



ORIGINAL CONTRIBUTION

Sports utility vehicle seat structure simulation of frontal oblique crash

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Index Terms

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Abstract— The seat structure of the Sports Utility Vehicle (SUV) has gained more attention in developing lightweight design using available materials different in grades and their strengths. The SUV industry has drastically shown an incessant growth in the present. By this scenario, safety issues are of interest mainly for the users. This work, therefore, simulates and analyzes an SUV's seat for stress distribution and deformation of its structure using finite element method. The seat is situated in the SUV where it is crashed in the front by oblique angle from 0 degree to 15 degrees adjacent to the straight direction in both right and left sides. This type of collision is considered to be an accident of vehicle resulting in serious injuries. The analysis employs an explicit dynamic simulation during the real frontal impact and includes a direct contact of Asia-EvaRID (ER) model with the backrest. Under the test by simulation conforming to the industrial standards, ECE standards in particular, the seat structure parts of the backrest relative to the sled were measured in displacement of deformation with a minimum interval time of accident, for the velocity ranging from 60 km/h to 100 km/h. The results have explored that the seat structure withstanding the stress distribution and deformation under static load evaluation testing was affected by vehicle velocity and crash direction in an accident. The analysis of the left and right side impact when fastened seat belt generated the maximum stress in the direction of 12.85 degrees head and 6.04 degrees chest from the lateral axis and 4.28 degrees head and 2.01 degrees chest from the lateral axis, respectively. The unfastened seat belt case has shown the maximum distribution at 9 degrees head and degree chest directions over the peak time.

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I. INTRODUCTION

SUV is a seven-seat light-duty truck with large estate carrying space of a minivan or large sedan. Seat comfort is primarily important when it has gained more recognition while the sale market of the SUV becomes larger. However, the issue of safety in transport has been enlarged for attention to people who are occupying the SUVs throughout the world.

The SUV seat structures under oblique frontal crash have been found to be globally important especially for the seatback and head, as by “the uniform provisions concerning the approval of vehicles with regard to the seats [1]”. The industry standards: “ECE Regulation No. 17 mainly examines head restraint [1]” while “JAMA [2]”, “FMVSS No. 208, and NHTSA [3, 4]” measure the crash worthiness of pas-

senger vehicle and specify performance requirements for protection of vehicle occupants in crashes. In general manufacturing process of the SUV seat structures, design and material in terms of strength, durability, and reliability for each single model are different. In addition, average vehicle SUV weight can vary significantly by the model and even the model year of a car.

The main aim of this research work is to analyze the SUV's seat structure in frontal overlap collinear car-to-car crash at the velocity ranging from 60 km/h to 100 km/h, within the 20 degrees side-by-side cushion. The comparison between fastened and unfastened seat belt conditions, and the backrest lock have been examined. The seat model is analyzed using an explicit dynamic simulation and the commercial software package ANSYS. The simulation con-

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ditions are an oblique impact from both in the right and left hands under speed variation. Deformation and stress distribution from the simulation conditions and the subsequent evaluation under the industrial standard are incorporated, related to safety test. In the end, the simulated results have been compared and discussed with those by simulation and experiment obtained from the literature.

II. LITERATURE REVIEW

The standard reference for the head restraints by the E/ECE/324 regulation No.17 [1] is to limit the rearward displacement of an adult occupant's head in relation to his torso to reduce injury of the cervical vertebrae in the event of an accident. For head restraints not adjustable for height, the height shall be not less than 800 mm in the case of front and acceleration applies of not less than 20g [1]. In addition, the standard reference of JAMA [2] on the appropriate static height of head restraint was accomplished using the BioRID model. JAMA examined these hypotheses with an actual car seat in rear effect experiments. The head restraint height equivalent passenger is considered to be in the range of 800 to 850 mm or higher that might affect [2].

In terms of real case scenarios, the reference of research in the Federal Motor Vehicle Safety Standard (FMVSS) No. 208 barrier test and the National Automotive Sampling System (NASS) [3] requires impact speeds up to 48 km/h, including crash modes to characterize the frontal crash and full barrier or oblique frontal impacts [3]. For side impact, the research protocols in the National Highway Traffic Safety Administration (NHTSA) oblique crash tests were performed in both the left and right side impact conditions. The speeds of vehicle crash were applied from 56 km/h to 113 km/h at a 15-degree angle, and 35 to 50 percent overlap. For the test model in this scheme, a THOR 50th percentile male Anthropomorphic Test Device (ATD) is seated for both the driver's and front passenger's positions [4]. [5] analyzed two van seat models using an explicit dynamic simulation for high-velocity frontal impact, starting from 50 km/h to 80 km/h at 0.0193 ms time for the crash condition. In the analysis of the EvaRID and BioRID models, deformation and stress distribution of the seats were determined in three dimensions. Meanwhile, the relationship between the measured data and design specifications of the "H" point and the "R" point is the value of the torso angle [6]. In addition, there was a relationship between body mass index and diabetes depending on age, sex, and region reported in [7]. An ATD was used to predict the drivers' behavioral differences before frontal collisions affect the grav-

ity of injuries suffered by the occupant as reported in [8]. The test condition was that the pre-crash sled was running at the speed of 67 km/h, at 0.873 seconds, the sled collided at the speed of 48 km/h. The kinematics of the THOR dummy were analyzed using finite element method under applied load for two seatbelt types [9]. The subsequent results were the data for the dummy kinematics in the real oblique crash loading condition. Meanwhile, the Global Human Body Model [10] used 3D kinematics data from a series of post-mortem human to test for far-side sled. The test conditions were two low-severities with and without seatbelt, and one high-severity for oblique and lateral impact directions [10]. An investigation on the effects of incorporating a belt-integrated airbag ("airbelt") into a rear seat occupant restraint system has been revealed by [11], at 29 km/h and 48 km/h speed tests. Frontal impact sled tests were performed with a Hybrid III 50th percentile male anthropomorphic test in the right-rear passenger position of a sedan buck [11]. In the seat design for the BioRID dummy, the controlled displacement and the seat deformation in combination with support for the whole spine have been explored either at 15 or 25 km/h [12]. Furthermore, an automotive seat underside impact crash of dynamically validating a typical finite element seat model was used in the virtual development of side impact protection systems [13]. The deformation after the test and differences in the behavior of middle cross member of the backrest are compared.

III. METHOD

A. Sports Utility Vehicle Model

The three-dimensional seat structure model of an SUV manufacturer sold in the market is shown in Fig. 1 with a concise dimension.

B. Reference Data: Characteristics of Body Weight for Seating Positions

The following characteristics of body weight data in Table 1 were applied to frontal oblique impact in left or right crash direction. The mass data for each body segment was estimated based on stature, weight and average size for the position load test [5]. In this work, the calculation of the mass and mass averaged for each body segment from the mass distribution were in the percentage of the EvaRID and BioRID models [6] for Asian men depending on the application: 4 types of the seat height in each model.

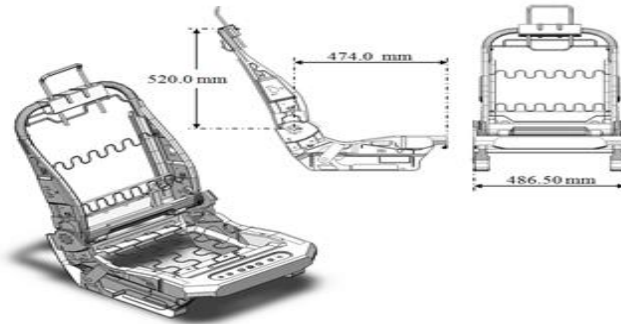


Fig. 1. The 3D seat structure model of SUV manufacturers sold in the market

TABLE 1
MALE'S BODY MASS OF ASIA-EVARID AND BIORID MODELS

Description	Models	Male Body Mass (kg)				Average (%)
		171.36 cm	170.98 cm	169.49 cm	168.17 cm	
Head	EvaRID	3.67	4.01	4.05	4.06	5.71
	BioRID	3.70	4.04	4.09	4.09	5.76
Chest	EvaRID	20.17	22.05	22.30	22.31	31.40
	BioRID	21.79	23.81	24.08	24.10	33.91
Pelvis	EvaRID	16.32	17.83	18.04	18.05	25.40
	BioRID	12.96	14.16	14.32	14.33	20.17
Upper arms	EvaRID	2.85	3.12	3.15	3.15	2.22
	BioRID	3.29	3.59	3.63	3.64	2.56
Lower arms	EvaRID	2.45	2.68	2.71	2.71	1.91
	BioRID	3.67	4.02	4.06	4.06	2.86
Upper legs	EvaRID	11.71	12.79	12.94	12.95	9.11
	BioRID	9.85	10.77	10.89	10.90	7.67
Lower legs	EvaRID	7.07	7.73	7.82	7.82	5.50
	BioRID	8.98	9.82	9.93	9.94	6.99
Total mass	EvaRID	64.25	70.22	71.01	71.07	100
	BioRID	64.25	70.22	71.01	71.07	100

These stature data in Table 1 and weight of body parts were averaged for Asian male adult and Body Mass Index (BMI) from the Asia-Pacific Perspective Redefining Obesity [7]. In this research, the analyzed data defined the mass distribution of 70.22 kg and derived by the EvaRID model.

C. Reference Data: Acceleration for Fastened and Unfastened Seat Belt

From the National Highway Traffic Safety Administration (NHTSA) oblique crash test protocol, the moving

deformation barrier to vehicle crash has the average mass 1,497 kg and the target vehicle speed of 113 km/h with 15° angle and 50% overlap. In addition, for the mass of 2,486 kg and the vehicle speed of 90 km/h, the 15° angle and 35% overlap were used [3-4]. In this work, the average weight of 1,620 kg impacted to a stationary vehicle with the speed range between 60 km/h and 100 km/h, and the 0° to 15° angles.

In the case of acceleration for fastened seat belt, pelvis, chest and head deflections were also used to predict the chest injury for the male occupant. The analysis for standard seat belt system is to run at 47 km/h with the new

center of gravity (CG) for chest acceleration of $39 \pm 0.4g$ and head acceleration $64 \pm 2.5g$ [8].

In the case of acceleration for unfastened seat belt, the NHTSA conducted the test at 40% overlap and the measurement acceleration was by 53.2g of the oblique impact at 47 km/h velocity [3-4]. In addition, the National Automotive Sampling System (NASS) data of the measurement acceleration were by 60g at 60 km/h, and the oblique test vehicles produced intrusion greater than 150 cm [4]. By comparing between NHTSA and NASS data, the 67.50g acceleration with “the starting velocity of 60 km/h is applied to this work for chest deflection, and 108g acceleration for head deflection [7]”.

D. Reference Data: Speed Analysis of the Impact

The quasi-static scheme resulting in partial or complete failure of the seat backrest across the base of the headrest under acceleration load test is more than 20g acceleration according to the Industrial Standard ECE [1] and so on. A high-speed test was the oblique crash in this research starting from 60 km/h to 100 km/h for the crash condition of the 1,620 kg weight SUV that was loaded by the acceleration for the whole body.

E. Reference Data: Speed Analysis of the Impact

The quasi-static scheme resulting in partial or complete failure of the seat backrest across the base of the headrest under acceleration load test is more than 20g acceleration according to the Industrial Standard ECE [1] and so on. A high-speed test was the oblique crash in this research starting from 60 km/h to 100 km/h for the crash condition of the 1,620 kg weight SUV that was loaded by the acceleration for the whole body.

TABLE 2
VELOCITY AND ACCELERATION DATA IN REAL TIME FOR THE SIMULATION OF FASTENED AND UNFASTENED SEAT BELT

Velocity		Acceleration	Time Interval
(km/h)	(m/s)	(m/s ²)	(s)
60	16.67[5]	3964	0.873[8]
80	22.22[5]		
100	27.78[5]		

In Table 2, the model was applied by impact loads to determine head and chest deflection conforming ECE acceleration tests; the input data for acceleration were for

fastened and unfastened seat belt, and the time interval [8]. The dummy for the oblique frontal crash determined the angle under the corresponding crash velocity from the positions of each reference target. By this manner, it shows the reference dimension of a new Center of Gravity (CG) of stature deflection in the axial plane and angular displacement for directions of force.

F. Reference Data: New Center of Gravity of Stature Deflection in Axial Plane

For the fastened seat belt case (Belted), the predicted and measured kinematics for the occupant in the reference and split buckle configurations were observed and collected in Mathematical THOR model evaluation in the oblique near side impacts [9]. The Mathematical THOR model was used to find the new CG of the pelvis and head deflections in x, y and z displacements, at 15° oblique impact and 35 km/h velocity.

For the unfastened seat belt case (Unbelted), the predicted standard posture of the Anthropomorphic Test Dummy (SB Scenario) focused on head and chest deflections in x- and y-axis displacements for the sled frontal collision against the barrier [8] evaluated at the speed of 45 km/h with and without braking. The running speeds of the sled were decelerated from 48 km/h to 67 km/h by breaking, and the sled collides against the barriers.

TABLE 3
NEW CG COORDINATES FROM THE MEASURED REFERENCE DATA

New CG	Body	Dummy CG Coordinates			
		x _i	y _j	k _z	Angle
Head, belted	THOR ^[8]	180 ^[8]	270 ^[8]	188 ^[8]	21.42°
Pelvis, belted	75 ^[8]	80 ^[8]	20 ^[8]	12.24°	
Chest, belted		Pelvis to Chest, 11.25° Approx.			
Head, unbelted		Head to Chest, 15° Approx.			
Pelvis, unbelted	SB 100 Scenario ^[8]	+20% ^[8]	15.53 15° Approx.	+20% ^[8]	
Chest, unbelted	SB Scenario ^[8]	216	158.50	15° Approx.	
		+20% ^[8]	+20% ^[8]		

Table 3 shows in the first three belted cases for the new CGs obtained from the Mathematical THOR for head and the pelvis directions at 15° crash obliquities. For the new CG of the chest direction, the approximation in z-axis displacement at 15° of pelvis deflection and then the new CG of chest would be in x-, y- and z-axis displacement. The CG direction effect of oblique impact reference is depicted in Fig. 2. In addition, TABLE 3 also shows the last three unbelted cases for direction at the new stature after the crash.

In Fig. 2, the Asia-EvaRID analyzed the new CG direction for fastened seat belt case affected by the frontal

oblique impact of SUV's seat structure in single each axis displacements. The H-point to seat end was employed to re-check the seat base from the parameter of bio-fidelity of the Global Human Body Model Consortium 50th percentile male occupant model (GHBMC AM-O) [10]. The GHBMC AM-O occupant model suggested the analysis of whole body kinematic behavior of a 60° oblique impact. In addition, the Asia-EvaRID used a body kinematic behavior in the position between 81 to 133 mm of H-point to seat end.

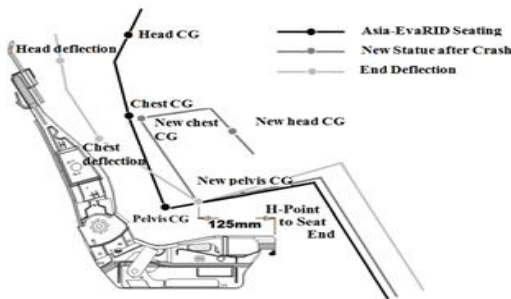


Fig. 2. The 2D-seat structure and Asia-EvaRID model, the new CG direction for fastened seat belt (Belted) as oblique impact on SUV's seat structure, and H-point to seat end

For the unfastened seat belt case, the new CG coordinates were obtained from the SB Scenario (Case III) [8] for the chest direction in x- and y-axis displacements, at 15°. The new CG of head direction was also found regarding the Asia-EvaRID stature at 15°. The direction affected by frontal impact is shown in Fig. 3.

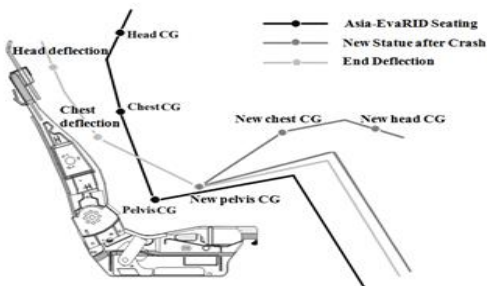


Fig. 3. The 2D seat structure and Asia-EvaRID model, the new CG direction for unfastened seat belt (Unbelted) as oblique impact on SUV's seat structure, and H-point to seat end

In Fig. 3, the Asia-EvaRID results showing the new CG coordinates for unfastened seat belt case were affected by 15° oblique impact on SUV's seat structure in x- and y-axis displacement. The displacement in z-axis was approximated by 15°.

G. Reference Data: Angular Displacement by Side Force

The oblique left side impact test for the cases of fastened and unfastened seat belt resulted in angular displacement by force acting under a stature of Asia-EvaRID model. The angular displacements of the head CG and chest CG are proportional to the force action with the time interval, and acceleration of a rigid mass. The data from a rear test in the case of frontal impacts conform to the following characteristics of seating CG displacements. In terms of angular displacements for fastened seat belt during the left side impact, the new belted head CG was measured for displacement for both reference and split buckle scale configurations. Meanwhile, the new belted chest CG displacement was predicted and measured from a sketch of 3D-CAD Asia-EvaRID model. The new belted pelvis CG displacement was measured for both reference and a stature of Asia-EvaRID model. The H-point of the stature was at pelvis according to chest scale configurations.

The predicted coordinates under oblique crash for the head in the new head CG and the head deflection when belted were calculated from a stature of Asia-EvaRID model and shown in the direction tested as enumerated in TABLES 4 and 5, respectively.

TABLE 4
HEAD COORDINATES FOR THE ASIA-EVARID MODEL FASTENED SEAT BELT AND THE DIRECTIONS OF FORCE IN THE ANGULAR TEST DURING LEFT SIDE OBLIQUE IMPACT

	K _z (mm)	Direction (degree)
New Head CG Coordinates (180.00 _i ¹¹¹¹ , 270.00 _j ¹¹¹¹ , k _z)	Head Deflection Coordinates (-71.75 _i , 313.36 _j , k _z)	Head Deflection
188.00 ¹¹¹¹	-193.98	21.420
150.40	-155.18	17.136
112.80	-116.39	12.852
75.20	-77.59	8.568
37.60	-38.80	4.284
0	0	0

Fig. 4 shows the angular displacement by force acting on the head and chest affected by accident of car-to-car crash, and analytical theory design of humans affects to the car seat and backrest. In terms of angular displacements for

unfastened seat belt, the left side frontal oblique impact was also examined using a stature of Asia-EvaRID. The angular calculation by the reference of SB Scenario data [8] was approximated at 0° to 15° of the new head and chest CGs; the directional test is enumerated in TABLES 6 and 7, respectively.

TABLE 5
CHEST COORDINATES FOR THE ASIA-EVARID MODEL FASTENED SEAT BELT AND THE DIRECTIONS OF FORCE IN THE ANGULAR TEST DURING LEFT SIDE OBLIQUE IMPACT

k _z (mm)		Direction (degree)	
New CG	Chest Coordinates (-161.75 _i , 293.36 _j , k _z)	Chest Deflection Coordinates (-270.00 _i , 222.71 _j , k _z)	Direction
20.00	12.47	10.070	
16.00	7.97	8.056	
12.00	5.95	6.042	
8.00	3.96	4.028	
4.00	1.97	2.014	
0	0	0	

TABLE 6
HEAD COORDINATES FOR THE ASIA-EVARID MODEL UNFASTENED SEAT BELT AND THE DIRECTIONS OF FORCE IN THE ANGULAR TEST DURING LEFT SIDE OBLIQUE IMPACT

k _z (mm)		Direction (degree)	
New CG	Chest Coordinates (540.00 _i [8], 220.00 _j [8], k _z)	Chest Deflection Coordinates (-361.44 _i , 413.03 _j , k _z)	Direction
380.89	116.60	15*	
304.712	93.28	12	
228.534	69.96	9	
152.35	46.64	6	
76.17	23.32	3	
0	0	0	

TABLE 7
CHEST COORDINATES FOR THE ASIA-EVARID MODEL UNFASTENED SEAT BELT AND THE DIRECTIONS OF FORCE IN THE ANGULAR TEST DURING LEFT SIDE OBLIQUE IMPACT

k _z (mm)		Direction (degree)	
New CG	Chest Coordinates (-270.00 _i [8], -198.00 _j [8], k _z)	Chest Deflection Coordinates (-138.43 _i , 182.57 _j , k _z)	Direction
137.54	10.79	15*	
110.03	8.63	12	
82.52	6.47	9	
55.01	4.31	6	
27.50	2.15	3	
0	0	0	

In Table 6 and 7, the head and chest deformations from the crash were in the x-, y- and z-axis directions. The head and chest deflection coordinates and directions were obtained from the data in Tables 3 and 4, a stature of dummy with SUVs seat structure in the x-, y- and z-axis displacements. The angular displacements by side force for the head and chest are shown in Fig. 5.

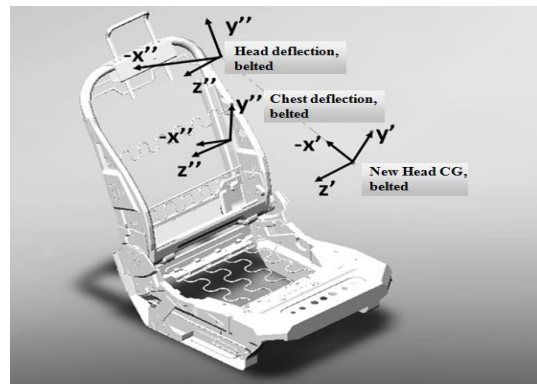


Fig. 4. The 3D seat structure and Asia-EvaRID model: The CG direction for fastened seat belt during left side force

For the right side oblique impact, the new head and chest CGs were simulated for fastened and unfastened seat belts. These generate angular displacements by force under a stature of Asia-EvaRID model. In addition, the new CGs of head and chest were also measured for both the SB Scenario [10] reference and a stature scale configurations.

The data from a real test by [10] were the following characteristics of the 2D (x, y) seating displacements. In this work, the approximated tests are up to +5% in degrees of the new head and chest CGs in the specified crash directions.

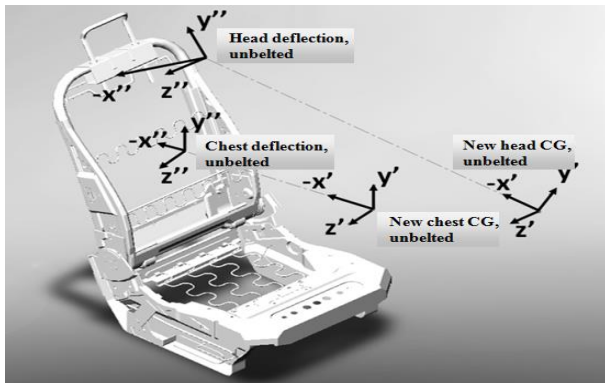


Fig. 5. The 3D seat structure and Asia-EvaRID model: The CG direction for unfastened seat belt during left side force

For the right side oblique crash when unbelted, the displacements were approximated as the same with those of the left side oblique crash with the same coordination.

IV. SIMULATION

The SUV seat structure in 3D CAD model was analyzed for stress intensity factors in the cases of fastened and unfastened seat belt under the oblique frontal crash (0-15°) with loading conditions: different dummy deformation in left and right side impacts and acceleration, using Finite Element Method (FEM) simulation. The preliminary FEM computational results were previously revealed in [5] that the model approach could be used to obtain accurate stress distribution factors and deformation effect for crash damage or failure structure under certain load test conditions.

The seat model was analyzed using an explicit dynamic simulation and ANSYS software; the conditions are impact angle, impact speed, and test device in both right and left sides. In addition, the analysis employs an explicit dynamic simulation during the real frontal impact and includes a direct contact of Asia-EvaRID model with backrest. The tests by simulation were conforming to the industrial standards and ECE standards in particular. The dummy for the oblique frontal crash was analyzed for head and chest displacements, in left side shown in Table 8 to 11, respectively.

TABLE 8
FORCE AT SPEED ON HEAD DEFLECTION FOR FASTENED AND UNFASTENED SEAT BELT DURING OBLIQUE LEFT SIDE IMPACT

Head Deflection	Direction (degree)	Force (N)		
		60 km/h	80km/h	100km/h
Belted	21.42	4,101.55	4,101.55	5,273.42
Unbelted	15.00	4,103.75	5,319.68	5,714.85
Belted	17.14	3,007.34	4,210.28	5,413.22
Unbelted	12.00	4,155.67	5,386.99	5,787.16
Belted	12.80	3,068.21	4,295.49	5,522.77
Unbelted	9.00	4,196.21	5,439.53	5,843.61
Belted	8.57	3,111.93	4,356.70	5,601.47
Unbelted	6.00	4,225.24	5,477.16	5,884.04
Belted	4.28	3,138.26	4,393.56	5,648.86
Unbelted	3.00	4,242.69	5,499.79	5,908.34
Belted	0	3,147.05	4,405.87	5,664.69
Unbelted	0	4,248.51	5,507.33	5,916.45

TABLE 9
ACCELERATION AT SPEED ON HEAD DEFLECTION FOR FASTENED AND UNFASTENED SEAT BELT DURING OBLIQUE LEFT SIDE IMPACT

Head Deflection	Direction (degree)	Acceleration ('g)		
		60 km/h	80km/h	100km/h
Belted	15 degree* (64.0g) ^{[3],[4]}	80.0g	112.0g	144.0g
Unbelted	40% overlap* (60.0g) ^{[3],[4]}	108.0g	140.0g	151.4g

TABLE 10
FORCE AT SPEED ON CHEST DEFLECTION FOR FASTENED AND UNFASTENED SEAT BELT DURING OBLIQUE LEFT SIDE IMPACT

Chest Deflection	Direction (degree)	Force (N)		
		60 km/h	80km/h	100km/h
Belted	10.07	9,905.73	11,503.43	13,101.13
Unbelted	15.00	14,106.64	15,674.05	20,376.30
Belted	8.06	9,961.44	11,568.12	13,174.80
Unbelted	12.00	14,285.13	15,872.37	20,634.08
Belted	6.04	10,004.83	11,618.51	13,232.20
Unbelted	9.00	14,424.47	16,027.18	20,835.34
Belted	4.03	10,035.87	11,654.56	13,273.24
Unbelted	6.00	14,524.27	16,138.07	20,979.50
Belted	2.01	10,054.50	11,676.20	13,297.89
Unbelted	3.00	14,584.25	16,204.73	21,066.15
Belted	0	10,060.72	11,683.42	13,306.11
Unbelted	0	14,604.27	16,226.97	21,095.06

TABLE 11
ACCELERATION AT SPEED ON CHEST DEFLECTION FOR
FASTENED AND UNFASTENED SEAT BELT DURING
OBLIQUE LEFT SIDE IMPACT

Chest Deflection	Direction (degree)	Acceleration (g)		
		60 km/h	80km/h	100km/h
Belted	15 degree* (39.0g) ^{[3],[4]}	46.5g	54.0g	61.5g
Unbelted	40% overlap* (57.8g) ^{[3],[4]}	82.5g	90.0g	97.5g

Those for the right side oblique crash is shown in Table 12 for impact speed analysis during fastened seat belt. The impact speed derived force generated head, and chest deflections by right side impact for unfastened seat belt were approximated and predicted, up to +5% in degrees of those when belted, and are shown for examples in Table 12.

TABLE 12
FORCE AT SPEED ON HEAD AND CHEST DEFLECTIONS FOR
FASTENED SEAT BELT DURING OBLIQUE RIGHT SIDE
IMPACT

Deflection	Force (N)	
Head	3,198.45	4,477.83
Chest	10,878.88	12,633.54
Head	3,292.46	4,609.44
Chest	10,946.41	12,711.95
Head	3,366.18	4,712.65
Chest	10,999.02	12,773.06
Head	3,419.17	4,786.83
Chest	11,036.65	12,816.76
Head	3,448.59	4,828.03
Chest	11,059.25	12,843.00

V. RESULTS AND DISCUSSION

The explicit dynamic simulation and ANSYS software analyses were accomplished during the frontal oblique impact and direct contact of the male Asia-EvaRID model with the backrest. Under the simulation test conforming to industry standards, the test conditions are impact angle, the direction of a crash, and impact speed[14] and [15]. The seat structure parts of the backrest relative to the sled were measured in the displacement of deformation with a minimum interval time of the accident, for the velocity ranging from 60 km/h to 100 km/h.

A. Asia-EvaRID Model Evaluation in Oblique Left Side Im-

part

The Asia-EvaRID model analysis includes maximum deformation in x-axis on peak time and maximum stress distribution of each case with the results shown in Fig. 6 and 7, respectively for the oblique left side impact for both fastened and unfastened cases.

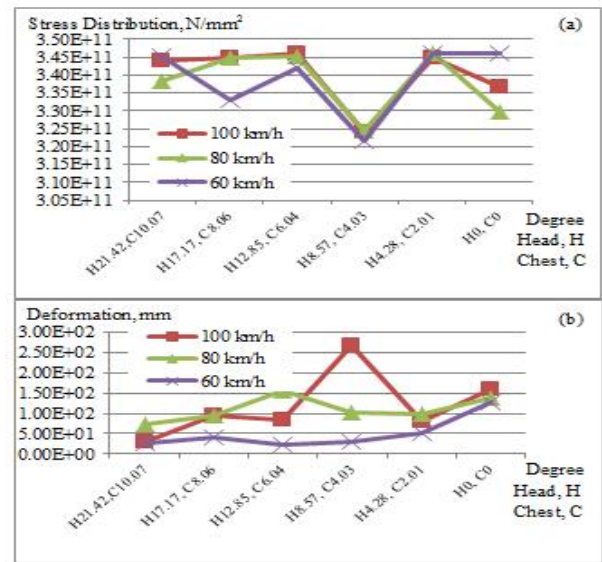


Fig. 6. (a) Maximum stress and (b) Maximum deformation of a male Asia-EvaRID dummy by oblique left side impact during fastened seat belt

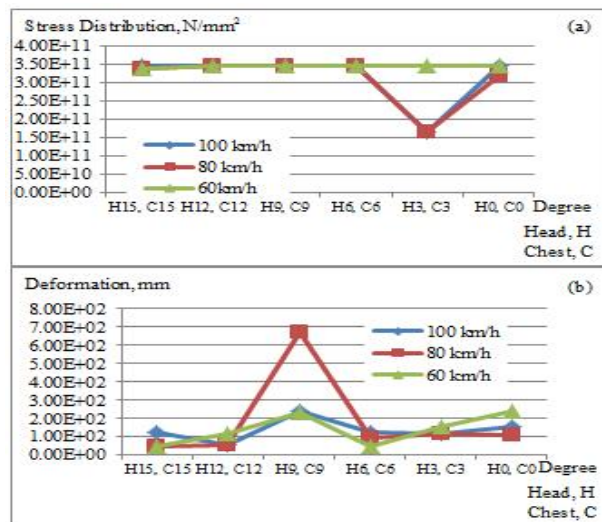


Fig. 7. (a) Maximum stress and (b) Maximum deformation of a male Asia-EvaRID dummy by oblique left side impact during unfastened seat belt

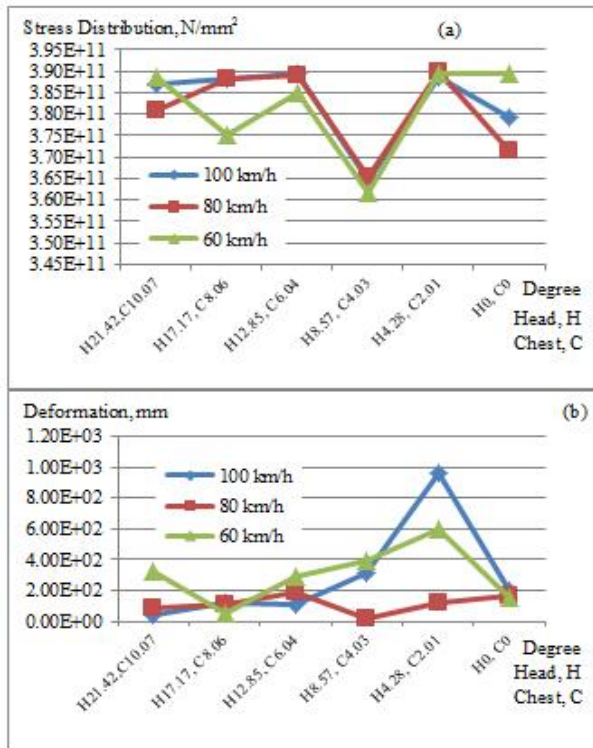


Fig. 8. (a) Maximum stress and (b) Maximum deformation of a male Asia-EvaRID dummy by oblique right side Head impact during fastened seat belt

Based on the results shown in Figs. 6 and 7, the fastened seatbelt case generated the maximum stress by 346.14 MPa and structure deformation by 101.77 mm, in the direction 8.57° at the head and 4.03° at the chest, with 0.01078 second peak time (80 km/h). Meanwhile, the unfastened seat belt case generated the maximum stress by 346.12 MPa and structure deformation by 674.85 mm, in the direction 9° with 0.06748 second peak time (100 km/h).

B. Asia-EvaRID Model Evaluation in Oblique Right Side Impact

The results depicted in Fig. 8 are for the maximum deformation in the x-axis and maximum stress distribution of Asia-EvaRID model evaluation in oblique right side impact for the fastened seat belt case. Their displacements were approximated in the same approach as previously mentioned.

The fastened Asia-EvaRID model generated the maximum stress by 389.73 MPa and structure deformation by 961.36 mm, in the direction 3° with 0.04687 second peak time (80 km/h).

C. Research Survey

The simulation results of the Asia-EvaRID Model are shown in Table 13 in comparison with other models: “the BioRIDII model [12]” and “the ABAQUS model [13]”. Those from the literature were appeared to deform by a crash between 122 and 164 mm at 7 m/s velocity. Meanwhile, from this work, the Asia-EvaRID model appeared to deform the backrest ranging from 111.64 to 152.00 mm at 16.67 m/s velocity. Although the seat structures as the models for deformation prediction were different in design and strength of materials used, deformation behavior is, however, comparable to each other but different in values.

TABLE 13
RESULT COMPARISON TO OTHER RESEARCH ON ASIA-EVARID MODEL

Seat	Model	Reference Data	Impact of Mass (kg)	Velocity (m/s)	Time (s)	Peak time (s)	Backrest Deformation (mm)
A	BioRID II	605-Test Result ^[12] 609-Test Result ^[12]	between 100	7 ^[12]	N.A.	0.129 ^[12]	164 ^[12]
B	ABAQUS	Test Result ^[13] FEA-Result ^[13]	100 ^[13]	7 ^[13]	0.916 ^[13]	0.033	122 ^[13]
C	Asia Eva-RID	Oblique left, belted Oblique left, unbelted Oblique right, belted, unbelted	100	16.67	0.873	0.067 0.002	137.28 111.64 0.002 152.00

VI. CONCLUSION

The SUV seat structure was under frontal overlap crash at the velocity ranging from 60 km/h to 100 km/h with standard references of male Asian stature using EvaRID and Bio-RID models under the backrest locked, and derived by the EvaRID model. The seat simulation model was analyzed in the conditions of impact angle in right and left side crash (0-15°) and speed at 0.873 second collision of vehicle resulting in serious injuries. The predicted results were compared in the cases of fastened and unfastened seatbelts. The dummy had the pelvis CG reference point and the other CGs vary by stature of the dummy.

The analysis shows the stress distribution and the displacement of deformation with a minimum interval time of accident that requires improvement in design to support such a harsh condition of the SUV’s passenger usages at present. The unfastened seatbelt case displayed the highest deformation structure and highest distribution stress than those of the fastened seatbelt case.

The analysis of Asia-EvaRID tests for fastened seatbelt has shown the maximum stress distributions and structure deformation in the oblique right side impact at 3° for head and chest at 0.04687 second peak time. For the crash in both sides, the fastened seatbelt cases resulted in higher tensile strength than the unfastened seatbelt cases. In com-

parison, the Asia-EvaRID in the left side impacts the structure deformed to a greater extent than that of the right side impact. This ongoing work precedes the upcoming determination of standard model effects and dynamic tests on seat structure. This presumes a provision of a deeper understanding of the potential benefits of different models, failure modes, side effects, and seatbelt conditions.

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— This article does not have any appendix. —