Drop Tests of a Type IP-2 Transport Package with a Bolted Lid

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ABSTRACT

IP-2 transport package for radioactive wastes shall be designed in accordance with designated regulations such as the IAEA Safety standard series TS-R-1. In general, IP-2 transport packages are used as ISO containers that have doors for a package closure. If the shielding thickness of the IP-2 package is thick, a bolted lid type may be safer or stronger than a door type. The closure mechanism of a bolted lid withstands a drop impact well. If the IP-2 package were subjected to the free drop test under the normal conditions of a transport, it should ensure the prevention of a loss or dispersal of the radioactive contents and a loss of its shielding integrity. Therefore, it is important that the integrity of the lid and its bolts are sustained under a drop impact. This paper presents the results of the type IP-2 package which undertook a vertical drop of 0.9 in height. An opening displacement of the lid and the torques of the lid bolts are changed before or after the drop impact of the type IP-2 package. Also the thicknesses of the shielding material are measured before or after the drop impact. The acceleration, strain and the bolt tension are measured during the test. The accelerations and the strains measured from a test are compared with the results from a finite element analysis.

INTRODUCTION

Radioactive waste generated from nuclear power plants should be transported in accordance with the designated regulations such as the IAEA Safety standard series TS-R-1, which is to protect radiation workers and the public against a potential radiation exposure caused by their transportation. Each transport package of the radioactive waste has to be designed to have enough safety to fulfill the regulations and the technical standards in the regulations.[1~2] In accordance with the IAEA safety standard series TS-R-1 which is accepted widely by most of its member states, an industrial package can be divided into IP-1, IP-2 and IP-3 along with other Type A and Type B packages. An IP-2 transport package should be designed to meet the designated requirements in addition to those for a type IP-1 transport package. If an IP-2 transport package were to be subjected to the free drop and stacking tests under the normal conditions of a transportation, it should prevent against (a) a loss or dispersal of the radioactive contents, and (b) a loss of its shielding integrity which would result in more than a 20% increase in the radiation level at any external surface of the package as regulated in the regulation. In this paper, a drop test for the type IP-2 transport package under normal transport conditions was undertaken. In general, the type IP-2 transport packages are used as ISO containers which have end doors for a package closure.[3~4] If the shielding thickness of the IP-2 transport package is thick, the weight of a transport package is heavier thus a bolted lid type may be safer or stronger than a door type. The closure mechanism of the bolted lid withstands a drop impact well. Therefore, it is important that the integrity of the lid and its bolts are sustained under a drop impact. This paper presents the results of the type IP-2 package which undertook a vertical drop of 0.9 in height. An opening displacement of the lid and the torques of the lid bolts are changed before or after the drop impact of the type IP-2 package. Also the thicknesses of the shielding material are measured before or after the drop impact. The acceleration, strain and the bolt tension are measured during the test. The accelerations and the strains measured from a test are compared with the results from a finite element analysis.

TYPE IP-2 TRANSPORT PACKAGE

The type IP-2 transport package is designed to transport eight radioactive waste drums, whose radiation level is 20~200 mRem/hr. The size and weight of a waste drum are 620(D) mm x 890(H) mm and 400 kg, respectively. For a shielding material, carbon steel with an 35 mm thickness is used. The clearance between the drums is 100mm. The internal dimensions are 2,980(=620 x 4 + 100 x 5) mm(L) x 910 mm(H) x 1,540(=620 x 2 + 100 x 3) mm(W) and the external dimension of the package are 3,300 mm(L) x 1,217 mm (H) x 1,940 mm(W). Packaging capacity is 1.6 ton and the total weight is about 9.42 ton. A corner fitting whose size and configuration are specified in ISO 1161[5] and fork-lift pockets whose dimensions are provided in ISO 1496-1[6] are used as a lifting device.

Fig. 1 shows the test model and locations of the sensors. To avoid a streaming radiation in the shielding path and to reinforce the structural integrity for the side drop, a 5 mm step between the bottom and the flange on the lid is made. There is a rubber gasket at the flange.

The fifteen-strain gauges (model: CEA-06-12UW-350 Vishy Micro-Measurements Co.), twenty accelerometers(model: 350B04, PCB PIEZOTRONICS, INC.) and four force sensors(Model : 260C, PIEZOTRONICS, INC.) are installed in the model as shown in Fig. 1. Points indicated by ‘S’ show the locations attached with a strain gauge. The line direction means the measured axis of the strain gauge. Points indicated by ‘A’ show the locations threaded to install a accelerometer. Force sensors are installed at the bolts indicated by ‘F’. To protect the data cable the steel tubes are installed for the square pipe of the model.

TEST

Test Method

To acquire and store the strains, accelerations and bolt forces the data acquisition system is used. The data acquisition system is composed of PXI-8186 (National Instruments Co.) which is an embedded controller 3U to control and store the data with the LabVIEW program, seven PXI-4220 modules(National Instruments Co.) to acquire the strains and two PXI-4472B modules(National Instruments Co.) to acquire the accelerations and the bolt force. The sensors are connected to the data acquisition system. The height, lower size and upper size of a drop structure which is an H-beam truss structure are 15 m, 8m X 8m and 4m X 4m. The weight of the drop target which is composed of a steel plate which is 4m X 4m X 0.1m and steel reinforced concrete which is 5m X 5m X 1.5m is 104 ton. The release mechanism is an opening tongs type by using a hydraulic pressure by an electric control.

The bolts are fastened with 200 N·m. The gap between the lid and the body and the dimensions of the model are measured. The drop height is 0.9 m which is regulated in the regulations such as the IASEA safety standard series TS-R-1[1] and the US 10CFR 71[2] for the weight of the transport package which is from 5,000 kg to 10,000 kg.

Test Results

Four square pipe columns of the model are mainly deformed by the impact. And other parts of the model are deformed insignificantly. The height of the model decreases by 2.3mm the lengths of the four square pipe columns decrease by an average of 4.8 mm. The change of the step of the lid is 0.07 mm which can be considered as an error for the measurement. The maximum and average torque to unfasten a bolt are 153 N·m and 57 N·m. Some bolts are unfastened by hand. But the bolts are not failed and unfastened. And the rubber gasket is working. The gap between the body and the lid increases from 2.79 mm to 3.55 mm. It is not the gap between the flanges of the body and the lid. The change of the gap between the body and the lid is 0.76 mm which occurred by a deformation of the square pipe of the body and the lid. However the change of the gap between the body and the lid, 0.76 mm is smaller than the step between the bottom and the flange on the lid. The height of a step, 6.17 mm is higher than the gap between the body and the lid obtained from a test and the bolts are not failed so there is no breach of the containment to cause any loss or dispersal of the radioactive contents due to the vertical drop test. Also, the eight waste drums are not harmed and the content of the waste drum are not loose by the impact loading.

The thicknesses of the shielding material are measured before and after a test by using an ultrasonic thickness gauge. The changes of the thickness of the shielding material are insignificant so that a loss of the shielding integrity is negligible in terms of the overall shielding integrity.

The 12 strains among the 14 gauges, the 11 accelerations among the 12 accelerometers and the 4 bolt forces are acquired as shown in Fig. 2. The data is filtered with a 600 Hz Lowpass filtering by using the LabVIEW program. 600 Hz is determined from a frequency of the strains obtained from the test. The strain obtained from the bottom of the body, S2 appears to be the maximum tensile strain, 535 $\mu\varepsilon$. And the maximum compress strain, -440 $\mu\varepsilon$ appears at the lid, S13. The tensile strain at the bottom and the compress strain at the lid appear to be because of the bending displacement of the model by the impact. Points S5 and S9 are symmetrical with the height from the bottom. So the strains at these points are similar. However, Points S6 and S10 and Points S7 and S11 are also symmetrical with the height from the bottom. But the strains at these points are different because an incorrect drop causes an inclined impact.

At point A7 the maximum acceleration, 333 g appears. Accelerations at points A3 and A4 which have symmetry show a similar result. But the accelerations at points A5 and A7 which have symmetry show a different result.

A bolt tension at a corner which has a short length is smaller than that at the corner which has a long length. The maximum bolt tension, 265 kN appears at bolt F4. An acceleration at point A10 which is near bolt F4 is smaller than that at point A5, point A6 and point A9 which are near bolts F2 and F3. The bolt tension is not in proportion with the acceleration.

FINITE ELEMENT ANALYSIS

Carbon steel was employed as the main structural material of the transport packages. The material properties of the carbon steel, the bolts and the waste drums inside are shown in Table 1. A plastic deformation for the carbon steel and the bolt was considered. A waste drum includes the drum and the radioactive waste. The density of the waste drum is assumed where the weight of the waste drum is 400kg.

A vertical drop for the type IP-2 transport package was considered. Due to the symmetry, a quarter of the model was sufficient enough for the vertical drop. The corner fittings were modeled by simplified. The model employed C3D8R (8-node linear brick, reduced integration with an hourglass control). The number of elements and nodes for the type IP-2 transport package were 45,629 and 68,416, respectively. ABAQUS/Explicit is used as a finite element code for this analysis. The initial velocity, 4,201.286 mm/sec, which was obtained by the height of the drop analysis, 0.9 m, and an acceleration of the gravity, 9,806 mm/sec2, were applied.

Fig. 3 shows the maximum Tresca stress curve for the body and the lid and the average Tresca stress for the bolt section. The Tresca stresses for the shielding materials are localized and large at the corners. The maximum Tresca stress at the body, 270 MPa appeared at the bottom which contacts with the square pipe column. And the maximum Tresca stress at the lid, 337MPa appeared near a corner bolt. The maximum Tresca stress, 337MPa is smaller than the tensile stress of the carbon steel so the shielding material is not failed. The average stress at the bolt, which is near the corner fitting, shows a low value and the average stress at the bolt which is near the center of the corner has a large value. The maximum of the average Tresca stresses at the sections with a bolt are 806.3 0MPa. They are smaller than the tensile stress of the bolts, 860 MPa so the bolts did not fail.

Fig. 4 shows the comparison between the analytic result and the test result. The strains at points S5 and S9 and the accelerations at points A3 and A4 are considered. The analytic maximum strain is 540 $\mu\varepsilon$, but the maximum test strains are 220 and 340 $\mu\varepsilon$. The analytic maximum acceleration at A3 is 340 g, and the test maximum acceleration is 250 g. The analytic results are larger than the test results. The inclined impact causes the difference in this value.[7]

CONCLUSION

The type IP-2 package undertook a vertical drop with a 0.9 height. An opening displacement of the lid and the torques of the lid bolts are changed before or after the drop impact of the type IP-2 package. A change of the gap between the body and lid, 0.76 mm is smaller than the step between the bottom and the flange on the lid. The height of a step, 6.17 mm is higher than the gap between the body and the lid obtained from a test and the bolts are not failed so there is no breach of the containment to cause any loss or dispersal of the radioactive contents due to the vertical drop test. Also the thicknesses of the shielding material are measured before or after the drop impact. The change of the thickness of the shielding material is insignificant so that a loss of the shielding integrity is negligible in terms of the overall shielding integrity. The acceleration, strain and the bolt tension are measured during a test. The accelerations and the strains measured from a test are compared with the results from a finite element analysis. The analytic results are larger than the test results. The inclined impact causes the difference in this value.

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Table I. Mechanical Properties used in the FEA

Mechanical properties	Carbon steel	The bolt	Waste drum
Density (ton/mm3)	7.89E-9	7.89E-9	1.1513E-9
Elastic modulus(MPa)	194,493	195,172	2E+7
Poisson's ratio	0.3	0.3	0.01
Yield stress(MPa)	257.109	206.9	-

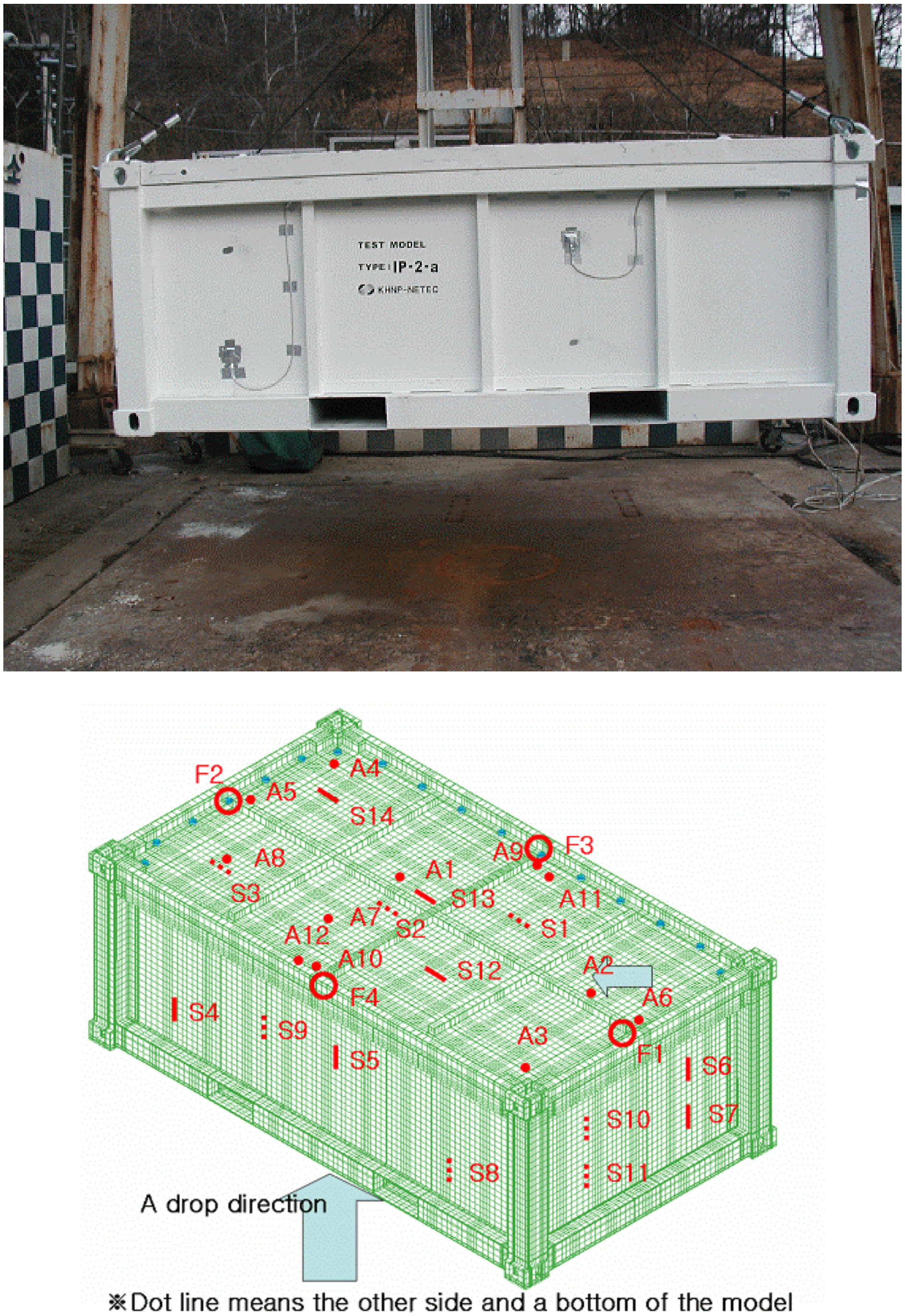
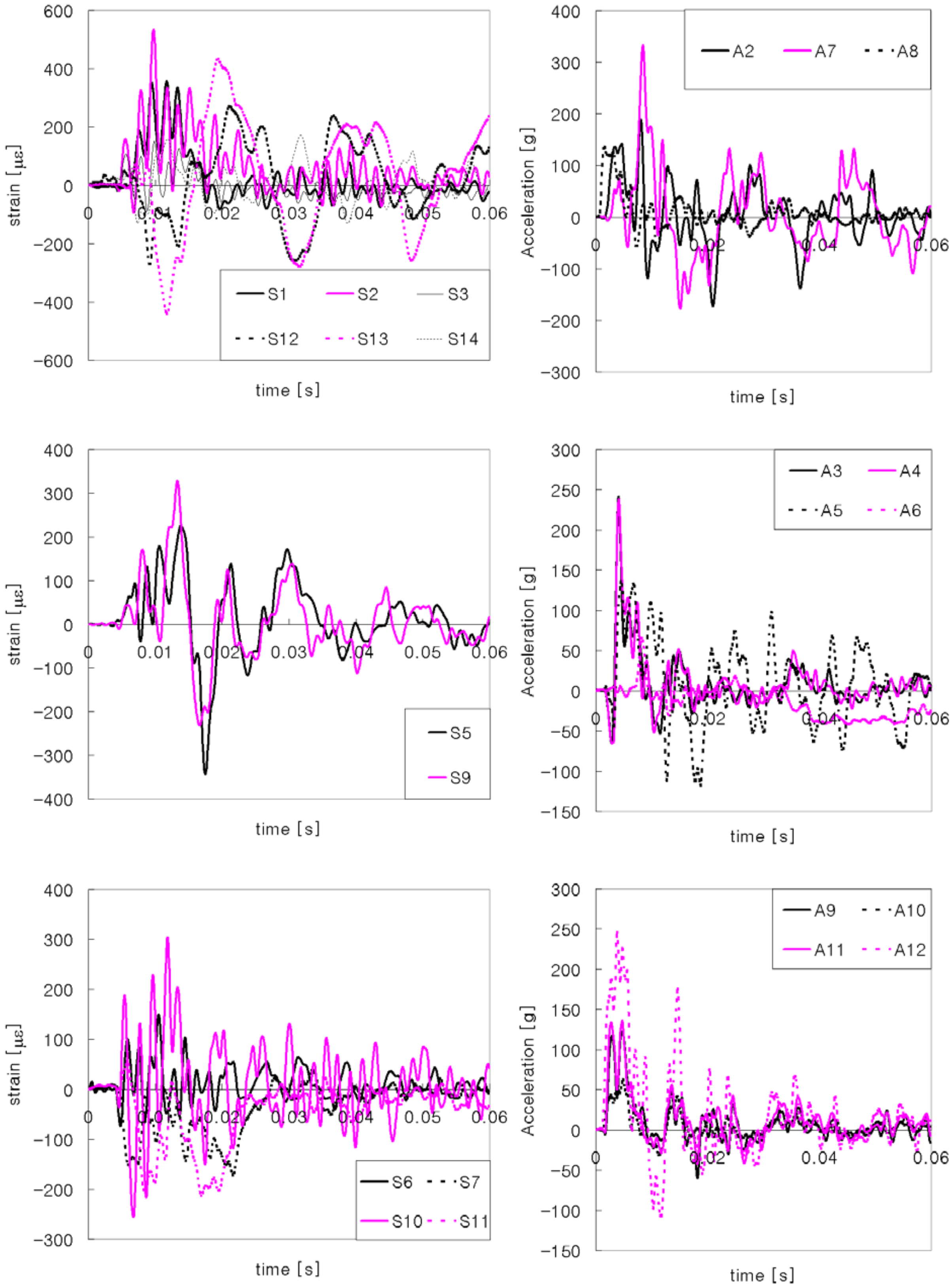
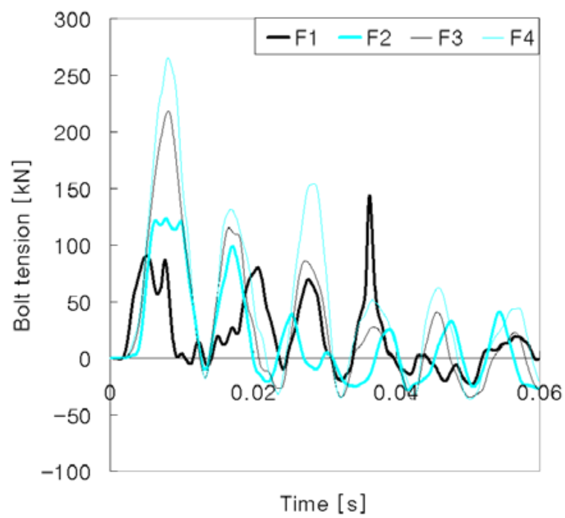


Fig. 1. The test model and the locations of the sensors



(a) Strains (b) Accelerations



(c) Bolt tensions

Fig. 2. Acquired data from the test. The data is filtered by a 600 Hz lowpass filtering by using LabVIEW

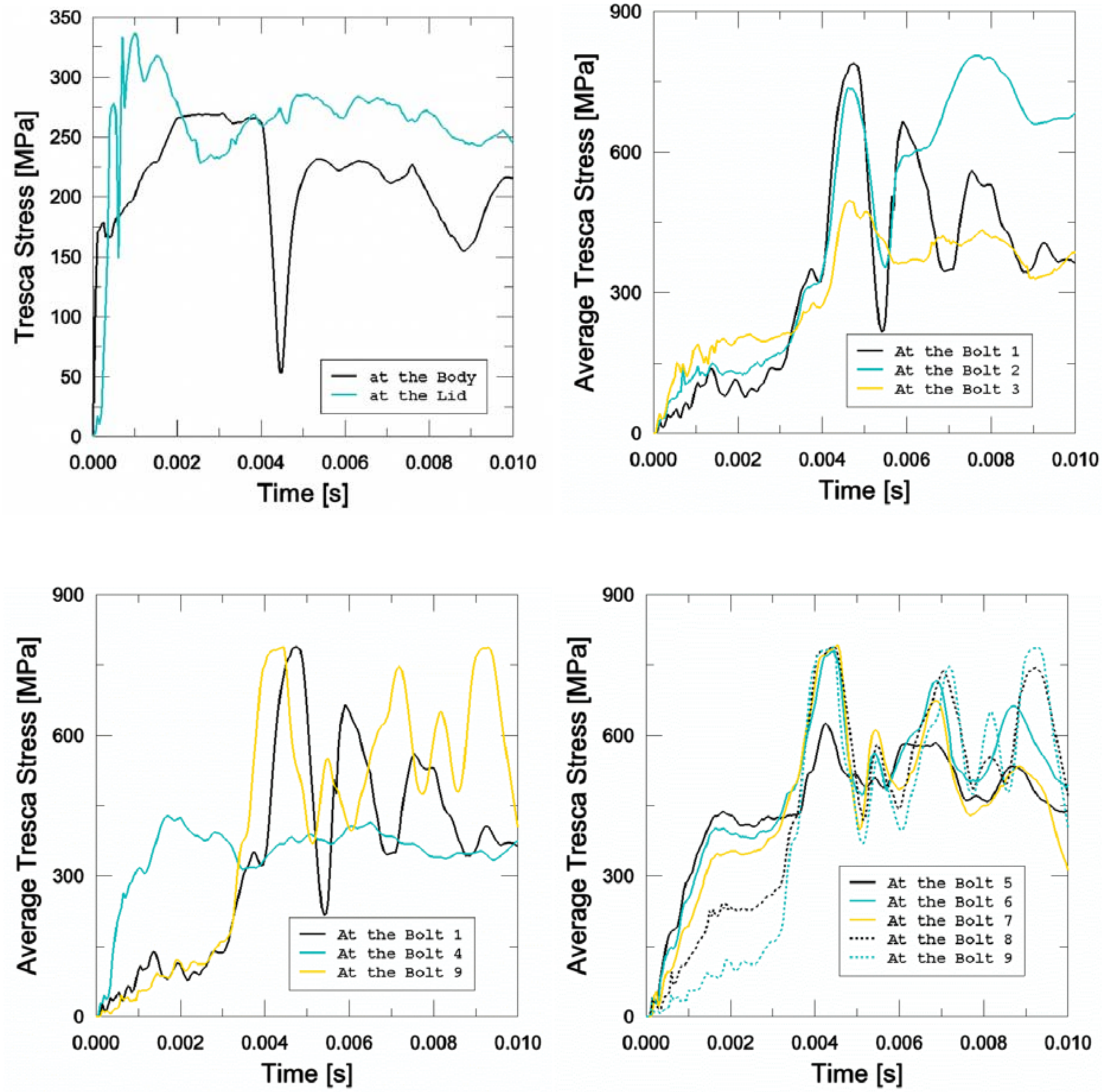


Fig. 3. The maximum Tresca stress of the body and the lid and the average Tresca stress at a section with bolts

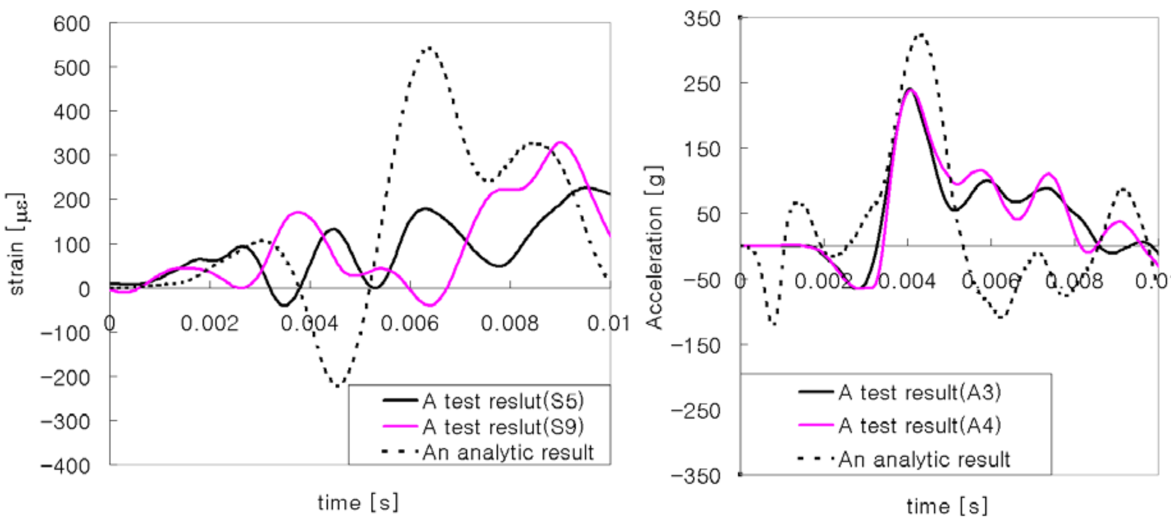


Fig. 4. The comparison between the test results and the analytic results