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Overview of Research of Rollovers

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Abstract: This paper describes the research of rollovers of passenger cars and proposes a ramp type test as a typical dynamic rollover test with evaluations of occupant injuries and vehicle deformation in accordance with various parametric functions. Many types of rollover tests have been conducted in the past and they have their merits and demerits. However, the ramp rollover test has a characteristic to evaluate both dummy injuries and vehicle deformations, and to perform tests under many conditions by exchanging ramp dimensions, steer timings made rotation and velocity of the vehicle.

Key words: Rollover, roof crush, dynamic ramp rollover test, FMVSS 216, crashworthiness, movement of passengers.

1. Introduction

This paper outlines the main research contents of passenger vehicle rollover that has been reported. The contents of this paper are the movement of the occupant in the vehicle, roof deformation, and movements of the vehicle, the mechanism rollover and rollover test. The newly updated roof crush standard FMVSS (Federal Motor Vehicle Safety Standards) 216 has been issued including the space for passengers after a crush test. However, this rule is a static test method, not a dynamic one. As the characteristic dynamic phenomenon does not appear in static phenomenon, differences occur between the final deformation of the roof deformation and the process in the rollover. Rotational motion occurs when the vehicle begins to roll beyond a certain value of the vehicle roll moment. Movements of the vehicle and of the passengers in the vehicle do not necessarily concur at this time. For this reason, the passengers' collision occurs with parts of the strength of the body and interior parts and passengers contact with each other. The case of rollover accident in the market reconstructed due to be beyond a certain value of the vehicle rolling moment. By analyzing typical rollover accidents, the mechanism of rollover is considered. Corresponding to these considerations, a dynamic test method is proposed called the ramp rollover test methods. The test method is advantageous compared to other experimental parameters, repeatability and cost.

Reduction of serious injuries due to rollover accidents is the responsibility of researchers and engineers. For the typical dynamic rollover test, a ramp type test is recommended as results of considerations about papers: (1) deformation of a roof under tests of FMVSS 216 shows the typical deformation; (2) from research of typical actual accidents, rollover mechanism is clear to understand; (3) the differences between the maximum deformation and the final deformation occur in dynamic phenomena; (4) in movement of vehicle, the rotation velocity, not only around the center of gravity but also around the instantaneous center, should be considered; (5) the dummy movement should consider the Coriolis' acceleration; (6) from various considerations, a ramp type test is recommended for the typical dynamic rollover method; (7) to design more safe body structures, making countermeasures would be requested.

2. Background

Papers on rollovers of the 1980s were based on the actual accidents and filed with discussion on the

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relationship between the ejection of passengers and their restraint or unrestraint of seat belt and accident investigation [1]. From the 1990s, there were many papers on the timing point of passengers to the strength part of body and maximum roof deformation [2, 3]. In addition, the first application of the roof to crush strength analysis by FEM (finite element method) can be seen [3, 4]. Recently, accident rollover injury mechanisms are discussed. The results of previous studies are summarized [5]. Not only static analysis but also dynamic analysis till leading to the rollover is introduced [6]. Body deformation and the behavior of the dummy are carried out [7-9]. There are also reports discussed from the theory of reinforcement of the roof structure. From basic tests to contact the roof to the dummy, some new static test methods have been proposed. This is the focus of how the accident investigation that is larger deformation is compared to the first contact point. A new test method that fixed point is changeable to rotate the loading plate and shear force loads on the roof of the components is introduced and also the dynamic analysis is introduced to calculate rollover phenomena by FEM as well as static analysis that has led to the behavior of the passengers further dynamic analysis [10]. The test method is introduced as a dynamic test [11]. Eventually, the roof crash test method is a secure space to reduce the amount of collapse, the value of the vehicle occupant injury. Recently, NHTSA (National Highway Traffic Safety Administration) issued a final ruling—the new FMVSS 216.

3. Rollover Phenomenon

3.1 Actual Rollover Accidents

Fig. 1 illustrates the typically actual rollover accident including the process leading to the rollover from the data of ITARDA (Institute for Traffic Accident Research and Data Analysis) [12]. This accident is one of the general road accidents only. The driver is a 60 year-old man driving a light car which has a constant velocity straight at 60 km/h on a lane road. He was driving with his head down and crossing the road into the other lane (A1, A2). He turned the steering wheel to the left suddenly and the vehicle was nearly out of control. The tire went on the right path (A3) and then the vehicle overturned with a rebound (A4, A5). From the event, the rollover mechanism would be considered.

Fig. 2 shows a rollover mechanism to rollover described above in rollover accident on the actual road. In the Stages A and B, when the steering wheel suddenly changes, the rolling with large roll rate occurs. At this time, the suspension of the outer wheel is in direct contact with the bump, and the sinking of the outer wheel becomes the maximum and it stops. In Stage C, outer suspension touches the bump and sinking phenomena of outer side stop. Inner wheel extends. In Stage D, the outer wheel raises, so-called bouncing. Grounding load is reduced by this outer wheel and reduction of the tire side force occurs, i.e., an increase in vehicle body slip angle. In Stage E, when outer wheel sinks, an exceeding side force occurs. As a result, roll moment increases. In Stage F, as a result, the roll moment is increased, leading to that the rollover exceeds the limit value of roll moment. The accident case is a typical example of the mechanism suggested exactly. It is found that there are many various factors to rotate vehicles.

3.2 Final Deformation and Maximum Deformation of the Vehicle

The author has conducted a static test in accordance with the rules of FMVSS 216. Vehicle deformation in

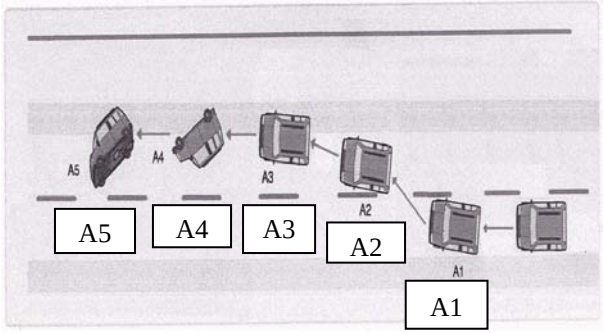

Fig. 1 Rollover accident on the actual road.

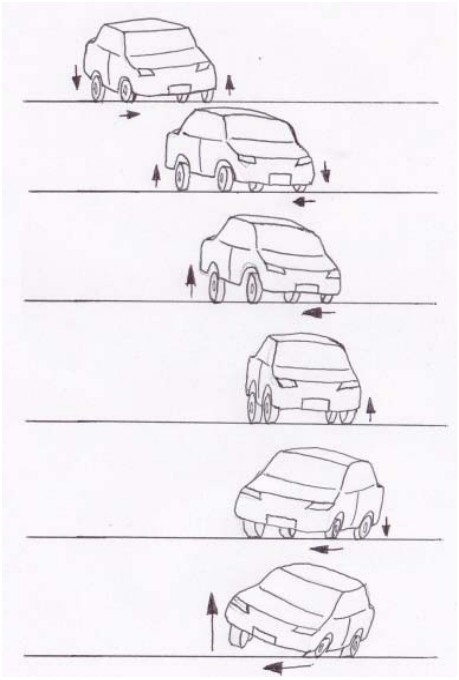

Fig. 2 One of the rollover mechanisms of vehicle.
A: rolling with large roll rate occurs;
B: rolling with large roll rate occurs;
C: outer suspension touches to the bump and sinking phenomena of outer side stops and inner wheel extends;
D: outer wheel extends to upper;
E: when outer wheel sinks, exceeding side force occurs. As a result, roll moment increases;
F: when roll moment exceeds the criteria of rollover, the vehicle begins to roll;
Here, capital letters (A~F) show the rollover phenomena at the each stage.

most vehicles discovered that the vehicle is destroyed by the line connecting the center pillar and header front tip (the tip of the engine hood) from the results of these reported [3]. In addition, a reasonable shape to rollover resistance has proposed a reaction force structure. By considering the structural strength of this breakdown reaction force from the shape, surface contact is reasonable from the contact point [8]. Concrete structure looks like an egg shape. There are also some reports that a large amount of deformation of the vehicle happened at the point of first contact with the ground. And the amount of deformation is the deformation of the roof due to measurement of the final deformation. Though roof deformations and the dummy motion during the crash of the roof are as important, only the final roof deformations have been noticeable. Both amount of deformation and processing deformation including the final amount of deformation in the roof crash should be focused. There are few reports about the relationship between the amount of deformation and maximum deformation amount in the final crash. Characteristic of material under deformation has a buckling, i.e., spring back. From the experience of crash tests by auto makers, the final deformation after the collision is not always equal to the amount of maximum deformation. That is a different meaning between the maximum deformation and the final amount of deformation. The reason for this is to be considered by two factors: one is due to the material and the other is due to the inertia force and structure in the dynamic behavior. The former deformation in plastic working is represented by the spring back. The latter impact load is applied to the structure and, in the process of dynamic deformation due to inertial force, excessive deformation structure but temporarily, things will be unloading and returned to a stable deformation of the loading. The final deformation amount does not represent the maximum amount of deformation in this way. The FMVSS 216 regulations on the amount of deformation are due to the final static test, not a regulation of maximum deformation. Buckling does not take into account the deformation process, dynamic spring back of the material. As discussed previously, if the time is close to the maximum amount of deformation behavior, the dummy roof would result in severe damage. Deformation of the roof should be discussed from the theory of vehicle shape and structural strength.

3.3 Movement of the Dummy inside the Vehicle

A considerable complexity of movement of the dummy has been reported in rollovers. Interference with the dummy to various parts occurs. For example, they are interiors such as seats and steering handles, structures such as roof and pillars, and occupants hit

each other. Dummy behavior must be a complex movement, also dependent to the seat position. To consider the events of the movement like those described above, it cannot be analyzed in the same coordinate system. Coordinate system will also require authors to propose [7]. Also, movement of the neck of the dummy compared to that of the human body deformation is more difficult. In the rollover test, the dummy in the vehicle should be equipped to measure dummy in injury value.

Even though "the rotation center" of body under rolling is the center of the body, "the instantaneous center" is not always the center of the body. In the case, the instantaneous center may differ from the center of rotation of the vehicle. It is understood that the velocity of each seating position of the dummy is dependent on their seat position.

Fig. 3 shows that the difference between the center of gravity and the instantaneous center affects the dummy accretion. The sign ☮ is the center of gravity of vehicle and sign ⊙ is the position of dummy head. Here, the definition of an instanteneous center is the point of the instant rotation center. Velocity of rotation center is basicaly with the center of gravity of the vehicle. Angular velocity of the center of the gravity of vehicle is ω. Fig. 3a indicates an initial position before rollover. The direction of rotation is the C.W (clock wise). Fig. 3b indicates the roof contact to grand firstly. The rotation center is the C.G (cenre of gravity) of vehicle and instanteneoue center. I.C is a point contact with the ground. In this case, the velocity of the C.G is larger than that of the dummuy position from the instanteneous center. Here, the velocity of the dummy is the similarity rule in geometry. Fig. 3c shows the one cycle rotation of the vehicle and the contact with tires to the ground. In this case, the head velocity of dummy is larger than that of the C.G. As shown in Fig. 3, the dummy angular velocity should be considered not ony around the center of gravity but also around the instanteneous center. Also, two kinds of accelerations occur on the head of dummy by rotation motion as indicated before in Ref. [7]. One is an angular acceleration and the other is Cariolis acceleration. When the vehicle rotates around the rotate axis with the rotate radius r and changes from r to $r + dr$ in a short time dt, acceleration α_1 occurs. When angular of the processing velocity changes from θ to $\theta + d\theta$ to the processing direction in a short time dt, acceleration α_2 occurs. Resultant of Cariolis acceleration becomes $\alpha_c = \alpha_1 + \alpha_2$.

Thus, complex velocity and acceleration occur on the dummy head.

4. A Dynamic Rollover Test Method Proposed

From the actual accident data and the mechanical analysis based on the actual rollover accidents, a variety of test methods of dynamic rollover with certain features have been proposed. In this revision of FMVSS 216, the dynamic test has not been included. Test method is described above from the mechanisms of the above rollover accident cases and can be proposed. Considering such events, a number of test methods have been proposed and "ramp test rollovers" have been selected which are shown in Fig. 4

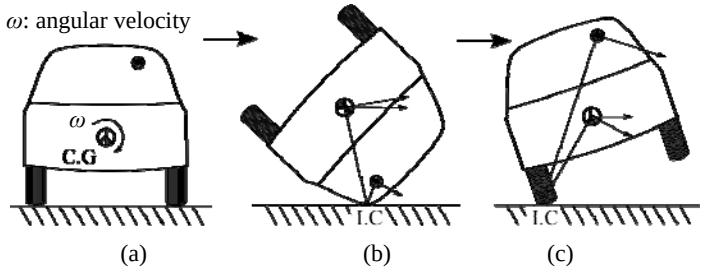

Fig. 3 Difference of velocity of dummy head around the center of gravity and the instantaneous center: (a) initial position; (b) during rollover; (c) after rotation.

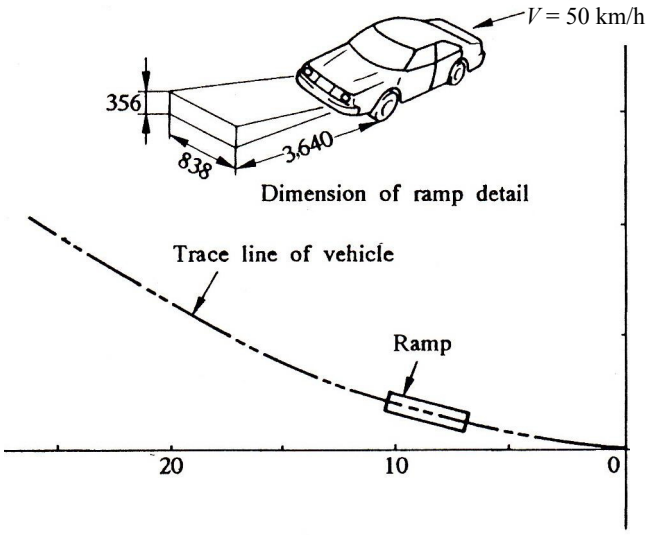

Fig. 4 Schematic ramp rollover test [3].

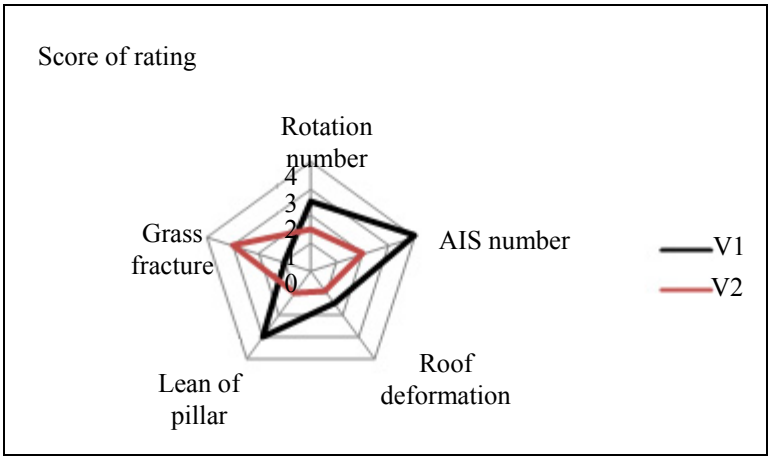

Fig. 5 Score of the rating of ramp rollover tests.

[3]. As shown in Fig. 4, after a vehicle processes along straight line, the front wheel of one side raises on the ramp and the control unit applies to steer the wheels on the opposite side at some point. Parameters such as vehicle velocity, height and length of the ramp, timing of rolling by the abrupt steering are selected in this test method according to actual accidents. Vehicle control is easy as an operator, or evaluation of test results collected by the camera situation, the rotational speed of the vehicle body, the amount of collapse of the body deformation, dummy injury values and behavior by the camera. It is difficult for rollover tests to cover all typical rollover accidents. The test can be simulated by the typical actual rollover accidents. Crashworthiness of vehicles and injuries criteria of dummy also can be evaluated and test results are indicated by the rating scores shown in Fig. 5.

5. Conclusions

From considerations of papers, it is necessary to make countermeasure to decrease serious accidents in rollover accidents. Seat belt was able to significantly prevent ejection of passengers. To prevent ejection from vehicles is to adopt a lamination of glass door. As the passengers escape from three-point seat belt during rotation in the vehicle to a certain direction, there is a possibility of contact with roof. From results of the reverse test of dummy, energy-absorbing parts should be installed to the energy absorbing structure effectively. Some reports say that improving the

structure of the roof rail should avoid the open cross section such as the structure and box, and it is desirable to be close to the cross section. In order to decrease the deflection of the roof, to increase the strength of the lower front pillar is effective. However, holes in the roof rail are required when using the spot welding in case of the unitized body. Structures having a cross section close to each other with spot welding are difficult to design and produce. Buckling deformation of the body structure, taking into account the elastic buckling phenomenon or recovery, in the static test should be evaluated as the final displacement. If they want to evaluate static final displacement only, affection of retuned deformation should be considered. Therefore, the dynamic test should be performed. The dynamic tests can be evaluated with maximum deformation during the deformation process. The test method is desirable to simulate a rollover accident on the market. Test method to simulate this situation is suitable for the ramp rollover test. By various shapes of ramps, velocity can change conditions. The experimental parameters are possible to exchange. In evaluations, the vehicle state such as position of the center of gravity affects the rotation number. Rotation velocity of vehicles relates to the dummy injury and amount of maximum deformation of structures. The reproducibility of the test is also important. A ramp method does not need so much large investment and cost. The NCAP (New Car Assessment Program) as a new rollover test should be performed evaluating the basic dynamic characteristic of vehicles.

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