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EFFECT OF IMPACT POINT OFFSET OF A SOLID MILD STEEL PLATE TO THE NUCLEAR MATERIAL TRANSPORT CASK IN DROP TEST III

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ABSTRACT

IAEA Safety Standards No.TS-R-1 para.727 (c) requires drop test III. To assure the integrity of a cask in drop test III, the specimen is required to suffer maximum damage. In this study, the analyses of drop test III were conducted considering offset drop position of a solid mild steel plate to a transport cask with a weight of less than 500 kg.

The deformation of a transport cask is an important factor related to the damage. Therefore, we studied the relationship between the offset drop position of the plate and the maximum deformation of the cylindrical transport cask with a vertical attitude.

The analysis model comprises a steel plate and the stainless steel transport cask with a radius of approximate 400 mm. The steel plate with a horizontal attitude dropped from 9 m height with changing the offset drop position.

As the result, it was found that the maximum deformation became significantly large in the drop analysis when the offset was taken into account. Therefore, it was concluded that the drop analysis considering offset drop position is important to evaluate of the maximum deformation in drop test III.

INTRODUCTION

The main purpose of small casks is to transport fuel material specimen for examination or radioisotope for medical usage. There is not a study about small casks in recent.

In Japan, the Great East Japan Earthquake disaster occurred on March 11, 2011 and some nuclear plants suffered serious damage. Therefore, the safety evaluation of the all types of casks becomes more important.

IAEA Safety Standards No.TS-R-1 para.727 (c) [1] requires drop test III as follows: For drop test III, the specimen shall be subjected to a dynamic crush test by positioning the specimen on the target so as to suffer maximum damage by the drop of a 500 kg mass from 9 m onto the specimen. The mass shall consist of a solid mild steel plate 1 m by 1 m and shall fall in a horizontal attitude.

To assure the integrity of a cask in drop test III, the specimen is required to suffer maximum damage. The deformation of the specimen is an important factor of the damage. Therefore, we studied the influence of offset position on maximum damage through investigating deformations of the transport casks in drop test III analyses using ABAQUS/Standard 6.11 [2].

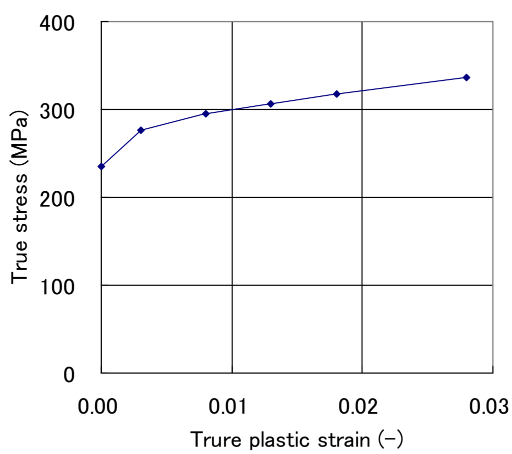
ANALYSIS MODELS

In this study, we prepared the analysis model of the cask without a flange and a lid for simplification. The outer shell of the cask has a uniform wall thickness. The corner of the outer shell has a fillet of 4 mm. We set a shape and the materials of the virtual cask as the analysis model.

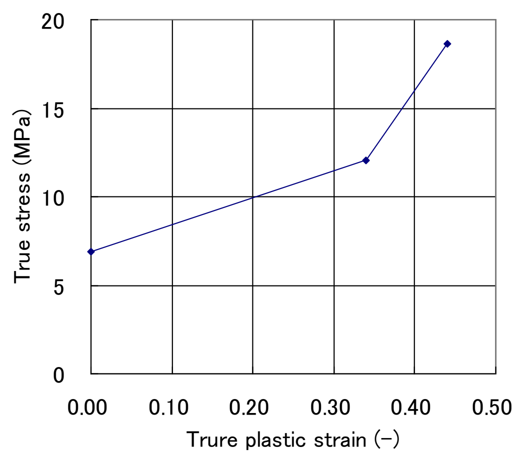
Implicit nonlinear dynamic analyses were performed using ABAQUS/Standard. Analyses were performed by auto time step function until the vibration by impact ended. Gravity acceleration was not applied in analysis model. A solid mild steel plate dropped from 9 m height. Therefore, a solid mild steel plate had a velocity of 13.3 m/s when it hit the cask. The cask was fixed on the floor. Contact interaction was considered for surface pair between the plate and the outer shell and surface pair between the outer shell and the outer shock absorber. Material properties are shown in Table 1. The stress - strain curves for austenite stainless steel (SUS304) and polyurethane - foam are shown in Fig. 1.

Table 1. Material properties

Material	Mild steel (SS400)	Stainless steel (SUS304)	Stainless steel (SUS304)	Polyurethane-foam (Pu-foam)
Part	Plate	Container	Outer shell	Shock absorber
Material model	Elastic	Elastic	Elastic-plastic [3]	Crushable foam [4]
Young's modulus (MPa)	210000	201000	201000	114.9
Poisson ratio (-)	0.3	0.3	0.3	0.001
Density (kg/mm^3)	7.90×10^{-6}	8.00×10^{-6}	8.00×10^{-6}	4.93×10^{-7} [5]



a) Stress-strain curve of austenite stainless steel



b) Stress-strain curve of polyurethane-foam

Figure 1. Stress – strain curves

Two kinds of wall thickness (2 mm and 4 mm) of the outer shell were taken into account. The specification of the analysis models of casks is shown in Table 2.

Table 2. Specification of analysis models of casks

Model name	Type A	Type B
Approximate radius (mm)	400	400
Total weight of cask (kg)	308	356
Thickness of outer shell (mm)	2	4

FEA model is illustrated in Fig. 2. 42381 nodes and 22573 elements were used. Shell and solid reduced integration element were used in the analyses, and shell element was only used for the outer shell. The offset = 0 mm means that the gravity center of the plate was dropped to the center of the top circle area of the outer shell. The offset position shifted every 100 mm (100 mm, 200 mm, · · ·, 500 mm) away from the central axis of the cask. The dropping plate with a horizontal attitude was assumed as initial condition in the analyses.

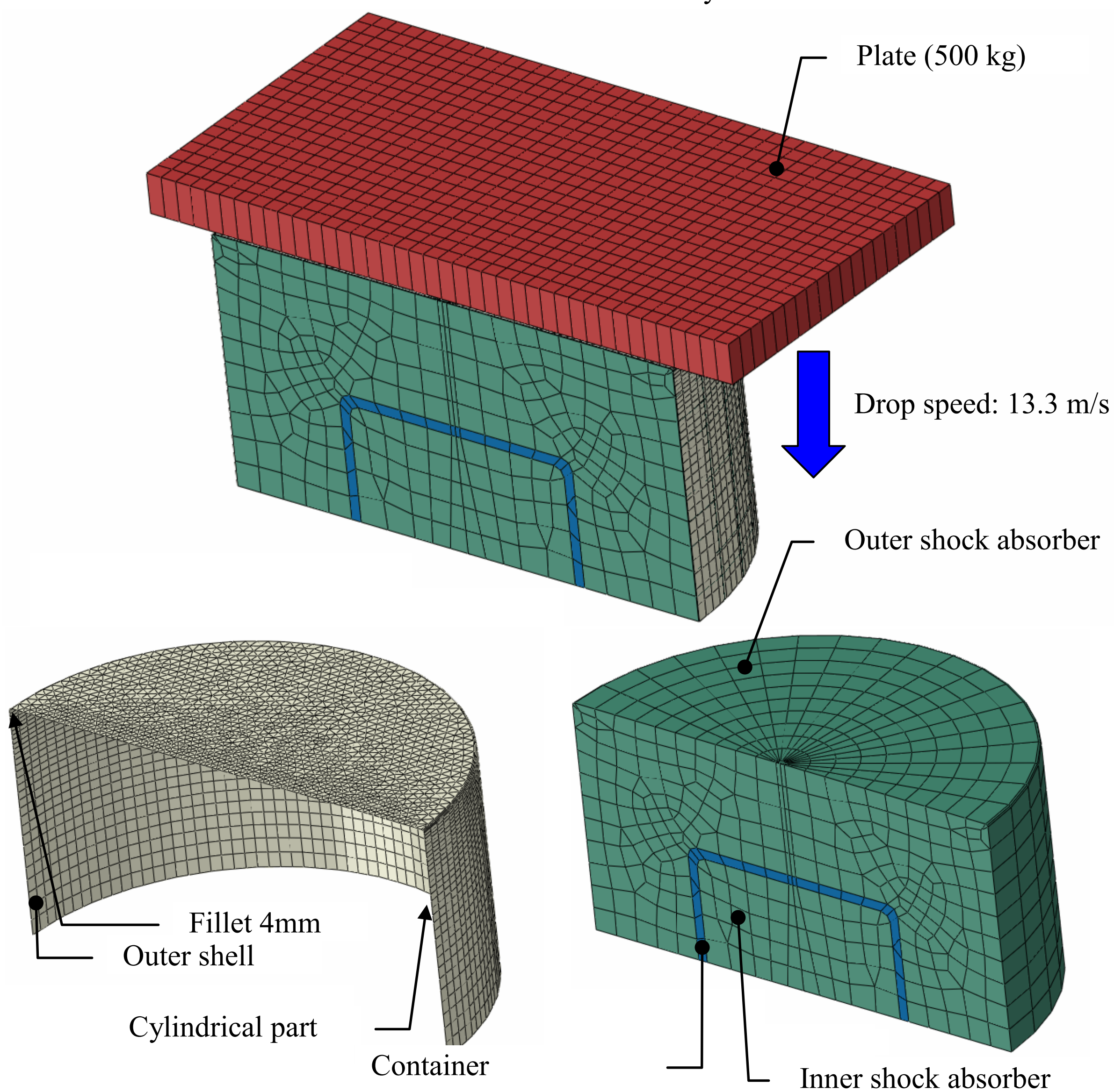


Figure 2. FEA model

ANALYSIS RESULTS FOR TYPE A

Results for different plate positions

The representative analysis results of deformation for different plate positions are sequentially shown in Fig. 3 when offset positions were 0 mm and 300 mm. When offset was 0 mm in Fig. 3 a), owing to the elastic energy stored in outer shell, the plate was bounced upside after the plate hit the cask. However, when offset was 300 mm (Fig. 3 b)) or more than 300 mm, the spin motion of the plate was caused by the kinetic energy in the part of the plate where did not touch the outer shell towards the fall direction. Due to, the plate gave a hit on the cylindrical part of the outer shell.

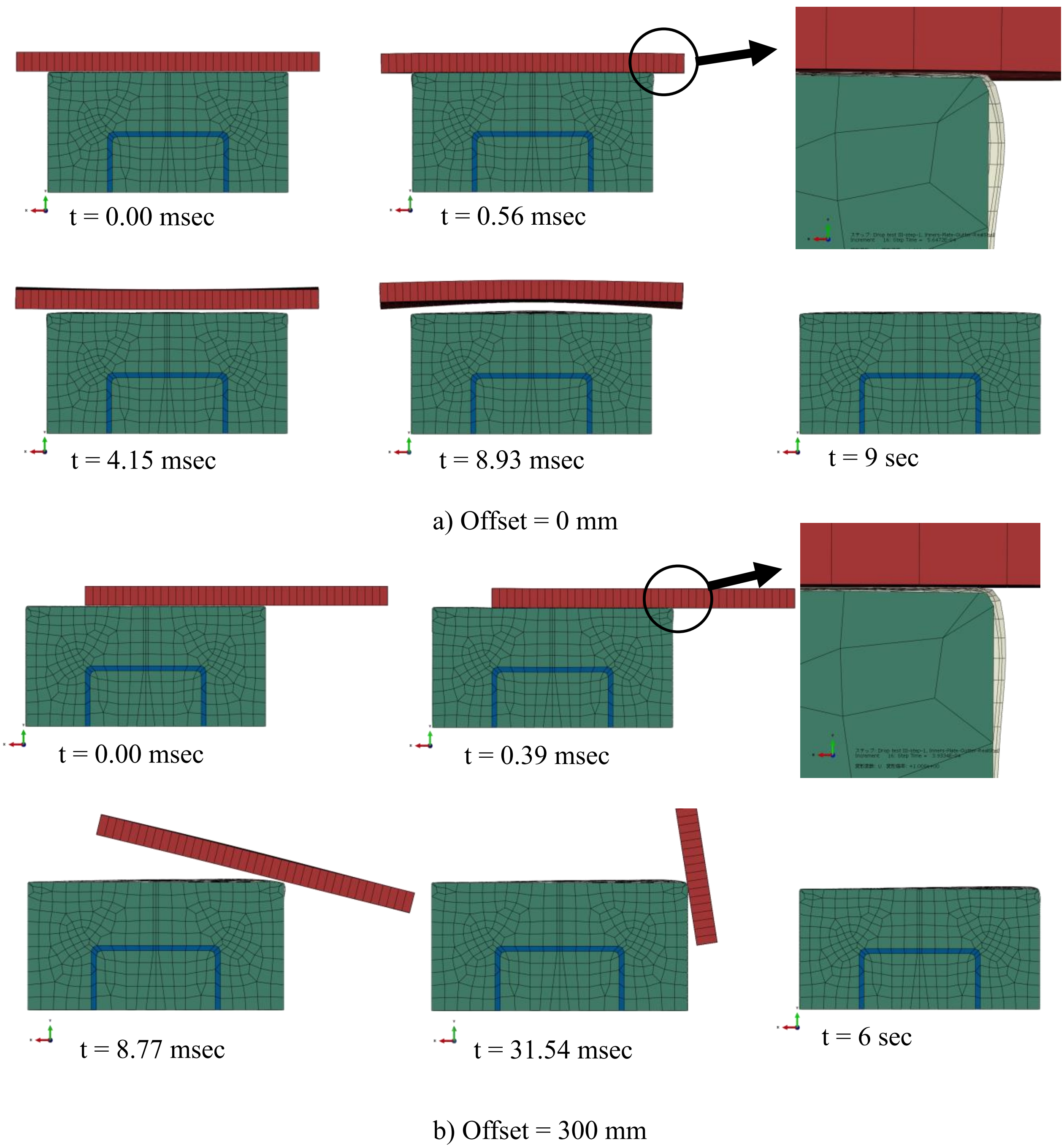
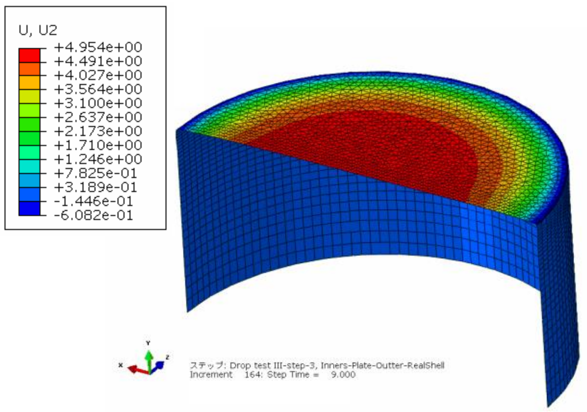


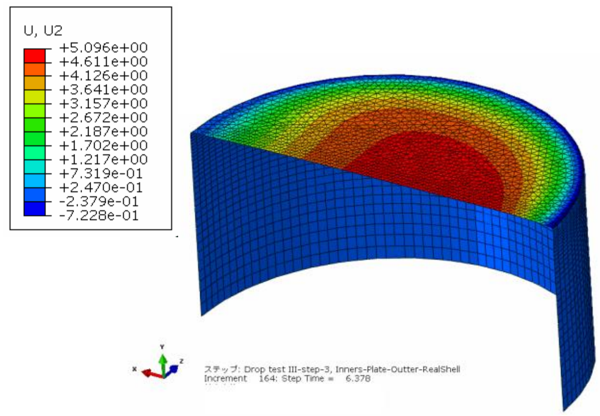
Figure 3. The representative analysis results for different plate positions

Displacement results

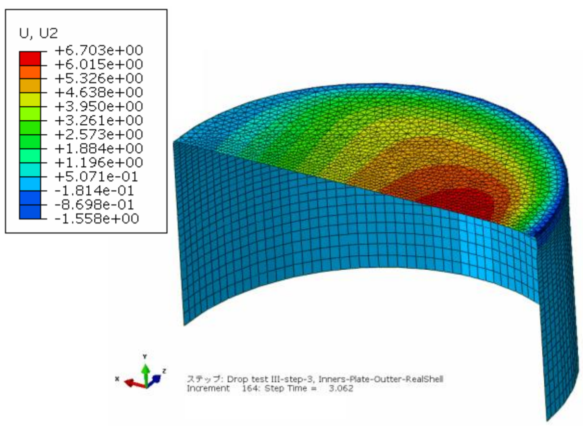
Figure 4 shows the analysis results of displacement of the outer shell in the axial direction of the cask. A separation between the outer shell and the outer shock absorber was caused after the plate hit the cask. The outer shell deformation in the axial direction outside of the cask became the maximum when offset was 300 mm.



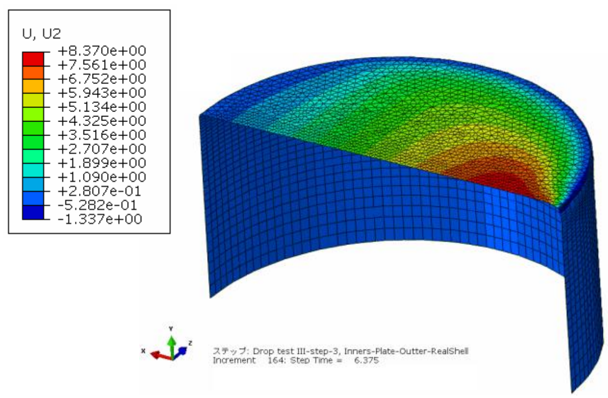
a) Offset = 0 mm



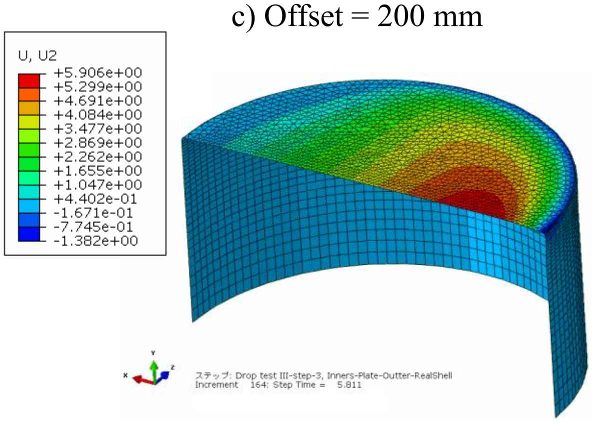
b) Offset = 100 mm



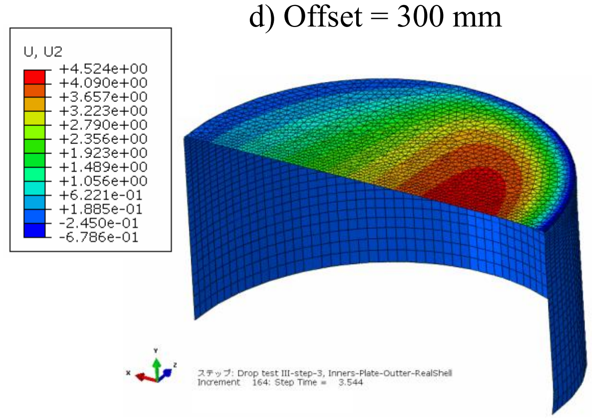
c) Offset = 200 mm



d) Offset = 300 mm



e) Offset = 400 mm



f) Offset = 500 mm

(Unit: mm)

Figure 4. The axial displacement of the outer shell after drop test III

In several representative cases, local deformations at the right side edge of the outer shell are summarized in Fig. 5. The top part of cylindrical with a length about 50 mm had the plastic deformations in the radial direction outside of the cask, because the plate pressed the top area of cylinder. Then the top circle area of the outer shell had an angle with the horizontal direction outside of the cask. When offset was 300 mm, in comparing t = 31.54 msec with t = 9 sec, it was found that local deformation of the top circle area was increased in the axial direction outside of the cask after the plate hit the cylindrical part due to the spin motion of the plate.

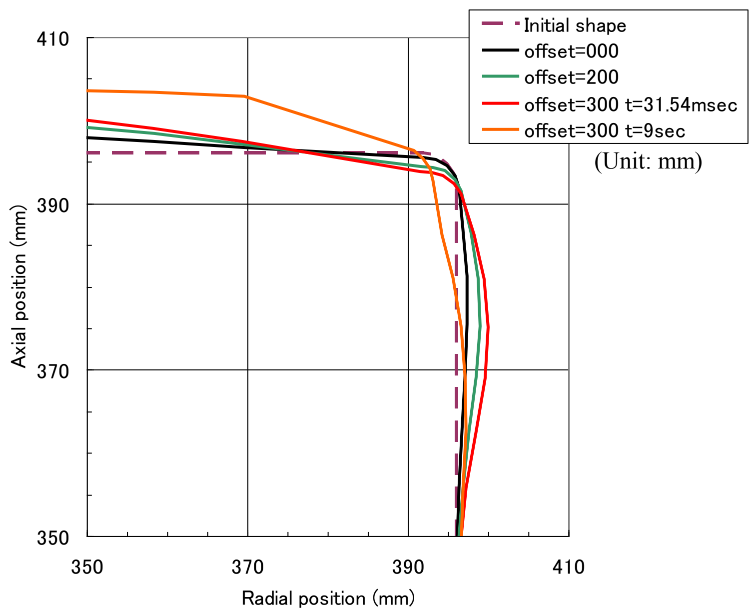


Figure 5. The representative local deformations at the right side edge of the outer shell

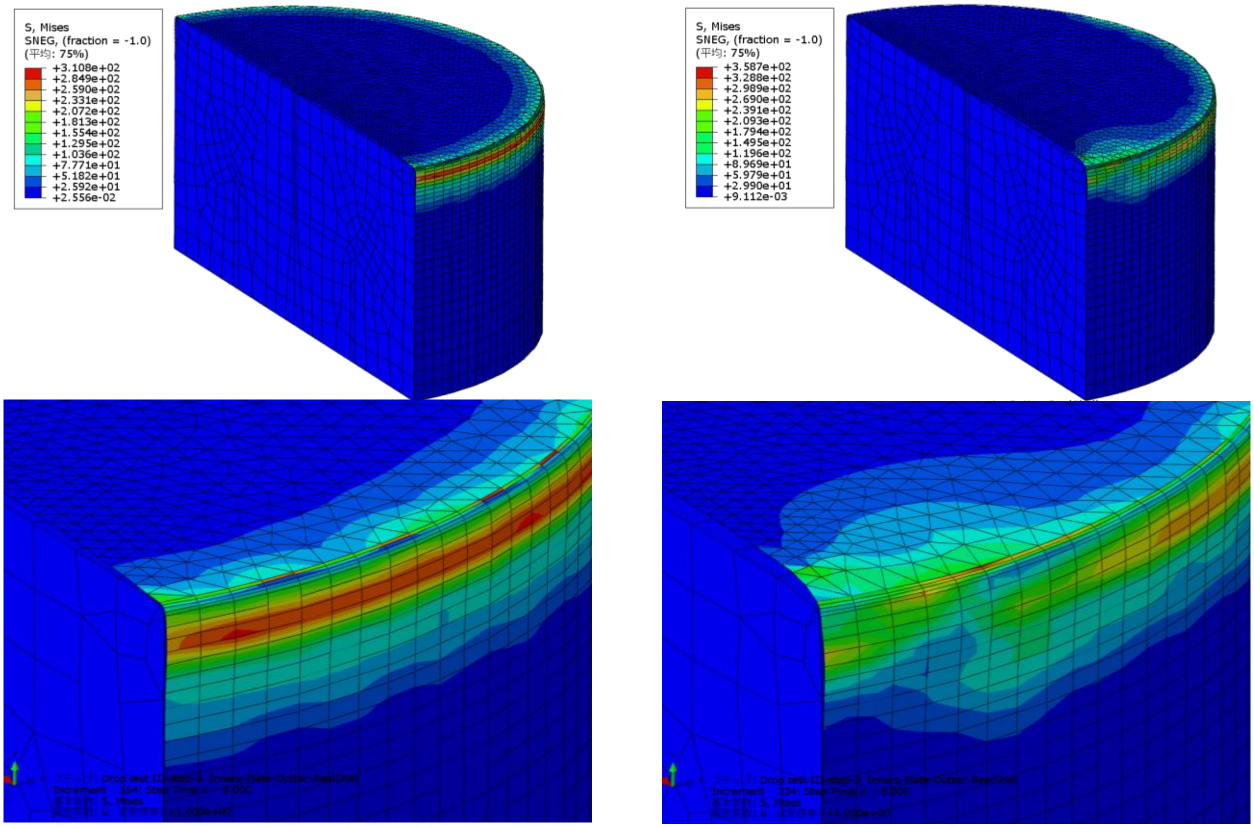
<u>Stress results</u>

The Mises equivalent stress distributions of the outer shell after drop test III are shown in Fig. 6.

The kinetic energy of the plate was sufficiently large to cause the plastic deformation of the outer shell, when the gravity center of the plate was within the top circle area of the outer shell after drop test III. When offset was 0 mm, the local plastic deformation along all over the edge occurred in the radial direction outside of the cask about the top part of the outer shell cylinder in Fig. 6 a). When offset was 300 mm, the local plastic deformation occurred in the radial direction outside of the cask in Fig. 6 b), and this local deformation becomes the maximum in right side of the outer shell. The shock absorber was deformed by the deformation of the outer shell, but no deformation was observed in the container.

EFFECT OF THICKNESS OF OUTER SHELL

In all cases (every offset for Type A and B), axial displacements of the top circle area of the outer shell at symmetrical surface are summarized in Fig. 7. In comparing Type B with Type A, it can be found from Fig. 7 that the deformation was decreased significantly with the increase of the wall thickness of the outer shell. The cylinder of the outer shell was pressed by the kinetic energy of the plate.

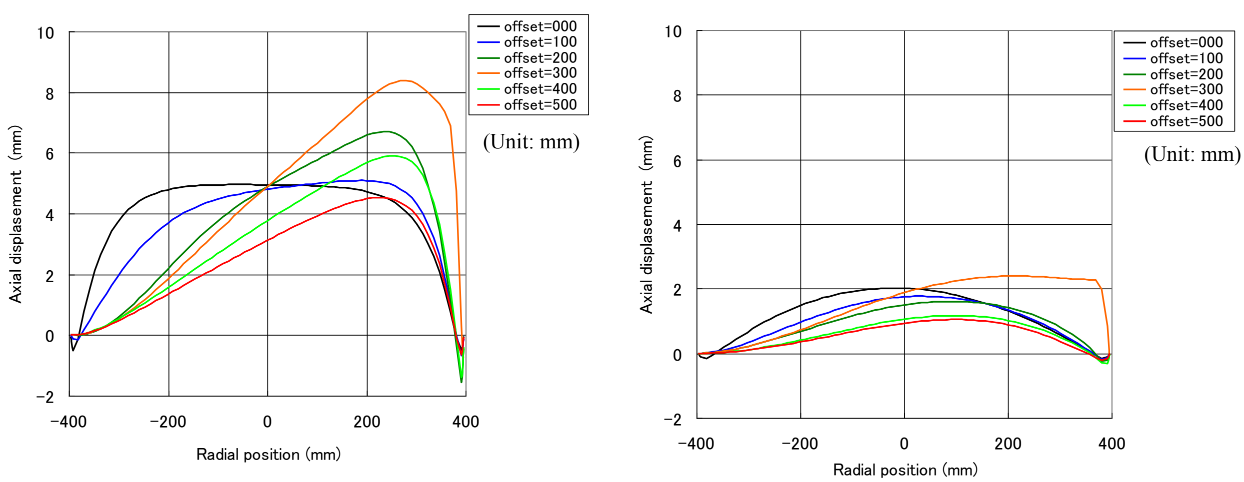


a) Offset = 0 mm

b) Offset = 300 mm

(Unit: MPa)

Figure 6. The representative mises stress distributions after drop test III



a) Model: Type A

b) Model: Type B

Figure 7. Axial displacements of the top circle area of the outer shell at symmetrical surface after drop test III

CONCLUSIONS

In this study, the analyses of drop test III were conducted considering offset drop of a solid mild steel plate to a transport cask with a weight of less than 500 kg. The offset drop position and the wall thickness of the outer shell were taken into account as main parameters. The evaluation method of the maximum damage in drop test III was provided in this paper.

As the result, it was found that the maximum deformation became significantly large in the drop analysis when the offset was taken into account. Therefore, it was concluded that the drop analysis considering offset drop position is important to evaluate of the maximum deformation in drop test III.

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