Development of simplified safety assessment procedure for paratransit buses

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Abstract

This paper describes development of a simplified procedure for the safety assessment of paratransit buses. The principal concept of the bus crashworthiness evaluation is adopted from the United Nations (UN), and ECE Regulation 66 [3]. The main objective of this study is to replace expensive and impractical full scale tests with a series of simple and well defined experiments on structural components. The research methodology utilized for development of a new procedure is based on two tracks of parallel research activities. The first research track consists of experimental tests conducted on three conceptual levels: material characterization, component testing, and full scale tests. The second track contains virtual testing representing the experiments. The virtual tests are performed using the nonlinear explicit dynamic code LS-DYNA® and well developed, verified and validated Finite Element models. The numerical results are used for extensive parametric studies and “what if” investigations. The FE models of the entire bus and its tested components are validated through comparison with the experimental data derived from several laboratory tests of the bus connections.

Keywords: crashworthiness, impact, industrial problems, numerical analysis, structural mechanics

1. Introduction

The so called “paratransit” or “cut-away” buses form a unique segment of vehicles in the USA. They are distinguished by two specific features. First, as commercial vehicles designed to transport up to 22 passengers on short distances, complementing regularly scheduled bus routes, they represent a class of vehicles with the weight of about 6 tons. It places paratransit buses between the classes of lighter passenger vehicles and heavier coaches. The gross vehicle weight is recognized as the main criteria for application of numerous federal standards which specify requirements and approval procedures. Unfortunately none of the regulations specifically addresses paratransit buses and especially their roof crush resistance. On the other hand, the production of the paratransit buses is carried out in two different stages. First, a major, reputable auto manufacturer constructs a vehicle with a driver cab and chassis under strict quality guidelines. Then a smaller company, a “body builder” attaches passenger compartments with all additional equipment, as required by a customer. The manufacturing process raises many technical problems, especially regarding the bus connections, while a large number of manufacturers results in variety of technical solutions.

The problem described above has been addressed in a series of research projects conducted since 1999 at the Crashworthiness and Impact Analysis Laboratory and resulted in the first version of the FDOT Crash and Safety Standard included in the Florida Vehicle Procurement Program [4]. The principal concept of the bus crashworthiness evaluation was adopted from the United Nations ECE Regulation 66 which refers to the integrity of the roof and is based on a full scale rollover test [3]. The purpose of this procedure is to ensure a superstructure of sufficient strength so that the precisely defined residual space stays intact both: during and after the rollover test. The current version of Florida Standard [4] provides two assessment methods by either experimental full-scale crash tests, or by the computational analysis using a validated Finite Element (FE) method. This safety assessment program is described in detail in recent publication [2]. Although the numerical approval procedure is recognized as an easier, more thorough and conclusive, both methods, which are based on full scale tests (experimental or virtual), have been found as either expensive or time consuming.

To overcome this inefficiency a new simplified procedure is currently under development. The main objective of this investigation is to replace expensive and impractical full scale tests with a series of simple and well defined experiments on structural components. The new procedure is supposed to estimate with high level of confidence if the considered bus is likely to pass the full scale rollover test.

The research methodology applied for the development of the new procedure is based on two parallel sets of activities. The first research track consists of experimental tests conducted at three conceptual levels: material characterization, component testing, and full scale tests. The second track contains virtual testing performed using LS-DYNA®, the nonlinear explicit dynamic code and verified and validated FE models. The numerical results are applied for extensive parametric studies, and to assist determination of the detailed test procedures, expected limiting values, and approval criteria. This paper describes the computational part of the research with FE model development, and its verification and validation.

2. FE model development, verification and validation

Development process of a finite element model of a bus closely replicated the actual bus manufacturing process. In the first stage, the FE model of the cutaway chassis was virtually extracted from a public domain FE model of the Ford Econoline.
Van, which was developed earlier by the National Crash Analysis Center (NCAC) at George Washington University [2]. In the second stage, a 3D FE model of the passenger compartment was built based on the centerline dimensions of the profiles, provided by a manufacturer. All structural and some nonstructural components of the interior including passenger weights were included in the model to fully replicate mass distribution and inertia properties of the bus.

Additionally, a multi-scale laboratory testing program was developed and implemented in support of the verification and validation of the FE model. It included: (1) material characterization tests [1], (2) connection testing [2], and (3) verification of energy transfer and validation of mass distribution for the whole bus [2]. As one of the verification procedures the energy balance is checked and compared with simple hand calculations. All the non-physical forms of energy, i.e. hourglass and contact energy were kept at minimum.

3. Program for parametric study using virtual testing

Fig. 1 depicts the main idea for ongoing parametric study. The whole investigation is based on the virtual testing using verified and validated FE models of the entire bus structure and its selected components. The goal is to find relationships between performance of selected components and the behavior of the entire bus during a rollover test. At the present stage three groups of component tests have been designed. The first group consists of the static four point bending and impact tests on single tubes. The impact tests are conducted using a specially designed impact hammer and different drop heights. Considered tubes are used as the main component of steel frames protecting a passenger compartment. If the steel frame is properly welded and firmly connected to the chassis most of the energy is dissipated during a roll-over test in plastic hinges generated in the steel tubes. The second group of the tests refers to side wall panels with and without skin, subjected to impact loading using a larger impact hammer. The tests are supposed to validate welded connections between vertical and horizontal tubes and the amount of energy absorbed by skin. Finally, the third group gathers quasi-static tests on wall to floor and wall to roof connections. They are used to determine moment rotation characteristic.

The numerical parametric study is supposed to deliver data which will be used to improve test procedures and establish limit values with relation to the basic bus structure characteristics. One of the issues analyzed numerically is the distribution of internal energy (elastic and dissipated) among different structural components. It has been identified that the total internal energy in the simulation of the full scale rollover test is absorbed mostly by parts shown schematically in Fig. 2: cage, skin, front fiberglass cap, and bus chassis cab. These parts were chosen for further investigation to establish energy absorption requirements for the simplified procedure tests.

A strong correlation between bus the performance of the bus connections and the overall crashworthiness of the bus should allow for derivation of simple analytical formulae evaluating results of component tests. It will be therefore possible to determine if the bus is likely to pass the rollover test based on the performance of its connections. Consequently, it will also be possible to determine the minimum and target energy levels of the connection to meet the desirable bus performance.

4. Summary

The paper presents a numerical development of a simplified method to assess crashworthiness and safety of paratransit buses. The method is based on multi-scale experimental tests. Each test is designed to determine actual amount of dissipated internal energy and compare it with minimum and target energy. Buses with connections meeting the minimum energy standards will be judged as likely of meeting the crashworthiness standard [3].

References