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Study on the Driver'S Lower Limb Injuries in Rear-End Truck Accident

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Abstract:

***Purpose*:** There is a high risk of lower limb injury in the rear-end truck accidents. This study aims to explore the biomechanical mechanism of lower limb injuries by establishing finite element (FE) simulation model of different collisions, and the installation height of the rear anti-collision barrier is analyzed.

***Methods*:**Using the minibus FE model and the total human model for safety (THUMS4.0) to construct the collisions that the minibus rear-end truck and the minibus head-on collision with the rigid walls of 0cm, 40cm, 50cm, 60cm in height, respectively. The velocity of this five collisions are 56km / h.

***Results*:**As the height of the rigid wall increases, the peak value of von Mises equivalent stress at femur increases gradually. If the lower edge of the rigid wall is higher than the height of front rails. The front rail will not produce a good deformation. The intrusion of the dashboard will be large. The injuries of lower limb were also increased.

***Conclusion*:** In minibus frontal collision, the driver's femur injury is related to the intrusion of the dashboard. The height of rear anti-collision barrier should lower than the front rails of minibus.

Keywords: Rear-end truck collision, FE model, Lower limb injury, Front rail

1 Introduction

Among the many traffic accidents, there is an accident more painful than others. It's the small car rear-end truck accidents. According to relevant statistics. China's annual number of rear-end accidents accounted for more than 45% of major accidents. The mortality rate is as high as 31%.

In order to prevent small car rear-end into the rear of large trucks. In 2002, the AQSIQ promulgated the mandatory standards for the rear underrun protection requirements of motor vehicles and trails[1]. The standard requires that a large vehicle tail must be fitted with a guard that effectively prevents other vehicles from being embedded. Standard clearly stipulates that the total quality of more than 3500KG in the use of all trucks and trailers should be installed in line with national standards of the rear protection device. The device should have sufficient blocking ability to prevent small cars from getting into the bottom of the truck. However, not all of the trucks are installed in accordance with the standard crash barrier in reality. Many truck crash barriers are useless. Some do not even install it. In addition, some owners thought that they have bought the transportation insurance. Even if they have been rear-ended. They have no responsibility.

In previous study, we have reconstructed an accident of minibus rear-end truck[2]. We found that cockpit intrusion has a direct impact on the driver's lower limb injury. The rear anti-collision barrier's height has a direct impact on the minibus collision deformation and driver's lower limb injury. In this paper, the collision model of the minibus and fixed barriers of different height are constructed respectively. Then the effect of different height of guardrail on driver's lower limb injury was discussed. The aim of this paper is to find out the optimal height of guardrail for the lower extremity injury of occupants in the rear - end truck accidents.

2. Materials and Methods

In 2015, we investigated an accident of minibus rear-ended the truck which occurred in the highway of Chongqing(Fig. 1).We got detailed information about the accident, including the deformation of vehicle and driver's injuries, and the speed of the minibus is 56km/h.

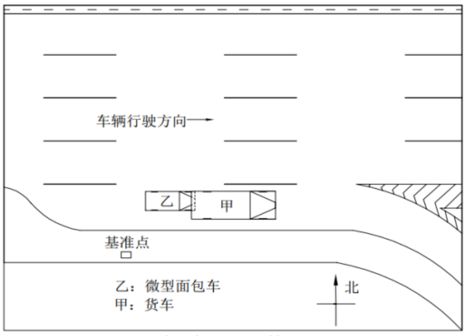

Fig.1. Draft of the traffic accident scene.

The minibus model used in this paper was provided by an automobile manufacturing company in Chongqing, China. The dynamic characteristic was successfully verified through head-on collision experiments [3].

The truck model was downloaded from the US national crash analysis center, which included 36593 elements. The rear anti-collision barrier is 50cm from the ground and the cargo floor is 110cm from the ground, which is consistent with the real-world accident.

The driver model we used in this article is the THUMS4.0, which was jointly developed, designed, and verified by Toyota Motor Corporation and Toyota Technical Centre (Japan) [4,5]. The model has a good biological fidelity. It can effectively simulate the human body's dynamics response process and revel the details of the injury. We adjusted the model's position to ensure that the model was placed on the seat accurately and ideally.

Friction coefficient was defined for the parts that come in contact during the collision. The coefficient of friction between the vehicle and the road surface is 0.7, and the coefficient of friction between the vehicle and the vehicle is 0.65[6].The acceleration of gravity imposed on vehicles and THUMS was 9.8 m/s2. In all of the simulated collisions, the impact velocities were set at 56 km/h.

Fig. 2Ashows the rear-end collision between the minibus and the truck. Fig. 2B -2E show the head-on collision of minibus with rigid wall, the height of the wall from the ground is 0cm(2B), 40cm(2C), 50cm(2D) and 60 cm(2E), respectively.

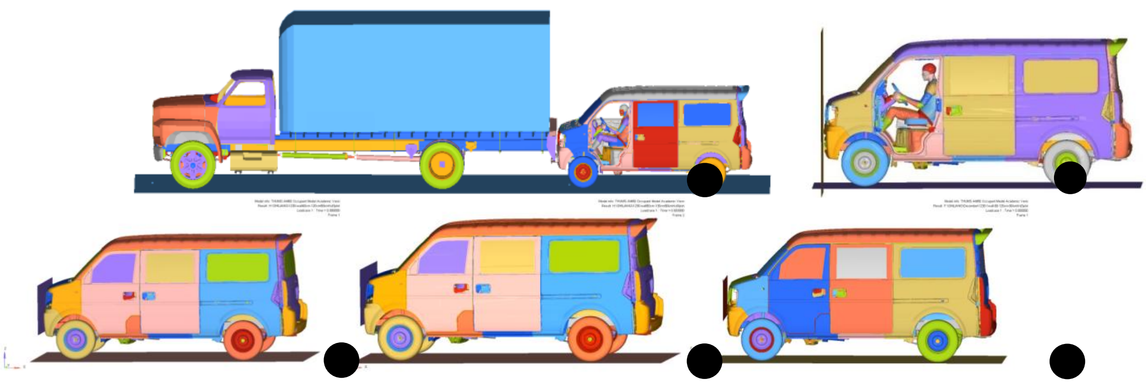

Fig. 2. Five collision models.

3 Results

3.1 vehicle’s front rails

The front rails of vehicle are the main energy-absorbing components in head-on collision by bending and collapsing. Fig.3 shows the longitudinal compression of the front rails of minibus in five collisions. We can see that the deformation of the front rails is almost the same in 0cm, 40cm, 50cm collisions, the longitudinal compression is 32cm, and the deformation concentrated in the front crush zone of the front rails, it means the front rails has played a major role in energy absorption.

While the longitudinal compression of the front rails in the rear-end collision is very small. It means that the front rails doesn't play a good role of energy absorption in rear-end collision. In 60cm rigid wall collision, the front rails came out a serious upward bending, the longitudinal compression is very small. The front rails don’t play a good role of energy absorption in 60cm rigid wall collision.

For the deformation of the front rails in the collision of 60cm rigid wall, the lower edge of the rigid wall is 60cm from the ground, which is higher than the upper edge of the front rails. In the collision process, the main deformation energy absorbing parts of the minibus are concentrated in the hood and the fore-cabin part, which is higher than the front rails. Compared with the front rails, the structural strength of the hood and the fore-cabin part is much lower. Severe impact of these parts leading to serious crushing deformation. The pulling action of each part causes the front rails to bend upwardly to absorb a part of the collision kinetic energy. While the energy absorbed by the bending is very low.

There is no obvious compression of the front rails in the collision of rear-end truck, and no crushing deformation in the front crush zone. This is quite different from the deformation to the same height collision of 50 cm rigid wall. The rear anti-collision barrier of the truck is plastic material. Collision caused bending deformation of the anti-collision barrier, reducing the impact of the front rails.

The front rails have a certain bent upward trend, but the bending angle is much smaller than the collision of 60cm rigid wall. Analysis shows that this is related to the rear space structure of the truck. When the minibus rear-end one truck. The rear anti-collision barrier of the truck will be squeezed between the cargo floor of the truck and the front rails of the minibus. So that the front rails of the minibus cannot be bent and deformed upward.

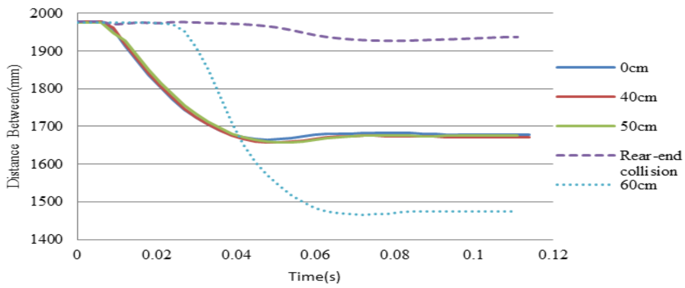

Fig.3. Compression of front rails.

3.2 Vehicle deceleration

Fig.4 is the deceleration curve of the minibus. We can see that the peak value of deceleration gradually decreased with the height of the wall increase.

In 0cm, 40cm, 50cm collisions, the deceleration curves are basically the same, and the peak time of deceleration is the same. Through the analysis of vehicle dynamic response, we can see that the deformation pattern of the front is similar in these three collisions. The deceleration curves of minibus are also basically the same in these three collisions.

The time of the deceleration peak in the rear-end collision was later than that in the 50cm rigid wall collision, and the peak value was lower. The vehicle's deceleration peak is the smallest and the time of the emergence is the latest appears latest in the collision with 60cm rigid wall.

In contrast to the rear-end collision, the peak value of deceleration in 50 cm rigid wall collision is larger, and the time of peak is earlier. Comparing the vehicle dynamic response process and vehicle deformation morphology in the two collisions, we can find that the rear anti-collision barrier occurred a certain bending deformation. This deformation can absorb part of the vehicle kinetic energy, which play a buffer role for the vehicle, so the vehicle deceleration is lower. For the rigid wall, it does not deform or absorb energy, which causes the vehicle deceleration is higher.

In the collision of 60cm rigid wall, the lower edge of the rigid wall is 60cm from the ground. The lower edge of the rigid wall is higher than the upper edge of the front rails. In the collision process, the main deformation energy absorbing parts of the minibus are concentrated in the hood and the fore-cabin part, which is higher than the front rails. Compared with the front rails, the structural strength of the hood and the fore-cabin part is much lower. Severe impact of these parts leading to serious crushing deformation. The pulling action of each part causes the front rails to bend upwardly to absorb a part of the collision kinetic energy.

When the front rails are bent to a certain angle, that is, when the rigid wall is "clamped" by the folded front rails and the compressed hood and the fore-cabin part, the vehicle suffered the greatest resistance. The bending of the front rails takes a certain amount of time. So the peak of the vehicle deceleration curve appears relatively late.

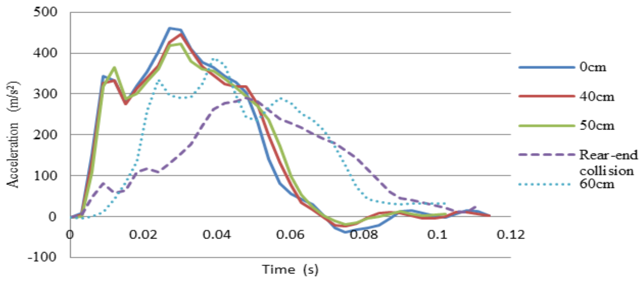

Fig.4. Vehicle deceleration curves of five collisions.

3.3 Intrusion of dashboard

In collision, the intrusion of dashboard will reduce the driver's leg space, which will increase the lower limb injuries. In this article, two points were chosen to measure the leg space changes of minibus driver: a point on the dashboard that faces the driver's left leg and another point on the middle of the front edge of the driver's seat. The change curve of the distance between these two points in X direction was obtained.

Fig.5 shows the change curve of the leg space in the five collisions. At the beginning of the collisions, the driver's leg space was 303 mm. In 0cm, 40cm, 50cm collision, the space deformation curves are basically coincident. The minimum distance between the driver's legs in X direction was 218-227 mm, obtained at 51-53 ms, the maximum distance of deformation was 85-76 mm.

In the rear-end collision, the leg space in X direction minimized to 112 mm at 90 ms. The maximum distance of deformation was 191 mm. In the 60cm collision, the minimum distance between the driver's legs in X direction was 83 mm, obtained at 51 ms, the maximum distance of deformation was 220mm.

In 0cm, 40cm, 50cm collision, the front rails and the rigid wall collide violently. Which induced the vehicle kinetic energy significantly reduced. The deformation of hood and the fore-cabin part are small. The instrument panel into the driver's leg space was also small. While in the rear-end and the 60cm rigid wall collision, the front rail does not provide a good energy absorption, so, the instrument panel into the driver's leg space is large.

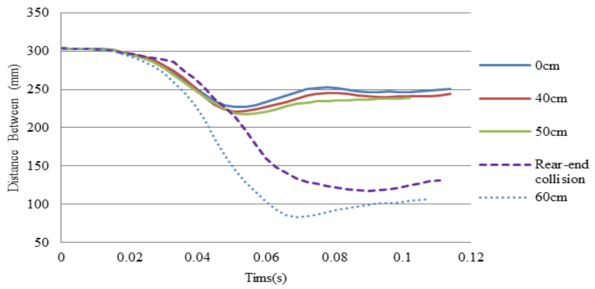

Fig.5. Leg space in X direction.

3.3 Driver's lower limb injuries

In a rear-end collision, the speed of the vehicle will reduce to a minimum in the moment of collision. The occupants will lean forward due to inertia effect. The lower limbs will be damaged. When the lower limbs begin to contact with the dashboard, they will suffer a great impact. The axial oppressiveness and bending stress is the mean cause of femoral injury. While the tibia and fibula injuries are mainly caused by shear stress, the patella injury is caused by the impact force of the dashboard. The yield strength of the femur ranges within 104-120 MPa (Bursteinet al. 1976)[7]. The failure stress of the tibia and the fibula is in the range of 100-125 MPa (MizunodK et al. 2002)[8].Table1show the peak value of von Mises equivalent stress at the driver's lower limb injury of the five collisions.

Table 1 von Mises peak stress on different parts under five collisions.

Collision	Peak von Mises equivalent stress							
	Femur		Tibia		Fibula		Tibia	
	Time/ms	Value/MPa	Time/ms	Value/MPa	Time/ms	Value/MPa	Time/ms	Value/MPa
0cm	42	99	33	139	36	126	57	101
40cm	42	106	33	125	42	123	63	117
50cm	42	110	33	129	42	116	66	101
Rear-end	63	126	63	133	48	85	69	73
60cm	63	133	48	136	51	119	39	87

It can be seen from the table that in these four rigid wall collisions (0cm, 40cm, 50cm, 60cm). With the height of the rigid wall increases, the peak value of von Mises equivalent stress at femur increases gradually. While the peak value of the von Mises equivalent stress at tibia, fibula and patella showed no significant change. It indicates that the driver's femur injury will increase gradually with the increase of the height of fixed barrier in the collision. For the collision with 50cm rigid wall and rear-end truck. Though the height of the fixed barrier is the same. But the driver's lower limb injury is inconsistent of the two collisions. The peak value of the von Mises equivalent stress at femur exceeded the failure stress range of 104-120Mpa in the rear-end collision, and the value is higher than that in the 50cm collision. The peak value of the von Mises equivalent stress at tibia exceeded the failure stress range of 100-125Mpa in the two collisions. In particular , the peak value of the von Mises equivalent stress at fibula and patella in the 50cm rigid wall collision is much higher than that in the rear-end collision.

Obviously, the peak value of the von Mises equivalent stress at femur, tibia, fibula in the 60cm rigid wall collision are the largest in these five collisions. It's mainly caused by the great amount of deformation between the instrument panel and the driver's leg.

4 Discussion

By analyzing the deformation of the vehicle's front fails after collision of different height of the fixed barrier, we can find that in the frontal collision, when the lower edge of the fixed barrier is higher than the height of the front rail of the minibus, the front rail will not produce a good deformation, then, it cannot play the role of protecting the driver.

Rear anti-collision barrier as the protective device of the truck, the main role is to protect the vehicle in the rear-end collision will not drill into the bottom of the truck. For the rear protective device, if it is too high, this will not be able to prevent the vehicle drill into the bottom of the truck. Conversely, if the rear protective deviceis too low, it will affect the passing of trucks. Therefore, it is necessary to design a suitable height of anti-collision barrier to reduce the injuries in the rear-end accident.

In the 60cm rigid wall collision, there is no direct contact between the front rails and the rigid wall, and hood and fore-cabin of the minibus are seriously impacted and deformed. The intrusion of the dashboard is very serious. The driver's lower limb is seriously injured. To the rear-end collision, although the height of the lower edge of the anti-collision barrier is not higher than the front rails, the simulation results show that the structure of the anti-collision barrier is too simple, the bending of the guardrail is serious and the front rail of the minibus does not appear obvious compress deformation. However, the deformation of minibus up to the fore-cabin, resulting in a large intrusion of the dashboard into the driver's leg space.

The rear anti-collision barrier should not be higher than the front rails. Domestic minibus's front beam height is generally 45-55cm. So, in order to reduce the phenomenon of drill into the bottom of the truck in the rear-end collision, the height of rear anti-collision barrier should not be higher than 45cm. The injury value of femur and tibia of 40cm rigid wall collision are relatively low in these five collisions.

In this paper, we can find that the material properties of the rear anti-collision barrier also have an influence on the driver's lower limb injury. When the stiffness of the anti-collision barrier is too high, it is difficult to deformation, then the rear anti-collision barrier cannot play an effective role in energy absorption, resulting in excessive vehicle deceleration and large dashboard invasion, which will increase the driver's lower limb injury. Therefore, the design of an anti-collision barrier with correct height, right material, and reasonable structure is very meaningful.

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