EFFECT OF TUMBLE-HOME ON ROOF STRENGTH OF A VEHICLE

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ABSTRACT—This study reports on the effect of vehicle tumble-home (side body inclination) on roof strength. The steep inclination of the side body of a vehicle increases its roof strength. Comprehensive analysis of the impact of high roof strength driven by the steep inclination on dynamic roof strength in rollover is described. Here, we have developed a numerical model using the ADAMS, which is capable of characterizing both of the static and the dynamic roof strength. According to the FMVSS 216 protocol, we achieve the strength to weight ratio (SWR; static roof strength) by applying loading plates to the roof of a vehicle. The Controlled Rollover Impact System (CRIS) allows us to quantitatively characterize the displacements of the top end of A-pillar and B-pillar, thus determining the dynamic roof strength by comparing the results. We demonstrated that the roof intrusion was one of the most critical causes which lead to injuries of occupants fastening seat belts. Our analysis revealed that the increase of the side body inclination of vehicles enhanced the static roof strength whereas it could not reduce the roof displacement (intrusion) in the dynamic rollover.

KEY WORDS: Static roof strength, Tumble-home (inclination of side body), Dynamic rollover test (CRIS; Controlled Rollover Impact System), NHTSA (National Highway Traffic Safety Administration), IIHS (Insurance Institute for Highway Safety)

1. INTRODUCTION

The rollover accidents have occurred over several decades with high fatalities all over the world. Korea is still ranked high among the OECD countries in terms of the mortality rate by traffic accidents although the traffic death toll has been reduced significantly. The number of vehicles and the number of traffic accidents have increased simultaneously along with the rise in national income. Especially, it is well known that the safety ignorance of vehicle drivers results in the increase of the traffic accidents.

As shown in Figure 1, a single vehicle collision such as rollover crash and run-off-road collision has a much higher fatality rate compared to other types of accidents (Korea National Police Agency, 2011). The rate of single-vehicle accidents in Europe and Korea is 25% and 4.6% in total, respectively. However, the results, shown in Figure 2, verify that the rate of fatal injuries by these accidents in Europe is 37%, twice as high as in Korea (19.8%), relatively, compared to the discrepancy in the aforementioned result (European Commission, 2008; UNECE, 2007).

In the U.S., the fatalities caused by rollovers are as high as 35% of those among all the traffic accidents while the proportion of rollovers is remarkably small, less than 3% in total (NHTSA, 2007). For this reason, the electronic stability control (ESC, FMVSS 126) devices are required to be installed in all vehicles by the regulation of the NHTSA. Also, the enhanced requirements for roof strength, which is given in the FMVSS 216a, are mandatory. The new regulation (FMVSS 226) with respect to restraining devices, which enable reducing the driver and passenger ejection during rollovers, will be effective from 2014. Furthermore, IIHS requires a new roof strength rating system which includes much more strict standards than those of NHSTA (2010). (http://www.iihs.org)

In order to satisfy such requirements for stronger roofs, consequently, automakers have developed several production

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technologies which include the use of materials with greater reinforced strength, the optimization of the cross sectional geometry for enhanced strength, and the increase of the side body inclination.

In this article, we investigate the effect of the current method increasing the side body inclination on the enhancement of the static roof strength and the roof displacement during a dynamic roof strength test.

2. ROOF CRUSH RESISTANCE TEST

2.1. Static Test for Roof Crush Resistance

In North America, the FMVSS 216a of the NHTSA and the roof strength test of the IIHS are commonly used to characterize the roof crush resistance. Both testing methods are capable of estimating the vehicle body strength that plays a key role to achieve the adequate space for survival in rollover accidents. On the basis of the FMVSS 216a, the contact between the dummy head and the roof is not allowed under the condition that a load, three times heavier than the standard kerb weight (SWR 3.0), is sequentially applied to the left side and the right side of a vehicle (Figure 4). In the IIHS roof strength test, a loading plate with the pitch angle of 5˚ and the roll angle of 25˚ is applied to the roof in the driver’s seat until it moves inside by the distance of 127 mm (5 inches). The SWR value is calculated by dividing the maximum load during the test by the unloaded kerb weight. The IIHS determines the appropriate grade to evaluate the roof strength of a vehicle. The detailed requirements of the both test methods are given in Table 1 (NHTSA, 2010). (http://www.iihs.org)

The intensified regulations on the roof strength of the SWR of 4.0 are required for the IIHS in comparison to the requirement of the SWR of 3.0 for the NHTSA. For this reason, the upper bodies with the SWR of 4.0 have been applied to the most recently developed vehicles. In addition, the side inclination close to 90˚, which results in the roof strength of the SWR of 7.2, has been applied to vehicles with boxy styles. These trends demonstrate the side inclination is a critical design factor for the roof strength.

2.2. Test Procedure of Dynamic Vehicle Safety

The dynamic tests generate continuous collisions between the vehicle body and the ground, thereby leading to the low repeatability and reproducibility in the results. Although numerous studies on dynamic vehicle safety have appeared, a standard testing method for dynamic rollover protection

Table 1. List of requirements in FMVSS 216a and IIHS.

<table>
<thead>
<tr>
<th>Performance measurement</th>
<th>FMVSS</th>
<th>IIHS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SWR based on Unloaded Vehicle Weight</td>
<td>SWR based on Curb Weight</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>216</td>
<td>216a</td>
</tr>
<tr>
<td>GVWR ≤ 2772</td>
<td>SWR ≥ 1.5</td>
<td>SWR ≥ 3.0</td>
</tr>
<tr>
<td>2772 &lt; GVWR ≤ 4536</td>
<td>none</td>
<td>SWR ≥ 1.5</td>
</tr>
<tr>
<td>4536 &lt; GVWR</td>
<td>none</td>
<td>none</td>
</tr>
<tr>
<td>Test side</td>
<td>1 side</td>
<td>2 side</td>
</tr>
</tbody>
</table>

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