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Original Article

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

Passengers seated in the extended cab of a pickup truck are often severely injured following a collision. The left offset-frontal collision from an actual accident was selected as the initial condition to determine the risk of injury for passengers in the extended cab using kinematic simulation. Seat adjustments in the longitudinal direction and backrest angles in the extended cab space were investigated. The results revealed that the head of the occupant in the middle of the rear seat had the highest risk of injury which can potentially be subjected to the corner of the front seat under the seat reclined-backrest angle adjustment. However, adjustment of the backrest angle does not affect pelvis injury of the 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 the WHO global status report on road safety in 2013, Thailand ranked as the world's third highest in road fatalities with 38.1 road deaths per 100,000 inhabitants in the year 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% of Thailand's overall deaths (Sivak, 2014). Based on accident data from the Royal Thai Police between October 2012 and September 2013, 869 vans and 8,702 pickup trucks from a total of 75,028 vehicles were involved in collisions. From the Office of Industrial Economics Thailand, the numbers of new vehicles were 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 were exported. Therefore, the pickup truck made up the majority of vehicles in 2012. Generally, users of those pickup trucks choose a low variant type which is not equipped with safety devices such as air bags. For this reason, the occupants of pickup trucks are severely injured following vehicle collisions.

The Human-Vehicle-Environment–Crash Site Investigator (HVE–CSI) vehicle database provides fundamental reconstruction and simulation capabilities used to reconstruct the vehicle dynamics collision using conservation of momentum and planar kinematics. From the HVE-CSI, the general environment data, vehicle data, and damage profile can be used to determine the position-time data, velocity-time data and final position during a 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 & Hargens, 1987, 1988). Based on numerical analysis of these software tools, the calculated results were at a high level of confidence and were able to predict the correct paths and damage profiles for vehicles (Gilbert *et al.,* 2015; Monatrakul, 2010; Wirth *et al.*, 2000).

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Anderson *et al.* found that the occupants of rear passenger seats had a 43% lower fatality risk than the front seat occupants from three different types of pickup trucks. However, rear seat occupants in the extended cab of a compact pickup truck had the lowest fatality risk in comparison with the extended cab of a full-size pickup truck and the large 4-door crew cab pickup truck (Anderson *et al.,* 2000). However, Pletschen *et al.* found that a re-design of the structure in a 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, the percentage of seriously injured front passengers was 95% 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, the New Car Assessment Program (NCAP) was set to conduct an offset 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 a higher risk of death and injury from the steering wheel (Cuerden *et al.,* 2007). Similarly, drivers were in greater numbers 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 to be common in Thailand (Monatrakul, 2010). Consequently, the front passenger who did not wear the seat belt suffered fatal injuries in this type of collision.

The extended cab type of a 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 the 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 passengers using the rear seat in the extended cab without the safety belts. Therefore, the left offset-frontal collision from an actual accident is selected for a case study to determine injury risk from three occupants in the extended cab space of a pickup truck using kinematic simulation of accident reconstruction. In this investigation, the rear seat can be adjusted in the longitudinal direction to 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 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 slightly injured female driver 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 the extended cab pickup truck (V-02) was traveling to Pol District in 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 was attempting to overtake the pickup truck (V-03), another extended cab pickup truck (V-01) was traveling in the opposite direction. When the V-02 driver found that her vehicle (V-02) was not overtaking the pickup truck (V-03), she steered to the right to avoid a 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% of 11,868 vehicles were striking vehicles whose drivers took avoidance action before the collisions (Sussman *et al.,* 1985). This type of vehicle collision may be the more common action for vehicle drivers to avoid a collision. Therefore, there is not much research on the left-offset frontal collision.

2.2 Injury mechanism analysis of left-offset frontal collision

Based on the HVE-CSI data with EDSMAC software, all crash information data, i.e. crash scene, evidence, and damaged vehicle from the real collected data of left-offset crash (Monatrakul 2010), were used to reconstruct the left-offset frontal collision for the vehicle kinematics. Furthermore, the vehicle information from the 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 (Table 1). A road friction coefficient of 0.6 for an asphalt road and vehicle tires was assumed in this simulation. With a presumably trial and error method for the initial impact speed, final vehicle position, and vehicle damage, a correlation was established with the real data (Figure 1). As a result, the output kinematic parameters such as the starting

Table 1. HVE-CSI vehicle database and specifications.

Items	Extended Cab pickup vehicle 1996-2001 Model (V-01)	Extended Cab pickup vehicle 1990-1996 Model (V-02)
Overall length (mm)	5020	4790
Overall height (mm)	1640	1630
Overall width (mm)	1720	1650
Track width mm	1460	1405
Standard curb weight (kg)	1495	
Moment of inertia (kg m^2)	4634.75	
Tire cornering stiffness (N/deg)	736.48	647.46
Crush load deflection characteristic (N/cm^2)	34.47	
Stiffness coefficient: A (N/cm)	136.6	
Stiffness Coefficient: B (N/cm^2)	27.6	

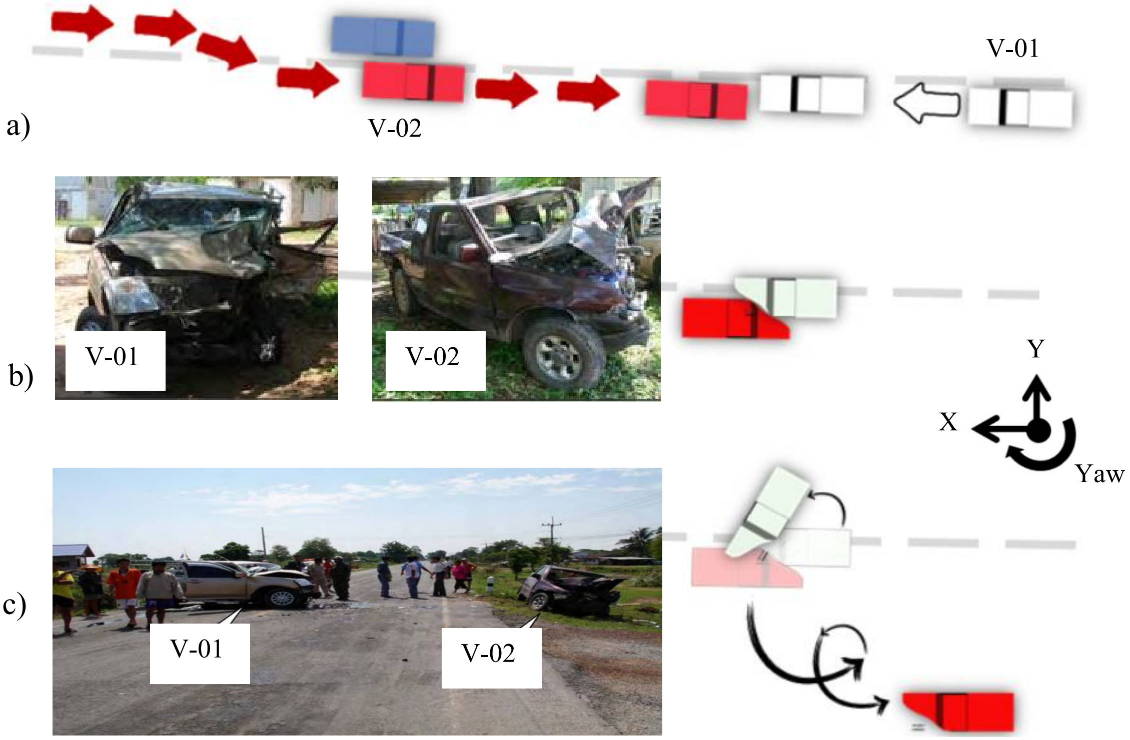

Figure 1. Actual accident scene (Monatrakul, 2010) and reconstruction of left offset-frontal collision: a) Pre-crash event; b) Real and simulated data of vehicle damage; c) Real and simulated vehicle positions at the end of accident event.

impact position of the center of gravity on the X, Y axis and yaw angle of the vehicle (V-01) with the impact time were calculated (Figure 2). The impact speed values of both vehicles (V-01 and V-02) were found to be 57.20 and 71.60 km/h, 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.

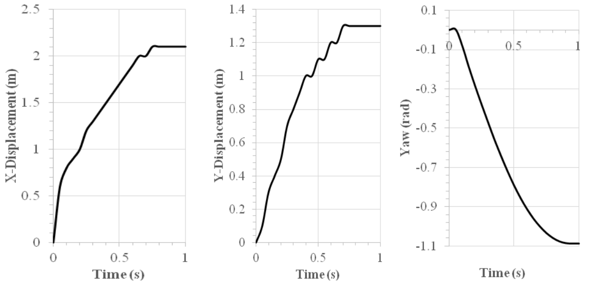

Figure 2. Kinematic data of vehicle (V-01) at center of gravity after starting the impact time.

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

Table 2. Occupant data of vehicle (V-01) in the real accident event (Monatrakul, 2010).

Occupant	Gender	Age	Weight* (kg)	Seat location	Safety Condition	
					Seat belt	Air bag
P-01	Male	35	70.22	Driver	Used	No
P-02	Female	35	56.26	Passenger Front	No	No
P-03	Female	16	52.70	Left Rear	No	No
P-04	Female	5	18	Mid Rear	No	No
P-05	Female	27	56.26	Right Rear	No	No

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 were used as the input parameters to investigate the occupant collision using the MADYMO software. The main body regions of the rear occupants from the seat track and back rest angle adjustment were analyzed as previously mentioned without a fastened seatbelt. 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 were 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.

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

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

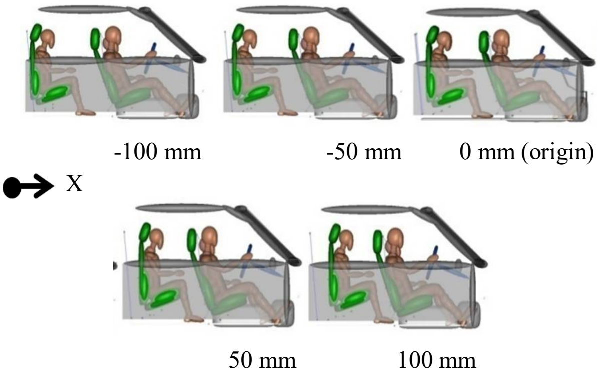

Figure 3. Seat track adjustment in backward and forward positions.

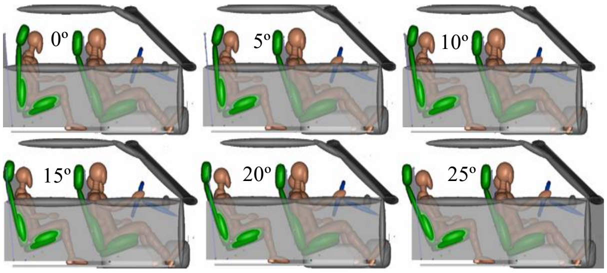

Figure 4. Rear seat angle adjustment between 0 and 25 degrees.

3. Results

3.1 Injury mechanism analysis of left-offset frontal collision

During the vehicle collision, the movement of the vehicle compartment with occupant dummies could be simulated (Figure 5). The peak acceleration of the main body regions, such as the head, chest, and pelvis of the occupant dummies, were determined with medical injury information from the real accident (Table 3) (Monatrakul, 2010). The data were compared with the biomechanics database of human tolerance in order to indicate the serious to unsurvivable conditions (Seiffert and Wech, 2007). For example, the peak acceleration of the head of 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 (Figure 6). On the other hand, the acceleration data at the impact body regions of the driver and mid-rear dummies (P-01 and P-04) were below or within tolerance limits of human body parts. However, the left rear dummy (P-03) was subjected to the solid side panel of the vehicle compartment (the door and side-window). Thus, the peak acceleration data at the chest and pelvis under the translation state of these dummies were above the upper human tolerance limit. In addition, there was high acceleration at the thorax of occupant dummy P-05 under the rotation state above the maximal human tolerance of 588.6 m/s^2 (Figure 7). The data from the left and right rear dummies (P-03 and P-05) were not related to the medical injury information because this simulation only predicted dummy responses based on the standard occupant posture prior to the impact condition (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 the medical injury information.

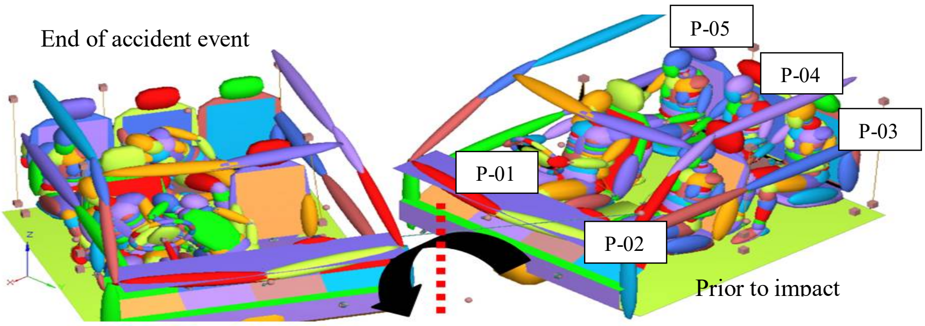

Figure 5. Occupant movement within vehicle (V-01) under the left offset-frontal collision.

Table 3. Peak acceleration results and medical injury information of the impacted regions of the bodies of the occupants.

No.	Body Regions	Translation State		Rotation State		Medical injury information***
		Time (ms)	Acceleration (m/s2)	Time (ms)	Acceleration (m/s2)	
P-01	Head-3ms Chest-3ms Pelvis	80 70.1 72.1	640.55* 359.56* 362.05*	533 518.7 6718	134.1* 171.59* 241.74*	Minor injury of chest and feet / A bit bleeding of mouth
P-02	Head-3ms Chest-3ms Pelvis	87.9 102.8 76.1	5751.71** 2989.55** 1739.38**	382.5 238.2 161.2	990.2* 128.41* 206.32*	Severe head concussion / Broken neck left arm and lacerated wound / Bleeding abdominal cavity / Death
P-03	Head-3ms Chest-3ms Pelvis	106.2 86.4 62.5	623.4* 677.2** 925.3**	540.2 959.2 436	1086.24* 405.61* 159.71*	Severe head concussion / Laceration of scalp 15 cm length
P-04	Head-3ms Chest-3ms Pelvis	83.3 90.1 65.4	1025.2* 686.1* 739.2*	151.1 151 426.5	576.56* 135.3* 192.72*	A bit contusion and scratch
P-05	Head-3ms Chest-3ms Pelvis	85.6 93 69.6	1168.3* 506.4* 762.2*	189.2 188.6 189.9	450.67* 717.5** 229.6*	Severe head concussion/ cut wound /Laceration of scalp 20 cm length

* Acceleration data are below or within tolerance limits of human body regions (Seiffert & Wech 2007):

- ○ Skull fracture at head: 80-300 g (784.8 - 2943.0 m/s^2);
- ○ Thorax / Chest: 40-60 g (392.4 - 588.6 m/s^2);
- ○ Pelvis: 50-80 g (490.5 - 784.8 m/s^2);

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

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

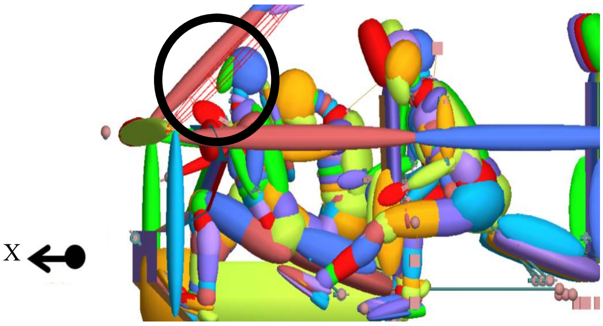

Figure 6. Head impact of front occupant (P-02) at 87.9 ms.

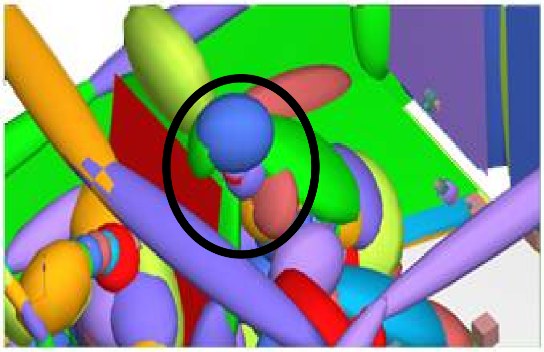

Figure 7. Chest impact of rear occupant (P-05) at 188.6 ms.

3.2 Influence of seat adjustment

3.2.1 Results of seat reclined-backrest angle adjustment

A greater inclination of the back rest angle causes more risk of head injury to occupant P-03 by two phenomena (Figure 8). 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 a higher relative velocity. Second, the head of P-03 was subjected to the rigid side panel of the occupant cabin which affected the increment of head acceleration in the seat back angles of 20 and 25 degrees. Conversely, the chest of P-03 was subjected to less acceleration as the result of the energy conservation with more inclination of back rest angle (Figure 9).

The data of the head and chest acceleration of P-04 increased and decreased in every reclined-backrest angle, respectively, as the result of relative velocity and energy conservation. Furthermore, the risk of P-04 was 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 of the head of P-05 gradually shifted from the back of the front seat to the gap between two front seats. These characteristic motions cause less impact acceleration of the head and chest. Thus, the impact acceleration of the head of P-05 gradually decreased and was related to the increment of backrest angle. However, adjustment of the backrest angle does not affect the pelvis injury of the rear occupants. In the back seats, the acceleration results of the pelvis under the reclined-backrest angle adjustment are rather constant because the position of the pelvis is always set at the same position (Figure 10).

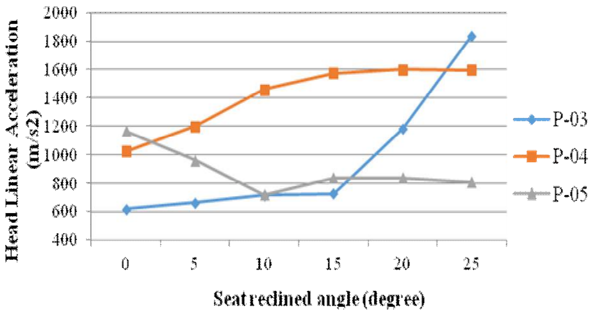

Figure 8. Head acceleration under the seat reclined-backrest angle adjustment.

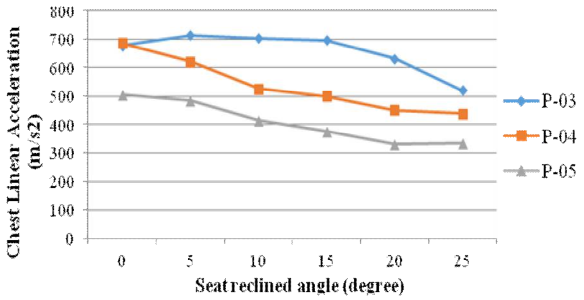

Figure 9. Chest acceleration under the seat reclined-backrest angle adjustment.

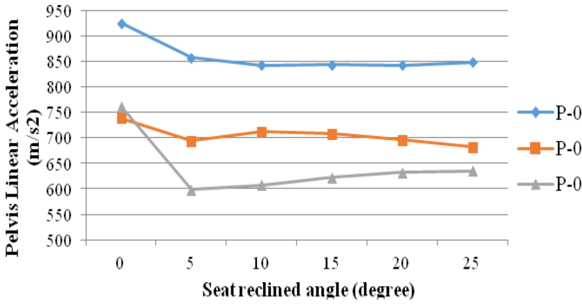

Figure 10. Pelvis acceleration under the seat reclined-backrest angle adjustment.

3.2.2 Results of seat track adjustment

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

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

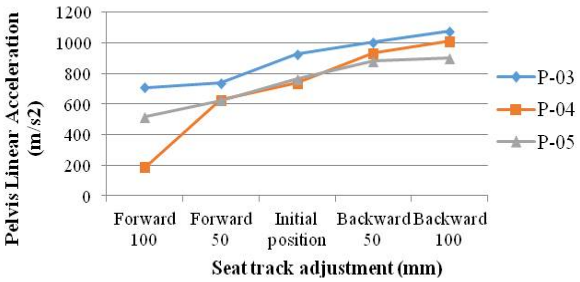

Figure 11. Pelvis acceleration under the seat track adjustment.

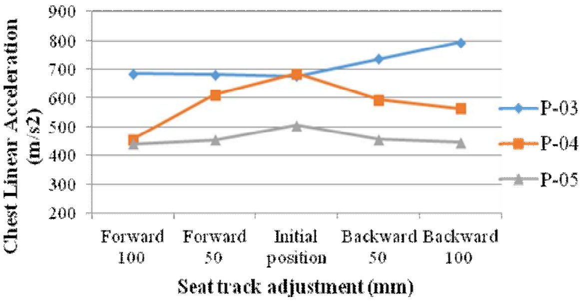

Figure 12. Chest acceleration under the seat track adjustment.

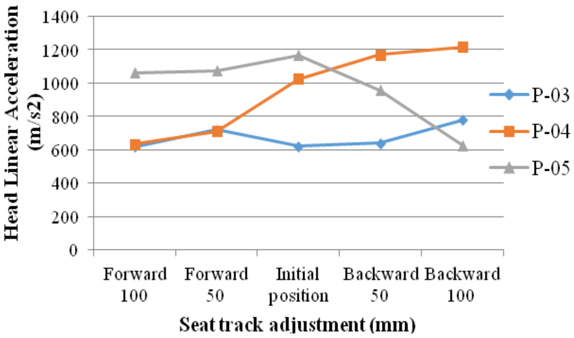

Figure 13. Head acceleration under the seat track adjustment.

4. Conclusions

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

In the case of seat backrest angle adjustment, there were almost constant results of pelvis acceleration due to the constant pelvis position. However, data from the head and chest acceleration of the rear occupants were affected by the backrest angle. In the case of the seat track adjustment, the simulation results revealed that the increment of pelvis acceleration was related to the seat adjustment in the backward direction. However, there was 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 could 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.

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