Study on Lower Extremities Injury in Pedestrian Accidents

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Abstract: The aim of the present work was to investigate the relationship of the mechanical load level to injury severity of the pedestrian lower extremities injury in the urban area of China. Accident data of four cases were recorded and reconstructions with mathematical method were carried out. The mechanical load suffered by the lower extremities was compared with the injury severity. It shows that the pedestrian in urban area have great risk to suffer lower extremity even in a low-speed impact with typical vehicle. A lower extremity model with redefined load index and tolerance will predict the long bone fracture in pedestrian accident correctly.
Key words: pedestrian accident, lower extremity, accident reconstruction, dynamic response

1 Introduction

It was reported that about 1,270,000 persons died in road traffic accident annually, 46% of them was vulnerable road user [1]. Researchers from Europe and Japan have done lots of works in pedestrian protection. Standards for pedestrian protection had been implemented for several years and there are lots of design styles for pedestrian protection for vehicle frontal structure. In Europe, the fatal injury risk of pedestrian was reduced 36.6% in the past decade [2]. In China, pedestrian protection is a new challenge. The Chinese standard for pedestrian test is a copy to the Global Technical Regulation for pedestrian protection. It's still unknown how dangerous the current running vehicle will be for pedestrian in a road accident.

Fortunately, Researchers from universities and institute have started investigation work in road accident, such as Tongji University in Shanghai, Hunan University in Changsha and CAERI in Chongqing. On-site investigation data is very useful to study the injury risk of car-pedestrian impact. It's important to establish the injury index to evaluate the risk of pedestrian injury to a specific vehicle in urban area of China. As the first step, this paper studied the investigating data of pedestrian accident recorded by Vehicle Transport Safety Center (VTSC) of Hunan University[3]. Four cases were represented and used for reconstruction. The dynamic response of pedestrian and the mechanical load suffered by the lower extremities were analyzed to study the correlation of the limitation of mechanical load to injury severity of lower extremities in pedestrian accidents.

2 Material and method

2.1 Accident data

Lower extremities and head are the most frequent injured region in pedestrian accident. In the car-pedestrian impact, the lower extremities often suffer bone fracture and knee injury (ligament rupture and other soft tissue injuries). These injuries result in long-time treatment and loss of moving capabilities. Statistic data shows the frequency of pedestrian injury in head and lower extremities (Table 1). In pedestrian accidents, vehicle frontal regions impacting the lateral side of pedestrian is the most frequent accident type and often result in injuries in lower extremities.

Table 1 Distribution of injuries by body region

Country/City	Hannover, Germany	Changsha, China	Chongqing, China
Head (%)	37.5	31.3	44.5
Low limbs (%)	54.1	51.3	22.4

VTSC in Changsha has started to study pedestrian accident since 1990's. The center collects not only the statistic data from police database, but also on-spot accident data with a special investigating team. An in-depth accident database was established. Through cooperation and project, we queried specific cases to study lower extremities injury. The sample criteria were described as below:

(1) The vehicle type is sedan, and it is better for a popular car, such as the vehicle used as taxi.
(2) The victims suffer an AIS 2+ injury in lower extremities.
(3) The pedestrian was impacted in the lateral side.

In this paper, three cases with different low limbs' injuries were represented, and a case with specific vehicle and no injury in the lower extremity was compared with them.

2.2 Reconstruction methods

Multi-body dynamic analysis was conducted to implement the accident reconstruction. The CPM pedestrian model, which was validated at Chalmers University, was used as the reference model. In each case, pedestrian model was adjusted based on the victims' height and weight (Table 2). This pedestrian model has a breakable leg model to predict the bone fracture. Two rigid bodies were connected with a spherical joint. If the joint force or torque exceeds the limitation, it was set free [4].

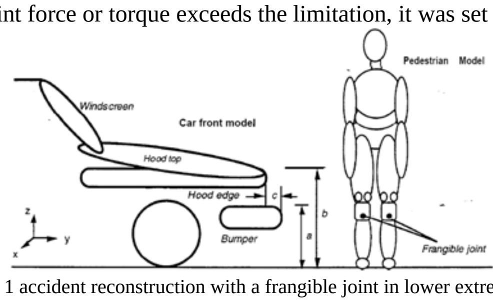

Figure 1 accident reconstruction with a frangible joint in lower extremities

The cars were developed with MBS model. The dimension and geometrical characteristic were according to the accident vehicles. The vehicle impact speeds were calculated based on the skid marks or throw distance. The correspondent stiffness curves were used to define contact properties. The postures and moving speed of pedestrian were set up based on the interview information of eyewitness and drivers. The impact locations on vehicle body were compared with dent and fragment location on accident vehicle to improve the accuracy of reconstruction.

3 Examples of reconstruction

To study pedestrian injury and implement accident reconstruction, detailed information were collected and represented. The pedestrian information includes human height, weight, age, etc. Car information consists of maker, model, making year and so on. Injury conditions were collected from the hospitals. Two cases were described as examples.

Table 2 Summary of accident data for reconstruction

No.	Pedestrian			Vehicle			Injury
	Height (cm)	Weight (kg)	Age	Model	Year	Impact speed(km/h)	
1	155	45	61	Jetta	2001	33.4	No injury in low limbs
2	174	70	50	Jetta	2002	27.0	Intertrochanteric fracture of the femur in right leg(2) Fractures of the upper tibia and fibula in right leg(2)
3	160	52	49	Fu kang	-	31.0	Fracture of the upper tibia in left leg(2)
4	150	58	73	Lioncell	2004	57.6	Tibial plateau comminuted fracture(3)

3.1 Case 2

The taxi was running near the middle line when the driver found that a male pedestrian stayed on the middle line and wanted to go across the street. The driver started braking the vehicle with a distance about 7-8 meters to the pedestrian. The pedestrian was still hit by the vehicle on the left side of the bumper and his head impacted with the left lower corner of windshield. The victim fell down on the left side of the vehicle. The pedestrian suffered a severe injury in low limbs.

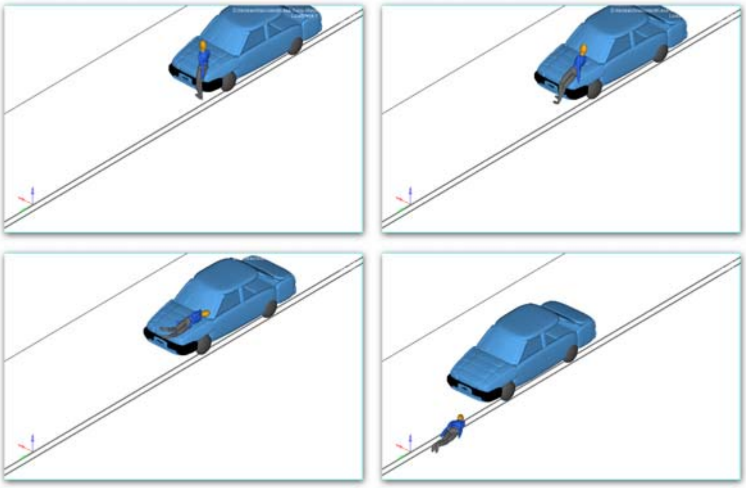

Figure 2: dynamic response of pedestrian in case2

The braking distance and pedestrian throwing distance were used to evaluate the impact speed. The pedestrian model was set up on a standing posture and walking speed is zero. Fig. 2 shows the impact process. First, the right leg was hit by left bumper corner, then shoulder on bonnet and head on the lower left corner of windshield. Finally, the pedestrian fell down. The reasonable impact speed is 27.0 km/h which is low than the speed before braking.

3.2 Case 3

The male pedestrian was walking on the zebra crossing when impacting by a taxi. The driver started to turn the steering wheel to avoid the accident. But the vehicle still impacted the pedestrian with the right bumper corner. Then the pedestrian fell toward the bonnet and head impacted with the right side of the windscreen.

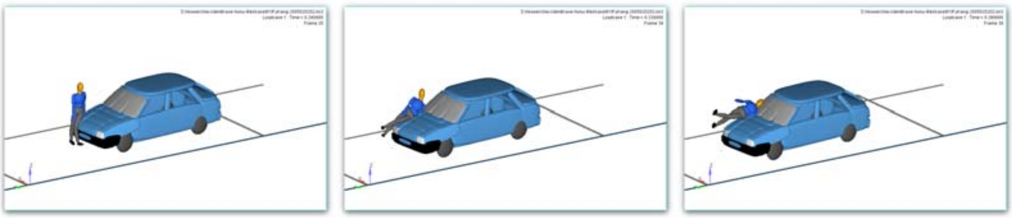

Figure 3: the dynamic response of pedestrian in case 3

The speed told by the driver was used as the initial speed for simulation. The contact points and final position of the pedestrian was used to determine the correct impact speed. Pedestrian model was set up in a walking posture. The calculated impact speed of the vehicle is 31.0 km/h.

4 Results and discussion

The results of accident reconstruction were summarized in Table 3. The predictors of leg fracture were checked. The peak of lateral force and resultant force in the frangible joint, and duration for lateral force large than 3000 N were calculated. It also includes the peak contact force between bumper and pedestrian leg.

Table 3 Results of accident reconstruction

No	First contact	Predicting leg fracture	Peak lateral force in the frangible joint(N)	Peak resultant force in the frangible joint(N)	Duration for lateral force>3000N(ms)	Peak contact fore between bumper and leg(N)
1	Right leg	No	982.2	2340.5	---	3371.6
2	Right leg	No	3478.1	4366.2	4	4163.6
3	Left leg	No	3255.5	6123.0	5	7123.34
4	Left leg	Yes	9060.0	12548.5	>>5	8226.8

Lower extremity injuries are most likely resulting from contact between vehicle-front contact and lateral side of pedestrian. In the first case, the older lady was impact with the middle frontal bumper of the vehicle. Because of her short body, the bumper hit the lower region of the thigh, knee and upper region of the tibia. The contact force and force in the frangible joint is not high. No fracture was predicted.

There were no prediction about leg fracture in case 2 and case 3. But the victims in two cases were severe injured in low limbs. The impact speeds of these two cases are very low, comparing with the speed in case 4 and test speed in GTR regulation. But the pedestrian legs in the three cases were hit on the upper element of the frangible joint by the corner of vehicle bumper. The criteria of injury index should be checked.

Table 4 Tolerance of the long bones in dynamic three-point bending test

Long bone	Axial compression force(kN)	Transverse shear force(kN)	References
Femur	7.7(M) 7.1(F)	3.9(M) 2.6(F)	Messerer.1880*
	---	2.5~8	Bunketorp.1983
Tibia	---	4.7±1.4(M) 4.1±1.2(F)	Nyquist et al., 1985
	10.4(M) 7.5(F)	3.4(M) 2.3(F)	Messerer.1880*
Fibula	0.6(M) 0.5(F)	0.5(M) 0.3(F)	Messerer,1880*

*Messerer’s tests were in static loading condition

It’s well known that bumper and bonnet edge is the leading cause of vehicle-involved injuries to tibia/fibula and femur. The bone material has visco-elastic property. The bone fracture process depends on the load pulse and loading duration (Fig. 4). In the origin CPM model, the frangible joint will be set free when a resultant joint force is great than 4000N and lasts for 5 ms. In the literature review implemented by Yang[5], the tibia fracture were reported at peak impact force from 2.5 to 8 kN (Table 4). For female, the tolerance will be decreased. These data were determined in dynamic three-point bending tests with cadaver samples and the loads were lateral force.

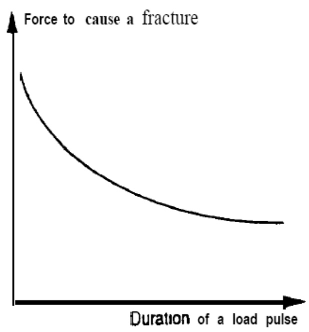

Figure 4 Load pulse and duration

As far as loading direction was concerned, the resultant joint force is not reasonable to be used as the index. The load pulses on the pedestrian low limbs in case 2 to case 4 were the contact force between bumper and the upper element of the frangible joint. The joint force lateral components, which are perpendicular with the axis of long bone, were most concerned with the bumper contact force. For case 4, high impact speed results in high lateral joint force and contact force. When the lateral joint force is used as the index, an index value of 4000 N lasting at least 5 ms will be enough. But for case 2 and case 3, the impact speed and loading condition were critical. In both cases, the joint forces in axis of long bone were caused by other factors. An index of 3000 N lasting at least 4-5 ms will be a reasonable limitation of the lateral joint force for the predictor of the pedestrian model. Then it can predict the long bone failure correctly. The contact forces between the bumper and the leg were in the corridor of cadaver tests. The reconstruction results shows that the current running vehicles couldn’t protect the pedestrian well and may result in severe lower limb’s injury with a low impact speed. But it is emphasized that more accident cases with a critical impact speed were needed to evaluate and improve the predictor.

5 Conclusions

Pedestrian accident in urban area of China were recorded and studied by research from VTSC and CAERI. The dynamic response and loading condition of pedestrian low limbs in vehicle-pedestrian impact were represented. The current running vehicle couldn’t protect pedestrian well.

The scaled CPM pedestrian model with new index value can predict bone fracture in the four cases. But more material will be needed to evaluate the capability of the reconstruction tool. It also should be noticed that the index value will vary when the pedestrian are female and aged person. If this model was validated with lots of accident cases in China, we will have a powerful tool to reconstruct accident and evaluate the effective of injury criteria in standard test.

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