Experimental study on side pole collision and deformable barrier collision of car

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Abstract. In order to study the characteristics of side pole impact and side deformable barrier impact test, a B-class car is selected to carry out the side pole impact test in Euro-NCAP and side deformable barrier (AE-MDB) test in C-NCAP. The characteristics of body acceleration and dummy injury are analyzed. The results show that compared with the deformable barrier collision, the side pole collision has a greater risk of injury to passengers for vehicle body acceleration, at the same time, the intrusion is greater and local deformation is more serious. In order to reduce the side impact damage, it is necessary to increase the local strength of the body at the side of collision to avoid small area overlapping rigid collision.

1. Introduction

The increasing car ownership has led to an increase in car collision accidents. In various types of collision accidents, side collisions account for 36\% of the total accidents [1]. Due to the weak stiffness of the vehicle side structure and the small space for buffer energy absorption, it will inevitably cause huge damage to the occupants when subjected to a large impact. Countries around the world have formulated a series of automobile side collision regulations, including ECER94, FMVSS214, NCAP, etc. In 2006, China promulgated the side impact regulations GB20071-2006, focusing on investigating the injuries of dummies in side impacts of moving deformable barriers. In side collisions, body deformation, energy dissipation, and dummy injury [2] [3] are the focus of research. Occupant injuries can be reduced by changing the body structure and using new materials [4] [5]. The side collision test can be divided into side moving deformable barrier collision and side pole collision. The characteristics of structural damage and occupant injuries in the collision of side pillars of cars were studied by numerical simulation [6]. In addition, MADYMO software was used to establish and optimize the occupant restraint system model in side collisions [7]. In order to reduce the occupant's chest injury in side collision, the head and chest airbag was optimized by using finite element analysis model, stepwise regression agent model and sequence optimization method [8]. The influence of the thickness of the door and B-pillar on the damage of the dummy was analyzed and studied by Lilehkoohi [9]. Zhang [10] studied the influence of B-pillar invasion speed on the injury of the dummy using 27 sets of side impact test data. Referring to actual vehicle test data, Wang [11] used the non-linear finite element software LS-DYNA to simulate two crash test forms and the damage characteristics of the body structure in the two tests were compared. Zhu [12] studied the Euro-NCAP,
FMVSS201, and FMVSS214 column-collision tests to analyze the body structure damage and dummy damage analysis under different test types as well as different type dummy.

In the study of this article, a B-class car was selected for the Euro-NCAP side pole collision [13] and C-NCAP AE-MDB test [14] to compare and analyze the characteristics of dummy injury and body deformation in the two tests. According to the regulations, the WorldSid dummy was used in the test to avoid the impact caused by the different types of dummy. The research results can provide a reference for the side collision design of the vehicle.

2. Test Format

2.1. C-NCAP side moving deformable barrier (AE-MDB) collision

Side moving deformable barrier collision is an important part of C-NCAP. Its test form is shown in Figure 1. The speed of the trolley is not less than 50km/h and its weight is 1400kg. The front end honeycomb aluminum type is AE-MDB. The centerline of the trolley collision is 250mm backward from the front seat R point, and the lower edge of the honeycomb aluminum is 400mm from the ground. The test vehicle was placed perpendicular to the speed direction of the trolley. A Hybrid 50% WorldSid dummy was placed at the driver's position and a SID IIS female dummy was placed at the rear of the driver. According to the C-NCAP side impact assessment procedure, it is necessary to collect and analyze chest rib displacement, abdominal rib displacement, and pelvic resultant force of the front and rear dummy.

![Fig. 1 AE-MDB test](image1)

![Fig. 2 Side pole collision test](image2)

2.2. Euro-NCAP side pole collision

The Euro-NCAP side pole collision test form is shown in Figure 2. The vehicle is placed on the sliding floor. Through the traction system, the floor drives the vehicle to collide with a rigid cylinder. The diameter of the cylinder is 254mm. The angle between the vehicle placement angle and the speed direction is 75° and the speed of the test vehicle is 32km/h. During the test, the Hybrid 50% WorldSid dummy was placed at the driver's position. The dashed line in the figure indicates the collision line, and its position is the projection line on the vehicle which passes through the center of mass of the dummy's head. According to Euro-NCAP requirements, the chest and abdominal rib displacements and pelvic resultant forces of the dummy were also collected during the side pole collision test.

3. Dummy injury analysis

A B-class car was selected for the C-NCAP side deformable barrier collision and the Euro-NCAP side pole collision. The test speeds were 50.3 km/h and 32.3 km/h and the vehicle’s curb weight was 1858kg (974kg front axle / 884kg rear axle). The WorldSid dummy is placed in the driver position of
the two types of tests to ensure the consistency of the dummy types. This article analyzes the injury of the dummy before the two tests according to different indexes of the head, chest, abdomen and pelvis.

3.1. Head injury analysis

The head injury index (HIC) and the 3ms combined acceleration (G3ms) are selected to analyze the head injury. The HIC is obtained by integrating the dummy's head resultant acceleration over a certain period of time, which is calculated according to formulas (1) and (2).

\[
R = \sqrt{A_x^2 + A_y^2 + A_z^2}
\]

\[
HIC = \left( t_2 - t_1 \right) \left[ \int_{t_1}^{t_2} \frac{A_R \cdot dt}{(t_2 - t_1)} \right]^{2.5}
\]

In the formula, \(A_R\) is the head's centroid composite acceleration, and \(A_x\), \(A_y\), \(A_z\) are the accelerations in the three directions of the head's center of mass respectively. During the test, \(t_2 - t_1 = 15\) ms, the maximum value of HIC15 during the collision is calculated and evaluated. The 3ms resultant acceleration (G3ms) is the maximum value of the head resultant acceleration with a cumulative time of 3ms. The resultant head acceleration curve in the side pole test and the AE-MDB test is shown in Fig. 3. From the curve, it can be seen that in the side pole collision test, when \(t=58.5\) ms, the combined acceleration of the dummy's head reaches a maximum of 71.25g. In the side deformable barrier collision test, when the collision time \(t=53.35\) ms, the combined acceleration of the dummy's head reaches a maximum of 28.53g. In addition, during the entire collision process, the combined acceleration value of the head of side pole collision test is higher than that of AE-MDB, and the head is affected more at this time.

After calculation, the G3ms side pole and AE-MDB test are 70.4g and 27.75g respectively. And the HIC15 of side pole and AE-MDB test are 505g and 54g respectively. Compared with the AE-MDB test, G3ms and HIC15 are greater in the side pole collision test. The height of the rigid cylinder is higher than that of the AE-MDB test side impact trolley and the impact range is wider in the vertical direction. Therefore, the side pole impact test has greater head injury.

Fig 3. Resultant head acceleration
3.2. Chest injury analysis

For the chest, it is necessary to analyze the displacement of each rib of the chest and its viscosity coefficient VC. VC is expressed by the product of the deformation rate of each rib and the compression rate of chest.

\[ V \cdot C = \frac{d[D(t)]}{dt} \times \frac{D(t)}{D} \]  

(3)

Where \( D(t) \) is the relationship between the thickness of the thorax over time. \( D \) is the initial thorax thickness and the unit of VC is m/s. Figure 4-7 show the compression of the chest ribs and the viscosity coefficient VC of the dummy during the collision of the side pole and the AE-MDB test. For the side pole collision test, the maximum displacements of the three chest ribs are 31mm, 24.2mm, and 28.8mm respectively, which are larger than the corresponding rib displacements of 25mm, 23.1mm, and 20.75mm in the AE-MDB test.

The chest rib adhesion index VC is analyzed. In the side pole collision test, the VC peaks of the three ribs of the chest were 0.200, 0.181, and 0.294, which are larger than the corresponding peaks of the AE-MDB at 0.203, 0.224, and 0.149. In the same test, the peaks of different ribs displacement are not same either. The reasons are listed. Firstly, there are different distances between the ribs of the dummy's chest and the door interior. Second, the AE-MDB test differs from the side pole test in the collision angle and collision position, both of which affect the relative distance of each rib to the door interior as well as the chest injury. As a result, the side pole impact test has a greater impact on the dummy's chest ribs, resulting in more severe chest deformation.

![Fig. 4 Thoracic ribs displacement in the side pole collision test](image1)

![Fig. 5 Thoracic ribs displacement in AE-MDB test](image2)
3.3. Abdominal injury analysis
Similar to the chest analysis method, abdomen rib displacement and rib VC are also compared. Figures 8-11 show the rib displacement and rib VC curves for side column collision and AE-MDB tests respectively. In the side pole collision test, the peak displacements of the two ribs at the abdomen are 32.7mm and 33.4mm respectively, which are larger than the corresponding peak displacements of ribs 26.4mm and 24.5mm in the AE-MDB test. Similarly for the viscosity index VC, the peak VC corresponding to the side pole test abdominal ribs are 0.285 and 0.276 respectively, which are larger than the VC peaks of 0.167 and 0.165 in the AE-MDB test. Different from the sternum, the displacement of the two abdominal ribs and VC are almost the same whether it is the side pole collision test or the AE-MDB test, so the two types of collisions cause relatively uniform damage to the dummy's abdomen. In the collision direction, the distance between the different ribs of the dummy's abdomen and the door interior area is almost the same, so the rib damage is approximately the same during the collision.
Fig. 8 Abdominal ribs displacement in the side pole collision test

Fig. 9 Abdominal ribs displacement in AE-MDB test

Fig. 10 Abdominal ribs VC in the side pole collision test
3.4. Pelvic injury analysis

In the analysis of pelvic injury, a comparison of the pelvic force curve in the side pole collision test and the AE-MDB test is shown in Figure 12. It can be seen from the curve that the peak of pubic force in the AE-MDB test is 1.44KN greater than the peak of 0.82KN in the side pole collision test. In both tests, the time at which the pubic force peaked is approximately the same. In addition, in the AE-MDB test, the pubic force decays more rapidly than the side pole collision test after reaching its peak.

Analyzing the reasons for the above characteristics, the two tests have different characteristics. During the AE-MDB impact test, honeycomb aluminum crashes test vehicle and dummy vertically. In the side pole collision test, the test vehicle and the rigid cylinder crash at an angle of 75 degrees. Besides, the collision line is the projection line on the body passing through the centroid of the dummy's head. At this time, the rigid cylinder and the dummy's pelvis does not collide in the velocity direction, so the peak value is smaller than that of AE-MDB.

In addition, the two test collision processes are different. For the AE-MDB test, the test vehicle is stationary and the dummy is away from the impact area when the collision occurs. In contrast, in the side pole collision test, the test vehicle hits a rigid cylinder at a certain speed. After the impact, the dummy still has a certain speed and contact continues to occur, so the pubic force curve of the dummy decays slowly.

4. Body Deformation Analysis

When measuring the deformation of the body of the test vehicle before and after the two tests, some characteristic points of the front and rear doors on the collision side are selected as the measurement
points. As shown in Figure 13, the red horizontal line 1-4 and the blue vertical line 1-15 divide the front and rear doors on the collision side. When establishing the body coordinate system, the center of the front axle of the vehicle is used as the origin point. Among them, the Z-coordinates of horizontal lines 1-4 are 615, 445, 280, and -4, and the vertical lines 1-15 are 150mm apart. The intersection point of horizontal line and vertical line 1-15 is Node0, Node150 ... Node2100 in turn, and the intersection points of horizontal and vertical staggered dotted lines are the body measurement points. Deformation curves of the intersections with the vertical lines under a certain horizontal line in the side pole collision test and the AE-MDB test are shown in Figs. 14 and 15.

![Fig. 13 Body measurement points](image_url)

![Fig. 14 Deformation of the side pole impact the body](image_url)
It can be seen from Figure 14 that in the side pole collision test, the trend of the displacement curves changing in the X direction at different heights on the door are the same. The curve shows a peak in the dotted box which is around the Node900. This area is the collision line position. In the test, the displacement changing is more concentrated.

On the contrary, in Figure 15, the displacement changing trend of the same position of the AE-MDB test vehicle body is different. Compared to the side pole collision test, the displacement changing is smaller. The displacement within the dotted box which is from Node900 to Node1200 is small. The larger displacement area is the front and rear doors of the vehicle body, while the relatively small displacement area is exactly where the vehicle's B-pillar is located. This location has a stronger structural strength. AE-MDB honeycomb aluminum collision surface is more uniform, this area can better reduce deformation.

For the position of the B-pillar, displacement measurements are also performed before and after the two tests. Figure 16-17 shows the shape and position of the inner surface of the B-pillar before and after the two tests, which intuitively reflects the amount of invasion. In the AE-MDB test, the top of the B-pillar is not deformed, and the deformation of the entire B-pillar is smaller before and after the test. In the side pole collision test, a certain displacement occurred at the top of the B-pillar and the deformation of the B-pillar is more serious.
The B-pillar acceleration curve can characterize the vehicle movement and body deformation. Figure 18-19 show the B-pillar acceleration curve of the collision side and the non-collision side in the side pole collision and AE-MDB test. It can be seen from the curve that the peak of the acceleration curve of the B-pillar on the impact side of the AE-MDB test is larger than the side pole collision test. On the non-impact side, the peak of B-pillar the acceleration curve of the side pole collision test is larger than the peak value of the AE-MDB test and the attenuation is slower.
5. Conclusion
By analyzing the damage of the dummy and the deformation of the body in the side pole collision test and the AE-MDB test, the following conclusions are obtained:

1. Compared with the AE-MDB test, the side pole collision test has more severe head injuries, greater chest and abdominal rib displacement, and a greater viscosity index VC. Due to the difference in the collision area in the two tests, the AE-MDB test has a greater pelvic resultant force than the side pole collision test.

2. According to the deformation characteristics of the vehicle body, the collision area of the side pole collision test is more concentrated. The deformation curves of doors have the same changing trend and the peak is obvious at different heights before and after the collision. In the AE-MDB test, the deformation curve of the vehicle body is relatively gentle, the displacement at the front and rear doors is large, and the displacement at the B pillar is small due to the strong structural strength.

3. For the B-pillar acceleration curve in the side pole collision and AE-MDB test, on the impact side, the peak acceleration in the AE-MDB test is larger. In contrast, the non-impacting side B-pillar that the side pole collision test has a larger acceleration peak and slower attenuation, at the same time, the impact process lasts longer.

4. Compared with the AE-MDB test, the side pole collision has greater damage to the occupants and the vehicle structure. It is necessary to avoid rigid collisions in small areas on the sides and strengthen the local strength of the side of the body to reduce occupant injuries.

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