Study of Motorcyclist's Injury Patterns in Motorcycle-Pickup truck Collision using Finite Element Simulations

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I. INTRODUCTION

Motorcycles (MC) have become the most popular means of transport in ASEAN countries. Almost 300,000 accidents involved MC in Thailand each year [1]. MC users including child pillion passengers were the most vulnerable road users accounting for 74% of all road fatalities in Thailand [2]. Injury proportion of child pillion passengers were as high as 62% [3]. Passenger cars (40.6%) were identified as the most frequent collision partners for MC while the pickup truck constituted 14.9% [1]. Improvement of countermeasures requires understanding of kinematics and injury mechanisms of the MC occupants. Carmai et al. [1] carried out some studies on kinematics and injury of motorcyclist during MC-to-car collision. Pedestrian-vehicle collision studies [4-6] reported that post-crash kinematics were affected by type of other vehicles. Kinematics of MC occupants play an important role in the injury outcomes. Therefore, the aim of this paper is to numerically study the injury patterns of the motorcyclist and a child pillion passenger in MC-to-pickup truck collision using finite element human body models and compare kinematics and injury outcomes with those obtained from [1].

II. METHODS

With the common motorcycle accident scenarios identified by Carmai et al. [1], two impact configurations including, motorcycle impacting other vehicles (MC-OV) and other vehicle impacting motorcycle (OV-MC) were selected for the present study. A finite element motorcycle-pickup impact model consisting of a motorcycle, a pickup truck, a rider and a child pillion passenger, was developed for both impact configurations. A validated pickup truck model was taken from the NCAC [7]. A small motorcycle with a capacity less than 125cc was selected due to the highest domestic sale in Thailand (86%). The model was developed using reverse engineering and preliminary validated as detailed in [1]. Fifth percentile and six-year old human body models (THUMS) were employed as a rider and pillion passenger. Pre-simulation technique was utilized to position THUMS onto the motorcycle. Friction coefficients of 0.1 and 0.3 were assumed for the contact between THUMS and other parts as well as the pickup-ground-motorcycle respectively. Four cases were simulated as shown in figure 1. Case 1 and 2 were selected to represent scenario when MC changing lane, overtaking, turning or making a U-Turn. The pickup therefore was set to impact the MC (OV-MC configuration). Case 3 and 4 were selected to represent scenario when the pickup was changing lanes, making U-turn or turning right across MC's path (MC-OV configuration). The MC was set to impact the pickup at its lateral side and at the front bumper.

Fig. 1. Model set-up for (a) Case 1: pickup impacting lateral side of MC (b) Case 2: the front corner of pickup impacting MC (c) Case 3: MC impacting pickup at ½ pickup length (d) case 4: MC impacting pickup at the front corner.

III. INITIAL FINDINGS

Overall kinematics obtained from case 1 and 2 simulations with OV-MC configuration are shown in figure 2

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and 3. The pickup front bumper was first in contact with the low extremities and hips of the rider and the passenger and rapidly attained the contact with the upper bodies due to the high bumper height. The upper torso of both occupants laterally bent around the hood leading edge. The head hurled towards the front-end and impacted the hood. Table 1 summarises the injury measures for all cases. The HIC were quite low for both case 1 and 2. This implied low risk of skull fracture. This was because the first impact was mainly on the torso. However, it was found that the brain CSDM-0.25 of the child from both cases were above 42.5% which led to high risk of diffuse axonal injury (figure4). For case 1 the pickup directly impacted at the back of a child first, rib 3,4,5,6,7,9 had stress exceeded the fracture limit (figure 4) while only rib 9 of the rider had stress beyond the fracture limit (figure 5). For case 2 in which the pickup impacted at lateral side of the MC. It was found that child's rib 2,3,8,9 and the rider's rib 8,9 had stress beyond fracture limit. More than 80% of lung volume of both occupants in both cases experienced pressure beyond 10kPa (figure 4 and 5). For both cases the rider's pelvic and femur stress was high but still below the fracture limit. However, it was found from case 1 that the child's left tibia was bent outward due to the MC frame and fuel tank. The child's tibia stress on the non-impact side was beyond the fracture limit (figure 4). While for case 2, both rider's and child's tibia experienced high stress beyond 130 MPa on the impact side. Almost 50% of liver volume had strain exceeded 0.3 threshold due to the first impact of the front end to the upper bodies. Risk of liver contusion was possible.

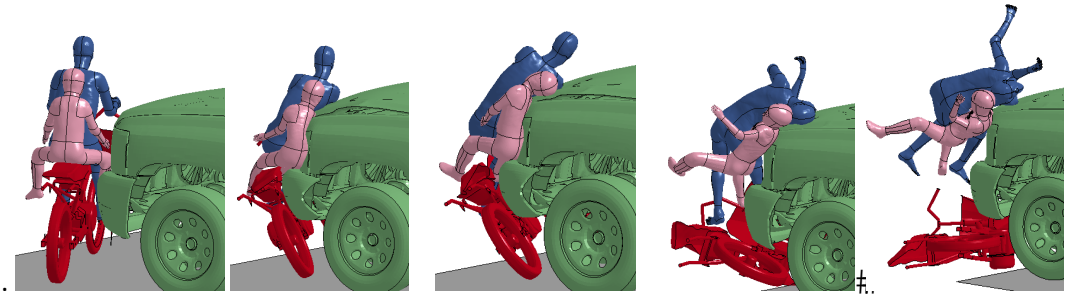

Fig. 2. Kinematics of MC occupants during the front corner of pickup impacting MC at 65° with velocity of 40km/h (case1)

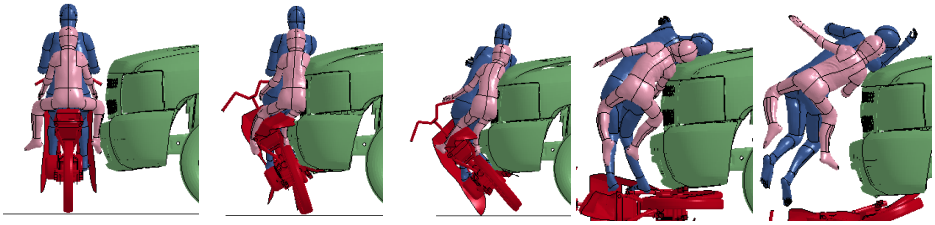

Fig. 3. Kinematics of MC occupants during the front-end of pickup impacting MC at 90° with velocity of 30km/h (case2)

Table 1 Summary of injury measures of all four simulation cases

Injury index	Criteria Injury type	Case 1(OV-MC) Rider	Case 1(OV-MC) Child	Case 2 (OV-MC) Rider	Case 2 (OV-MC) Child	Case 3(MC-OV) Rider	Case 3(MC-OV) Child	Case 4(MC-OV) Rider	Case 4(MC-OV) Child
HIC	700 -skull fracture[8]	400	790	169	243	1436	885	692	943
Brain-CSDM	42.5% - DAI [9]	<1%	66%	<1%	55.7%	<<42.5%	58%	<<42.5%	40.8%
Rib stress	130MP-fracture [10]	Rib 9>130	Rib 3-7 and 9 >130	Rib 8,9>130	Rib 2,3,8,9> 130	Rib3,4,5, 6 >130	<130	Rib4 >130	<130
Lung pressure	±10kPa-contusion [11]	85%vol	84% vol> 10	86% vol> 10	83%> 10	95%vol> 10	85%vol >10	98% vol> 10	95% vol >10
Femur stress	130MPa-fracture [10]	<130	<130	<130	<130	<130	<130	<130	<130
Tibia Stress	130MPa-fracture [10]	<130	>130	>130	>130	<130	<130	<130	<130

Overall kinematics resulted from simulations case 3 and 4 with MC-OV configuration are shown in figure 6 and 7.The front wheel of the MC hit the pickup and slipped underneath the pickup truck at the impact point. Both rider and child passenger were translated towards the impact point while the MC tilted and laterally fell onto the ground. The rider's hand and upper extremities impacted the pickup structure followed by the rider's torso and head. The rider's head impacted to the door frame near to B-Pillar in case 3 and to the hood in case 4

resulting in HIC of 1436 and 692 respectively. Case 3 has high risk of skull fracture but little risk of DAI. As the child pillion passenger translated together with the rider, the head and upper body impacted to the rider's back. Child's HIC was 885 and 943 respectively. Child head had low risk of skull fracture. However, the child CSDM-0.25 were quite high and exceeded the threshold for diffuse axonal injury (table1). Due to the direct impact of torso to the vehicle structure, ribs 3,4,5,6,7 and 9 in case 3 had high risk of fracture as shown in table 1 and figure 7. Similar to case 4 of which rib 9 had potential for fracture. Large compression of thorax was seen. Both rider and child had large volume of lung which experienced pressure greater than 10 kPa. This implied high risk of pulmonary contusion.

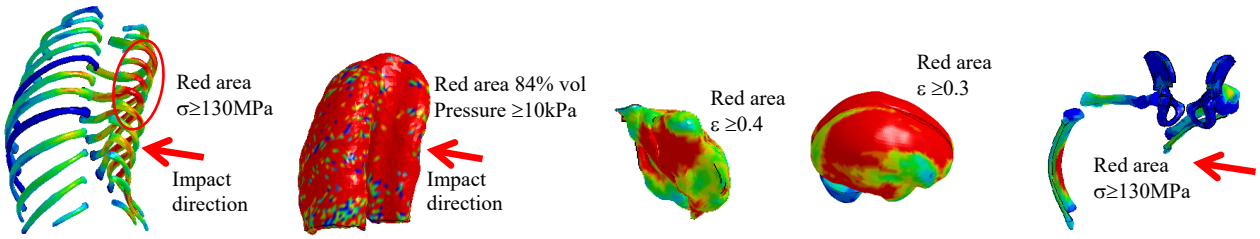

Fig. 4. shows contour plot of child's (a) rib stress (b) lung pressure (c) liver strain (d) brain strain (e)tibia stress obtained from simulation case 1.

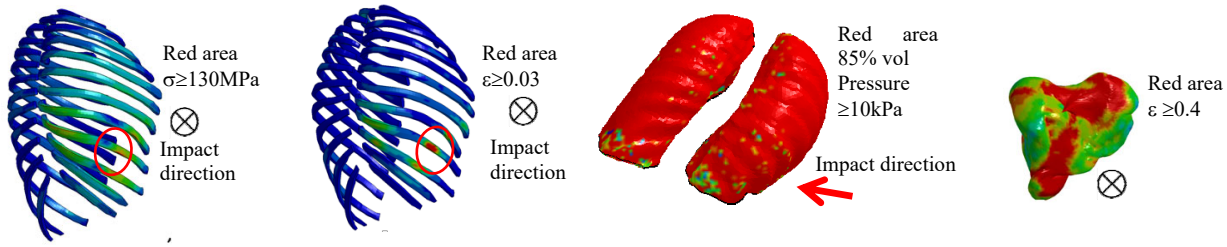

Fig. 5. shows contour plot of rider's (a) rib stress (b) rib strain (c) lung pressure (c) liver strain obtained from simulation case 1.

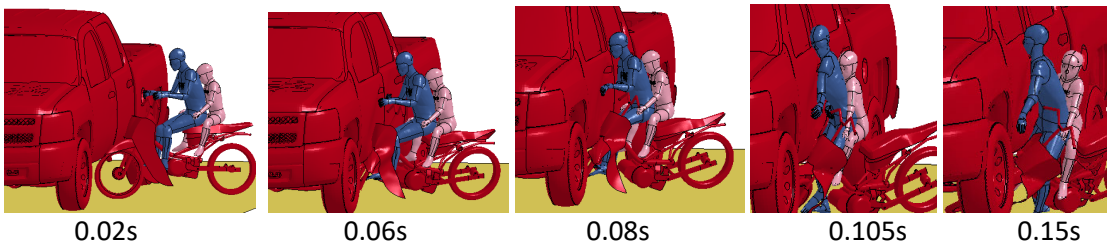

Fig. 6. Kinematics of MC occupants during MC impacting lateral side of pickup at 60° with velocity of 40km/h (case3)

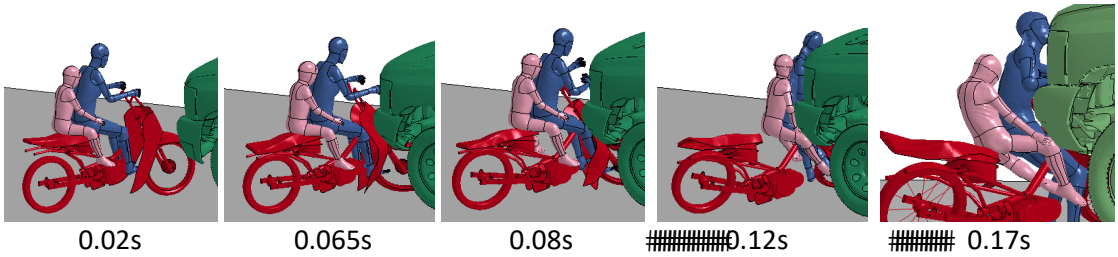

Fig. 7. Kinematics of MC occupants during MC impacting the fron corner of pickup at 120° with velocity of 40km/h (case4).

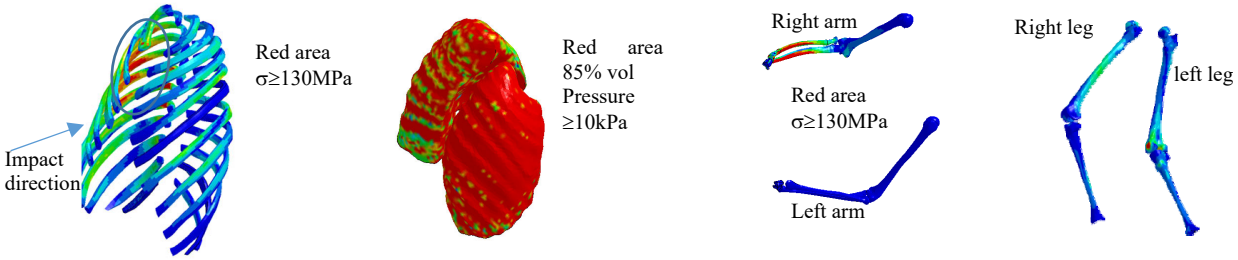

Fig. 8. shows contour plot of rider's (a) rib stress (b) lung pressure (c) humorous stress (d) lower extremities stress obtained from simulation case 3.

IV. DISCUSSION

Rider and child pillion passenger kinematics and injury patterns during collision with the pick-up truck were classified into two overall patterns. The first pattern generated when the pickup truck impacted the MC and the other generated when the MC impacted pickup truck. For the pickup truck impacting MC, the upper bodies of both rider and passenger were directly impacted by the pickup front-end and bent around the hood leading edge. This led to severe thorax injury. High risk of multiple rib fractures were observed in both rider and passenger. Pulmonary and liver contusion was possible due to high lung pressure and liver strain. The heads impacted the hood last before rebounding. The skull fracture due to head impact was unlikely as the HIC value was low. Most of the impact energy was absorbed by the torso during the first contact with the pickup front. Even though the HIC was low but the child brain strain were high in both case 1 and case 2. The CSDM-0.25 for the child's brain exceeded 42.5% which implied high risk of DAI. The main injury outcome was due to the direct impact of the front-end of pickup truck on the torso. The kinematics and injury mechanisms of the rider and passenger resulting from the pickup impact show significantly different from those resulting from the passenger car impact. When a passenger car impacting the motorcycle, the impact point was located below the pelvis of both rider and passenger. The pelvis of both occupants ran onto the hood both upper bodies twisted and move towards the passenger car front [1]. Whereas a pickup impacted around the pelvis and upper body area. The pelvis were restrained from running onto the hood. The upper body instead bent towards the front end causing different injury mechanism. The main severe injury in the car impacting the MC was the head injury while in the pickup impacting the MC was the thorax injury.

For the MC impacting the pickup truck, both rider and pillion passenger translated together towards the impact points while the front wheel of the MC deformed and slipped underneath the pickup truck. The rider's lower and upper extremities moved forward and impacting the vehicle structure which could result in risk of tibia and humorous fracture. The torso then impacted the vehicle structure leading to possibility of thorax injury. Head injury severity depends on the vehicle parts that head impact to. For example in case 3 the head stroke the door frame near to the B pillar which is a very stiff part, the HIC was then quite high but if the head striking the hood the HIC would be lower. The child pillion passenger had lower risk of severe injury when comparing with the child passenger in the OV-MC configuration. This is because the child was at the back of the rider and translated together during impact, the possibility for the torso and head impacting the vehicle structure was low regardless of ground impact. However, the lung injury could occur due to thorax compression with the rider's back. The kinematics and injury mechanisms from MC impacting pickup were similar to the results in [1] for the MC impacting the passenger car. Slight difference can be seen at the front wheel of the MC which deformed and slipped underneath the pickup. This could also lower the height of the handlebar during the impact and could lead to lower possibility of the rider torso to impact the handlebar. The initial findings highlights the injury patterns resulting from MC-Pickup collision which are different from the passenger car impacting the MC. The main injury mechanisms found are due to torso impact leading to thorax injury. This proposes that helmet usage may not be enough for rider and passenger protection. Chest protection also needs to be considered. In addition, motorcycle child seat which has leg and side protection could also help mitigate child pillion passenger injury. It is noted that for case 3 and 4, the pickup was set stationary. If the pickup is moving at low speed, the overall kinematics of the occupants may not differ much. However, the locations on the pickup where the occupants impact to will be different due to the relative motion of the vehicles. Further work can be carried out with both vehicles moving to investigate the occupants' interaction with the pickup. This initial work has subjected to limitations that THUMS internal organ impact response validity was only confirmed for the force conditions selected by [12]. In addition the validity of CSDM to predict the occurrence of DAI [9] has not yet been approved.

V. ACKNOWLEDGEMENT

The authors would like to thank Toyota Motor Corporation for the financial support of this study (LPD002342).

VI. REFERENCES

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