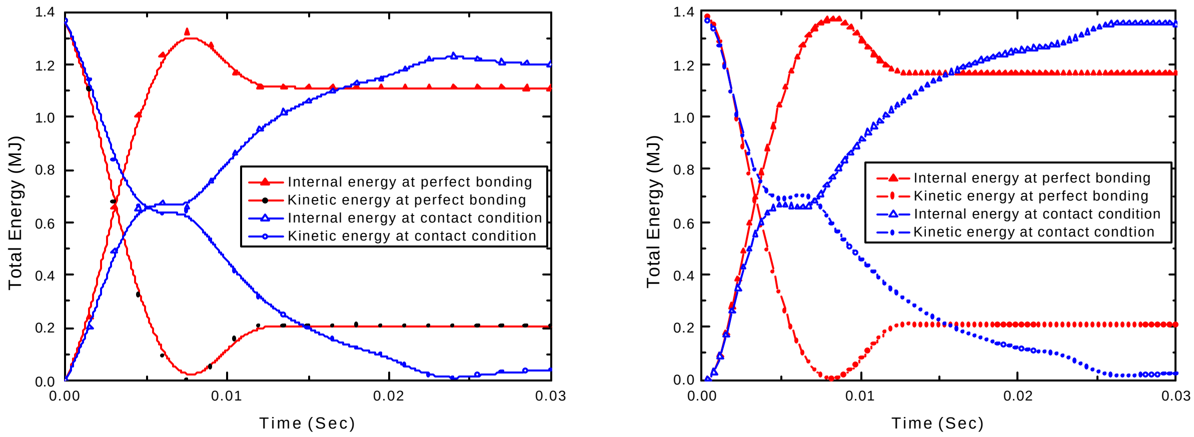
We apply the hypothetical accident conditions defined IAEA Safety Standards Series No. ST-1 [4] and Regulatory Guide 7.8 [5] to loading conditions. To make 9m drop effect in the hypothetical accident conditions, initial velocity (13.28 m/s ($v = \sqrt{2gH}$)) is applied to KSC-4 shipping cask. We analyze vertical drop and horizontal. The bottom is modeled as rigid body not to be deformed. Analysis time is 0.04 seconds.

Table 2, Material properties for the component of the cask [3]

| Material | Density (Kg/m3) | Young's modulus (GPa) | Poisson's ratio | Yield strength (MPa) | Hardening modulus (MPa) | Material behavior |
|---|---|---|---|---|---|---|
| SA 240 Type 304 | 7913 | 186.69 | 0.32 | 258 | 1894 | Elastic-Plastic |
| Resin | 1710 | 3.86 | 0.35 | 60 | 450 | |
| Lead | 11070 | 98.98 | 0.40 | 6 | 183 | |
| Red wood | 376 | 1.56 | 0.49 | 45 | 0 | Elastic perfectly plastic |
| Balsa wood | 160 | 0.67 | 0.49 | 13 | 0 | |

## RELIABILITY APPRECIATION OF THE ANALYSIS RESULTS

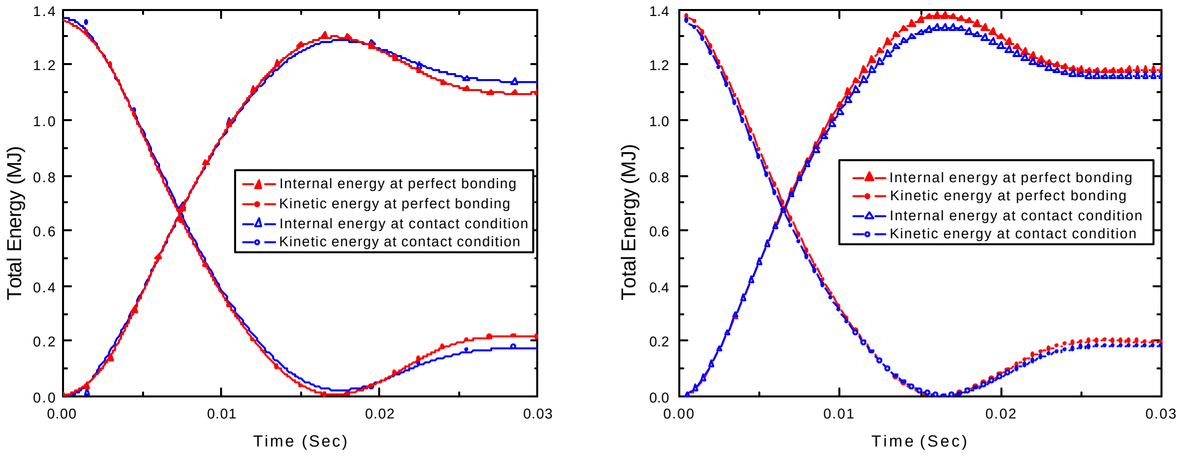
Chart 1 and 2 show energy time history of the 9m vertical drop and horizontal drop in the LS-DYNA3D and ABAQUS/Explicit. Both Charts show that kinetic energy translates internal energy during impact. Comparing both Charts relatively total energy lost in the LS-DYNA3D. This means that hourglass energy and sliding interface energy are generated as well as internal energy during impact analysis. But this energy is less than 0.1% of the total energy, so the results of LS-DYNA3D are reliable. Also in the most case, maximum effective stress of the containment boundary inner shell of the KSC4 cask is less than Pm (0.7Su= 330Mpa)(Chart 4,6). During vertical drop, the variation of energy is slow in the case of contact condition between cask stuctural shell and lead (radiation shielding) such as Chart 1. The reason is slump phenomenon of the lead. On the other hand, slump phenomenon of the lead less than that of the vertical drop in the case of horizontal drop, so we obtain the Chart 2 that energy difference is a litle.



(a) LS-DYNA3D

(b) ABAQUS/Explicit

Chart 1, Time history of the energy at the vertical drop

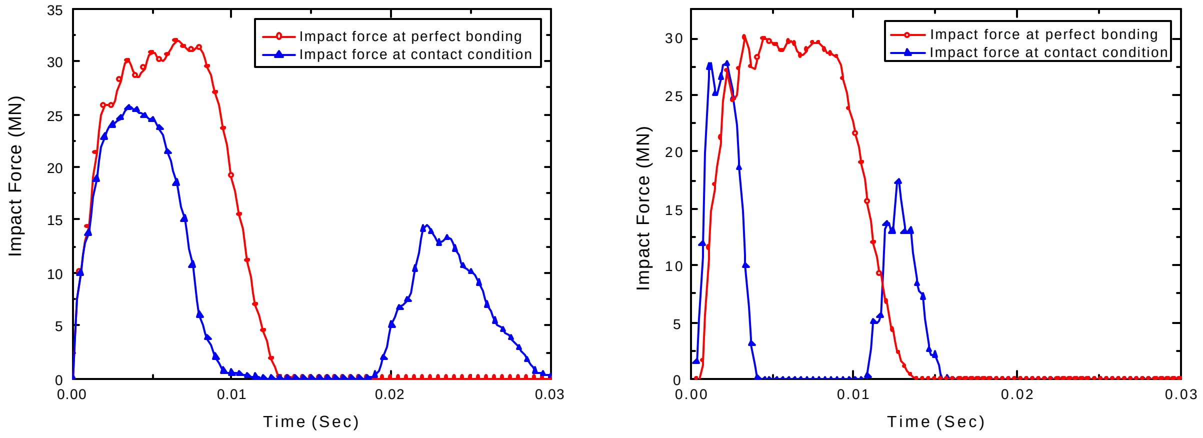


(a) LS-DYNA3D (b) ABAQUS/Explicit

Chart 2, Time history of the energy at the horizontal drop

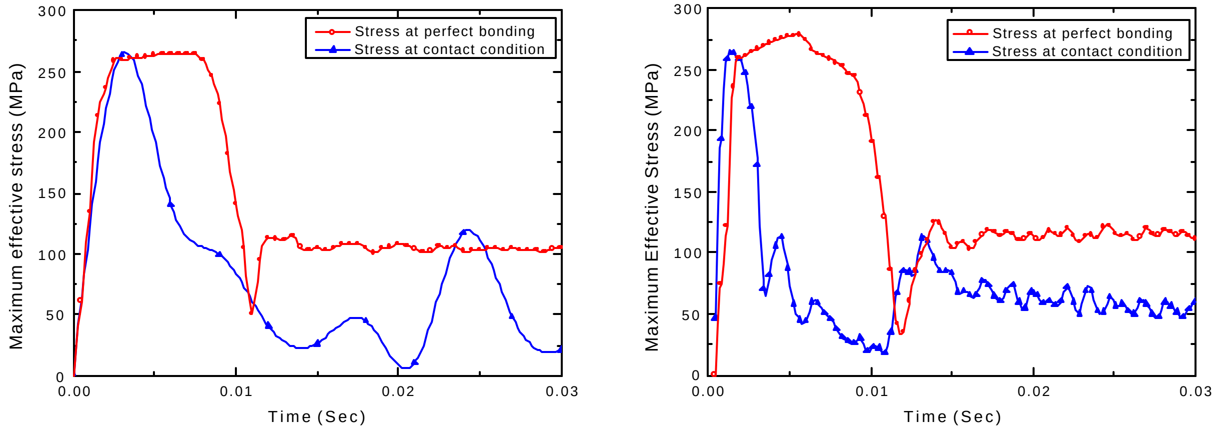
## IMPACT CHARACTERISTIC

Chart 3 shows impact force characteristic of the cask for vertical drop. During the vertical drop, impact characteristic of LS-DYNA3D is similar to that of ABAQUS/Explicit in the absence of contact condition between the cask structural shell and lead. In the case of the contact condition impact time of ABAQUS/Explicit is shorter than LS-DYNA3D, therefore maximum effective stress time history of the inner shell (containment boundary) is different such as Chart 4. The main reason of these differences is slump mechanism of the lead. Figure 3 shows slump mechanism of lead and stress contour with contact condition in LS-DYNA3D and ABAQUS/Explicit. Especially Figure 3(a) shows slump mechanism of the lead.



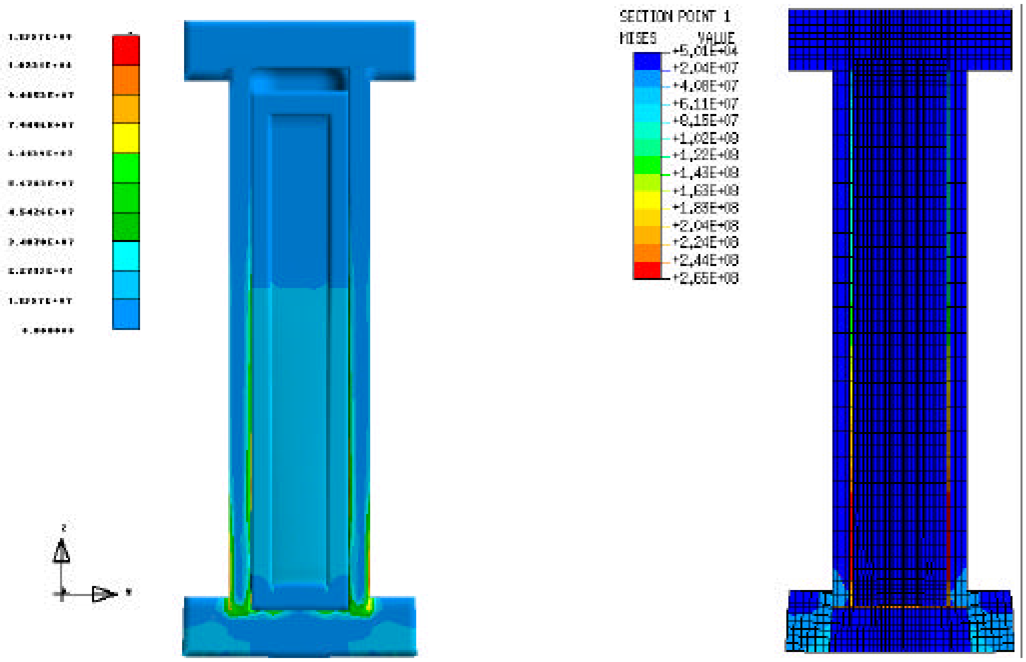
(a) LS-DYNA3D (b) ABAQUS/Explicit

Chart 3, Time history of the impact force at the vertical drop



(a) LS-DYNA3D (b) ABAQUS/Explicit

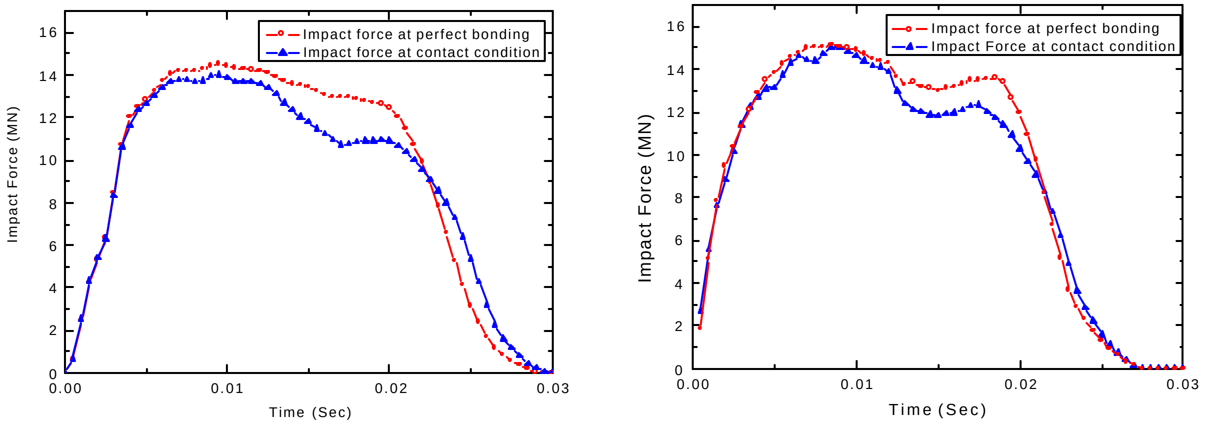
Chart 4, Effective stress of the inner-shell at the vertical drop



(a) LS-DYNA3D (b) ABAQUS/Explicit

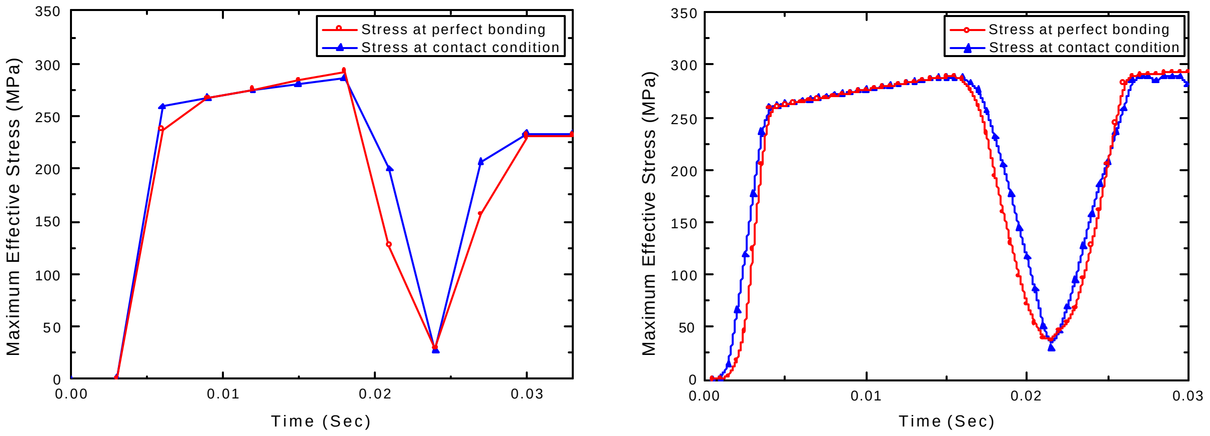
Figure 3, Effective stress contour with contact condition between cask body and lead

Chart 5 shows impact characteristic of the horizontal drop of the cask and there is no difference between contact conditions and no contact conditions at the lead interface. Chart 6 shows that stress of the inner shell with contact condition is similar to that of the no contact condition. Particularly Chart 6 shows the stress hardening effect and this results in higher stress than that of vertical drop. Figure 4 shows the stress contour and deformation of the horizontal drop with no contact condition at the lead interface. Moreover, it is predicted that lead deformation causes the bending of the inner shell for the horizontal.



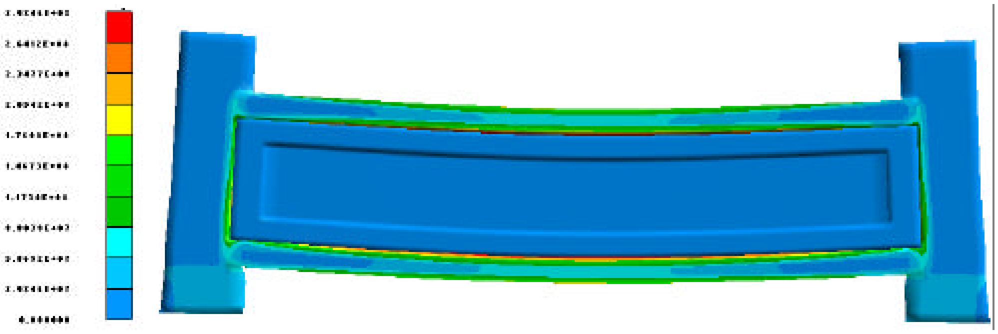
(a) LS-DYNA3D (b) ABAQUS/Explicit

Chart 5, Time history of the impact force at the horizontal drop

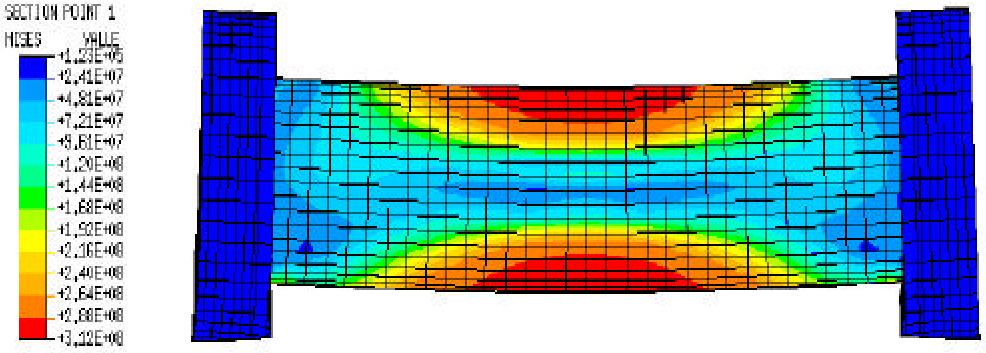


(a) LS-DYNA3D (b) ABAQUS/Explicit

Chart 6, Effective stress of the inner-shell at the horizontal drop



(a) LS-DYNA3D



(b) ABAQUS/Explicit

Figure 4, Effective stress contour with no contact conditions between cask body and lead

## CONCLUSIONS

In this study, impact analysis is performed about KSC-4 shipping cask using nonlinear explicit FE codes LS-DYNA3D and ABAQUS/Explicit. The 9m vertical drop and the horizontal drop are analyzed and slump mechanism of lead is studied. We lead the following conclusion.

1. If there is no contact condition of the lead interface during vertical drop and horizontal drop, the analysis results of LS-DYNA3D are similar to that ABAQUS/Explicit.
2. If there is contact condition of the lead interface during vertical, the second impact occurs. According to slump mechanism of the lead the results of LS-DYNA3D are so different from that of ABAQUS/Explicit. According to analysis codes impact characteristics are difference between LS-DYNA3D and ABAQUS/Explicit during vertical drop. Therefore slump mechanism of the lead must be considered during vertical drop.
3. The slump mechanism of the lead would cause fatal damage to fuel-basket during the vertical drop.
4. For the horizontal drop the second impact is not occured and impact force are similar between contact condition and no contact condition of the lead interface. So, slump mechanism of the lead should be ignored to save time and money.
5. Stresses appear according to impact force characteristic at the inner shell of containment boundary and are satisfied with NRC Regulatory Guides 7.6 (0.7*Su = 330MPa). Especially in the comparison of vertical drop and horizontal drop, impact time of the horizontal drop is longer than the vertical drop. And stress hardening effect occurred for both LS-DYNA3D and ABAQUS/Explicit during the horizontal drop.

## REFERENCES

[1] LSTC, "LS-DYNA3D User's Manual Ver. 950", 1999

[2] H.K.S. Inc., "ABAQUS/Explicit User's Manual Ver. 5.8", 1998

[3] H. J. Rack, G. A. Knorovsky, "An Assessment of stress Strain Data Suitable for Finite Element Elastic-Plastic Analysis of Shipping Containers", NUREG/CR-0481, Sand77-1872, Sandia Lab., 1978

[4] IAEA Safety Standards Series No. ST-1, Regulation for the Safe Transfort of Radioactive Material, 1996

[5] NRC Regulatory Guide 7.6, Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels, USNRC, 1978