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Car Side Structure Crashworthiness in Pole and Moving Deformable Barrier Side Impacts

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Abstract: To clearly understand passenger car structure's crashworthiness in typical side impacts of pole and moving deformable barrier (MDB) impact modes, which could assist the establishment of Chinese vehicle side impact safety regulations, a full midsized car finite element model, calibrated by pole side impact test, was built and the pole side impact according to European New Car Assessment Program (EuroNCAP) and the MDB side impact according to ECE R95 regulations were simulated with LS-DYNA. The accelerations and the structure deformations from simulations were compared. It can be concluded that the pole side impact focuses primarily on side structure crashworthiness as a result of large intrusions, while the MDB side impact focuses primarily on full side structure crashworthiness. Accordingly, occupant protection strategies focus on different aspects to improve side impact safety. In the pole side impact the objective is to maintain the passenger compartment and protect the passenger's head from impacting the pole, while in the MDB side impact the objective is to protect the full human body. In the design of the car side structures, at least these two tests should be considered for assessing their side impact crashworthiness. Conducting these two side impact tests as certified tests provides insights into car safety during side impacts.

Key words: car; side impact; pole side impact; crashworthiness; finite element simulation

Introduction

Side impact accidents rank high in almost every country. Much research has focused on the development of countermeasures including the vehicle side structure energy absorption[1] and human response[2,3] in side impact events. New composite materials[4] and structure optimization[5] have been widely used and some advanced methods have been developed to protect the occupants during side impact accidents[6]. Tests and simulations similar to frontal impact safety tests[7,8] are performed to evaluate a vehicle's side impact safety. Various side impact test methods exist[9], and the moving deformable barrier (MDB) with pole side impact test are being used as the standard certified test on a car for side impact safety analysis.

In China, the research focus is also switching from the frontal impact safety[10] to side impact safety due to frequent occurrences of this type of accident. According to the Chinese road traffic accident statistics in 2002[11], more than 33% of the accidents were side impacts. Furthermore, this led to high fatality rates for the small crash zone between occupants and vehicle structures. Starting in 2006, a side impact test, similar to the ECE R95, will be specified as the certified test for all new M1 class vehicles in China.

In addition, many side impacts are narrow-object impacts, during which the passenger compartment may split, thus causing in severe injuries to the occupants. Some pole side impact tests have been conducted according to procedures as specified in EuroNCAP and FMVSS.

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A typical midsized passenger car was selected to perform pole and MDB side impact simulations. The comparison between the side crashworthiness performances of this vehicle under these two impacts is discussed. According to the different characteristics of the two impact modes, some suggestions are made for designing a safer car for side impacts.

1 Selection of a Midsized Car and Its Side Structures

Midsized cars are more popular in China and may have the ability to provide better protection for occupants than small cars. In this research, one type of passenger car was selected according to the ranges that represent the midsized class as shown in Table 1.

Table 1 Standard for midsized car selection

Length (mm)	Curb weight (kg)	Sale price (RMB￥)
4500-5000	1400-1500	150 000-200 000

The selected car's side structures are also representative in multi-layer B-pillar and side framework, strengthened door panel, anti-impact rod in all the four doors, and not-heavily-packed devices between the inner and outer door panels as shown in Fig. 1. The framework of the vehicle body is usually made of high-strength steels with nominal yield stress above 500 MPa.

Fig. 1 Side structure of the selected car

The finite element analysis (FEA) model of the selected vehicles used in this research is provided by its manufacturer, which has 323 795 Belyschko-Tray shells, 26 Hughes-Liu beams, and 5967 spotwelds. Most of the shells are of piecewise-linear-plastic material and all the beams are elastic. All parts are included in one single-contact for simplification. Since the pole side impact time period is more than 300 ms, which is relatively long, a single-integration scheme is selected to reduce CPU time. The LS-DYNA 970[12] MPP version provided by ANSYS China was used to perform the simulations.

2 EuroNCAP Pole Side Impact Test and Simulation

The pole side impact test, according to EuroNCAP pole side impact test protocol[13] as shown in Fig. 2, was performed in the Automobile Crash Laboratory of Tsinghua University, Beijing.

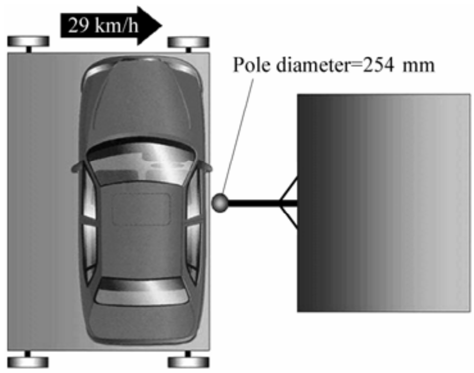
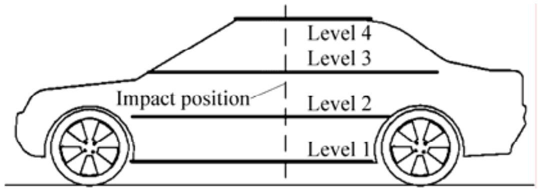


Fig. 2 Pole side impact test

The test vehicle was placed on a large planar trolley, which allowed the free motion of the vehicle to be no less than 1 m. The trolley and the vehicle were accelerated together to 29 km/h, impacting a 254-mm-diameter rigid cylinder pole. The impact position aimed at the center of the gravity (C.G.) for the dummy head. Since the test vehicle was not equipped with a side airbag system, no dummies were used in this pole side impact test. However, the impact position was decided by the ES-2 dummy sitting in the driver seat.

At the same time, finite element simulation of the same impact situation was conducted and the model was validated against the test results. The simulated results were compared with test data in terms of time histories of acceleration measured at the "low" point of the "B"-pillar on the unstruck side, the velocity derived from the acceleration, and the side permanent deformations. The side deformation data taken at four different height levels (show in Fig. 3) were representative of the characteristics of the car side structure.

Compared results were shown in Figs. 4 and 5 for acceleration, velocity, and deformation. In the deformation plot shown in Fig. 5, *X*-axis represents the coordinate in the longitudinal direction with the zero point



Level	Position
4	Roof edge
3	Lower window frame
2	Middle of 1 and 3
1	Door sill

Fig. 3 Four height levels to measure the permanent deformations

being defined as the impact position, and *Y*-axis is the deformation while zero means no deformation. Therefore, the curves show the profiles of the deformed side directly. The peak values of each deformation curve are listed in Table 2. The maximum deformation occurred during the entire impact was larger than the maximum permanent deformation because of the structure's spring-back behavior. The maximum deformation during the impact was 478 mm, taken from the motion image analysis. From all these comparisons, predictions of the finite element model are judged to be accurate enough for use in other side impact simulations.

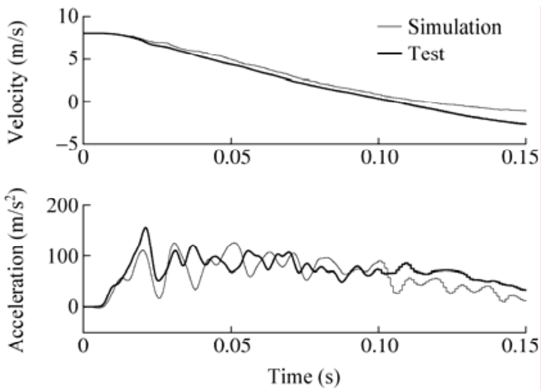


Fig. 4 Velocity and acceleration comparison

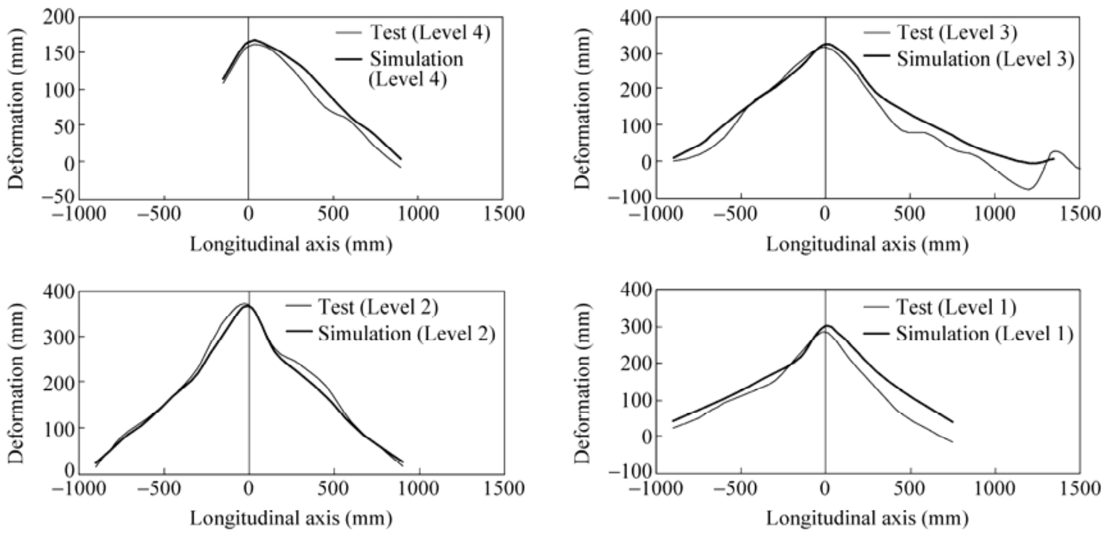


Fig. 5 Permanent deformation of pole side impact test and simulation

Table 2 Maximum permanent deformation in 4 levels (mm)

Level	Test	Simulation
4	160	166
3	317	326
2	369	368
1	285	300

3 ECE R95 Side Impact Simulation

In the ECE R95[14] side impact simulation, modeling of the MDB is important. The details of the MDB model can be found in the work of Jin[15].

In the MDB side impact simulation, doors were pushed deeper than the A or B-pillar for their lower intensity. Most deformations of the car were centralized in the lower part of the vehicle but distributed almost over the side structures, which was covered by the MDB. Similarly the accelerations and deformations were picked for assessing the side crashworthiness, which were compared to those data from pole side impact simulation in detail in the following descriptions.

4 Comparison Between Pole Side Impact and MDB Side Impact

4.1 Vehicle permanent deformation and energy absorption

Comparisons of permanent deformations of the post-test vehicle after the pole and MDB side impacts were shown in Fig. 6. Their peak values were summarized in Table 3. In the MDB side impact, structure portions at Levels 4 and 2 were almost intact, i.e., did not contact the MDB, and thus their deformations were much smaller than their counterparts in pole impact.

Table 3 Maximum permanent deformation at four levels

Level	Pole (mm)	MDB (mm)	Decrease ratio (%)
4	166	65	35.80
3	326	251	23.00
2	368	246	33.20
1	300	61	79.70

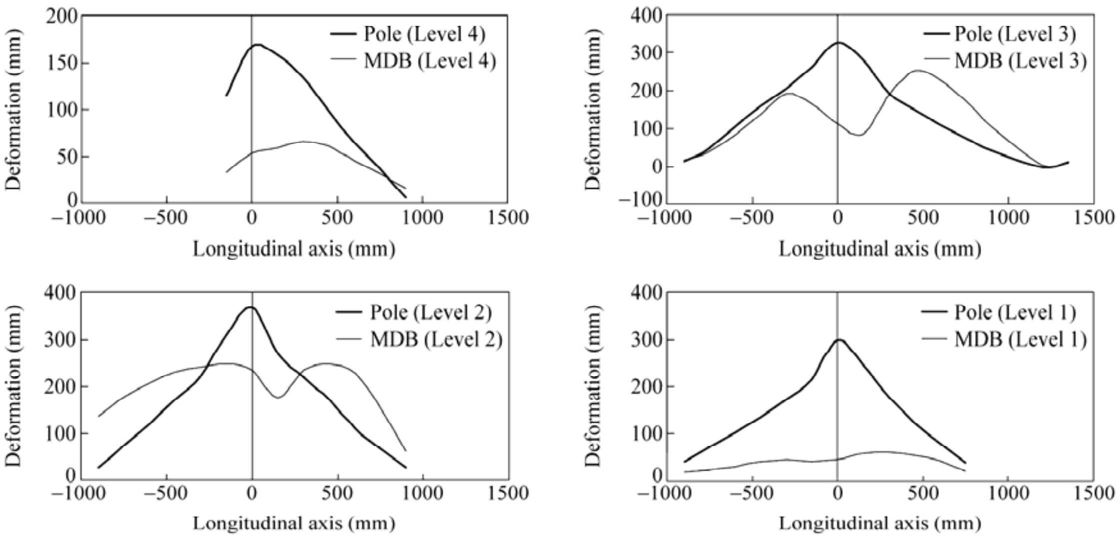


Fig. 6 Permanent deformation of pole and MDB side impact

The energies absorbed by the car in these two modes are calculated. The FEA results show that energy in the pole side impact is 50 345.23 J and in the MDB side impact is 39 202.06 J. The energy absorbed in the MDB side impact is found to be 22.1% less than that in the pole sick impact, which is far smaller than those deformation ratios shown in Table 3.

Although the amounts of energy imparted into the car did not differ much, the deformations differed greatly. This is apparent because of the energy distribution shown in Fig. 7. In the pole side impact, the energy is centralized within a very narrow area, which leads to the same amount of energy producing larger intrusions. As a result, this is significant in terms of the occupant protection.

4.2 Acceleration at the lower B-pillar of unstruck side

The acceleration time histories obtained from the "low" point of the "B"-pillar on the unstruck side in the two side impacts are shown in Fig. 8. The magnitudes of acceleration level in the MDB side impact are about two times that of the pole side impact. It is understood that more structures are involved in the MDB side impact so that the effective vehicle lateral stiffness is greater.

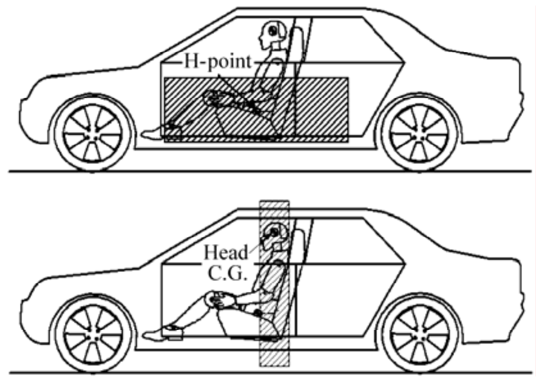


Fig. 7 Side impact area

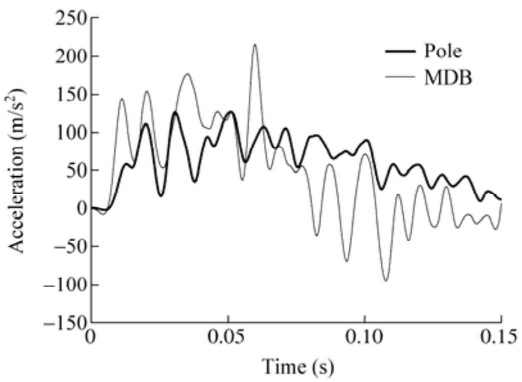


Fig. 8 Acceleration comparison

4.3 Occupant protection

Based on the aforementioned deformation and acceleration results, we can see that in the two different patterns of deformations in the pole and MDB side impacts, the occupants would be subjected to two conditions: under either smaller acceleration with larger intrusions in the pole side impact or larger acceleration with smaller intrusions as in the MDB side impact. However, the acceleration levels of the two conditions are low enough so that the injury criteria based on acceleration would be at a low level. Therefore, to maintain the passenger compartment is the key in the side impact occupant protection, especially in the pole side impact, during which an intrusion of 478 mm would be vital to the occupants.

Another concern is the head impact in the pole side impact. Because the position of the pole in the test setup is in line with the occupant head C.G., the head would impact to the pole directly and cause serious injury, if there were no head airbag. The side head airbag is becoming a safety countermeasure in newer vehicles.

5 Conclusions

The relationship between the pole side and MDB side impacts is discussed and the results are summarized as follows:

(1) Post test vehicles of the two side impact tests or simulations were examined to evaluate the car side crashworthiness. In the pole side impact, the magnitude of acceleration is smaller than that of the MDB side impact, while its structural deformation or intrusion is much larger than that of the MDB side impact.

(2) The pole and MDB side impact tests can be characterized by their higher acceleration or larger intrusion. Accordingly, the occupant protection concepts for these two impacts require different strategies.

MDB and pole side impacts have different structure crashworthiness requirements. For a full assessment of the side structure crashworthiness, the pole side impact test is being recommended as a supplement to the MDB side impact test, which will be set as the certificate test for all new M1 class cars.

The head side airbag is one kind of important occupant protection device for protecting an occupant's head during side impacts and is recommended to be added to all passenger cars.

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Inauguration Ceremony for Newly Named Peking Union Medical College, Tsinghua University

The newly re-named Peking Union Medical College, Tsinghua University was officially introduced to the press and the public at the Great Hall of the People on September 5, 2006.

The government of China in recent years has pursued aggressively a policy to develop world class universities through cooperation and collaboration agreements. In order to build universities in China into world-class universities and to transform education and promote the innovative use of technology, the Ministry of Education and Ministry of Health in September of 2002 gave their support to the establishment of close cooperation between Tsinghua University and Peking Union Medical College.

According to the agreement, Peking Union Medical College will be renamed Peking Union Medical College，Tsinghua University. Peking Union will maintain its own administration, assets, and management of funds. It will operate under the co-lead of the Ministry of Education and Ministry of Health while maintaining its legal person status.

Attending the ceremony were Mr. Wu Jieping, Former Vice Chairman of the NPC Standing Committee, Mr. Zhou Ji, Minister of Education, Mr. Gao Qiang, Minister of Health, Mr. Zhu Shanlu, Member of the Standing Committee of the CPC Beijing Committee and the Secretary of Municipal Educational and Working Committee, Tsinghua President Gu Binglin, Tsinghua University Council Chairman Chen Xi, Professor Liu Depei, President of Peking Union Medical College, and Professor Liu Qian, Party Secretary of the Peking Union Medical College. Mr. Jiang Zuojun, Vice Minister of Health, hosted the ceremony.

The clinical medicine students will have the benefit of joint status at both the sponsoring institutions.

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