The Reconstruction and Simulation Study of Vehicle-Bicycle Crash

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Abstract: A real vehicle-bicycle collision is reconstructed by establishing vehicle and bicycle models. Simulative results of human body injury are coincident with the results of forensic identification, which validate the reliability of the numerical models. Based on the models, virtual simulation of vehicle-bicycle collision has been conducted at different speed and collision direction, and then discuss the law of throwing distance,the largest impact accelerration of head,and the maximum impact force suffered by legs. Numerical simulation method combined with forensic work will provide Traffic Accident Identification with scientificly theory basis and numerical reference.

Keywords: accident reconstruction, bicycle, multi-rigid-body, injury

1 Introduction

It's significative to quickly reconstruct the course of traffic accidents for analyzing the cause and judge the responsibilities of the accident. Because of the diversity, complexity and instantaneity of traffic accident, the precision of traditional accident processing method is too low. With the development of simulation and high-powered calculation technologies, numerical simulation can provide vehicle collision reconstruction with scientificly theory basis[1].

At home and abroad, many reconstruction studies and experiments of vehicle-pedestrian and vehicle-vehicle collision has been conducted, and they gradually become important assistant means of handling traffic accidents. However, there are few researches on vehicle-non-vehicle collision reconstruction, one of the reason is that this kind of accidents were relatively fewer, the other one is that this kind of accidents are more complex than vehicle-pedestrian accidents. At the same time, the interactions between vehicle and body, body and ground, body and non-vehicle, vehicle and non-vehicle, non-vehicle and ground all should be considered.

In vehicle-non-vehicle accidents, personal casualty rate is extremely high, and annual average is over 80%. So it's of positive practical significance to study and prevent vehicle-non-vehicle accidents, and it has become an important task for traffic supervisory organ.

Based on the proved numerical models, three kinds of vehicle-bicycle accidents are simulated,and rules are summarized from these simulations, which could provide Traffic Accident Identification with scientificly theory basis and numerical reference.

2 Methodology

Generally speaking, a collision problem could be simplified to a dynamic problem of two particles in a plane, namely regarding the vehicle as two dynamic particles. However vehicle-pedestrian collison can't be predigested like that, because human body is a complex multi-body system, and its movement is completed by both knaggy bones and boned muscle.

In order to study the kinetic state and biomechanics numerical value of body parts in the crash, the human body is usually treated as a multi-rigid-body system composed of finite rigid bodies.

In the multi-rigid-body system, the rigid body's kinetic equation could be got from Newton-Euler Equation. The force and moment equation of a certain rigid body in the system is:

$$m_i \ddot{\vec{r}}_i = \vec{F}_i \tag{1}$$

$$J_i \cdot \vec{\omega}_i + \vec{\omega}_i \times J_i \cdot \vec{\omega}_i = \vec{T}_i \tag{2}$$

in the equation, m_i is the rigid body's mass; $\ddot{\vec{r}}_i$ is it's acceleration; J_i is its inertia tensor relative to the centroid; $\vec{F}_i$ is the primary vector of external force; $\vec{T}_i$ is the primary moment relative to the centroid.

Through the virtual work principle, may obtain the non-damping multi-rigid-body system kinetic equation:

$$\sum_{i=1}^{n}[\delta\vec{r}_i\cdot(m_i\ddot{\vec{r}}_i-\vec{F}_i)+\delta\omega_0(J_i\dot{\vec{\omega}}_i+\vec{\omega}_i\times J_i\cdot\vec{\omega}_i-\vec{T}_i)]=0 \qquad (3)$$

in the equation, $\delta\vec{r}_i$ 、 $\delta\omega_0$ are respectively on behalf of displacement and original variable of the body.

Then we can work out the equation by Lagrange method[2] or transforming the matrix[3] to get the dynamics numerical value of every rigid body of the system.

3 Case Study

3.1 Accident Introduction

In one evening of February, 2005, flurry, A was driving a Santana from south to north along a certain roadway, at the same time B was riding a bicycle from east to west. They crashed togethe,and the rider was hit to death.

According to the checkup of the car and body, as shown in Fig 1, the car's front bumper was broken off, and there were many scrapes and concaves on the front of engine cover, the front windshield chips, the left front light and foglight were broken; the left front fork,the front wheel, the back wheel, the front fender were all distorted, the axle was ruptured, the bodywork was bent to right, the left knighthead was bent to right; the rider's head had been badly damaged, which lead to the B's death. The middle part of left tibia was fractured.

(a)

(b)

Figure 1 Car and bicycle of the accident

3.2 Simulation Models

According to the accident scene situation, using multi-rigid-body dynamics method to establish the models of road, car, bicycle and rider, and then simulate the accident course.

The detailed steps of establishing models are as follows:

(1)Set up ground plane: Use the plane to present ground, and create a suitable size plane according to the actual situation;

(2)Set up vehicle and bicycle models: Define vehicle itself coordinate system, and specify the car's front direction as X axis, left direction as Y-axis; the above direction as Z-axis, and select the car's central position as the origin. Use ellipsoids to present car's surfaces, according to the real car's parameters to define ellipsoids' parameters, such as the geometry center position and the axle length. Divide the car's surface into ellipsoids, and they are all attached to a rigid-body in the car's center of gravity. The rigid-body is connected with the reference space by a free-hinge, to control the car's location and rotation. At the same time, the properties of the ellipsoid,such as the stiffness, acceleration of gravity, and the tire's material properties, also should be input, so the car model will be established in such way.

(3)Set up the rider model：As shown in figure 2, select a dummy model based on the rider's height, weight and other information, and adjust all rolling hinges of the dummy to be consistent with bicycling posture. Then modulate the dummy's position and let it be seated on the bicycle model naturally.

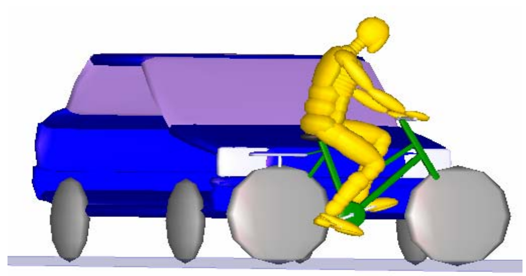


Figure 2　The vehicle-bicycle-rider model

(4)Set the contact type：Set up all possible contacts between surfaces, such as car-bicycle, car-ground, bicycle- ground, rider- car, rider-bicycle and rider-ground.

There are three kinds of contact types, main surface deformation, auxiliary surface deformation, and composite deformation. For example, both the car and bicycle deform, so the contact between them belongs to composite type.

(5)Adjust the balance:It primarily refers to adjusting the balance of the car, the bicycle and the ground, and the rider's balance on bicycle. Adjust the balance of car-ground firstly. The tire-ground contact blongs to ellipsoid-plane contact,as shown in figure 3, the tire deforms,and λ presents the value of penetration, and the penetrating force can be got from the tire's stiffness curve, and the force can be used to balance the car's gravity. Set the car's speed to zero, adjust the magnitude of λ, and then compute. We can see the displacement curve of the car in Z direction from the post-processor. The curve must eventually fluctuate around a certain position, adjust λ according to the arc of oscillation till the displacement curve fluctuates in a considerable scope, then it can be considered that the ground and the car have achieved the balance.

Adjust the bicycle's balance with the same method, what is different is to adjust the dummy in advance, to enable it to sit on the bicycle smoothly. The driving posture can be achieved by adjusting rolling joints. As the dummy model can not maintain the posture as rider can, its joints will freely turn under the gravity, so it is impossible for the dummy model to maintain an absolute balance.

In order to ensure that the dummy model could keep a balanceable gesture on the bicycle before collision, all fixed joints must have been adjusted firstly, to restrict their movements, thereby to maintain the driving gesture.The rider-bicycle contact belongs to ellipsoid-ellipsoid contact, as shown in figure 4. The balance can be achieved by adjusting the factor λ .

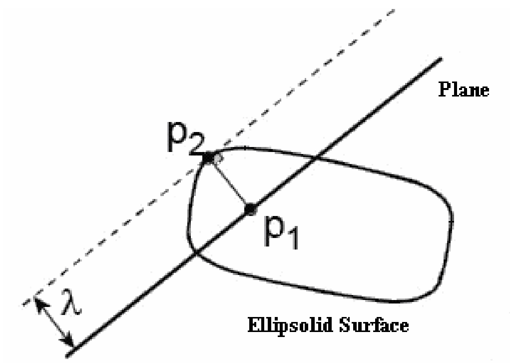


Figure 3 The ellipsoid surfac-plane contact

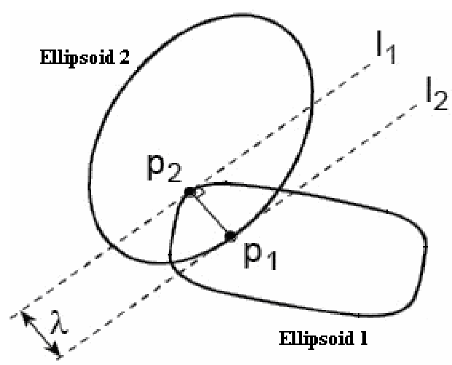


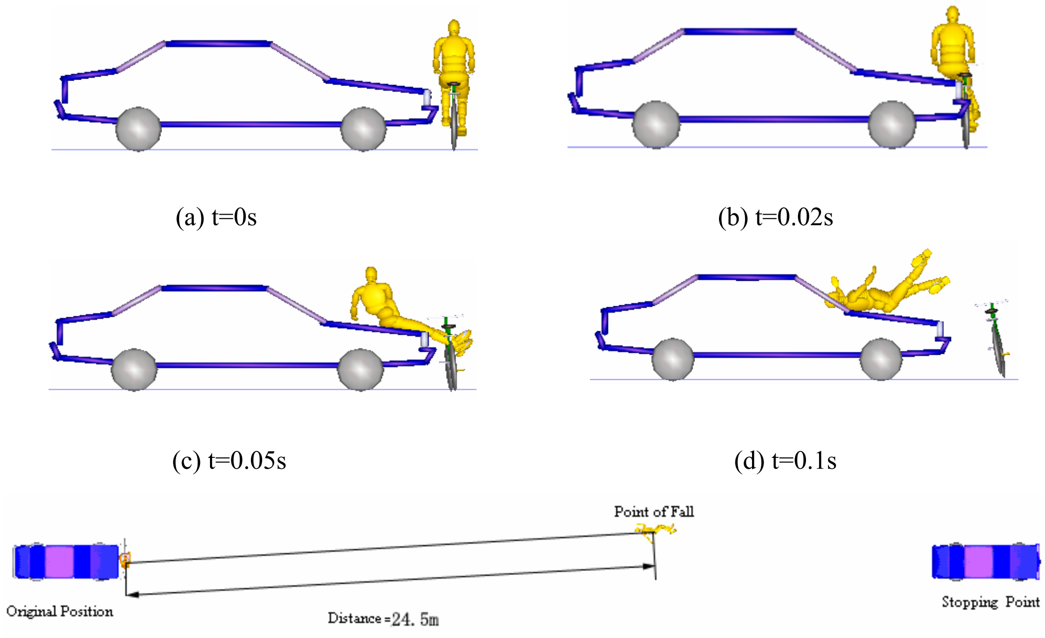
Figure 4 The ellipsoid-ellipsoid contact

3.3 Simulation and Analysis

According to the accident scene information, such as the location of vehicles, the throwing distance of human body, use the trajectory optimization method to calculate till the simulated track and the actual collision trajectory are as coincident as possible[4].By this way,it can work out that the car's velocity before collision is about 70km/h. Then make use of multi-rigid-body dynamics to calculate the injured parts' biomechanical values, such as acceleration, force, torque, and so on.

Figure 5 shows the course of collision at five different times,and figure5(a) to (d) reflect the colliding situations of the initial moment, the moment of contacting the bumper, the moment of contacting the hood, the moment of contacting the windshield. As the bicycle's ejecting mechanism is more complex than the rider in a vehicle- bicycle accident [5], there are many uncertain factors, so here it only concerns with the rider's finall state and the throwing distance. As figure 5 (e) shown, the fall point of human body and the throwing distance can well accord with the accident scene.

During the simulation, we can see that the calf collides with the bumper, and the buttocks and head collides with the hood and windshield. All of these can be proved by spot information, such as the broken bumper, concave hood, cracked windshield, and so on.



(a) t=0s (b) t=0.02s

(c) t=0.05s (d) t=0.1s

(e) t=5s

Figure 5 The course of vehicle-bicycle crash

According to the crew member forehead injury appraisal method stipulated by the CMVDR294 compulsory standard, the formula to calculate HIC value is as follows:

$$HIC = MAX[(\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a_{Head}\,dt)^{2.5}(t_2 - t_1)]$$

In the formula, t_1 and t_2 represent two arbitrary time intervals, in which the maximum value of HIC (in seconds flat) appears two times; a_{Head} represents the head's synthesis acceleration (g gravity units); 2.5 is the coefficient got from experiment. Internationally, HIC = 1000 is often recognized as a safety threshold [6].

The rider's head acceleration curve is shown in figure 6, the first peak occurs in 0.1s around, when the head collides with the windshield. Another peak occurs in about 1.3s, when the human body has fallen to the ground. The peak is caused by the impact with the ground. We can see that the head acceleration has approached 3.4km/s2 at the first impact and HIC is 5030, far exceeding the limit of safety standards 1000,and it is enough to cause brain damage. The result is consistent with the postmortem examination result that brain was severely injured. Meanwhile, we can definitely consider that the first impact with the windshield leads the rider's death.

Figure 7 is the impact force curve of the rider's calf.The first peak 11.8kN appears at 0.02s, and it is caused by the leg-bumper collision.The second and third peaks respectively appeared at 1.33s, 2.15s, and the rider and the car have separated at this point. They are caused by the leg-ground impact. Literature [7] thinks, when the force reaches 4.95kN, that the fracture risk is 50%, so we can consider that the force 11.8kN can definitely cause fractures.

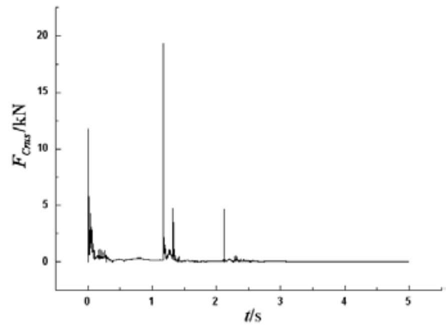


Figure 6 Head acceleration curve

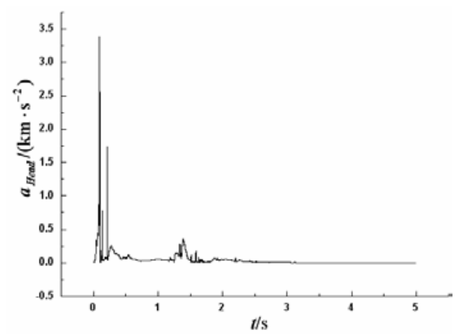
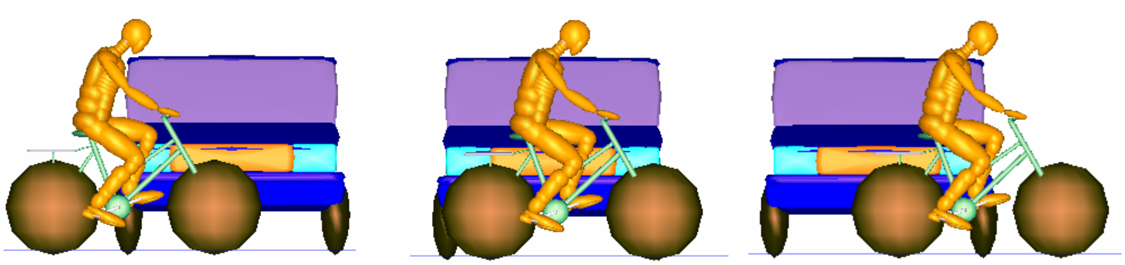


Figure 7 Force curve of calf

Through the above analysis, we can see that simulation results are well consistent with the actual situation,meanwhile they can prove mutually, therefore we have good reason to think that the reconstruction model is correct and reasonable.

4 Experiment and Discussion

Based on the above case models, conduct virtual experiments by taking the most common bicycle accident as example. The selected experimental conditions are as follows: fine, cement road surface, the brake is applied completely, the car's velocity changes from 20km/h to 60km/h, the bicycle's velocity is 15km/h, the impact points are the front wheel, bodywork and back wheel of the bicycle, as Fig8 shown.



(a) Front wheel (b) Bodywork (c) Rear wheel

Figure 8 Original positions of the bicycle

Figure 9 is composed of the throwing distance curve of human body, the head largest acceleration curve,the largest impact force curve sufferred by calves.

According to the simulation results,the law can be summarized as follows:

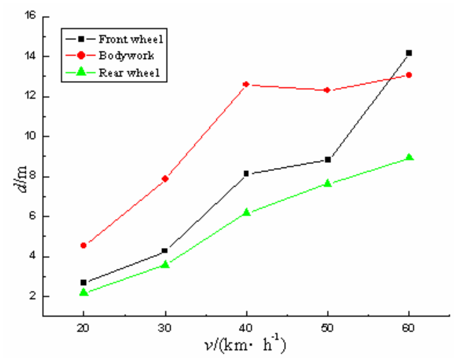
In vehicle-bicycle accident, the rider's head and crura are easiest to be injured, and the main parts they impact with the car are windshield, bumper and engine cover.

In same vehicle type and same impact position, the faster the speed of vehicle, the larger the impulse, the farther the throwing distance, the greater of the maximum impact acceleration of head, the greater of the maximum impact force of calf;

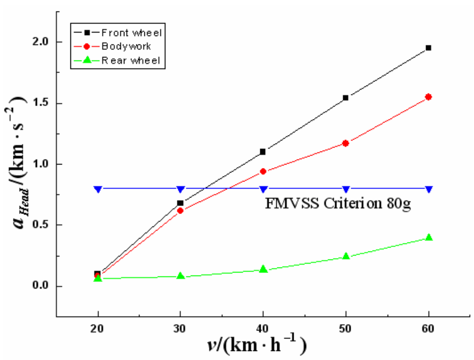
When the vehicle collide with the bicycle at the same speed, the head damage caused by impacting the bicycle's front wheel is severer than impacting the rear wheel;

When the vehicle collide with the bicycle at the same speed, the impact force hasn't much relationship with the position of the bicycle in front of the car, that is, as long as the bicycle cross road at the same speed, the impact force suffered by the calf will not change much;

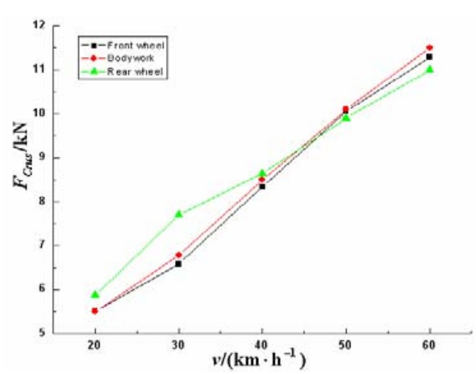
According to Wayne State Tolerance Curve[8], when the head impact acceleration is larger than 80g($g = 9.8\mathrm{m}\cdot\mathrm{s}^{-2}$), that is, if the car's speed is faster than 35km / h, the rider's skull injury risk will increased significantly.



(a) The throwing distance curve of human body



(b) The largest impact acceleration curve suffered by head



(c) The largest impact force curve suffered by calf

Figure 9 Biomechanics numerical values of injury

5 Conclusion

A real vehicle-bicycle collision is reconstructed by establishing vehicle and bicycle models. Simulation injury results of human body are coincident with the results of forensic identification, which validate the reliability of the numerical models.

Based on the models, virtual experiment of vehicle-bicycle collision has been conducted at different speed and collision direction, and then discuss the law of throwing distance,the largest impact accelerration of head,and the maximum impact force suffered by legs. Numerical simulation method combined with forensic work will provide Traffic Accident Identification with with scientificly theory basis and numerical reference.

At the same time, essentially, bicycle, electric bicycle and light motorcycle are all two-wheels transportation vehicle, and there are many similarities in structural safety [9].Although there are some differences, such as quality, speed, etc, it will not have much difference to the severity of the accident. Therefore the law obtained from this article has certain reference value to the electric bicycle, light motorcycle traffic accidents.

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References

[1] Zhang Xiaoyun, Jin Xianlong, Qi Wenguo, et al. Parallel Computing with Domain Decomposition for the Vehicle Crashworthiness Simulation, Vehicle System Dynamics, 2007, 45(11): 1051~1064

[2] Aaron GreenfieldUluc. SaranliAlfred A. Rizzi. Solving Models of Controlled Dynamic Planar Rigid-Body Systems with Frictional Contact. The International Journal of Robotics Research, 2005; 24; 911

[3] Wang Liang-Ming .Matrix Transform Method for Dynamic Analysis of Rigid Multi-body Systems. Journal of Nan Jing University of Science and Technology ,1999,23(6):503~506

[4] Zhang Xiao-yun, Jin Xian-long, Shen Jie. Virtual Reconstruction of Two Types of Traffic Accident By the Tire Marks [J], Lecture Notes in Computer Science, 2006, 4282:1128~1135

[5] Xu Hong-guo, Su Jian, Gao Wei. Determination of Collision Velocity for Motor Vehicle-Bicycle Accident. China Journal of Highway and Transport,1996 , 9 (3) : 98~103

[6] Huang Jing. Study on Computer Simulation of Vehicle Kinematics and Occupant Injuries in Vehicle Crash Accident Reconstruction. Master Degree Paper of Shanghai JiaoTong University,2005:61

[7] TNO. MADYMO Human Models Version 6.2 , Holland , June 2004 : 80

[8] Brian G.McHenry. Head Injury Criterion and the ATB. McHenry Software , Inc , 2004

[9] Ma Guo-zhong; MING Shi-jun WU Hai-tao, On Safety Character of Electric Bicycle. China Safety Science Journal,2006 , 16(4): 48~52