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RESEARCH ARTICLE

SIMULATION OF CAR-PEDESTRIAN CRASH: INJURY ASSESSMENT AND IMPACT POSITIONS

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Abstract

In car-pedestrian collisions, pedestrian fatal injuries account for a great number of health risks in the world. A real-world accident case with a medical examination record would improve the reliability of simulation of car-pedestrian accidents but is rarely captured. The goal of this report was to assess the pedestrian injuries, and impact positions. A case of a pedestrian impacted by a car traveling at a speed of 22 km/hr was simulated using the MAthematical DYnamic MOdel (MADYMO) program. The results showed that Abbreviated Injury Score one (AIS1) head injury and Abbreviated Injury Score two (AIS2) toe fracture are caused by pedestrian impact with windshield and wheel. The maximum head linear acceleration and right foot force that led to head injuries and toe fractures are 1688.61 m/s^2 and 15799.00 N, respectively. The results obtained in terms of head impact location, left forearm impact, and the right foot impact positions are comparable with the real-world road accident. This report can help in the future design of automobiles that are friendly to vulnerable pedestrians.

Introduction:-

In recent years, traffic road accidents have become a major problem threatening the lives of road users in the world. According to the World Health Organization (WHO), it is reported that about 1.2 million road users die and 50 million tolerate injuries every year due to road accidents. It is predicted that road accident cases in fast developing countries are likely to be the third major contributing factor to global disaster in coming years [1]. In 2008, the United States estimated the number of pedestrians who were killed in road accidents to be 4,500 and 69,000 injury cases [2]. In 2013, out of 84,589 people who were killed in road accidents in Europe, 39% of the death cases were among cyclists, motorcyclists, and pedestrians [3].

Even though efforts to avoid injuries resulting from car-to-pedestrian collisions are underway [4, 5, 6], China's pedestrians are frequently exposed to road collisions with less protection due to increased motorization. In 2012, the Chinese Ministry of Public Security reported approximately 15,000 deaths, accounting for at least 25% of yearly road accident injuries [7]. One of the major problems the world is facing today is car-pedestrian impacts. Due to this health problem, researchers have been experimenting and simulating car-pedestrian impacts with focus on methods to mitigate fatal accidents.

Among several computer programs that can be used for the reconstruction of car-pedestrian collisions, MAthematical DYnamic MOdels (MADYMO) program is always adopted for the evaluation of model's biofidelity and injuries [8, 9].

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The consequences of severity impact on different body regions of pedestrians have been well examined. Other studies showed that pedestrian injuries concentrate on some body parts such as head, pelvis, and lower limbs [10, 11, 12]. The distribution of injuries to each of the body parts has various severity scores. The mini buses and the light passenger cars have been regarded as the major cause of pedestrian’s head and foot injuries [13].

In the simulation of car-pedestrian scenarios, pedestrian injuries and impact positions have been found and compared with the real-life crash. The pedestrian incurred minor head injuries (AIS1), and moderate toe fractures (AIS2). The results have been validated successfully against real accident reports. The pedestrian’s head, left forearm, and the right foot impact locations against the car have been proven for the visual comparison of pedestrian kinematics. Liu et al. [14] reported that angle collision is considered as one of the common types of accidents in car-pedestrian impacts. As head injuries to pedestrians have been specified as the highest cause of injury and death in road accidents, a number of studies have analyzed the pedestrian response and head impacts against cars and found that the impact positions varied according to the height of pedestrian and car during impact time [15].

Despite the fact that various investigations concerning car-pedestrian impacts have been simulated to avoid fatal injuries in both developed and developing countries [16, 17, 18], it is alarming that pedestrian injuries pose health risks. This report assesses the pedestrian injuries, and impact points or positions.

Method and Materials:-

The reconstruction of the accident was performed by using a multibody MADYMO program in order to assess the pedestrian injuries, and locate impact positions on the car. From the simulated car-pedestrian accident, the maximum resultant linear acceleration, angular acceleration, linear velocity, and angular velocity values were found using MADYMO program and plotted using Altair HyperGraph. The results obtained from MADYMO and Altair HyperGraph were considered for pedestrian head and foot injury, and impact locations.

Accident description

The accident took place on South Lushan road, number 1096, Changsha City, Hunan Province, China. After the car-pedestrian crash, the researchers (Jiang Xiaoqing, Prof. Li Fan, and Jikuang Yang) from Hunan University with a medical and traffic police authority team traveled to the scene to collect the data. The detailed information regarding the car (type, model, mass, and dimension), pedestrian (gender, age, height, and weight), and environment (road surface, and weather) during the pre-impact, impact, and post-impact phases was recorded. The skid marks, final location of the car and the victim after the collision, and the contact locations on the car were documented.

A male pedestrian was crossing the road from west to east when he was hit by the Honda Accord (2001 model) with an estimated impact velocity of 25 km/h. The initial speed of the victim was about 3 m/s. The weather was fine and the road surface was asphalt concrete. The driver got a sight of the pedestrian and braked the car. The right front wheel pressed on the right foot of the pedestrian. His leg impacted on the fender and his head impacted on the windscreen. The Throw Out Distance (TOD) was 2.4 metres and the Wrap Around Distance (WAD) was 2.24 metres. The injuries sustained by the pedestrian were documented after forensic examination: scalp hematoma with AIS1, and right foot toes fracture with AIS 2.

Figure 1:- Impact locations of the male pedestrian on the Honda Accord 2001 model.

Simulation Results:-

Figure 2 shows the pedestrian model in a running position and the car moving at speed of 22 km/hr. The simulation is presented in a three-dimensional animation file and it lasts for 2000 milliseconds (2 seconds). The pedestrian's right knee contacts the right front wheel of the car at 20 ms. The pelvis impacts with the right fender and the left forearm contacts with the hood at the same time (30 ms). The right front wheel of the car presses the pedestrian's right foot at 60 ms. After the pelvis and left forearm have collided with the car, the pedestrian's whole body starts to rotate in a clockwise direction at 70 ms. The head of the pedestrian hits the windshield of the car at 150 ms. The pedestrian's head strikes the ground at 780 ms and the body completely comes to rest at 2000 ms.

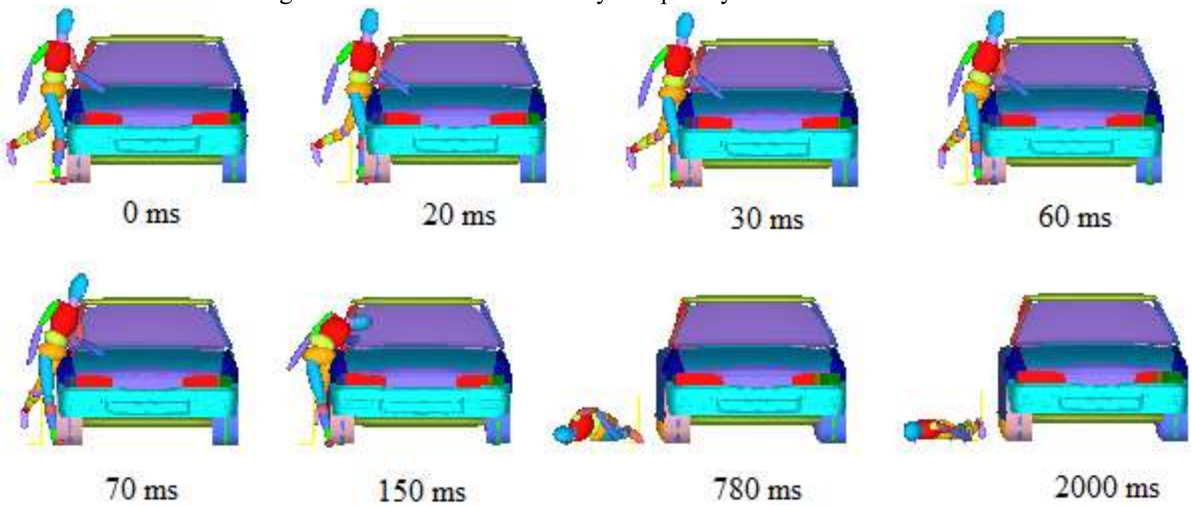

Figure 2:- Simulated impact phase.

Pedestrian kinematic response during impact

In figure 3, it is observed that head acceleration increases to 120.68 m/s^2 at 6.53 ms before it reduces to 2.63 m/s^2. After the car's front right wheel has pressed the pedestrian's right foot, the acceleration increases to 225.892 m/s^2. The head struck the windshield with acceleration of 1208.74 m/s^2 at 147.52 ms. The pedestrian continued to rotate in a clock's hands direction while the pedestrian's head was moving with linear acceleration. The pedestrian's head collided with the asphalt at 771.54 ms with maximum acceleration of 1688.61 m/s^2.

The angular head acceleration curve of the pedestrian model is also displayed (Figure 4). It can be noted from the curve that the head suffered two major strikes; the first strike occurred at 146.60 ms when the head hit the windshield, and the second strike occurred at 774.10 ms when the head hit the ground. The corresponding angular acceleration peak values at the time of the strikes were 15314.10 rad/s^2 and 13593.4 rad/s^2, respectively.

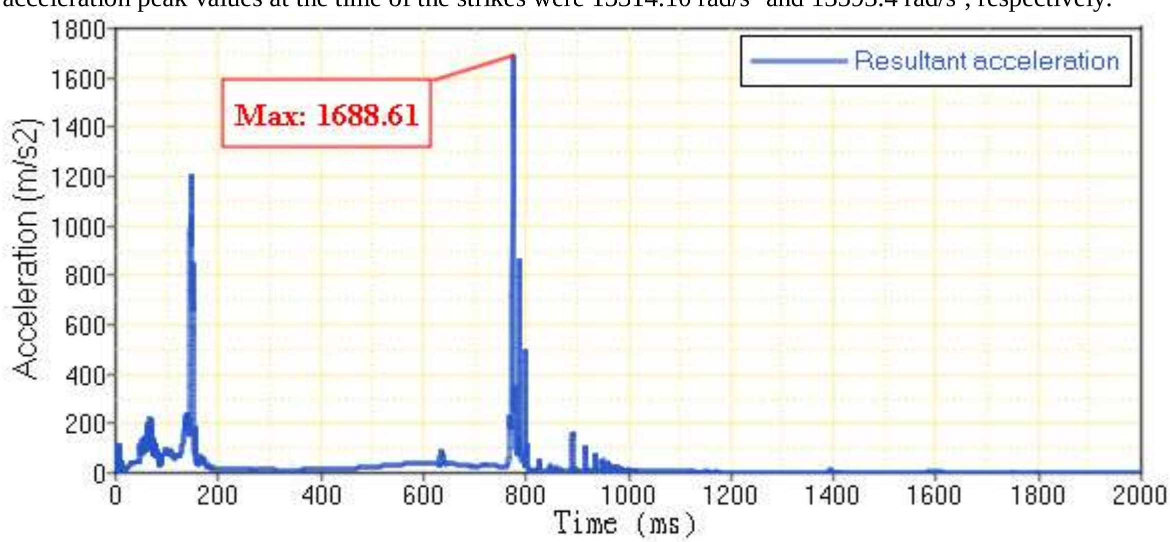

Figure 3:- Head linear acceleration curve.

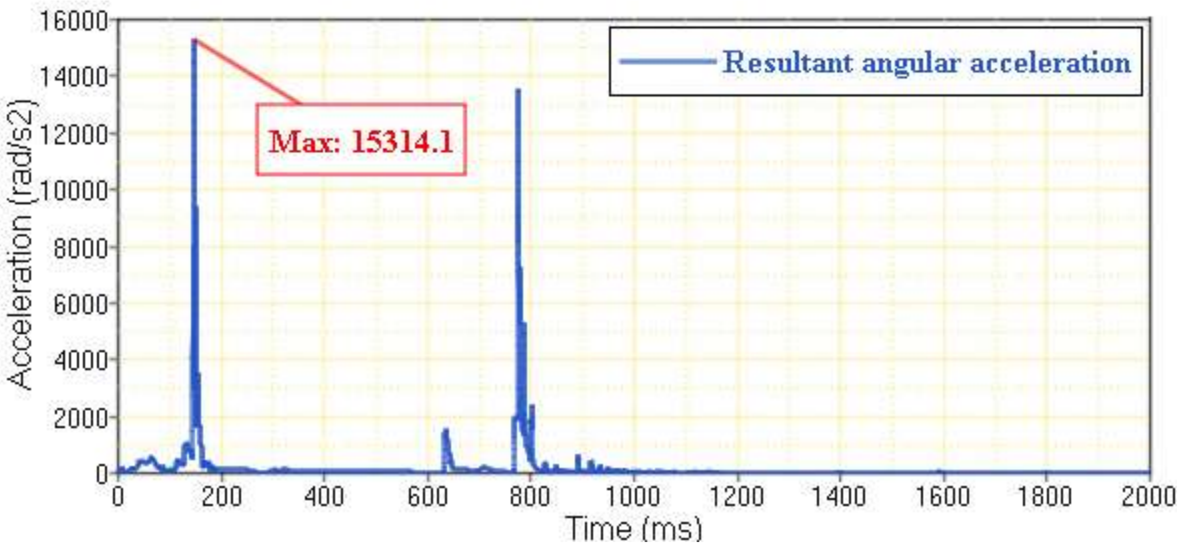

Figure 4:- Head angular acceleration curve.

Pedestrian injuries

To be able to understand how the pedestrian was injured, it is important to deal with each injured part and give its Abbreviated Injury Score (AIS). An AIS value tells whether the injuries sustained by the pedestrian are minor, moderate, serious, severe, or critical. Table 1 shows the simulation results of injured parts of the pedestrian.

Table 1:- Pedestrian injury results.

Injured part	**Max. linear acceleration and time**	**Max. angular acceleration and time**	**Max. angular velocity and time**	**HIC15**	**3 ms**
Head	1688.61 m/s^2, 774.10 ms	15314.0 rad/s^2, 146.60 ms	31.83 rad/s, 144.20 ms	938.15 m/s^2	337.00 m/s^2
Left Thigh	928.66 m/s^2, 5.70 ms	-	-	-	-
Right Thigh	5599.70 m/s^2, 5.69 ms	-	-	-	-

Pedestrian impact positions on the car

From figure 5, it can clearly be seen that the results obtained in terms of head impact location, left forearm impact, and the right foot impact positions are comparable with the real-world accident. The total throw distance noticed from the simulation result is 3.21 m at a maximum time of 2000ms, which is fairly comparable to the real situation.

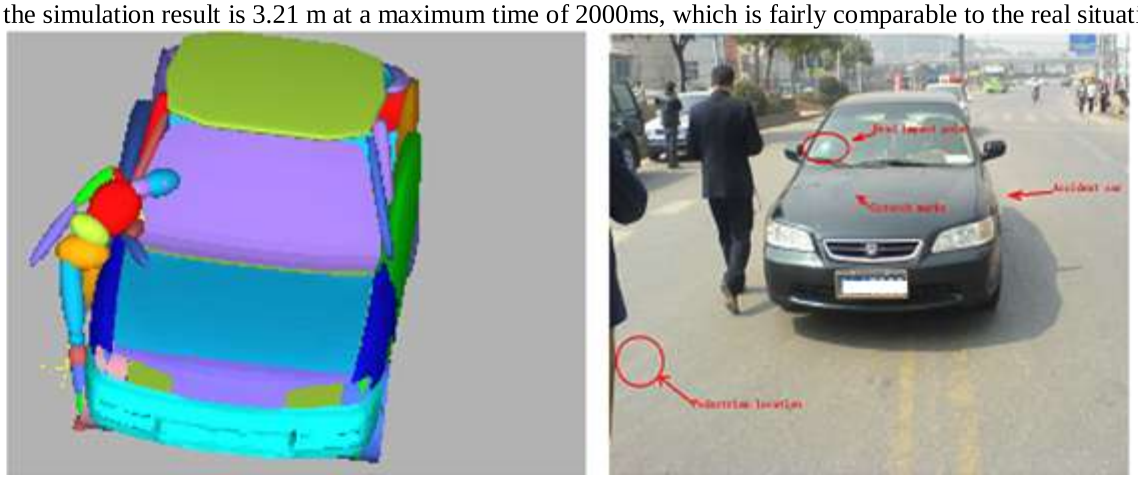

Figure 5:- Comparison between simulation impact location and real impact point on the car.

Discussion:-

Table 1 lists the pedestrian head injury. It can be found that AIS1 head injuries (scalp haematoma) were caused by head impact with surface ground. The HIC_{15} (time interval limited to 15 milliseconds) and 3 ms (time interval limited to 3 milliseconds) that corresponds to AIS1 are 938.15 m/s^2 and 337.00 m/s^2, respectively. The numerical result of head injury is consistent with other findings reported by Fredriksson et al. [19], and Ohlin et al. [20]. The Head Injury Criterion (HIC) is considered to be within the safety range when linear acceleration is no more than 1000 [21, 22]. The throw distance obtained from the simulation result is closely in comparison with recorded real distance.

For pedestrian head impact, there was evidence of correlation between the maximum resultant linear acceleration and the severity of head injury (Figure 3). Probably, there may also be a severe injury to the head at 1688.61 m/s^2 for pedestrian's head contact with the surface road. In a study of pedestrian responses and head injury evaluation, Peng et al. [23] predicted that 50% of head injuries for AIS2+ and AIS3+ were caused by head linear acceleration greater than 1160 m/s^2.

Head injury is mainly caused by high impact applied to the neck and head when the body is speedily accelerated. This can result in scalp haematoma, concussion, and skull fracture. As illustrated in figure 4, it can be observed that the injury to the head at an angular acceleration of 15314.10 rad/s^2 is a minor case. This keen observation is supported by other studies conducted by Fijalkowski et al. [24], King et al. [25], and Zhang [26].

In terms of impact locations; the head, left forearm, and right foot agree well with real-life car-pedestrian crashes. The car-pedestrian impact position depends on the car size and front-end profile, pedestrian height, and impact speed. From the simulation of car-pedestrian collision, it was clearly noted that primary impact (contact between pedestrian's head and car) increased the severity of head injury over secondary impact (contact between pedestrian's head and surface ground). This finding is in line with the observations of Zhao et al. [27], and Oh et al. [28].

Conclusion:-

The work in this paper is aimed to take further steps in the assessment of pedestrian injuries using real world cases. A real case of a car-pedestrian accident is reconstructed using the MADYMO program in order to evaluate pedestrian injury conditions. As expected, it was found that the pedestrian has minor head injuries (AIS1) and moderate toe fractures (AIS2). The maximum head linear acceleration and right foot force that led to head injuries and toe fractures are 1688.61 m/s^2 and 15799.00 N, respectively. These findings are validated against the hospital reports. Furthermore, the results obtained in terms of head impact location, left forearm impact, and the right foot impact positions are comparable with the real-world road accident. The marked areas on the car are windshield, hood, right fender, and the right wheel of the car. The findings of the simulated car-pedestrian model can help in the future development of automobiles that are friendly to vulnerable pedestrians. In order to address challenges resulting from the simulation of car-pedestrian accidents, more road accident cases with forensic medical examination records are needed to get reliable data for further assessment of injuries of pedestrians and impact locations.

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