Frontal impact on bus superstructure as per UNECE R29 and NCAP

M A A Afripin, A Z Zainudin, M A H F M Sahar and M Yusof*

School of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia.

Abstract: Frontal crash for the large vehicle is less severe compared to the lightweight vehicle due to the height position of the driver compartment in the vehicle which sits well above the impact area in any accident involving a passenger vehicle. Due to this reason, most of the coachbuilder does not include crumple zone in their design as what the car’s manufacturer did. However, in the case of frontal collision between two large vehicles or with the rigid wall, the possibility of energy absorption of the structure is very low and the remaining energy will be transferred directly to the driver and occupants. In this respect, two prominent regulations for frontal impact, namely United Nation Economic Commission of Europe (UNECE) Regulation no. 29 and New Car Assessment Program (NCAP) is used to determine whether the structures are having enough strength to withstand the load produced by the impact. This paper deals with the finite element simulation of a frontal impact on bus superstructure by applying both of the regulations. Then, the results for both simulations are compared in terms of energy produced, structure deformations, maximum stress, and the corresponding plastic strains. It is found that the energy from the ECE R29 regulation is lower than NHTSA’s NCAP with 55 kJ and 142 kJ respectively. However, the deformation observed from R29 simulation, the front structures is severely deformed. Meanwhile, the structures in the NCAP simulation are still intact and the steering wheel structures are still not in contact with any body parts of the driver.

1. Introduction

Road traffic accidents are always a huge issue in developing countries such as Malaysia. The high numbers of fatalities due to the road accident are recorded by a motorcyclist with compromised about 60% of the total fatalities [1]. In addition, the number of accidents involving commercial vehicles such as bus also increases significantly. For bus, the cases of road traffic accidents increase significantly by 48% between the year 2006 to 2008 [2].

In the United States of America, an average of 55,000 buses crashed each year result in an average of 250 occupant fatalities and 14,000 injuries. The common types of bus-involved accidents are frontal collision, side impact, rear impact and rollover. The most severe accidents recorded by the Fatality Analysis, Reporting System (FARS) are rollover which contributed 44 pct. of fatal events involving road vehicle. However, the study of rollover is commonly done by previous researchers and following UNECE Regulation 66. However, the frontal impact on the bus is still at infancy [3]. The existing regulation for frontal impact is UNECE R29, which adapts from regulation specifically designed for heavy truck [4].

Studies on crashworthiness and safety of vehicles have gained concerns for the past years [5]. Frontal accident fatalities compared to all fatalities in bus accidents shows the highest in Netherland, 83.3% [6]. In this study, we are focusing on frontal crash of the bus. Accidents due to the frontal crash causing
damage to the frontal bus structure and this will lead to the serious injury towards bus driver and in some cases, death on the spot. Providing the safety of the driver is crucial, since bus driver is a key person for keeping the control of the bus within the event of accidents, safety of the passengers is going to be ensured [5]. The safety of the bus driver is important as the driver that control the bus movement and keep their passenger in safe and comfortable journey. Thus, it is important to investigate the performance of the safety zone of a bus driver.

Most common methods used by researchers are by doing an analysis of dynamic simulation using various kinds of software [4, 7, 8]. Finite Element Method (FEM) is vital to get the data analysis.

To carry out the research, certain regulation need to be considered to meet the international standards. In this study, United Nation Regulation No.29 and New Car Assessment Program (NCAP) had been used. Finally, to provide assurance of protection in potentially serious injury crashes, the test procedures must be severe enough to represent a crash in which occupants could be seriously injured or killed [9].

2. Methodology

Frontal impact simulations have been executed following UNECE R29 and NCAP regulations.

2.1 Frontal Impact Assessment follows ECE-R29 and NCAP

The assessment technique used in the frontal impact study is ECE R29 and NCAP, which covered on frontal crash of the vehicle. The main difference between these two regulations are the type of loading which for ECE R29, the pendulum is used with particular angular velocity while for NCAP, the vehicle are moving towards a rigid wall with assigned velocity.

According to ECE Regulation 29, the vehicles with a gross mass of 7500 kg or more, the impact energy produce from the pendulum must be 55 kJ. There should be no contact between the structure and the driver to ensure the structure is meeting the requirement in the regulation. In view of this, the manikin should be used which is described in R29.

In the New Car Assessment Program (NCAP) frontal impact test under National Highway Traffic Safety Administration (NHTSA), a test vehicle is moving towards a rigid wall with a speed of 56 km/h perpendicular to the wall surface. In this study, similar size of manikin used in the R29 will be used in the NCAP frontal impact virtual simulation.

2.2 Material Properties

A series of tensile test are being performed prior to the simulation to obtain accurate input material properties for bus superstructure. The structure is assumed to behave in an elastic-plastic manner. Since the interested results are the plastic deformation of the structure, the input used are up to inelastic properties. The extensometer is used as the measurement device to capture the elastic and plastic strain within the gauge length. Four specimens had been tested to ensure the best repeatability measurement produce from the test. The yield stress is 327 MPa and the elastic modulus measured based on the gradient of elastic regime is 210 GPa. Properties of mild steel with material density of 7800 kg/m$^3$ were used in this study. The strain rate effects of the structures are model using Johnson-Cook constitutive model [10] as shown in Equation 1.

$$\sigma = [327 + (534) e^{(0.423)}][1 + (0.0756) \ln \dot{\varepsilon}]$$

The input strain rates dependent stress-plastic strain curves in this study are covered for rates ranging from 0.01 to 1600 s$^{-1}$. The resulting strain rate-dependent stress-true strain curves for different rates are displayed in Figure 1.
Figure 1. Stress-strain curves for different strain rates.

2.3 Loading and Boundary Conditions
The parameters used in this paper is partially based on previous researchers [5, 11, 12]. The pendulum has a striking surface of 2500 mm x 800 mm and is made of steel with evenly distributed mass of at least 1500 kg. The pendulum is suspended by two rigid beams of 1000 mm apart and 3500 mm long from the axis of suspension to the geometric centre of the impactor. Its striking surface is in contact with the foremost part of the vehicle and the vertical position of the pendulum’s centre of gravity (H-point) is 50 + 5/-0 mm below the R-point of the driver’s seat as shown in Figure 2.

The front parts of the bus body are meshed with beam element B31 (A 2-node linear beam in space) elements. The mesh size is chosen to be 50 mm. The boundary conditions are according to the actual test specified in the regulation. The pendulum mass moment of inertia is 2453 kg.m². The configurations for frontal impact based on R29 and NCAP are shown in Figure 2 and 3 respectively.

Figure 2. Simulation setup for UNECE R29. Figure 3. Simulation setup for NCAP.

3. Results and discussion
3.1 Deformation Response of Bus Superstructure
3.1.1 R29 Simulation. The evolution of the deform shape of the bus superstructure during the frontal impact simulation following UNECE R29 is shown in Figure 4. Figure 4 (a) and (b) shows the structure
during initial condition and first impact respectively. It can be observed that in Figure 4 (c), the steering wheel is approaching manikin body. However, the maximum deformation is still in elastic region and the steering wheel structure is bouncing back up to the plastic deformation and a clearance can be seen in Figure 4 (d). The maximum von-Mises stress record is 551 MPa which exceeding the yield stress of quasi-static condition. The displacement of critical nodes of the steering wheel along the z - direction is calculated and the maximum displacement of 140 mm is recorded at 125 ms.

![Figure 4. The evolution of structural deformation during frontal impact following R29.](image)

3.1.2 NCAP Simulation. The evolution of deformation shapes following NCAP requirements is shown in Figure 5. Figure 5 (a) showing the initial condition of the bus superstructure. At 3ms, the front structure is fully crush and start to crumple inside the driver compartment as shown in Figure 5 (c). Final deformation at t=198.3ms is shown in Figure 5 (d). During the deformation, the steering wheel doesn't infringe into the driver manikin indicating that the structure is passing the requirement by following the NCAP.

![Figure 5. The evolution of structure deformation during frontal impact following NCAP.](image)

4. Conclusion
The frontal impact simulation of the bus superstructure by following UNECE R29 and NCAP have been demonstrated. Results show that:

- Energy produce from the frontal impact following NCAP requirement is much higher than UNECE R29 by the difference of 61 %.
- In R29 simulation, the energy from the impact are fully absorbed by the superstructure simulation while for NCAP, the energy is also borne by the chassis of the bus.
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