STUDTY OF BODY CONFIGURATION AND SUPERIOR OCCUPANT PROTECTION DURING ROLLOVER

Toshiaki Sakurai
Department of Mechanical Engineering, Iwaki Meisei University, Japan
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ABSTRACT

This paper describes reconstructions of rollovers involved in the initial velocity before accidents are very important and the body structures of automotive vehicles with some curved configurations that have the incontestable superiority for occupant protection in rollover accidents over plain square body structures. The oval configuration and the curved structure are recommended. Furthermore, in a rotational movement system, acceleration force, inertia force and rotational moment of the vehicle to dummy should be considered as input forces.

INTRIDUCTION

Researching the safer body structures for occupant protection during rollovers, main analyses are performed as indicated below:

1. Introducing the accident data reported by the Institute for Traffic Accident Research and Data Analysis in Japan regarding rollovers.
2. Discussing the deformation of body structures and the conditions of contact areas between the roof and the loading panel after testing according to the FMVSS No.216.
3. Considering occupant behavior in the cabin based on not only the equation of inertial motion but also the equation of motion including the Coriolis' force and the force of inertia.
4. Researching the influence of the initial distance between the occupant's heads and the roofs of vehicles before accidents, and the occupant survival space after accidents.

INTRODUCING ACCIDENTS DATA [1]

The accident data reported by the Institute for Traffic Accident Research and Data Analysis [ITARDA] in Japan regarding rollovers are introduced. The data was taken during 10 years from 1993 to 2003 in the Tsukuba area located north of Tokyo.

Results classified all the accidents into a single accident and a mutual accident of auto vehicles with four wheels.

The total numbers of accidents were 1965. Rollover accidents are about eleven (11) % among the total accidents. They also classified the trigger of rollover into three categories:

/From side slip to rollover
/Instability after riding on the banks
/Dropping

They reported on the velocity of vehicles before accidents of drivers that did not use the brakes. The rate of accidents in the higher velocity shows the high scores compared with the lower velocity. Also the rate of accidents of rollovers on highways is higher than that of standard roads.

The rate of rollover accidents of classified vehicles is shown in **Figure 1**. Light vehicles, sports utility vehicles (SUV) and cargo trucks occupied higher averages. The unbelted passengers face more danger compared with the belted passengers. Research was conducted to determine the impact point of the head to the car body of passengers not using seatbelts. They showed that the necks of passengers made contact with the roof interior during rollovers. There is no information of the relationship between roof strength and occupant injury.

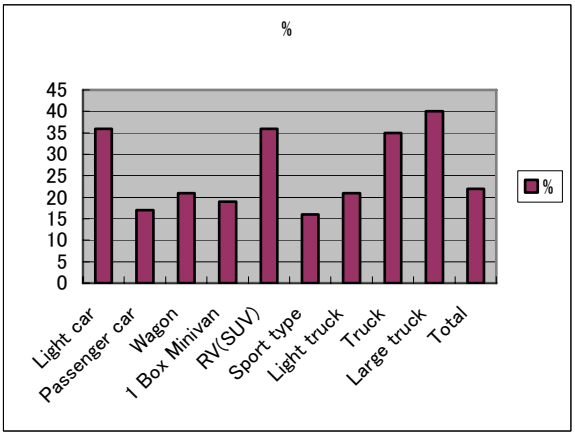


Figure 1. The relation of the rate of rollover accidents of classified vehicles

Investigation of the accident cases reconstructed with real accidents.

Case 1:

On a highway road, a belted driver turned the steering wheeled sharply when the vehicle encountered a strong side wind. The vehicle slipped to the side and after the vehicle rolled over with one turn. Two unbelted occupants seated in the rear seats were ejected and one suffered a fatal injury.

Recently, all passengers including rear occupants are required to fasten the seat belt in Japan and it is assumed that the ejections from vehicles will reduce during rollovers.

It is important in the actual accidents that the processes to rollover are clarified by considering the reconstruction.

FMVSS216, DROP TEST AND RAMP ROLLOVER TEST BY SAKURAI [2]

In 1991, T. Sakurai published a paper with tests results according to FMVSS 216, dummy drop test and ramp rollover test.

Figure 2 shows the schematic drawing of the body structures after tests carried out according to FMVSS216.

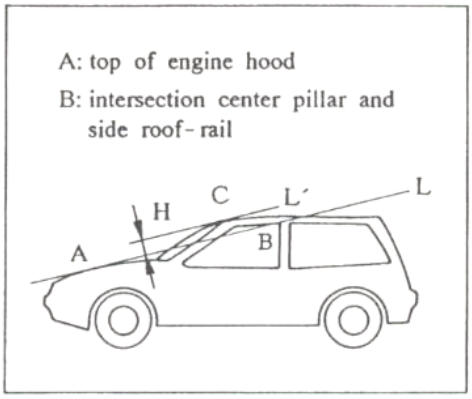


Figure 2. The schematic drawing of the body structures after tests according to FMVSS 216

In **Figure 2**, the line HL' shows the base line of the load plate and point C indicates the first contact point with the loading plate and the body structure before testing according to FMVSS 216. The line AL shows schematically the line of collapse of the body after testing. Point A indicates the position of the top of the engine hood and point B the intersection of the center pillar and the side roof rail.

We would like to design a body configuration along the Lines with the final body configuration after testing. Because of the curved roof configuration, contact areas are wider compared to the plain square ones as described later. As a result, the stress level becomes lower.

We performed the drop test with the inverted Hybrid Ⅲ dummy whole body drops and the ramp rollover tests. The relationship between the initial height of the drop tests and ramp rollover tests and the neck loads is shown in **Figure 3.**

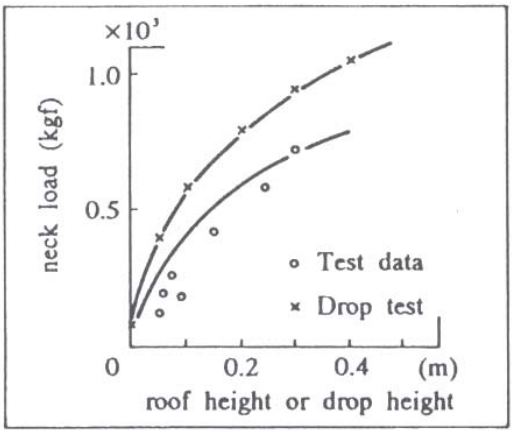


Figure 3. The relation between dummy neck load and the height of drop tests and the ramp rollover test.

As shown in **Figure 3**, the higher the height, the more the neck loads. Comparison of the loads, the loads of the ramp tests are lower to the drop test. The reasons why lower values are considered is that in the ramp rollover test dummy neck loads would be applied to not only the axial load but also bending load or twist loads.

The ramp rollover tests were performed.

Figure 4 shows the relationship between the neck load, roof deformation and time history.

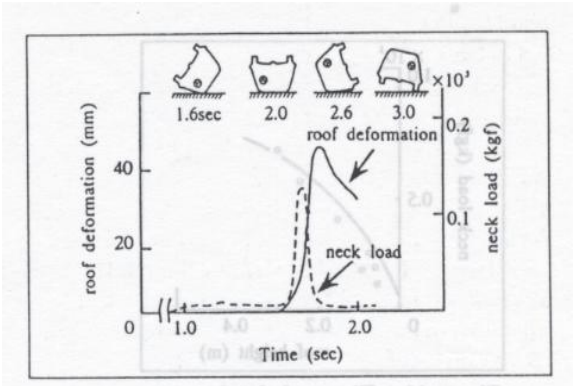


Figure 4 The relationship between the neck load, roof deformation and time history.

First, the neck would contact the side roof rail, and then the position of the roof located at the conjunction of the side and front roof rails and front pillar are formed and reaches the maximum roof deformation. When the maximum load of the dummy neck occurred, the roof deformation would still be deformed at the position less than 10mm. Important to note is that the dummy head and the deformed roof do not contact at the time of the roof's forming.

Here, summarized data referring the dolly test [3] is shown, **Figure 5** indicates the time, the neck load, and roof deformation.

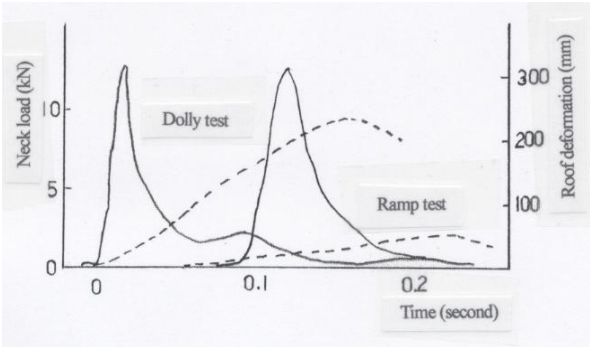


Figure 5. The time, dummy neck load, and the roof deformation

In ramp rollover tests, first, the dummy neck maximum load appears and next the maximum roof deformation occurs. The interval Δt of the two phenomena is about 0.1 second. By reading the maximum of neck load, the value shows about 1250N. The roof deformation at the point of maximum neck load is around 10mm. In dolly rollover tests, the same tendency occurs. The interval Δt is about 0.14 second. .

It is known that the human endurance is a higher value at the shorter duration time. By the reference of the Wayne State Tolerance Curve, the acceleration depends effectively on the duration times.

In the ramp test, duration time is very little and is very little in the dolly test.

BODY CONFIGURATION TO ROLLOVER

As shown in the previous **Figure 2**, we understand that bodies collapsed a certain configuration according to FMVSS216 test method. In the first design stage, a body configuration should be considered to be superior to rollover.

It is necessary to consider kinematics and plastic deformation of the body. There are many textbooks teaching these principles in the nature. We selected an egg. The egg has a dimension that the long axis is 46mm and short axis is 40mm, and thickness is 0.5 mm. One of the typical characteristics is that it transfers toward direction during rotation. We can explain the mechanism by using a formula and schematic figure.

Figure 6 shows the schematic feature of rotation and its kinematics formula (2). The configuration having a deviative elliptical oval configuration can change the direction in rotation.

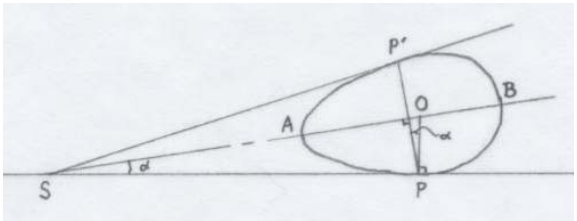


Figure 6. Rotation of egg feature

$$OP = SP \tan\alpha \qquad (1)$$

We try to make a deviative elliptical oval configuration by using the mathematical formula. It is found that the oval of Cassini curve is suitable for the mathematical expression in many formulae as shown in the formula.

$$r_1 r_2 = b^2 \qquad (2)$$

Figure 7 indicates Cassini Curves of oval configuration.

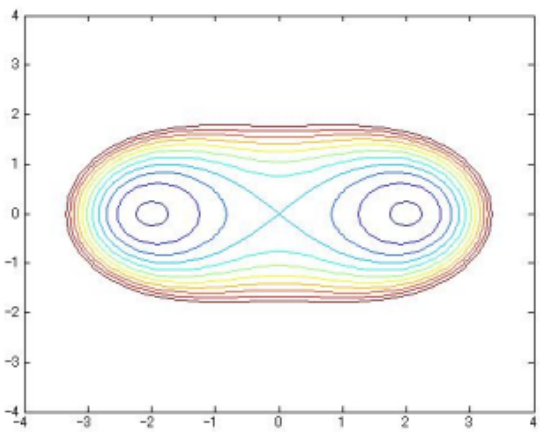


Figure 7. Cassini curves of oval configuration

By using the Computer Aided Design (CAD), we can identify an elliptical oval configuration of an egg as shown in **Figure 8**[4].

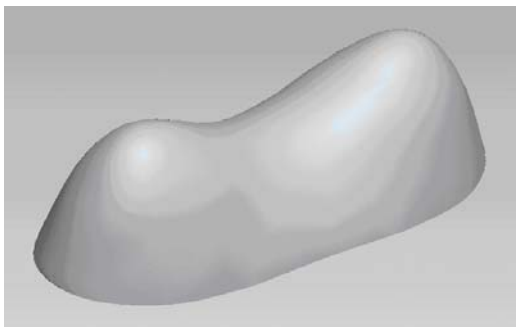


Figure 8. An expression according to Cassini curves shown in Figure 7 by using CAD

Figure 9 shows an identification of an elliptical oval configuration using CAD, not using free curves like B-spline function.

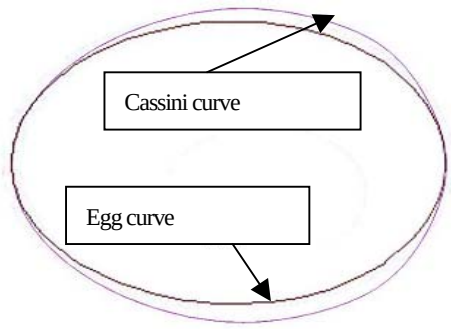
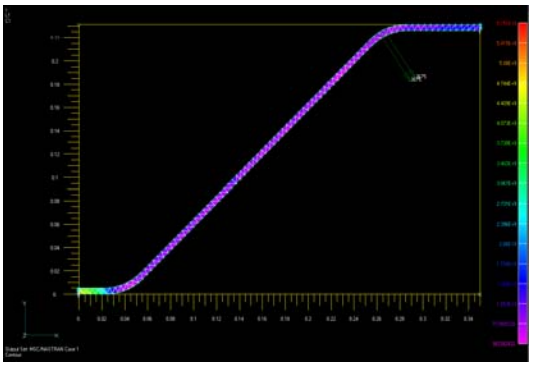


Figure 9. Identification of an elliptical oval configuration using CAD

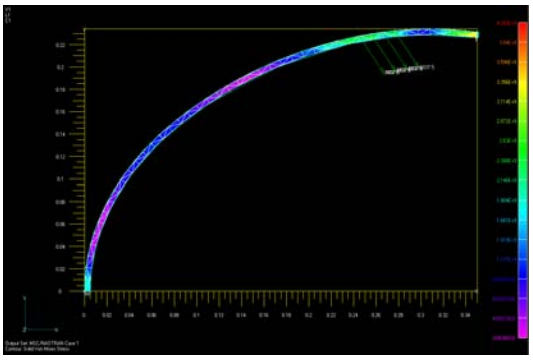
As an example, by using the Finite Element Method (FEM), we try to calculate stress analysis of frames that are constructed from the box and oval configurations. Calculation results shown in **Figure 10** are the same as mechanical conditions like dimensions, materials, and restraint conditions. As shown in **Figure 10**, the feature having an elliptical oval configuration has a constant stress distribution compared with the box type configuration.

The strength of the oval type frame is superior to that of the box type frame if the same mechanical conditions are used. From the point of contact fields, occupants contact with the body structures having curvatures to be a lower stress level.

The oval body structure as satisfied with the above effects will make it possible to decrease occupant injuries. But we have not yet confirmed these characteristics by using actual vehicles.



(A) Box type frame



(B) Oval type frame

Figure 10. Calculation results of box and oval type frames by using FEM

CONSIDERING OCCUPANT BEHAVIOR

As rollover phenomena of the occupant movements in the cabin are complicated, we must consider not only the deformation and the configuration of body but also kinematics motion. In rotational motion, the equation of motion (3) should be introduced into the accident analysis to correctly seek the precise solutions.

$$\frac{f}{m} = \frac{dV}{dt} + \left(\frac{dv'}{dt}\right)' + \left[\frac{d\omega}{dt} \times r'\right] + 2\left[\omega \times v'\right] + \left[\omega \times \left[\omega \times r'\right]\right] \qquad (3)$$

Here, $\frac{dV}{dt}, \left(\frac{dv'}{dt}\right)'$: Acceleration,

$\frac{d\omega}{dt} \times r'$: Inertia,

$2\left[\omega \times v'\right]$: Coriolis acceleration,

$\left[\omega \times \left[\omega \times r'\right]\right]$: Centripetal acceleration.,

(non-prime): the motion from the fixed coordinate systems,

(‘: prime): the motion from the motion coordinate systems.

In case of $d\omega/dt = 0$, $\left[\frac{d\omega}{dt} \times r'\right]$ is equal to zero and $2\left[\omega \times v'\right]$ is precisely called Coriolis Acceleration.

The motion as shown in formula (3) is considered as relative motion in the rotational system. We must assume the coordinate systems during rollover.

Again we think the occupant movement during rollover as shown in **Figure 5**. Here, a coordinate is defined as Cartesian coordinate system (x, y, z). X-axis is a direction of processing of vehicle by the right hand system clockwise.

In the ramp rollover test, the test vehicle goes to the ramp. When the right wheel of the vehicle reaches the ramp, the vehicle leans slightly toward the left side y-axis. The direction of both vehicle and dummy faces straight. The vehicle leans to the left direction and also the torso of dummy when the front wheel is swiftly compelled to turn to left in the center of x-axis (rolling). On the other hand, the head (neck) on the torso of dummy keeps moving straight ahead. The phenomenon raises the relative motion between the vehicle and the head (neck) of dummy. When the vehicle touches down on the ground rolling, head (neck) relatively rotating to the vehicle hits the side roof rail and soon the neck load reveals the maximum load. When the head hits these parts of the vehicle, the roof deformation reveals about 10mm and does not yet reach the maximum deformation when the neck reaches a maximum load. Progressively, 0.01second after, the roof deformation shows the maximum deformation, about 20mm far from the neck hit to the roof position. As for these phenomena, it does not seem that the strong relationship between the neck load and the roof deformation exists. By these phenomena, the relative motion of the dummy and the first impact to the vehicle body might become fatal injuries of the dummy.

From the point of relative motion, if the motion of the head (neck) of dummy is considered to be the fixed coordinate system, the motion of roof deformation is the motion from the motion system. On the contrary, if the roof deformation is looked upon as the fixed coordinate system, the head (neck) of dummy is the motion. It moves toward the roof and contacts the body structures. It looks like diving movements relatively.

PROPOSE RESEARCH AND TEST METHOD

In reports regarding real world rollover accidents, the relation between roof strength and injuries of the occupants is studied. When they inspected the body deformation collapse after rollover accidents, the roofs showed severer collapses and there were no survival spaces in the cabins. They proposed designing a stronger roof.

According to consideration of the ramp rollover test, we must investigate the phenomena of actual rollover accidents.

First, what is the initial velocity of vehicles before rolling?

Why happened to the rollover, and what triggers is it to roll?

The relative motion of occupants to the vehicle like acceleration force, inertia force, rotational moment occurs and the first impact of the head to the vehicle body occurs before producing larger collapses of roof and these factors might become fatal injuries of occupants.

When ultimately fatal injuries occur during rollover, where is its position in the vehicle body?

By considering these papers, we have to find evidence in order to request car makers to make countermeasures of body structures to prevent fatal injuries as follows:

1. Reconstructions of rollover accidents involved in the initial velocity
2. Considering roof configuration, deformation and rotational movement with the dummy
3. To make the dummy for rollover with the neck having measurements of axel force and bending load (tort ional load)
4. To make test procedure and methods reflecting the actual rollover accidents [5]
5. To evaluate not only the strength and intrusion of the roof but also deformation situations of the roof like sharp edges, folding patterns, etc.
6. To evaluate the survival space areas after collapse

CONCLUSIONS

Some results of our researches are summarized as follows:

1. It is very important to study reconstructions of rollover accidents involved in the initial velocity before accidents occur
2. The body configuration should be considered from point contact fields.
3. In rotational movements, acceleration force, inertia force, rotational moment should be considered as input forces.
4. In order to reduce fatal injuries in rollover accidents, some proposal items are recommended.

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