Risk of rear occupant injuries under seat configuration in extended cab pickup truck: Actual left offset-frontal collision in Thailand

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Risk of rear occupant injuries under seat configuration in extended cab pickup truck:

Actual left offset-frontal collision in Thailand

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ABSTRACT

Severely injured occupants are often found due to usage of the extended cab for the passenger seats. The left offset-frontal collision from the actual accident is selected as the initial condition to determine injury risk for passengers in the extended cab pickup truck using kinematic simulation. With such condition, seat adjustments in the longitudinal direction and backrest angles in the extended cab space are investigated. The results reveal that the head for occupant in the middle of the rear seat has the highest risk of injury which can be potentially subjected to the corner of front seat under the seat reclined-backrest angle adjustment. However, the adjustment of backrest angle does not affect the pelvis injury of rear occupants. The seat track adjustment in the forward direction can minimize the risk of pelvis injuries due to less relative velocity.

Keywords: Left offset-frontal collision; Accidental reconstruction; Seat adjustment
1. Introduction

According to WHO global status report on road safety 2013, Thailand ranks the world’s third in highest road fatalities with 38.1 road deaths per 100,000 inhabitants per year in (2010). However, a recent study by the University of Michigan’s transportation research institute states that Thailand ranked number two in the university’s study of road fatalities in the world, with 44 road deaths per 100,000 people. It was second only to Namibia, which had 45 road deaths per 100,000. Fatalities from road accidents made up 5.1 percent of Thailand’s overall deaths (Sivak, 2014). Based on accidental data from the Royal Thai Police between October 2012 and September 2013, there were 869 vans and 8,702 pickup trucks from a total of 75,028 vehicle accidents. From the Office of Industrial Economics, Thailand, the number of new vehicles was composed of 899,200 one-ton pickup trucks, 537,987 passenger cars, and 20,608 commercial vehicles in 2012. In addition, domestic sales reached 794,081 units, and 735,627 vehicles for the export. Therefore, the pickup truck was the majority vehicle in 2012. Generally, road users of those pickup trucks choose a low variant type that was not equipped with safety device e.g. air bag. For this reason, severely injured occupants from vehicle collisions were often found.

HVE-CSI (Human-Vehicle-Environment - Crash Site Investigator) provides a fundamental reconstruction and simulation capabilities used to reconstruct the vehicle dynamics collision using conservation of momentum and planar kinematics. In HVE-CSI, the general environment data, vehicle data, and damage profile are used to determine the position-time data, velocity-time data, and final position during collision. It includes two well-known reconstruction software tools called EDCRASH “Engineering Dynamics Corporation Reconstruction of Accident Speeds on the
Highway” and EDSMAC “Engineering Dynamics Simulation Model of Automobile Collisions” (Day and Hargens, 1987, 1988). Based on numerical analysis of these software tools, it was revealed that the calculated results were at a high level of confidence and were able to predict the correct paths and damage profiles for vehicles (Monatrakul, 2010; Wirth et al., 2000; Gilbert et al., 2015).

Anderson et al. found that occupants of rear passenger seats had 43% lower fatality risk than the front seat occupants from three different types of pickup trucks. However, rear seat occupants in extended cab of compact pickup truck had the lowest fatality risk in comparison with the extended cab of full-size pickup truck and the large 4-door crew cab pickup truck (Anderson et al., 2000). However, Pletschen et al. found that re-design of structure in vehicle can reduce injury in frontal crash by 10% for the 40% offset-frontal crash test (Pletschen et al., 1990).

Forman et al. studied the injury of the far-side frontal occupant and found that the 60 degree oblique impact causes greater lateral head excursion than the 90 degree oblique impact (Forman et al., 2013). In the vehicle-to-vehicle and fixed object collisions, there were 95% of seriously injured front passengers in near-side impacts from the William Lehman Injury Research Center (WLIRC) and National Accident Sampling System/Crashworthiness (NASS/CDS) databases (Augenstein et al., 1999). Therefore, New Car Assessment Program (NCAP) are set to conduct the off-set crash test at the driver side i.e. right-offset frontal collision with adult dummies in the driver and front passenger positions. This is because the driver is at higher risk of death and injury from the steering wheel (Cuerden et al., 2007). Similarly, drivers were higher than passengers from the 6371 injured persons who reported their roles in Thailand (Stephan et al., 2011). However, the left offset collision with the pickup truck with the
extended cab type was found in Thailand (Monatrakul, 2010). Consequently, the front passenger who did not wear the seat belt was dead in this collision.

The extended cab type of pickup truck is the most popular for carriage of goods especially in the extended cab space for passengers throughout local roads in Thailand. This is because government subsidizes the road tax for single and extended cab types of vehicles as part of supporting small and medium enterprises. For this reason, severely injured occupants are often found due to usage of the extended cab for the passenger seats without the safety belts. Therefore, the left offset-frontal collision from the actual accident is selected for a case study to determine injury risk from three occupants in the extended cab space of pickup truck using kinematic simulation of accidental reconstruction. In this investigation, the rear seat can be adjusted in the longitudinal direction with five different positions and six backrest angles in the extended cab space.

2. Methodology
2.1 General accident information

From the real accident under the left-offset frontal collision, the damaged vehicles and accident information were preliminarily collected and found that there were a total of six occupants of both vehicles in this road crash (Monatrakul, 2010). Five occupants were found (one male driver and four female passengers) in the pickup truck with extended cab (V-01: ISUZU model year 2000) and there was one female driver who was slightly injured in the same type of vehicle (V-02: ISUZU model year 1990). In vehicle (V-01), the driver and mid-rear passenger were severely injured. Rear left and right adult passengers were also severely injured. Only the front passenger of vehicle (V-01) died. All occupants were transported to Wang Noi Hospital after the crash.
With a secondary source of collected data, it was revealed that the driver of extended cab pickup truck (V-02) was traveling to “Pol” district “Khonkaen” province on the two-lane-divided road, and following a lead vehicle – pickup truck (V-03) which was slower. While the V-02 driver attempted to overtake the pickup truck (V-03), another extended cab pickup truck (V-01) was travelling in the opposite direction. After the V-02 driver found that the vehicle (V-02) was not overtaking the pickup truck (V-03), the driver steered to the right direction for avoidance of collision. However, the collision occurred on the left offset-frontal collision of each vehicle. From the analysis of 1982 National Accident Sampling System (NASS) data, 49.8 percent from 11,868 vehicles were striking vehicle whose drivers took avoidance action before the collisions (Sussman et al., 1985). This type of vehicle collision may be more common action for vehicle drivers to take the avoidance action. Therefore, there is not much research on the left-offset frontal collision.

2.2 Injury mechanism analysis of left-offset frontal collision

Based on HVE-CSI procedure with EDSMAC software, all crash information data e.g. crash scene, evidence and damaged vehicle from the real collected data of left-offset crash (Monatrakul 2010) are used to reconstruct the left-offset frontal collision for the vehicle kinematics. Furthermore, the vehicle information from vehicle specification and HVE-CSI database are necessary for kinematic simulation such as vehicle geometry, moment of inertia, tire cornering stiffness, vehicle stiffness coefficients and crush load deflection as shown in Table 1. For asphalt road and vehicle tires, the road friction coefficient of 0.6 was assumed in this simulation. With a presumably trial and error method for the initial impact speed, final vehicle position and vehicle damage are correlated with the real data as shown in Figure 1. As a result, the output kinematic parameters such as the starting impact position of center of gravity on X, Y axis
The yaw angle of vehicle (V-01) with the impact time are calculated as shown in Figure 2.

The impact speed values of both vehicles (V-01 and V-02) are found at 57.20 and 71.60 km/hr respectively. This impact speed of vehicle (V-01) is similar to the requirement of impact speed 56 -0/+1 km/h from United Nation Vehicle Regulation No. 94 “Uniform provisions concerning the approval of vehicles with regard to protection of the occupants in the event of frontal collision”. This regulation is set to simulate the vehicle collision based on numerous studies of “Real-world” crash environment which results in the highest frequency and risk injury/fatality. In the test procedure, the vehicle shall overlap the barrier face by 40% ± 20 mm.

To investigate the occupant collision within the vehicle compartment, the MADYMO “MAthematical DYnamic Models” software were used. The kinematic data of vehicle and the geometry of vehicle compartment are set as the input condition. The 50th (male) and 5th (female) percentile of human dummies are allocated according to the occupant data and safety conditions of the real accident event as shown in Table 2.

2.3 Seat track and backrest angle adjustment conditions of the pick-up truck

Under the real left-offset frontal collision, the kinematics data of vehicle (V-01) at center of gravity from Figure 2 are used as the input parameters to investigate the occupant collision using MADYMO software. Main body regions of rear occupants from the seat track and back rest angle adjustment are analyzed as previously mentioned without fastened seatbelt condition. The purpose is to investigate and compare the original rear seat geometry of 35 cm length and 0 degree backrest angle with other seat configurations for the pickup truck with extended cab (V-01). Therefore, the rear seat track and backrest angle parameters which are different from the original condition are
set to determine the injury risk of main body regions using the MADYMO software which is able to adjust the position of the seat and the backrest angle.

In seat track adjustment, there are two directions i.e. forward and backward directions. For this research, the distances are changed in the forward direction by 50 mm and 100 mm and the backward direction by -50 mm and -100 mm. Therefore, there are 5 conditions including the original seat in the extended cab of the pickup truck to be investigated as shown in Figure 3.

In the real vehicle seat, the backrest angle can be adjusted for good ergonomics condition. But in the extended cab of the pickup truck, the backrest angle of rear seat is set in the vertical direction (0 degree). Thus, this research is assumed to investigate the backrest angle conditions from 0-25 degrees with 5 degree of increment as shown in Figure 4.

3. Results

3.1 Injury mechanism analysis of left-offset frontal collision

During the vehicle collision, the movement of vehicle compartment with occupant dummies can be simulated as shown in Figure 5. The peak acceleration of main body regions such as the head, chest and pelvis of occupant dummies are determined with medical injury information from the real accident as shown in Table 3 (Monatrakul, 2010). These data are compared with the biomechanics database of human tolerance in order to indicate the serious-unsurvivable conditions (Seiffert and Wech, 2007). For examples, the peak acceleration of head dummy (P-02) which is the highest over the upper human tolerance limit is related to the medical injury information from the real medical data as shown in Figure 6. Whereas, the acceleration data at the impact body regions of the driver and mid-rear dummies i.e. P-01 and P-04 are below or within
tolerance limits of human body parts. However, the left rear dummy (P-03) is subjected to the solid side panel of vehicle compartment such as door and side-windows. Thus, the peak of acceleration data at the chest and pelvis under the translation state from these dummies are above the upper human tolerance limit. In addition, there is high acceleration at the thorax of occupant dummy (P-05) under the rotation state above the maximal human tolerance of 588.6 m/s² as shown in Figure 7. These above data from the left and right rear dummies (P-03 and P-05) are not related to medical injury information because this simulation only predicts dummy responses based on the standard occupant posture prior to the impact condition as shown in Figure 5. In the real accident event, the pre-crash occupant posture under personal self-protection was unknown. Therefore, non-severe injuries at the thorax and pelvis for rear occupants (P-03 and P-05) were not found in medical injury information.

3.2 Influence of seat adjustment

3.2.1 Results of seat reclined-backrest angle adjustment

In Figure 8, more inclination of back rest angle causes more risk of P-03 head injury by two phenomena. In the first one, the head injury against the back of the front seat is increased by the relative backrest angles from 0 to 15 degree due to higher relative velocity. Secondly, P-03 head is subjected to the rigid side panel of the occupant cabin which affects the increment of head acceleration in the seat back angles of 20 and 25 degree. Conversely, the P-03 chest is subjected to less acceleration as the result of the energy conservation with more inclination of back rest angle as shown in Figure 9.

The data of P-04 head and chest acceleration are increased and decreased in every reclined-backrest angle respectively as the result of relative velocity and the
energy conservation. Furthermore, the risk of P-04 is the highest at the first impact of all cases which can be potentially subjected to the corner of the front seat. This impact area at the front seat causes no degree of freedom in the forward direction.

With the increment of reclined-backrest angle, the impact area from the P-05 head is gradually shifted from the back of the front seat to the gap between two front seats. These characteristic motions cause less impact acceleration of head and chest. Thus, P-05 head impact acceleration is gradually decreased and related to the increment of backrest angle. However, the adjustment of the backrest angle does not affect the pelvis injury of rear occupants. In the back seats, the acceleration results of pelvis under the reclined-backrest angle adjustment are rather constant because the position of pelvis is always set at the same position as shown in Figure 10.

3.2.2 Results of seat track adjustment

Since the pelvis is the first impact region against the back of the front seat after collision, the acceleration data at the pelvis from the seat-track adjustment of all rear occupants are continuously rising with almost constant proportions as shown in Figure 11. It can be concluded that longer distance increases pelvis acceleration because of the higher resulting relative velocity. Furthermore, there is no significant increments of chest accelerations from dummies (P-04 and P-05) under seat track adjustment as shown in Figure 12. However, there are slightly increment of chest acceleration of dummy P-03 due to higher relative velocity in the backward seat position.

In Figure 13, the trend of P-03 head acceleration is slightly the same because the chest and the pelvis are simultaneously subjected to the solid side panel of vehicle compartment. The trend of P-04 head acceleration in case of the backward seat adjustment is similar to that in case of the reclined-backrest angle adjustment because P-
head is gradually shifted from the gap between the front seats to the corner of the front seat. Generally, there is no degree of freedom at the front seat of vehicle under the impact force at the corner. This incident is vice-versa for P-05 head that is gradually shifted from the back of front seat to the gap between the front seats in the backward direction.

4. Conclusions

The accident reconstruction provides the injury causation within vehicle compartment. The results can reflect the kinematic of occupants and injury mechanism in the real accident case. However, the simulation is based on the standard occupant posture prior to the impact condition. The pre-crash occupant posture under personal self-protection was unknown in real accident. Therefore, some simulation data from dummies are higher in comparison with the medical injury information from occupants.

In case of seat backrest angle adjustment, there are almost constant results of pelvis acceleration due to the constant pelvis position. However, data from the head and chest acceleration of rear occupants are affected by the backrest angle. In case of the seat track adjustment, the simulation results reveal that the increment of pelvis acceleration is related to the seat adjustment in the backward direction. However, there is no significant increment of head acceleration for the left rear occupant under the backward seat adjustment. Furthermore, the seat adjustment in either the forward direction or the reduction of reclined-backrest seat can minimize head injuries of all occupants except for the rear right occupant. However, the head injuries of rear right and left occupants with seat configuration under the right-offset frontal collision can be predicted in the opposite trends as that under the left-offset frontal collision.
5. References


Figure 1: Actual accident scene (Montrakul 2010) and reconstruction of left offset-frontal collision a) Pre-crash event b) Real and simulated data of vehicle damage c) Real and simulated vehicle positions at the end of accident event

Figure 2: Kinematic data of vehicle (V-01) at center of gravity after the starting impact time
Figure 3: Seat track adjustment in backward and forward positions

Figure 4: Rear seat angle adjustment between 0 and 25 degrees
Figure 5: Occupant movement within vehicle (V-01) under the left offset-frontal collision

Prior to impact condition

End of accident event

Figure 6: Head impact of front occupant (P-02) at 87.9 ms

Figure 7: Chest impact of rear occupant (P-02) at 188.6 ms
Figure 8: Head acceleration under the seat reclined-backrest angle adjustment

Figure 9: Chest acceleration under the seat reclined-backrest angle adjustment

Figure 10: Pelvis acceleration under the seat reclined-backrest angle adjustment
Figure 11: Pelvis acceleration under the seat track adjustment

Figure 12: Chest acceleration under the seat track adjustment

Figure 13: Head acceleration under the seat track adjustment
Table 1: HVE-CSI vehicle database and specification

<table>
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<th>Items</th>
<th>Extended Cab pickup vehicle</th>
<th>Extended Cab pickup vehicle</th>
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<tr>
<td></td>
<td>1996-2001 Model (V-01)</td>
<td>1990-1996 Model (V-02)</td>
</tr>
<tr>
<td>Overall length (mm.)</td>
<td>5020</td>
<td>4790</td>
</tr>
<tr>
<td>Overall height (mm.)</td>
<td>1640</td>
<td>1630</td>
</tr>
<tr>
<td>Overall width (mm.)</td>
<td>1720</td>
<td>1650</td>
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<tr>
<td>Track width mm.</td>
<td>1460</td>
<td>1405</td>
</tr>
<tr>
<td>Standard curb weight (kg)</td>
<td>1495</td>
<td></td>
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<tr>
<td>Moment of inertia (kg.m(^2))</td>
<td></td>
<td>4634.75</td>
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<tr>
<td>Tire cornering stiffness (N/deg)</td>
<td>736.48</td>
<td>647.46</td>
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<tr>
<td>Crush load deflection characteristic (N/cm(^2))</td>
<td>34.47</td>
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<tr>
<td>Stiffness coefficient :A (N/cm)</td>
<td></td>
<td>136.6</td>
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<tr>
<td>Stiffness Coefficient :B (N/cm(^2))</td>
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<td>27.6</td>
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Table 2: Occupant data of vehicle (V-01) in the real accident event (Montrakul 2010)

<table>
<thead>
<tr>
<th>Occupant</th>
<th>Gender</th>
<th>Age</th>
<th>Weight* (kg)</th>
<th>Seat location</th>
<th>Safety Condition</th>
<th>Seat belt</th>
<th>Air bag</th>
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<tbody>
<tr>
<td>P-01</td>
<td>Male</td>
<td>35</td>
<td>70.22</td>
<td>Driver</td>
<td>Used</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>P-02</td>
<td>Female</td>
<td>35</td>
<td>56.26</td>
<td>Passenger Front</td>
<td>No</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>P-03</td>
<td>Female</td>
<td>16</td>
<td>52.70</td>
<td>Left Rear</td>
<td>No</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>P-04</td>
<td>Female</td>
<td>5</td>
<td>18</td>
<td>Mid Rear</td>
<td>No</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>P-05</td>
<td>Female</td>
<td>27</td>
<td>56.26</td>
<td>Right Rear</td>
<td>No</td>
<td>No</td>
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Table 3: Peak acceleration results and medical injury information at the impacted body region of occupants

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<thead>
<tr>
<th>No.</th>
<th>Body Regions</th>
<th>Translation State</th>
<th>Rotation State</th>
<th>Medical injury information***</th>
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<tr>
<td></td>
<td></td>
<td>Time (ms)</td>
<td>Acceleration (m/s²)</td>
<td>Time (ms)</td>
</tr>
<tr>
<td>P-01</td>
<td>Head-3ms</td>
<td>80</td>
<td>640.55*</td>
<td>533</td>
</tr>
<tr>
<td></td>
<td>Chest-3ms</td>
<td>70.1</td>
<td>359.56*</td>
<td>518.7</td>
</tr>
<tr>
<td></td>
<td>Pelvis</td>
<td>72.1</td>
<td>362.05*</td>
<td>6718</td>
</tr>
<tr>
<td>P-02</td>
<td>Head-3ms</td>
<td>87.9</td>
<td>5751.71**</td>
<td>382.5</td>
</tr>
<tr>
<td></td>
<td>Chest-3ms</td>
<td>102.8</td>
<td>2989.55**</td>
<td>238.2</td>
</tr>
<tr>
<td></td>
<td>Pelvis</td>
<td>76.1</td>
<td>1739.38**</td>
<td>161.2</td>
</tr>
<tr>
<td>P-03</td>
<td>Head-3ms</td>
<td>106.2</td>
<td>623.4*</td>
<td>540.2</td>
</tr>
<tr>
<td></td>
<td>Chest-3ms</td>
<td>86.4</td>
<td>677.2**</td>
<td>959.2</td>
</tr>
<tr>
<td></td>
<td>Pelvis</td>
<td>62.5</td>
<td>925.3**</td>
<td>436</td>
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<tr>
<td>P-04</td>
<td>Head-3ms</td>
<td>83.3</td>
<td>1025.2*</td>
<td>151.1</td>
</tr>
<tr>
<td></td>
<td>Chest-3ms</td>
<td>90.1</td>
<td>686.1*</td>
<td>151</td>
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<td></td>
<td>Pelvis</td>
<td>65.4</td>
<td>739.2*</td>
<td>426.5</td>
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<tr>
<td>P-05</td>
<td>Head-3ms</td>
<td>85.6</td>
<td>1168.3*</td>
<td>189.2</td>
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<tr>
<td></td>
<td>Chest-3ms</td>
<td>93</td>
<td>506.4*</td>
<td>188.6</td>
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<tr>
<td></td>
<td>Pelvis</td>
<td>69.6</td>
<td>762.2*</td>
<td>189.9</td>
</tr>
</tbody>
</table>

* Acceleration data are below or within tolerance limits of human body regions (Seiffert and Wech 2007):
  - Skull fracture at head: 80-300 g   (784.8 - 2943.0 m/s²);
  - Thorax / Chest: 40-60 g   (392.4 - 588.6 m/s²);
  - Pelvis: 50-80 g   (490.5 - 784.8 m/s²);

** Acceleration data are over the tolerance limits of human body parts

*** Data from the real left offset collision (Montrakul 2010)