ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 2, Issue 1, January 2013

Fatal Injury Mechanism Analysis of Occupants Especially Death of Left-Front Passenger for Offset-frontal Collision in Thailand

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Abstract*— Road accidents are very common in big cities as there are many modes of transport and road under narrow and overcrowded situation. Some accidents often result in life and economic losses. In every year, 1.2 million people are killed and up to 50 million are injured and disabled as the consequence of road accidents. However, the rate of road crash was decreased by 25% during 2006-2011 according to the annual report "Traffic Accident on National Highways 2011" of Department of Highways, Ministry of Transport, and Thailand. Although it was reduction, pick-up vehicle was still outstanding and becoming a majority road accident in the near future. In Thailand, collision type was mostly found on vehicles driving in the same direction. Nevertheless, the opposite direction of collision type had 25% possibility of fatality. Therefore, frontal collision is an important issue for studying the fatal and severe of occupant injuries. This research studies the case of offset-frontal collision between two pick-up vehicles which was previously investigated at initial velocity of 60.2 and 68.5 km/h, respectively To understand injury mechanism by using MADYMO-Exchange software, Hybrid III 5th and 50th percentile dummy models are used to represent average Thai female and male, respectively. With the validation from the actual data, the computational results through dummy models and injury values illustrate high acceleration during collision due to tremendous energy from velocity difference. In addition, airbag and seatbelt can be used to prevent injury from passenger in moving forward direction as mentioned Thai law enforcement only in the front passenger seatbelt. Similarly, rear passengers are severely injured. Therefore, it reveals that Thai law vehicle safety enforcement should be implemented in vehicle to minimize severe injury of rear passenger when the vehicle speed is above 60 km/hr.

Index Terms— **Injury Mechanism, Occupant Analysis, Offset-Frontal Collision, Road Accident.**

I. INTRODUCTION

A. Background of the study

A recent survey showed that more than 9,000 people die in crashes in Thailand every year[7]. Automobile accidents are one of the major sources of deaths in the country. According to the annual report "Traffic Accident on National Highways 2011" of Department of Highways, Ministry of Transport, and Thailand [4]. During the last 3 years all type of vehicle was decreased continually however, pick-up vehicle was still outstanding and becoming a first majority road accident before 2013. Furthermore, frontal collision is the second most road accident type, after the rear collision. Nevertheless, frontal collision is the highest severity index which is 25% chance of fatality [1]. Therefore, frontal collision is an important issue for studying the fatal and severe of occupant injuries. Biomechanics is an essential issue in the development of passive safety. Knowledge of this behavior is very useful in order to develop adequate measures for the protection of the human body under these extreme conditions. The capability to design a less injurious environment, i.e. safer vehicles, depends partly on our understanding of injury mechanisms and injury thresholds. There are many factors related to the severity of injury. For example, interior safety devices usage that have been invented and developed to reduce the chance that the occupant's body path will strike some part of the vehicle's interior. Characteristic of occupant is also considered as injury factor such as height and weight. Although seatbelt has been installed in vehicles, and the airbag has been installed in some vehicles at the present, many people are still injured in road crash because they do not use the provided safety devices. Not only these devices can prevent occupants from road crash injury, but also there are many cases that the occupants get injury in road crash even using safety devices. Therefore, it is necessary for this study to find how the occupants are injured in road crash.

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ISO 9001:2008 Certified
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Injury mechanism analysis, how occupants suffer injuries, of road accident victims is emphasized in this report. It is considered as the first step of the new approach in Thailand. The results from the study are hoped to give a picture of the complete scenario of a particular accident case and for injury prevention as well.

B. Objectives of the study

- To analyze the crash events through accident reconstruction and simulate the scenarios by HVE-CSI software
- To understand the injury mechanism of occupants through Mathematical Analysis and MADYMO dummy based on the results of MADYMO/Exchange software.

C. Scope of the study

- The study examines the process to get injury or the force impacted on the occupants in road crash.
- The study investigates the causes for road crash injuries mainly from crash scene.
- The result of study focuses the output from simulation program and interprets with real injury data from investigation.

II. METHODOLOGY

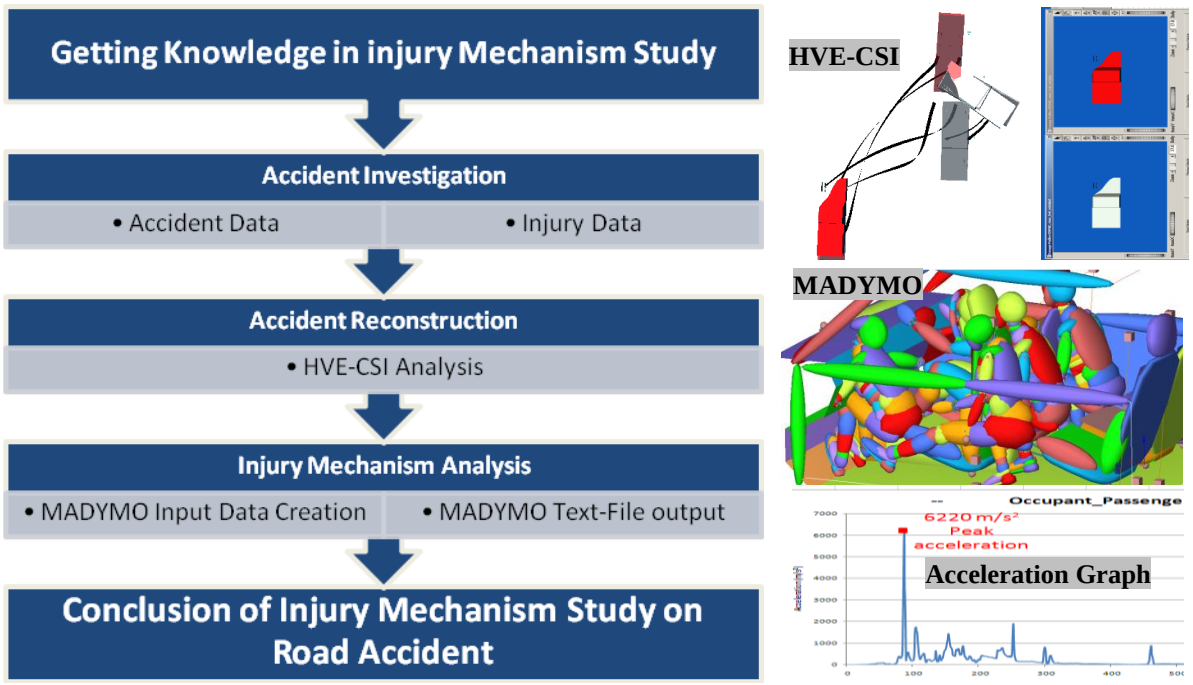

Fig. 1: The Logical Framework of Study

The development framework of the study is shown in Figure 1. The principle methodology is considered from accident investigation and reconstruction process and is accomplished with injury mechanism analysis.

A. Mathematical Analysis

$$F \times d_{post-impact} = \frac{1}{2} m_{occ} {V_{pre}}^2 - {V_{post}}^2 \quad (1)$$

$$F = m_{occ} \times a \quad (2)$$

$$V_{post} = V_{pre} + at_a \quad (3)$$

$${V_{rest}}^2 = {V_{pre}}^2 - 2as \quad (4)$$

where,

F = Impacted force on the occupant (N)
$d_{post\text{-}impact}$ = Post-impact distance (m)
V_{rest} = Rest position speed = 0 (m/sec^2)
V_{pre} = Pre-impact velocity (m/sec^2)
V_{post} = Post-impact velocity (m/sec^2)
s = Occupant translation movement distance
m_{occ} = Mass of occupant (kg)
a = acceleration of occupant
t= Time of receiving the acceleration

While the collision occurs, the occupants receive the impact force which is converted from energy of moving object (Kinematic energy). According to the law of conservation of energy, time of receive acceleration, acceleration and impact force. These factors can be calculated from Equation 1 to 4, respectively. Pre- and Post-impact speed, Post-impact distance can be obtained from the output of HVE-CSI analysis.

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B. Model Analysis

Crash test dummies are full-scale replicas of human beings, weighted and articulated to simulate the behavior of a human body in a motor-vehicle collision, The result from HVE-CSI, X (meter), Y (meter) and Yaw (radian) are required for motion input in MADYMO then instrumented to record as much data as possible on variables such as speed of impact, crushing force, bending, folding, or torque of the body, and deceleration rates during a collision. MADYMO software is applied as a main tool for injury mechanism analysis of this study[3]. It can generate a simulation of a crash victim or dummy in three-dimensional motion in a crash environment. Head, Thorax and pelvis are derived automatically to acceleration during vehicle collision.

C. Accident Investigation – Case Study

The driver of pickup (V-02) was traveling to "Pol" district "Khonkaen" province which is two-lane divided road, and following the lead vehicle – pickup (V-03) which was slowed traveling then V-02 desire to overtake that car but during overtaking there was another vehicle – pickup (V-01) travel by in opposite directions. After the driver find it in oneself that this was inevitable overtaking then control vehicle to right direction for avoiding the collision however the collision was occurred on the offset-left-frontal crash of each vehicle[8].

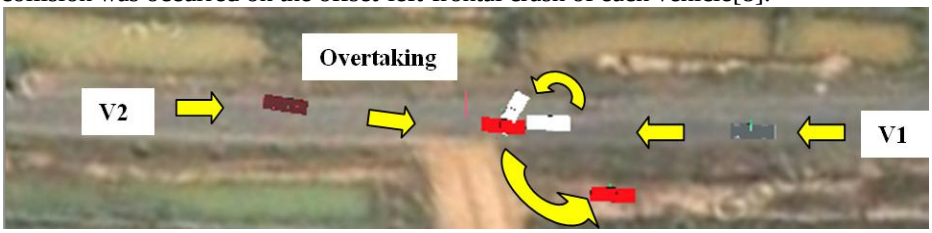

Fig. 2: Top View of Crash Scene

Fig. 3: Damaged vehicle: V-01* (left), V-02 (Right)**
***V-01 extend cab truck model,**V-02 Extend Cab Truck 1996-2001**

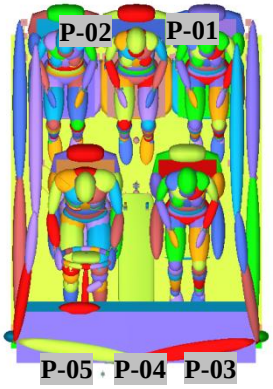

Fig. 4: Seating Position

Table 1: Summary of Occupants' Information and Injuries

Ref.	Gender	Age	Weight* (kg.)	Seating Position	Injury
P-01**	Male	35	70.22	Driver	- Minor injury of chest and feet - A bit bleeding mouth
P-02***	Female	35	56.26	Front-left	- Severe head concussion - Broken neck - Broken left arm and lacerated wound - Bleeding abdominal cavity (Haemoperitoneum)
P-03	Female	16	52.70	Rear-left	- Severe head concussion/stab/cut wound - Laceration of scalp 20 cm length
P-04	Female	5	18	Rear-center	-A bit contusion and scratch
P-05	Female	27	56.26	Rear-right	- Severe head concussion - Laceration of scalp 15 cm length

* Weight reference from NSTDA, NECTEC Source: (http://www.sizethailand.org/region_all.html)

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ISO 9001:2008 Certified
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**Only P-01 used lap-shoulder seatbelt ***Only P-02 was dead person

D. Simulation of Crash Events – Accident Reconstruction

Crash events were reconstructed and simulated in HVE-CSI software. Pre and post-impact speed of V-01 was 51.2 and 6 km/hr. respectively.

III. Injury Mechanism Analysis

A. Mathematic Analysis

Speed change effect to kinetic energy which related to injury parameters, calculated from Equation 1 to 4.

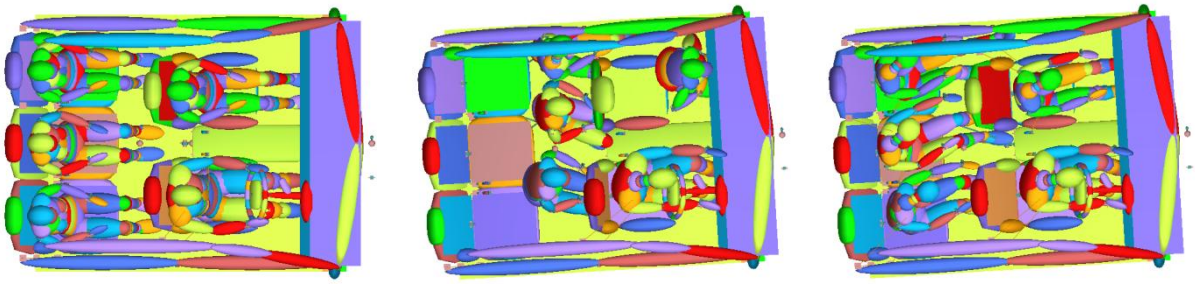
Table 2: Result of Occupants' Injury Analysis

Injury Parameter	Occupants' Reference				
	P-01	P-02	P-03	P-04	P-05
t (s)	1128				
F* (N)	3116	2497	2339	799	2497
a (m/s^2)	44.39				
t_a (s)	282.87				
s (m)	2.279				

* Parameter depended on weight of each occupant
Note: **t** = Contact time between V-01 and V-02(ms)
F = Impact Force (kN)
a = Acceleration of occupant (m/sec^2)
t_a=Time of receiving acceleration (ms)
s = Occupant translation movement distance

B. MADYMO Analysis

To study the response of the occupant a MADYMO model is used. An average Thai male is represented by a Hybrid III 50th percentile dummy model and 5th percentile dummy model for female occupants are used in MADYMO model setup. All contacts type is used for realistic simulation. Therefore, each occupant perceives interior compartment effect to high peak of acceleration.



Initial step (0 ms) Real case (90 ms) All fasten seat belt case (90 ms)

Fig. 5: Pre-impact (0 ms) and post-impact position (140ms) of occupants

C. Occupant Impact Response

At 0 ms, all occupants sit at normal positions then they moved forward due to high acceleration from the frontal collision. Meanwhile left-offset collision, left passenger hit the left-panel. Then, all passengers begin to chuck off to left direction because of counter-clockwise rotation. After 90 ms all passengers start to hit interior compartment and each other until the end of simulation.

IV. Interpretation of Crash Results

A. Occupants' injury by Motion Analysis

All unfasten seatbelt occupants would be minor injured to their head because of striking the car console or knee bolster for front occupants, or striking front seat for rear occupants.

B. Occupants' injury by Impacted Force and Acceleration

All occupants have a chance to be injured because of excessive time of receiving acceleration. Especially, P-01 has excessive force on Cervical Vertebra. However, P-01 is only one who fastens seatbelt result in no injury.

Table 3: Human Body Tolerances

Injury Parameter	Limit of Human Tolerance
Time of receiving acceleration (ms), t_a	160~220 ms
Threshold force on occupants (kN), F	Forehead, F_x=4-6 kN, a=784.8~2943 m/s^2 Cervical Vertebra, F_x=1.2~2.6 kN Chest, F_x=4~8 kN, a=392.4~588.6 m/s^2 Pelvis&Thigh, F_x=6.4~12.5 kN, a=490.5~784.8m/s^2 Shin bone, F_x=2.5~5.0 kN

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ISO 9001:2008 Certified
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V. MADYMO SIMULATION OUTPUT

MADYMO simulation displays the peak acceleration suffered by occupants in Table 4. Head, Thorax and pelvis of each occupant in V-01 are displayed also.All occupants had a chance to receive any injury of head, thorax and pelvis during 70-150 ms because of high acceleration during contact time between V-01 and V-02 except for P-01 who fastened seatbelt did not receive any injury. After offset-frontal collision, counter-clockwise rotation of vehicle cause P-03 and P-05 risk to be injured. P-03 was injured at left side of the head by striking to front passenger's head restraint at 270 ms and P-05 was injured at back side of the head and pelvis by striking to left panel at 230 ms. In the all fastened seatbelt case, all occupants did not injury but only P-05 was injured by lap-shoulder seatbelt during pulling back then affect to back of the head strike to the rear seat at 183 ms.

Table 4: Comparisons of Peak Acceleration and Human Body Tolerance

		Real Case	Used only Seatbelt	Used only Airbag	Used Airbag & Seatbelt
	Body Region	**Peak Acceleration (m/s^2)**	**Peak Acceleration (m/s^2)**	**Peak Acceleration (m/s^2)**	**Peak Acceleration (m/s^2)**
P-01	HeadCG	640.55	587.39	4199.07	803
	Thorax	359.56	353.04	2132.73	374
	Pelvis	362.05	427.16	907.78	445
P-02	HeadCG	5751.71	661.78	2589.04	623
	Thorax	2989.55	430.31	650.66	364
	Pelvis	1739.38	417.65	1528.23	342
P-03	HeadCG	1119.02	622.18		
	Thorax	455.35	352.89		
	Pelvis	607.21	445.7		
P-04	HeadCG	2131.72	655.33		
	Thorax	564.33	386.83		
	Pelvis	697.81	483.43		
P-05	HeadCG	2695.31	2690.79		
	Thorax	1273.5	487.51		
	Pelvis	897.73	457.2		

Note: Red zone means" Expected to have injury", Yellow zone means "Some impact from moving" and Green zone means "No injury"

The tolerance limit of head is shown in the Table 3 for frontal, lateral, and occipital area. The last version of tolerance limit for each area is preferable limit for fracture of skull injury analysis. Contact force is calculated by Newton's Law (F=ma) with average mass of head is 4.54 kg [2].

A. Interpretation of Injury Results

Possible injuries caused by the impacted force, striking to interior compartment. Not only contact affect to injury, high acceleration of occupants' motion is also.

Table 5: Occupant Injuries Interpretation

Occupant	Injury	Causation
P-01	- Minor injury of chest and feet - A bit bleeding mouth	-Lap shoulder seatbelt -Steering wheel
P-02	- Severe head concussion - Broken neck - Broken left arm and lacerated wound - Bleeding abdominal cavity (Haemoperitoneum)	-Main console -Left panel -Knee bolster
P-03	- Severe head concussion/stab/cut wound - Laceration of scalp 20 cm length	-Front seat
P-04	-A bit contusion and scratch	-Front seat
P-05	- Severe head concussion	-Front seat

ISSN: 2319-5967
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	- Laceration of scalp 15 cm length	-Left panel

Figure 6 illustrates comparison of used/unused safety devices results for a case of P-02 who was dead person in the real situation. Due to high acceleration value which is 5752 m/s^2 at 88 ms, this peak acceleration cause from main console striking which impact to head for P-02 cause of head injury. This acceleration was transformed into contact force which is 26.1 kN. It is more than tolerance limit at occipital area of skull which is 12.5 kN. Which cause a skull fracture injury at head of occupant. On the other hand, the used lap-shoulder seatbelt in assumed case influence the small value of acceleration which is 662 m/s^2 at 67ms without striking to main console in figure 7 and figure 8. This peak acceleration is from the lap-shoulder tightening. The contact force is absolutely decreased to 3 kN which is in the safe zone. Safety devices especially lap-shoulder seatbelt was very effectively decreases acceleration in the short time. More than 10 times acceleration reduction could be help P-02 survived in the used lap-shoulder seatbelt in assumed case.

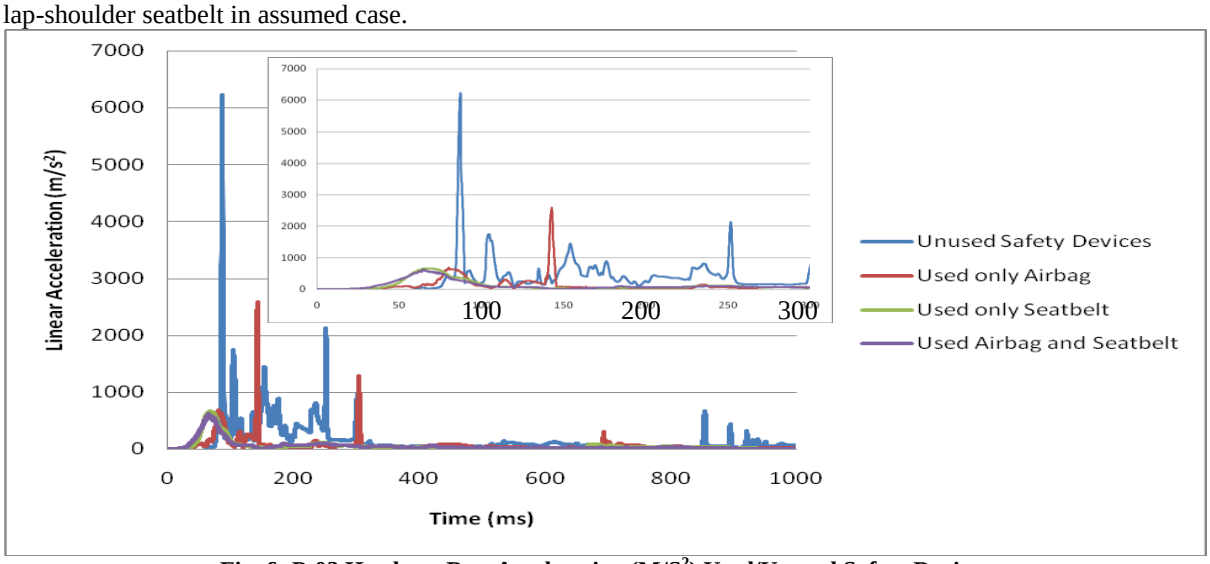
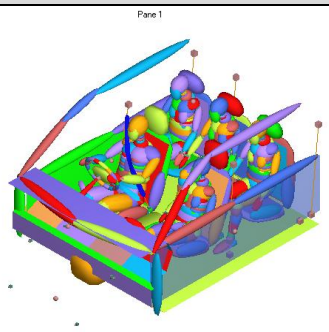
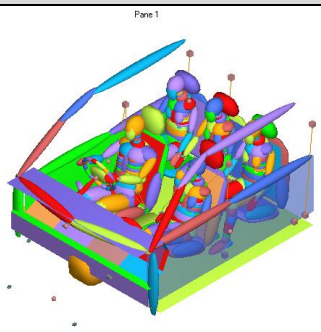
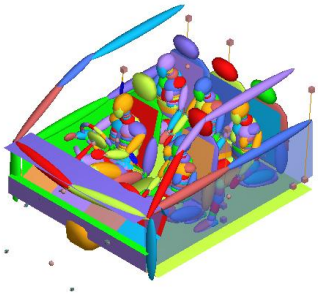
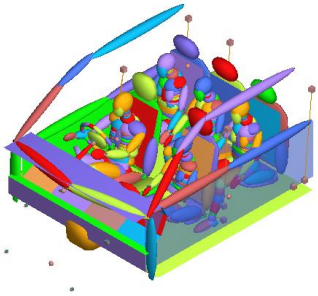


Fig. 6: P-02 Headcg – Res. Acceleration (M/S^2) Used/Unused Safety Devices

	Real case	Used lap-shoulder seatbelt in assumed case
0ms		
50ms		

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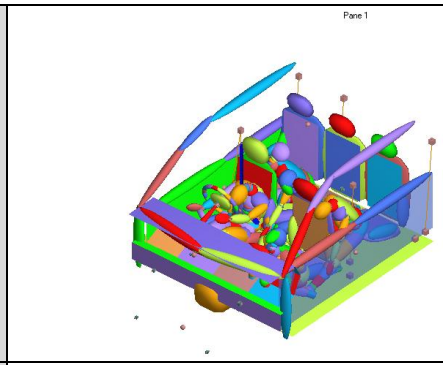
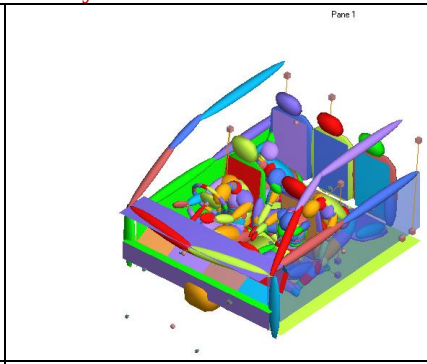
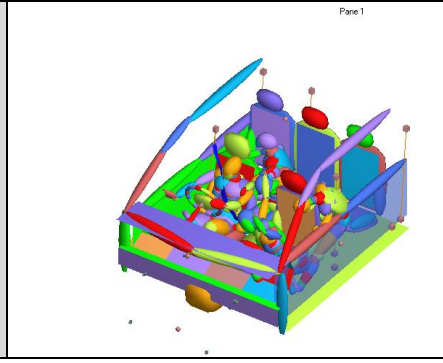
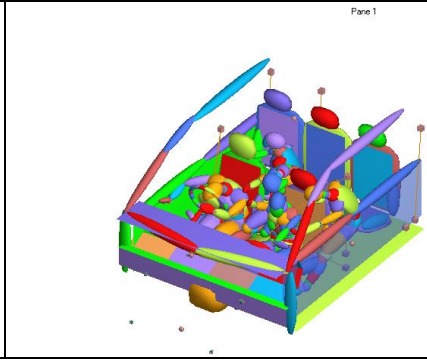
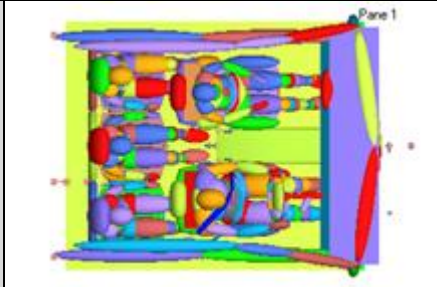
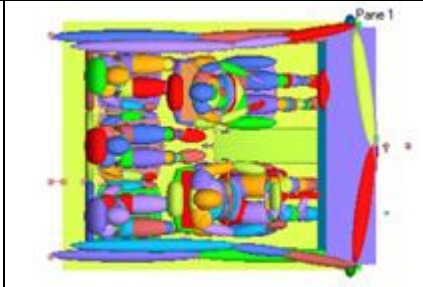
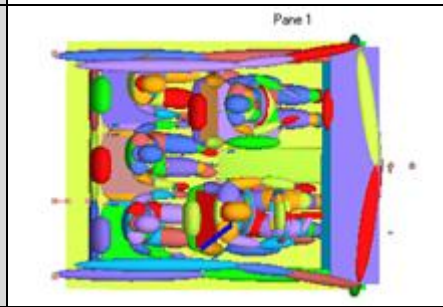
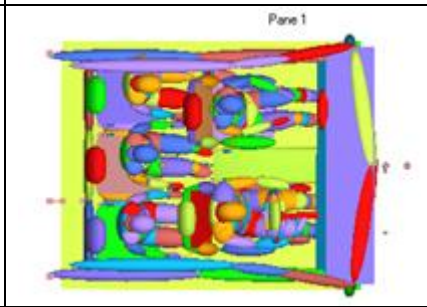
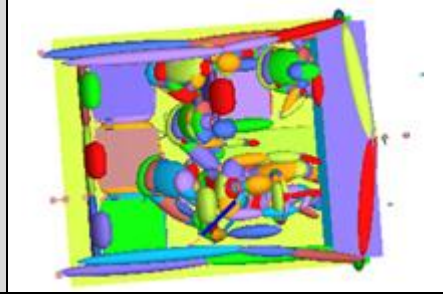
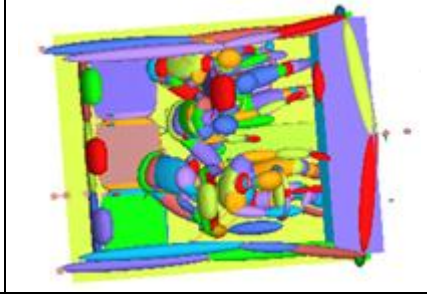
100ms		
150ms		

Fig. 7: Occupants' Motion Simulation in ISO-view

	Real case	Used lap-shoulder seatbelt in assumed case
0ms		
50ms		
100ms		

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ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
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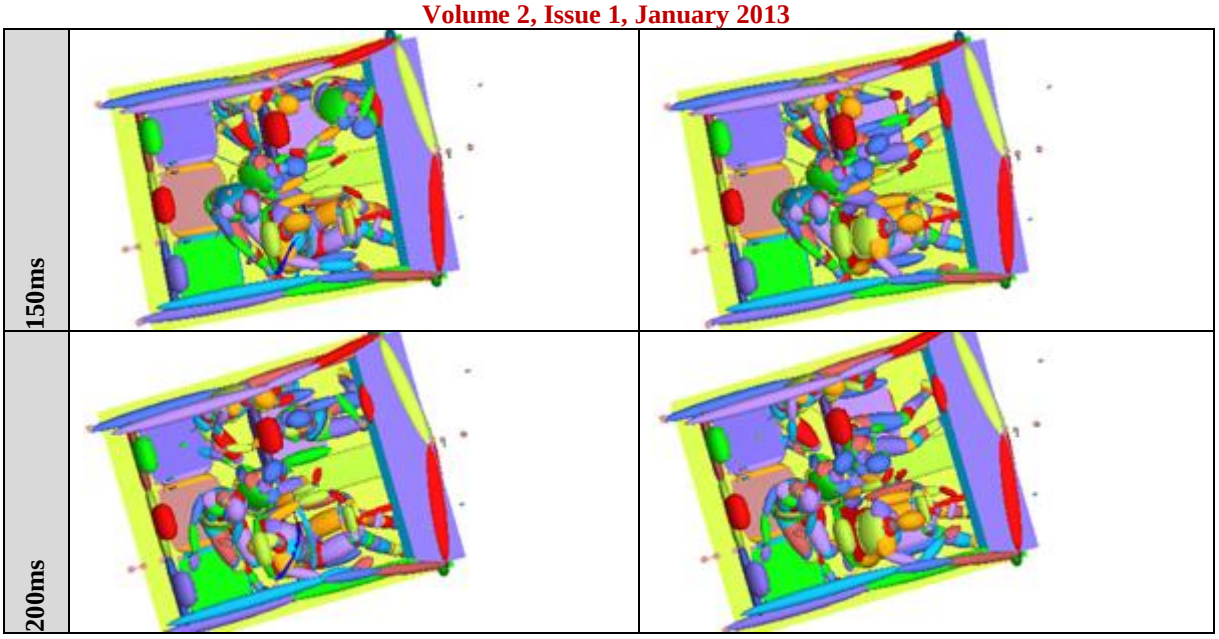

Fig. 8: Occupants' Motion Simulation in Top-view

VI. CONCLUSION

All occupants have a chance to get the injury because of long duration of time of receiving acceleration. High acceleration during crash deformation affect to all occupants injured because acceleration of occupants' body are over the limit of human tolerance. It is clearly result of comparison that the seatbelt decrease the severity to safety value. Approximate 3 times of maximum acceleration are decreased effect to rear occupants. And approximate 7-9 times is decreased for front occupants. In case P-02, she had broken neck which relate to the real data from this accident. The used lap-shoulder seatbelt in assumed case result to a very disparate value of acceleration. If P-02 used seatbelt she would survive from the accident and has a bit contusion of thorax from seatbelt tightening. In case P-05, stretching lap-shoulder seatbelt could hurt the back of head to the seat also. Definitely, seatbelt are important safety device for frontal collision. Thai law enforcement only compelled driver and front passenger to use the lap-shoulder seatbelt when travelling which did not cover to rear passenger. According to the result, the rear passengers have a high risk to get severe injury from striking to the front seat. Therefore, the law enforcement should force occupants to use rear seatbelt also.

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