SHORT COMMUNICATION
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Development of Multiple Crash Events to Understand Occupant Behavior and Injury Based on Real-World Accidents

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ABSTRACT – Approximately a quarter of automobile accidents in the United States involve multiple impacts, but no standard test methodologies exist for the evaluation of these types of events. In this study, four categories were used for the selection of multiple crash scenarios, resulting in ten representatives of multiple scenarios. NASS-CDS was analyzed to determine the types and percentages of multiple crash accidents. Simulation was conducted with variable such as initial velocity of each vehicle, and items such as overlap and angle between vehicles. And it was used determine the final test conditions. The review of the test results, indicated different vehicle dynamics, vehicle damage and occupant kinematics compared with NCAP test modes. This data can be helpful to understand how the severe accidents are happening and how the occupants move and are injured inside the vehicle in which accidents are occurring in the field.

INTRODUCTION

Multiple impact crashes occurred in more than 30% of incidents in the United States from 2000 to 2012. In multiple impact accidents, occupant injuries were more severe than in single impact crashes [ref]. Digges and Bahouth (2003) showed that the MAIS3+ injury rate of multiple impact crashes was more than twice compared to that of single impact crashes [ref]. Here, the rate means the number of people with MAIS3+ injuries per 100 exposed to each crash mode. This finding highlights the need to understand what occurs inside and outside the vehicle during these multiple impact events. The purpose of the current study was to develop a multiple crash test method for multiple impact crashes to aid the improvement of crashworthiness of vehicles and protection of occupant restraint systems so that we can better protect occupants during such crashes.

Table.1: Single vs. Multiple Impact; by Number of Crashes, MAIS 3+ Injuries, and MAIS3+Injury Rate per 100 Exposed [ref]

Crash Mode	People %	MAIS 3+ %	Rate
Single Impact Crashes	76%	58%	1.74
Multiple Impact Crashes	24%	42%	4.03

METHODS

The current study consisted of four steps; selection of multiple crash scenarios, analysis of real world accident data, simulation of candidate multiple crash test modes, and test methodology development. In the first step, four categories were created to evaluate multiple crash scenarios, resulting in ten candidates. In the second step, the candidate scenarios were compared with NASS-CDS from 2000 to 2012. In the next step, simulation was conducted to determine the proper test parameters. In the last step, the actual car to car multiple crash test was performed. Finally, a methodology was developed to reconstruct the multiple crash accident.

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1. Selection of the candidate scenarios

Fig.1 shows four categories for the selection of multiple crash scenarios such as crash mode, crash categories, PDOF and overlap. The combination of frontal and side crash created four different multiple crash modes. Rollover events were not considered for multiple crash modes in the current study. Crash categories include a movable obstacle such as a vehicle and a fixed obstacle such as poles, guardrail and rigid wall. Pedestrian, bicycle, motorcycle, animal and curb were not included in the crash categories because they are not typically severe enough to activate passive safety devices. In terms of PDOF, four total conditions were used for each frontal and side crash such as Flat, Low Angle, High Angle and Sweep. Finally, the Overlap category followed the definition of NASS-CDS.

Ten candidate scenarios were selected from hundreds of multiple crash scenarios. After reviewing the possibility of the multiple events in hundreds of the combination of four categories, the cases of low possibility were removed from the final scenarios. Finally, the cases of combination that have the categories of high approach angle, sweep and narrow overlap became ten candidate scenarios.

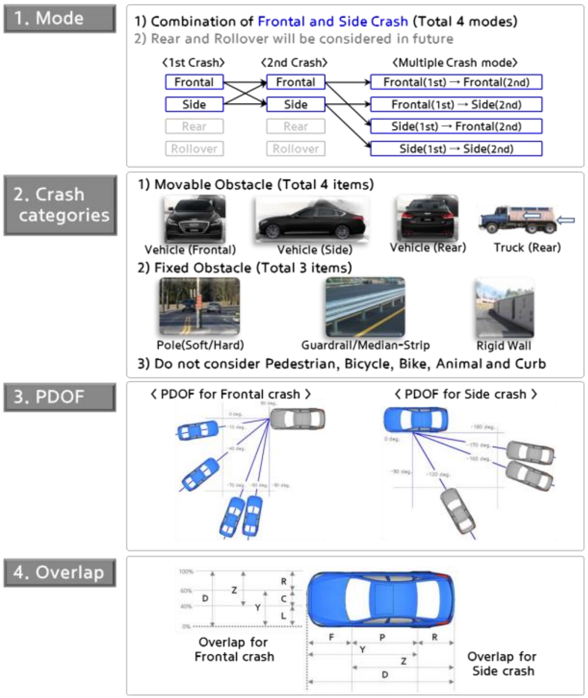

Fig.1 Four Categories for the Selection of Multiple Crash Scenarios

2. Analysis of NASS-CDS

NASS-CDS from years 2000 to 2012 was analyzed to figure out the portion of the types of multiple crash accidents. The number of multiple crashes is 28,228 while the total overall number of all accidents was 55,997 (Fig.2). The portion of multiple crash accidents was approximately 30% after it was applied to Ratio Inflation Factor (RIF). These cases were filtered so that only the cases with the airbag deployments (6,916 cases) were included. Lastly, cases with crash categories as vehicle, pole, guardrail, or rigid wall were only considered, and this filter left 3,833 cases. Crash categories such as pedestrian, bicycle, motorcycle, animal and curb were not considered in making the scenario representatives. In addition, duplicated cases in the same accident, the case without information on the airbag deployment, and conditions with more than three impacts were removed. After reviewing the occurrence rate of four modes, which means the combination of frontal and side impact crash modes (Fig.1), in the 3,833 interested cases, the frontal crash as the first event and followed by the side impact crash was the most common multiple impact crash modes, which accounted 35% out of 3,833 cases. In terms of the crash category, vehicles accounted for 79% of the 3,833 cases. Next, each target case was compared with the possibility matrix of multiple events. Each multiple event that is defined by the combination of four categories has a number of actual accidents in the field. From this comparison the top ten multiple crash scenarios that were derived from actual accidents, which were very similar to ten candidate scenarios. There are some limitations for comparing PDOF directly with vehicle approach angle and deformation location with overlap.

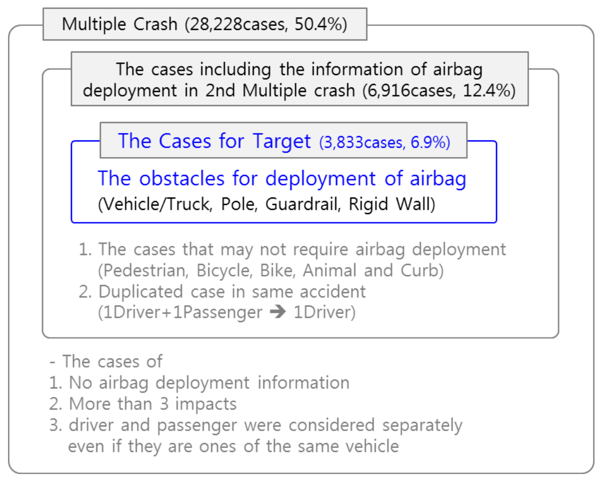

Fig.2 The portion of multiple crashes from NASS-CDS (Total 55,997cases, 2000~2012)

3. Car to Car Simulation

In order to select the target test condition for the reconstruction of the multiple crashes, extensive car to car simulations were conducted with variable such as initial velocity of each vehicle, and items such as overlap and angle between vehicles. Fig.3 shows the car to car simulation. In this simulation, we used multiple vehicles. Reviewing each target vehicle deformation, direction and velocity after the first impact, the final test conditions were determined.

Fig.3 Car to car simulation to select test condition (vehicle behavior)

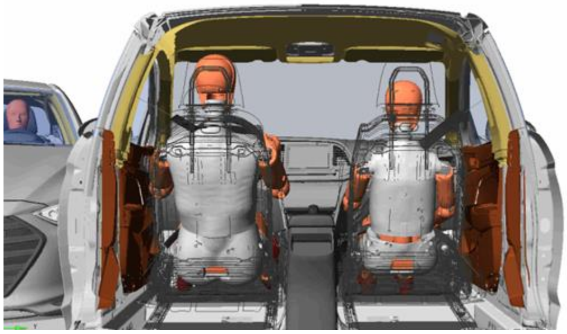

Fig.4 Car to car simulation to select test condition (occupant movement)

Fig.4 shows occupant movement during the whole crash event. The worst case position and timing for deploying restraint system was estimated by monitoring the simulated occupant movement.

4. Car to Car Testing

Fig.5 shows one of the car to car multiple impact crash tests involving multiple vehicles approaching at different angles at different velocities. A traditional crash test towing system and steering robot system were employed for pulling each vehicle at different directions and velocities. Target impact point, impact angle and the delay time between the first impact and the second impact were determined by simulation.

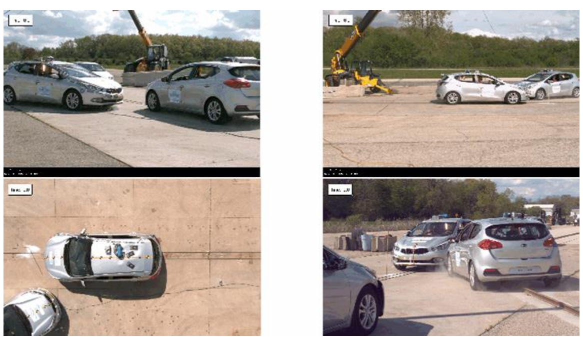

Fig.5 Car to car multiple impact crash test involving multiple vehicles

The research test was also performed to evaluate the pulse difference between an undamaged vehicle and damaged vehicle (Fig.6). Vehicle development testing typically performs a full-frontal crash test to the rigid barrier with an undamaged vehicle. The same test was conducted by using the vehicle that had been damaged in the oblique test. The deformation and the pulse of the vehicles are quite different in both single and multiple crash tests.

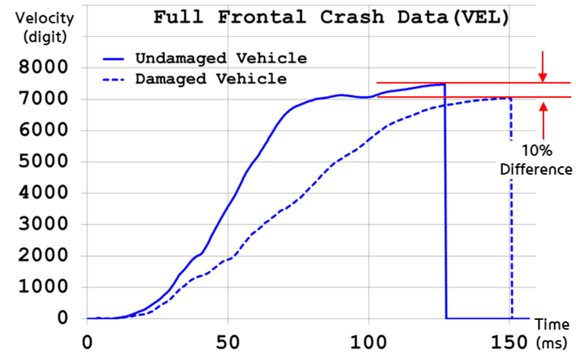

Fig.6 Comparison of vehicle velocity between the undamaged and damaged vehicle during the crash

RESULTS

Some of the multiple crash scenarios were reconstructed as expected. Fig.7 shows, over the centerline crash, one of the multiple crash scenarios that was developed in this study. In this scenario Vehicle 1 passes over the centerline and then impacts Vehicle 2, which is traveling in the opposite lane, and then impacts Vehicle 3, which is trailing Vehicle 2. Vehicle 1 has the first frontal oblique car to car crash mode and the second frontal offset car to car crash mode. Vehicle 2 has the first left side crash and the second right side crash to the deformable pole on the road side. Vehicle 3 has the single frontal offset-oblique crash like the proposed New NCAP.

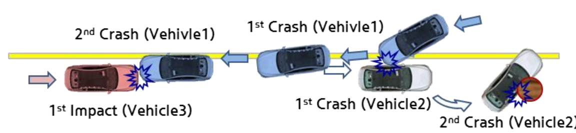

Fig.7 Multiple Crash scenario – Over the centerline crash

DISCUSSION

In the reconstruction test of multiple crashes, the occupant moved from “in position” to “out of position” after the first impact. Fig.8 shows that the movement of dummies sitting on the driver side and passenger side in Vehicle 2 during the multiple crash events. In this case, the occupant on the passenger seat moved to left-hand A-pillar at the first left-hand oblique car to car side impact. And then both dummies moved to the opposite side right after the second impact on the right side front door from the pole. Finally, it was occurred to impact to each other between both dummies due to “out of position”. In this case, shoulder belt was removed from the thorax right after the first impact. Therefore, they cannot be back “in position” before the second impact. So, it is necessary to develop a new countermeasure or decide the proper timing of deploying the current restraint system.

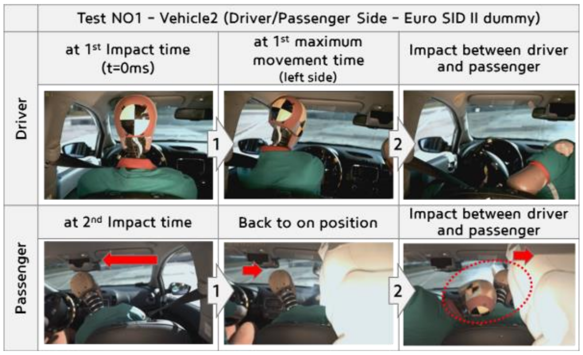

Fig.8 The movement of Euro SIDII dummy during the multiple events – Over the centerline crash test

Fig.9 and Fig.10 show the difference of occupant movement between THOR and Hybrid III during the multiple crash events. The movement of upper body of THOR was followed the shape of circle to the counter clockwise direction on the driver seat during the whole event. But one of Hybrid III drew the line from the point of on-position to the point of A-Pillar. Especially, the impact of the head of THOR to the steering wheel and B-pillar was easier than one of Hybrid III after the second crash. In the test of reconstructing field accident, vehicles deflect into different direction and rotate after the initial impact. The occupants in these vehicles can also deflect after the initial impact. Biofidelity is important for understanding the behavior and the injury of human occupant in the field accident, and will be vital in the next step for the safety, including autonomous vehicle safety in the future.

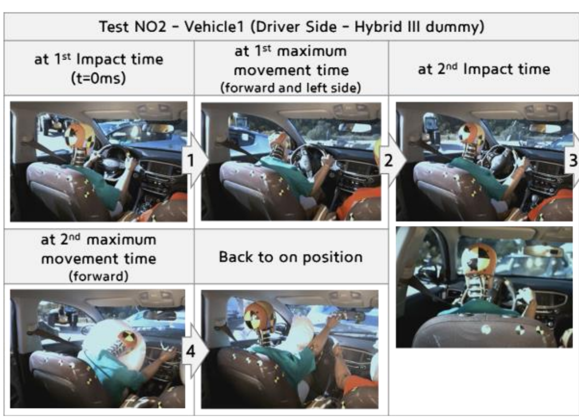

Fig.9 The movement of Hybrid III dummy during the multiple events – Over the centerline crash test

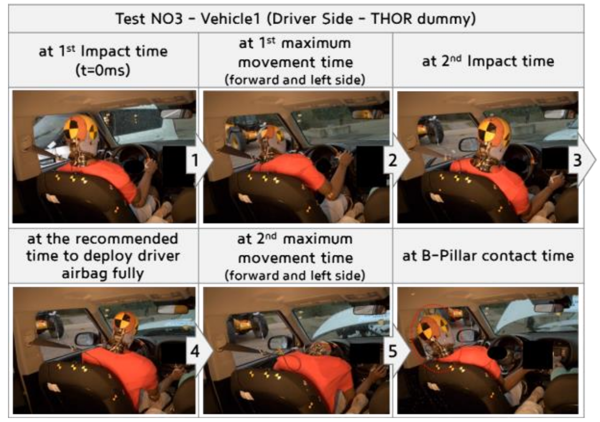

Fig.10 The movement of THOR dummy during the multiple events – Over the centerline crash test

CONCLUSION

In the field, there are approximately 30% multiple crash accident. To reduce the occupant injury in such a severe accident, the multiple crash test method was developed.

(1) Four multiple crash scenarios were selected from the representative that was based on the NASS-CDS.

(2) To decide the proper test condition, simulation was performed with variable such as approach angle, initial velocity and overlap between two vehicles.

(3) The crash pulse of the damaged vehicle was different from the undamaged vehicle under the same crash condition.

(4) The occupant was moved away from the in-position to out-of-position after the first impact.

(5) The test results from current study can help to understand vehicle and occupant kinematics in field accidents.

REFERENCES

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