Railroad Passenger Vehicle Collision Analysis

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Introduction

In this study, crashworthiness assessment and suggestions for the modification of a railroad passenger car are presented. To assess the crashworthiness, collision of the railroad passenger car onto a rigid wall is simulated by using finite element (FE) methods. A full-length, detailed passenger car model is used in FE analyses. In order to validate the FE model, simulation results obtained for different types of static loading conditions in compliance with various scenarios defined in UIC CODE OR 577 are compared with experimental measurements before running collision analyses of the railroad passenger car. The good agreement between static tests and FE analyses results indicates that the FE model accurately represents the real structure. Then the collision behaviour of the railroad passenger have been investigated in two stages. First, the crashworthiness of the initial concept design of the railroad passenger car is analysed. It was observed that local buckling takes place at various points. Having revealed the structural weaknesses, the initial design was modified and simulated again under the same conditions. Using size optimisation, thickness of some sheet metal components is changed in order to obtain the intended progressive damage behaviour. As a result of the modifications, the passenger car design with better crashworthiness properties was obtained, in which large plastic deformations occur around the collision side of the car while mainly elastic deformations occur in the car's body away from the bumpers.

When a high speed train crash occurs, optimum occupant protection is very important to prevent loss of life. It was observed in many crash accidents that the traditional structural design approach, which satisfies the design requirements only for static loading conditions, does not provide optimum occupant protection; thus, considerable research has focused on structural crashworthiness of train design in the last two decades. The most popular occupant protection approach is passive protection. According to this approach, when a collision occurs, a passenger car deforms and collapses in such a controlled manner that large plastic deformations occur around the collision side of the passenger car; mainly, elastic deformations occur in the other regions and impact energy is absorbed safely outside of passengers' living regions. Most of the studies on the crash behaviour of railroad vehicles simulate a collision with a rigid wall. This is a simple and ideal model to reveal the general characteristics of impact behaviour of a full-scale car with impact test and/or computational simulations.

Crash analyses of a railroad passenger car - *FE model*

A railroad passenger car called 'N13-type' used by Turkish State Railways is examined in this study. End regions of the car contain entrance doors, corridors, water supplies, toilets and electric distribution cupboards. This layout enables the use of these areas as energy absorption regions far away from the main occupant area. The middle part of the car is the cabin, fromwhich large deformations are to be kept away. Bogies and rail tracks have not been modelled explicitly, but corresponding point masses and boundary conditions were applied to simulate the effect of bogies and auxiliary equipments. The total car tare weight is approximately 50 tons, including bogies and other equipments. The complete solid model of the passenger car contains approximately 1,650,000 elements. The FE model of the end region of the passenger car is shown in figure 1.

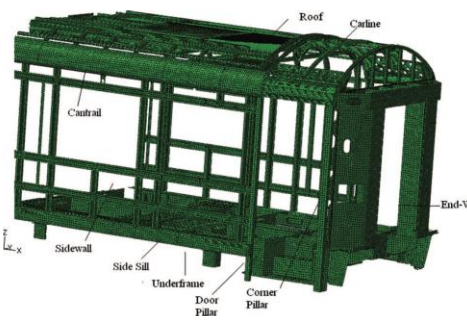

Figure 1. FE model of the end part of the passenger car

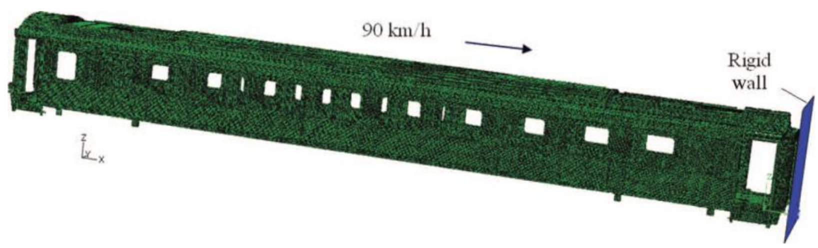

Figure 2. Passenger car crash model and the rigid wall.

In order to investigate the damage progress in the passenger car, the crash speeds are chosen to be high enough to yield the collapse of the whole vehicle end areas. The duration of collision is selected to be 100 ms in simulations in which the software Abaqus/Explicit is used. The coupler system treatment is an important issue in the assessment of the crashworthiness of railroad vehicles, as it is the first component to contact the rigidwall in a crash, and absorbs a certain amount of impact energy. As our main concern was to investigate the worst case to which a railroad car is subjected, and the crashworthiness of the passenger car would be positively affected by the the coupler system, the coupler system is not included in the model. The passenger car underframe is the most important component for crash energy dissipation that can be divided into two zones by considering the crash characteristics.

Validation of the FE model by comparisons with static tests

To validate the FE model, static FE simulation studies are completed according to the International Standard UIC CODE OR 577. The same tests are also been applied to a prototype passenger car located at TUVASAS (Turkish Wagon Industry Inc.) in Adapazari, Turkey. A total of 30 strain gauge rosettes were applied to a quarter of the car body to capture the plane-stress behaviour of the structure, and the simulation resultswere compared with experimental measurements. Figure 3 shows the experimental car test setup and a sample strain gauge application. Static tension and compression loads have been applied according to the related international standards.

Figure 3 : Experimental Car Test Setup and a Sample Strain Gauge Application

Figure 4 shows the comparisons of the measurements with FE stress results obtained for a symmetrical compression force of 2000 kN at the strain gauge points. Figure 5 shows the comparisons for the measurements obtained for a tensile force of 1500 kN at various strain gauge points. In conclusion, the results of FE model were observed to be in good agreement with experimental strain gauge measurements (in brief, 27 gauge locations demonstrate less than 10% error in von Mises stress values).

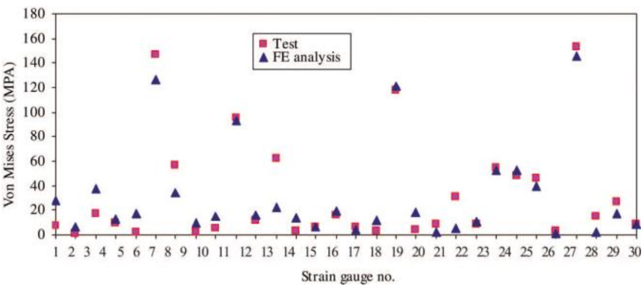

Figure 4. Results of compression force of 2000 kN

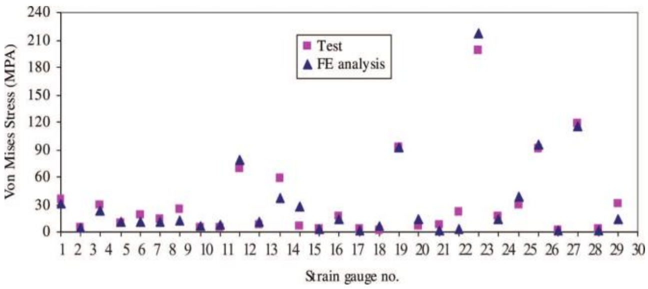

Figure 5. Results of tensile force of 1500 kN

Structural weak points and crashworthiness enhancement

It is already observed that the side sill buckling occurs during the crash and structural improvement is needed to stabilise the process. The side sills are long and thin components in the passenger car. So, they can be easily bent in the lateral plane. Several support beam and side sill thickness values are taken into consideration in order to adjust the relative stiffness of different under floor zones, enhance the structural stability of zone 2 and avoid lateral bending of the side sill. Subsequently, collision of the modified railroad passenger car onto a rigid wall is simulated and the results of the modified and original structures are compared. In Figure 16, the modified passenger car crashes into a rigid wall at an initial speed of 90 km/h. It is concluded from that the end structure of the passenger car undergoes progressive deformation, and the problems that appeared in the original passenger car body were overcome as a result of the modifications. Desired large plastic deformation occurs at the end region of the passenger car and small elastic deformation occurs in the passenger cabin. Zone 1 collapses fully at the time instant of 18 ms (similar to that of the original model), and then zone 2 undergoes the deformation of about 2200 mm at 100 ms.

Conclusion

The energy absorption capability of the full-scale original and modified railroad passenger cars is examined during a crash into a wall. This is evaluated by simulating the crash of the railroad car onto a rigid wall at 90 km/h. It was shown that the original passenger car structure absorbs the collision energy in a stable trend, but the deformation of the car body does not follow the desired progressive form and local buckling occurs. These undesired deformation characteristics occur due to the side sill buckling and too stiff behaviour of zone 2 components, that is, support beams. Side sill buckling causes plastic deformation of the passenger cabin region and destroys the stability of the structure. In addition, excessively stiff components do not deform in the desired manner, which in turn transmits the crash force into the interior regions and prevents the structural stability as well. In order to improve the progressive deformation feature and enhance the energy absorption ability of the car structure, the thickness values of the side sill and various zone 2 components were modified to adjust relative stiffness of different underfloor regions. As a result of the size optimisation of the thickness values of these components, the plastic deformation of the cabin is prevented and desired progressive deformation of the passenger car end regions is satisfied. The modified passenger car absorbs about 13% more energy than that of the original passenger car structure. In these analyses, only rigid wall crash scenarios were considered. This is the simplest and most ideal crash scenario, but it is very useful to obtain general characteristics of crash behaviour of railroad vehicles.