Occupant Risk Evaluation Based on Frontal Collision of Bus

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Abstract—*This article took the type of 6900 passenger car as an object reference, referred protection of the occupants in the event of a frontal collision (ECE R94) and protection of the occupants of the cab of commercial vehicles (ECE R29). Through the analysis of the initial energy when the bus was collision and took advantage of the software LS-DYNA to analyze the impact tests of pendulum and fixed barrier wall, respectively. By calculated the displacement and acceleration of the framework, it determined using the frontal collision evaluation was reasonable. On this basis, it selected the collision speed-30 km/h to conduct the frontal passenger crash test in real vehicle that of fixed barrier wall. And then, it analyzed the impact of two-point and three-point seat belts harness on the bus occupant safety. The results showed that: the three-point seat belt protection was better than two-point seat belts, so the three-point seat belts arrangement should be installed on buses, possibly*.

Keywords- Crashworthiness; frontal collision; ECE R94; ECE R29

I. INTRODUCTION

According to the accident statistics for buses, accidents involving frontal collision constitute an important percentage among all bus accidents. In this type of accidents, front body of the bus structure gets severely damaged and this puts the driver and crew in great injury risk. And most of the frontal collision accidents result in death of the bus driver. Because of this, the safety of both the bus driver and the crew should be ensured in the case of frontal collision accidents. Providing the driver's safety is crucial since the driver is the key person for keeping the control of the bus in the event of an accident so that the safety of the passengers will be ensured [1].

There is no complete test methods and evaluation system, also no mandatory regulatory requirements in currently systems. This article takes a type of 6900 bus as study object, using the FEA procedure LS-DYNA to investigate the test techniques and the evaluation methods in the front structure of bus. On this basis , with the real vehicle tests to analysis of the bus occupant safety on the two-point seat belts and three-point seat belts, and provide technical support for the development of relevant standards.

II. BASIC THEORY

Even though the most of the passive safety standards are related to the safety of the passengers, some international regulations exist for the driver's safety for heavy vehicles. The European regulation ECE-R29 is arranged to provide the safety of the truck cabin and the driver. This regulation involves a frontal crash pendulum test in which a plate with a specified mass strikes the cabin of the vehicle. A regulation specifically arranged for the safety of bus in the case of frontal crashes does not exist, but some proposals similar to ECE-R29 are being discussed in Working Party on Passive Safety (GRSP) in UNECE.

The pendulum is simulated as rigid elements, without considering the deformation of the pendulum during the impact. In view of no unifed regulations in impact energy for bus, a reasonable impact velocity must be established in terms of different commercial vehicles. Volvo has done the experiment with impact energy twice as the specifed value based on ECE R29. The 96th International Conference of WP29/GRSG [2] has been proposed 80 kJ energy as impact energy of pendulum. Federal Motor Vehicle Safety Standard proposed some requirements on Front crash about the school bus . In 2009, the Chinese bus academic forum annual meeting proposed to draft the national standards "Front crash of bus' requirements" for the first time. There are two test methods: 1.The front pendulum tests; 2.The front barrier crash tests [3][4][5].

When the bus has a front impact on the fixed rigid barrier, in accordance with the 7000Kg quality to calculate, we can know that when the impact velocity is 30 Km/h, the initial impact energy is about 243.1KJ, and the impact energy is approximately 5 times of the pendulum impact energy (44.1KJ) or 8 times (29.4KJ).

III. ANALYSIS OF IMPACT ENERGY

A. Finite Element Model

This article takes the type of 6900 passenger car as an object reference, the bus body consists of front body, front chassis, right and left side walls, roof, steering systems. The overall bus finite element model consists of 467,999 nodes and 467,248 shell elements.

TABLE I. BASIC PARAMETERS

Item	Parameters	Item	Parameters
Kerb mass	8500 kg	front / rear overhang	1905/2790 mm
Wheelbase	4300 mm	Axle load	3800/8190 kg
number of axles	2	l* w* h	8995/2480/3335 mm

B. The Pendulum Test

The finite element analysis of this study was conducted by using explicit nonlinear finite element code LS-DYNA. The bus structure was crashed with a pendulum having a mass of 1500 kg as described in the ECE R29 regulation.

The regulation proposes an impacter plate which is made up of steel material and having a mass of 1500 ±250 kg. This impacter has to be a rectangle with a width of 2500 mm and a height of 800 mm[6][7]. According to the regulation the impact energy should be at least 45 kJ for the vehicles exceeding 7000 kg of mass. Under these conditions the driver's survival space should be checked after the test. For this purpose, a manikin should be used which is described in the regulation.

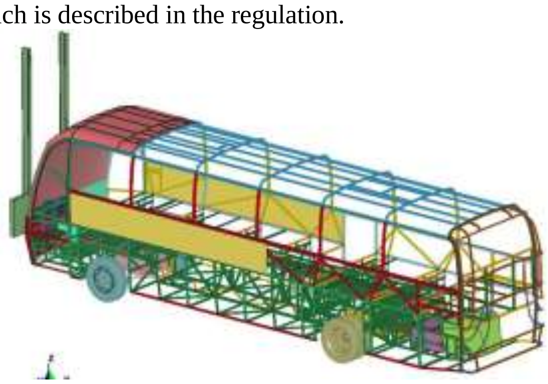


Figure 1. Pendulum and Bus

According to ECE R-29 regulation the desired kinetic energy of the pendulum is 45 kJ. This energy is given to the system as a kinetic energy. The desired angular velocity of the pendulum can be calculated by Equation 1, in order to obtain the required kinetic energy. The mass moment inertia of the pendulum plate about y-axis can be calculated by Equation 2.

$$E = \frac{1}{2} I_{yy} \omega_y^2 \qquad (1)$$

$$I_{yy} = I_{y_c y_c} + mL^2 \qquad (2)$$

The angular velocity of the pendulum was found to be ω = 2.2131 rad/s.

C. Frontal Collision of Bus

If want the energy of the 7000Kg bus hits the rigid barrier equals to the pendulum impact energy (29.4 KJ and 45 KJ), the corresponding bus impact velocity were 10.4Km/h and 12.8 km/h by Equation 3.

$$E = \frac{1}{2} mv^2 \qquad (3)$$

If want the pendulum impact energy reach to the initial impact energy (243 KJ) of the 7000Kg bus hits the rigid barrier with the speed of 30 km/h, supposing the arm length unchanged, is still 3500mm, then the pendulum mass should be increased to 7000 Kg (the existing mass is 1500 Kg) or heavier. Therefore, the initial impact energy of the existing two kinds of test methods has a greater difference, as well as the caused deformation, and two test modes are difficulty to equate.

Figure 2. Fixed barrier wall and bus

In this paper, we used the initial collisions speed of 30 km/h, 35 km/h and 40 km/h to analyze the initial collision energy. The front door frame longitudinal deformation is shown in tab.2. By calculated the displacement and acceleration of the framework, it determined using the head-on collision evaluation was reasonable.

TABLE II. FRONT DOOR FRAME LONGITUDINAL DEFORMATION

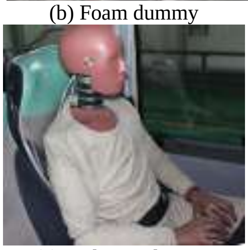
Test speed	The upper sampling point	The central sampling point	The lower sampling point
30km/h	18mm	291mm	140mm
35km/h	35mm	378mm	210mm
40km/h	54mm	557mm	355mm

IV. REAL VEHICLE TEST AND ANALYSIS RESULTS

The vehicle's requires suspensions, tires and steering systems should be in a normal working condition. The fixed counterweight should be evenly distributed in the interior of the vehicle[8]. According to the pre-developed real vehicle crash test program requirements, a GB foam dummy which's size is same as the HybridⅢ 50th percentile adult male test dummies is placed in the drive's position, and a HybridⅢ 50th percentile adult male test dummy is placed in the seat which is on the left of the first row after the driver's seat and near the channel, and than a HybridⅢ 50th percentile adult female test dummy is placed in the seat which is on the right of the first row after the driver's seat and near the window, and in the head, the knee should be coated with color, as shown in Figure 3.

(a) Test bus

(b) Foam dummy



(c) Male test dummy

(d) Female dummy

Figure 3. Data Collection Instruments layout

A. Deformation Analysis of Collision Area

During the collision, that the bus frame is all-bearing truss structure and the impact energy is almost absorbed by the front deformation results in a great deformation of the bus front and a about 430mm crumple distance; the collision makes the dashboard and steering wheel move back and seriously squeeze the driver; after the collision, the front windshield is broken but not deciduous and the other windows are in good condition; the doors do not pen themselves during the test and the passenger door and driver side door get stuck after the test and can not be used; the fuel system does not have fuel leakage after the test. Deformation of the bus front structure is shown in Figure 4.

(a) right front 45°

(b) driving area

Figure 4. Deformation of the Bus Front Structure

B. Injury Criterions and Dummy Appraisement

The performance of all the test dummies should meet the following requirements: the head performance indicators (HIC36) should be less than or equal to 1000; the thorax performance indicators (ThPC) should be less than or equal to 75mm; the femur performance indicators (FPC) should be less than or equal to 10 KN [9][10]. The criterion of HIC is worked out by CMVDR 294 and occidental rule based on Equation 4 [11][12].

$$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\} < 1000 \qquad (4)$$

Where, a(t) is the resultant linear acceleration time history (g's) of the center of gravity of the head, and t_1 and t_2 the interval between every 36ms of the crash process which produced the maximal HIC. C3ms is the 3ms criterion of the chest acceleration.

From the tab.3, we can see that the chest compression of the test dummy 1 is 37.42 mm, far less than 75 mm which is provided in the standards and regulations, will not hurt the dummy' chest; The chest compression of the test dummy 2 has not been colleted. The left and right leg axial force of the two test dummies is 0.7 to 1.41 kN, less than 10 kN which is the thigh bone axial tolerance limit.

TABLE III. THE IMPACT PARAMETERS OF THE TEST DUMMY

Test Project	Maximum Value	Time(s)
Passenger 1-Chest-Distance	37.42mm	0.2264
Passenger 1-Left-Leg-Force	0.703KN	0.0789
Passenger 1-Right-Leg-Force	1.277KN	0.1481
Passenger 1-Neck- FX	2.046KN	0.1488
Passenger 1-Neck- MY	79.85Nm	0.1507
Passenger 1-Neck- FZ	0.887KN	0.1463
Passenger 2-Left-Leg-Force	1.211KN	0.0124
Passenger 2-Right-Leg-Force	1.411KN	0.1322

C. Safety Belt Protection Effect

From the tab.4, we can see that the test dummy 1 wore a two-point belt, and the upper limb generated whiplash action made head X-acceleration is too large, and the maximum reached 250g made the value of HIC36 is 1586 which is beyond the tolerance limits of the human body. We know the test dummy 1 will die because of head injuries; the test dummy 1 wore a three-point belt which can better restrain the dummy, so each of the head acceleration are relatively small.

TABLE IV. THE IMPACT PARAMETERS OF THE TEST DUMMY

Passenger 1-Head (two-point belt)			Passenger 2-Head (three-point belt)		
Test Project	Maximum Measured Value	Time(s)	Test Project	Maximum Measured Value	Time(s)
X-Acceleration	250.2g	0.1480	X-Acceleration	23.9g	0.1277
Y-Acceleration	69g	0.148	Y-Acceleration	5.635g	0.1434
Z-Acceleration	30.03g	0.1482	Z-Acceleration	15.66g	0.0839
HIC_{36}	1586	/	HIC_{36}	76	/

According to Equation 4, safety belt protection effect is shown in Fig.5 and Fig.6. By comparing the analysis of the test results, three-point safety belt protection was better than two-point seat belts, so the three-point seat belts arrangement should be installed on buses, possibly.

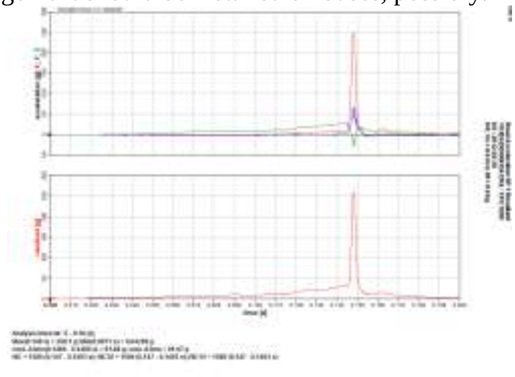


Figure 5. dummy wore two-point belt

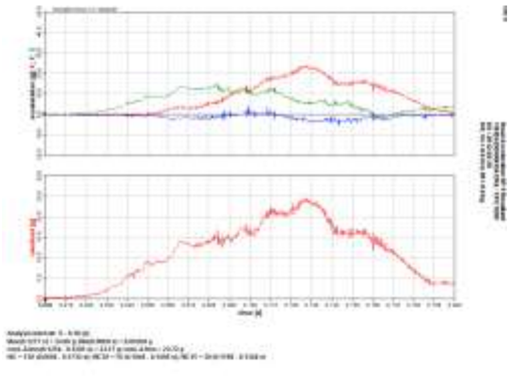


Figure 6. dummy wore three-point belt

V. CONCLUSIONS

(1) Referring to the regulations of protection of the occupants in the event of a frontal collision (ECE R94) and protection of the occupants of the cab of commercial vehicles (ECE R29). Revolved the two ways of the pendulum hammer and the fixed barrier wall, used the initial collisions speed of 30km/h, 35km/h and 40km/h to analyze the initial collision energy, and determined the speed of 30km/h bump under the fixed barrier wall to evaluate the front passenger structural safety.

(2) On this basis, it designed the test program of the front passenger crash, including the test site, the orientation of the barrier, the vehicle conditions, the dummies, the vehicle's driving system, the test speed and the location and other requirements of the vehicle's dates measurement. It conducted the tests in the real vehicle, repeatedly. By comparing the analysis of the test results, three-point safety belt protection was better than two-point seat belts, so the three-point seat belts arrangement should be installed on buses, possibly.

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