Validation of the Numerical Model of Impuls I Electric Multiple Unit Driver's Cab

Paweł Wątroba, Mariusz Pawlak and Damian Gąsiorek

Abstract The article presents the validation of a numerical model of the electric multiple unit (EMU) driver's cab. The subject of the study was the cab of the driver of the Impuls I rail vehicle of Newag S.A. The numerical model was developed in the LS-Dyna environment based on the documentation received from the manufacturer. The driver's cab was modelled as shell elements, the additional parts required for the crash test were modelled as solid elements. Experimental research was carried out on the order of Newag S.A. on the experimental track of the Railway Institute in Węglewo near Zmigrod according to PN-EN 15227. The collision was recorded by 3 cameras used for fast changing phenomena. Additionally, acceleration sensors were placed at specific locations of the construction. The article presents results from experimental research and their comparison with the results of numerical simulation.

Keywords Rail crash · Crash worthiness · Validation

1 Introduction

The requirements for structural integrity of rail vehicles in Europe come mainly from the International Union of Railways (UIC) and normative documents such as the PN-EN 15227 standard describing the requirements for calculations, experimental studies and validation of rail vehicle collisions. The requirements included in the standard

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do not cover all possible accident scenarios but provide some degree of resistance to damage that will provide an adequate degree of protection in most cases where active safety measures are insufficient. It is required to provide a level of protection consistent with the probable threat of collision and this can be achieved by simulating the most common types of collisions causing injury and death [1–4].

Validating a numerical model is a very important modeling process. It involves comparing the results of numerical simulations with experimental results. The purpose of this process is to quantify the errors resulting from the assumptions made in the model, which has been solved numerically. For a model to be considered as correct it must meet the following criteria [2, 5, 6]:

- sequences in crash are the same,
- there are similar deformations,
- the difference of dissipated energy cannot be greater than 10% of the initial energy from the test,
- the simulation produces a global force curve, which exhibits the same general characteristics as measured in the test.

If collision energy is absorbed by many different mechanisms or progressive stages, the following comparison criteria should be applied:

- The permissible difference in displacement is 10% compared to the test value,
- The average force value read out from the force-displacement graph should be 10% of the test value.

The high compatibility of the numerical model with real tests depends mainly on the quality of the numerical model and kinematic imaging. Material properties used in crushing zones should be empirically determined, while nominal values may be used in other parts of the model. Ideally, only the mass and speed should be matched to the results of the calibration test [2].

Simulations of reference scenarios (based on which the validation is done) must be carried out using numerical models that faithfully reflect construction geometry and energy absorbing devices. On the other hand, the numerical calculations of complete vehicles must be based on the same modeling techniques and degree of detail as the simulations of real tests [2].

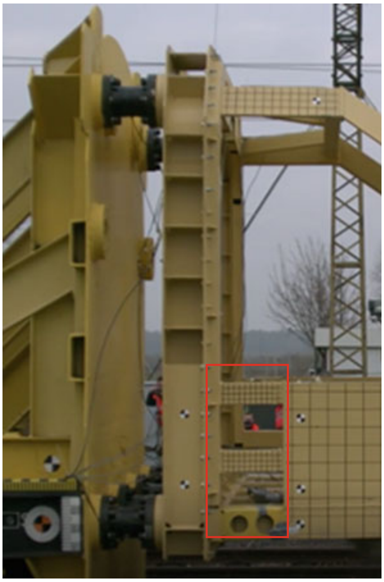
Poland is one of the few countries in the world that have rolling stock and infrastructure to conduct experimental research (currently there are 8 in the world), which is situated in Węglewo near Żmigród. Using the available infrastructure, in this study we analysed the driver's cab of the Impuls I rail vehicle of Newag S.A.

2 Experimental Tests

Experimental tests were carried out at the Test Track of the Railway Research Institute in Żmigród on the order of Newag S.A. Two crash tests were carried out, the first including the side absorbers and the second without the absorbers. The purpose of the first test was to determine how the vehicle would behave while absorbing energy

Fig. 1 Driver's cab with and without the side absorbers [7]

Fig. 2 Method of fixing EMU driver's cab to the coach wall with highlighted crash zone [7]



from the side absorbers, while the second was to test the impact of the crush zone in the rear of the driver's cab. In this paper, we consider only the second test [7] (see Fig. 1).

Experimental research required special preparation of the driver's cab and the coach during the collision. The front wall behind the driver's cab was modified in such a way that it could be bolted to the coach wall by force sensors [7] (see Fig. 2).

Additionally, for the second test, anti-climbing plates were installed in place of the absorbers (see Fig. 3). The same plates were on the second coach wall. The crash zone in the vehicle Impuls I is located behind the driver's seating position [7] (see Fig. 2).

Fig. 3 Anti-climbing plates instead of side absorbers [7]

Table 1 List of masses

	Coach C [t]	Coach A [t]
Coach frame	10	10
Bogie	5	5
Back wall	3.66	–
Front wall	3.2	3.5
Additional frame	3	5.94
Load box 1	14.25	–
Load box 2	3.71	–
Load box 3	3.6	–
Load box 4	3.79	–
Summary	55.21	29.44

The cab and coaches are fitted with quadrant symmetry markers that allow analyzing the sequence of collisions and obtaining additional parameters from the crash test. Looking from the side, there were 13 markers, two on the front wall, while looking upwards, two markers in the seat, 6 markers on the crossbar connecting the side walls of the cab and one on the front wall. Two markers were located on the frame of Coach A [7].

The mass of the wagon with the cab mounted was added to steel boxes filled with concrete to achieve the most even pressure on the wheels. The total weight of the wagon C with the installed cab was 55.21t (Coach C), while the standing wagon was 29.44t (Coach A). The list of masses of an individual coach is shown in Table 1 [7].

The collision was carried out in accordance with the diagram shown in Fig. 4. The coach C with the driver's cab, was accelerated by a locomotive up to 34 km/h,

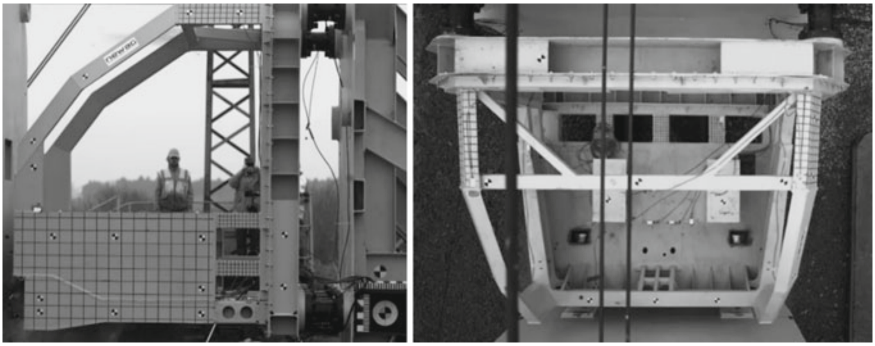


Fig. 4 Location of quadrant symmetry markers [7]

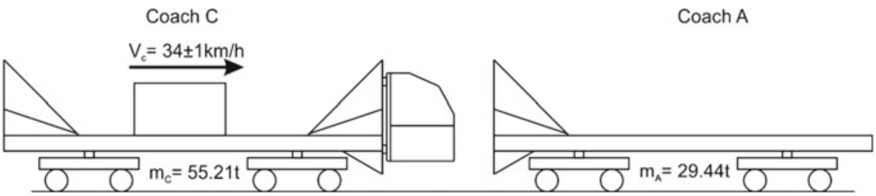


Fig. 5 Scheme of crash test

and just before the collision a coach was disengaged, and impacted on the unbraked coach A [7] (Fig. 5).

The crash test proceeded well, the velocity of the coach measured just before the impact reached 34.2 km/h. The greatest deformations occurred in the crumbling zone, thus absorbing the greatest part of the energy. Figure 6 shows the driver's cab just after the collision [7].

3 Numerical Model

The numerical model was based on the documentation received from the vehicle's manufacturer Newag S.A. The driver's cab model was simplified to a surface model. Surface model was prepared in SpaceClaim environment [8] (Fig. 7).

The prepared surface model was imported into the LS PrePost environment and then a finite element mesh was created. On the coach, a coarse mesh of finite elements was created. A high-quality mesh was created on the driver's cab [9–13] (Fig. 8).

The exact numerical model has created many finite elements, 450,000 nodes and above 600,000 elements, so it was decided to simplify the model in order to reduce the calculations time. Reduction of time is very important for optimization, which will be carried out later. The geometry of the coach was replaced by a lumped mass with a moment of inertia. The m1 represents the mass of coach C without wheelsets,

Fig. 6 Driver's cab after crash test [7]

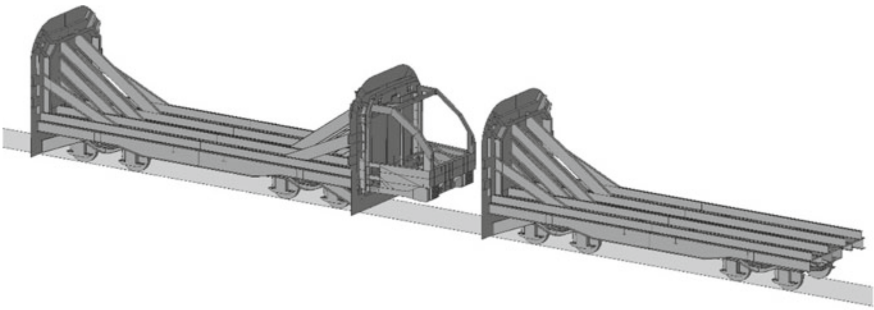


Fig. 7 Surface model from SpaceClaim environment

m1 equals 51,048 kg. The m2 is 25,193 kg and corresponds to the weight of coach A without wheelsets. The m3 weight is 1050 kg and corresponds to the weight of half of two wheelsets. Primary suspension spring was reduced to equivalent stiffness. The k_{eq} is equal 5.28 [kN/mm] (Fig. 9).

The moment of inertia was appointed from full model and shown in Table 2.

The simplified model is shown in Fig. 10. The numerical model has about 300,000 nodes and 300,000 elements. Accelerometers were modeled in LS Dyna by *ELEMENT_SEATBELT_ACCELEROMETER in locations similar to markers in real

Fig. 8 Finite element mesh for the full model

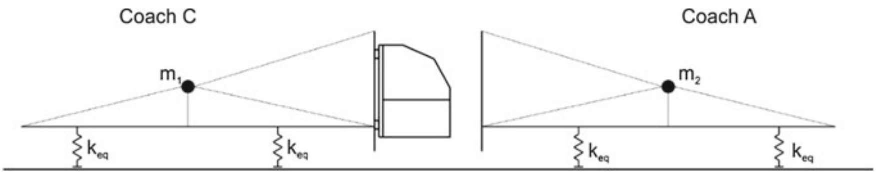


Fig. 9 Scheme of simplification model

Table 2 List of moment of inertia

	Coach C (kg/mm^2)	Coach A (kg/mm^2)
I_{xx}	3.42e+10	1.56e+10
I_{yy}	5.46e+11	2.21e+11
I_{zz}	5.42e+11	2.21e+11
I_{xy}	2.75e+8	6.86e+7
I_{yz}	6.84e+7	−3.03e+7
I_{xz}	−8.99e+9	1.88e+10

tests. This approach is popular in the automotive industry to measure the safety of passengers during crash tests [14–16].

The material properties were defined based on the experimental results obtained from the NEWAG company. True stress versus true plastic strain was shown in Fig. 11 [17].

4 Validation of the Numerical Model

The scheme of crash test presented in Fig. 5 was also applied in the numerical model. Time of crash simulation was set to 100 ms and as a result of the collision and crash

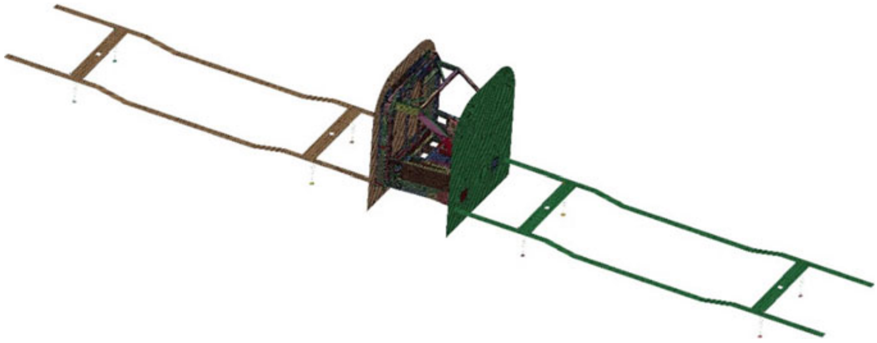


Fig. 10 Simplified model in LS-PrePost

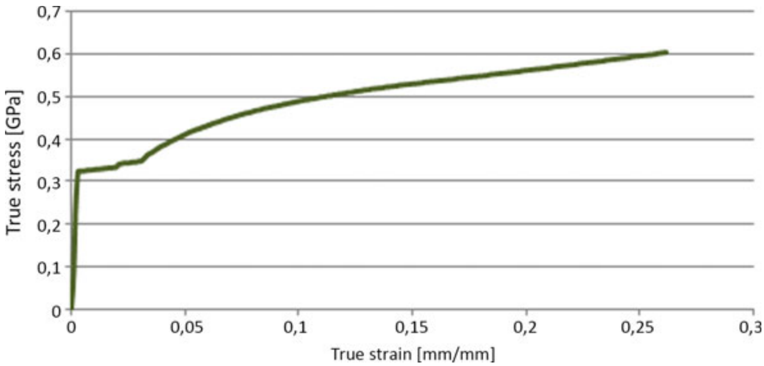


Fig. 11 True stress versus true strain

sequence and deformation character in the crash zone was the same as on the real test. In Fig. 12 a comparison between crash test and simulation has been shown [18–20].

The velocity was measured on the rigid bodies coaches in center of mass. The comparison velocity has been shown in Fig. 13.

In figure, velocity characteristics are similar. At the beginning, the velocity measured on the high-speed camera is clearly distorted. The difference in results between test and simulation in 100 ms was 7% for coach C and 10% for coach A. The energy characteristic has been shown in Fig. 14.

Dissipated energy in the real test was equal to 804 kJ. In numerical model, total dissipation energy was close to the real test. The total dissipation energy in the simulation was equal to 850 kJ. The difference of dissipated energy was equal to 2% of initial energy from real test.

The total deformation in the crash zone was measured between two markers. First was located on the front wall, second on the driver's cab (Fig. 15).

In figure, the deformation in the crush zone is very similar to the real test, with the difference in deformation less than 6%. There is a good correlation between deformation of the real object and simplified model, what gives the ability to make

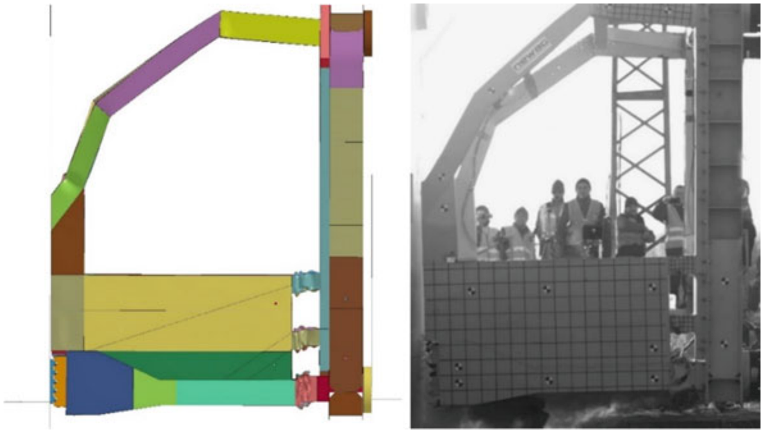


Fig. 12 Comparison of geometry after the collision of a numerical model with the test

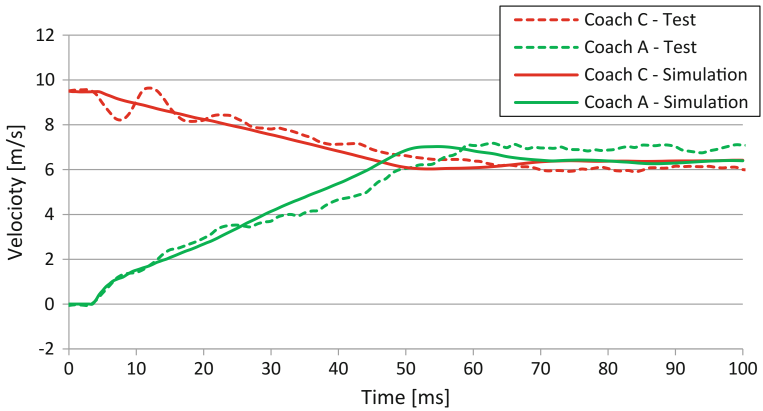


Fig. 13 Comparison of velocity between numerical model and crash test

sensitivity analysis of cab for optimization purposes in a similar way as in literature [21, 22].

The acceleration was measured at the driving position in the cab. The characteristics of acceleration were shown in Fig. 16.

In figure, it is noticeable that the acceleration curve from the simulation is different from the actual test. This is likely due to the simplification of the model and the sizing of the finite element mesh. To receive better acceleration characteristics much better mesh quality model must be applied. This issue will be the subject of further work.

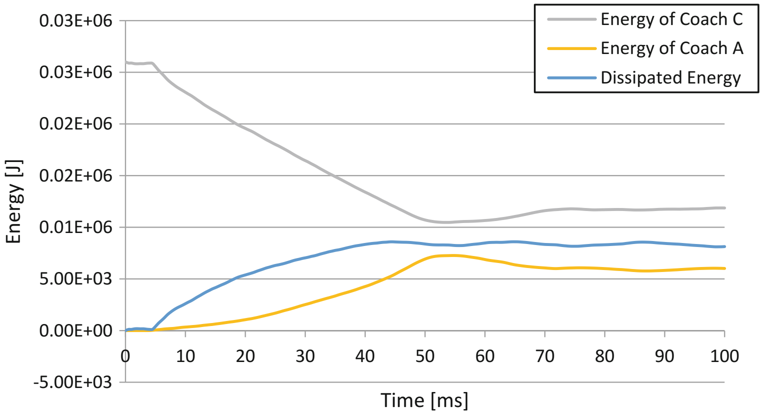


Fig. 14 Energy characteristics of simulation

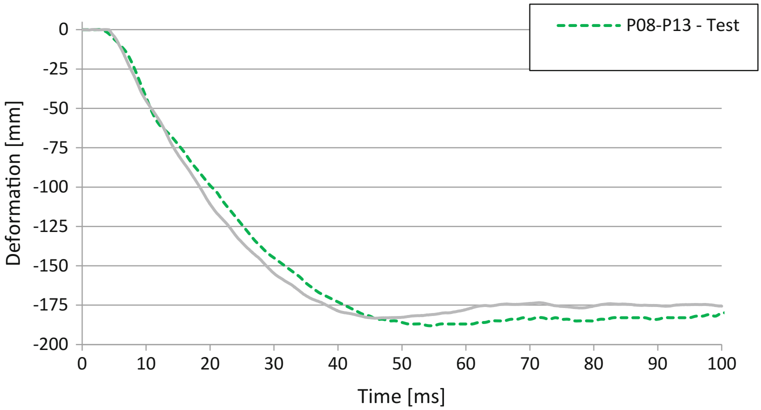


Fig. 15 Comparison of deformation in crash zone

5 Conclusions

The work has shown that there is a convergence between velocities and energy of coaches the from the test and the simulation. The difference in absorbed energy is only 2% of the initial energy. The velocity and displacements fall within the error limits of 10%. The exception is in the acceleration, for which convergence has not been achieved. The conclusion is that to analyze acceleration a more detailed model is required and finer mesh must be applied. Simplification of the numerical model has significantly reduced computational time, which is very importance for optimization purposes. Further work must be done to fully validate the numerical model with the acceleration characteristics. The obtained numerical model will be used to solve shape optimization problem of deformation tubes.

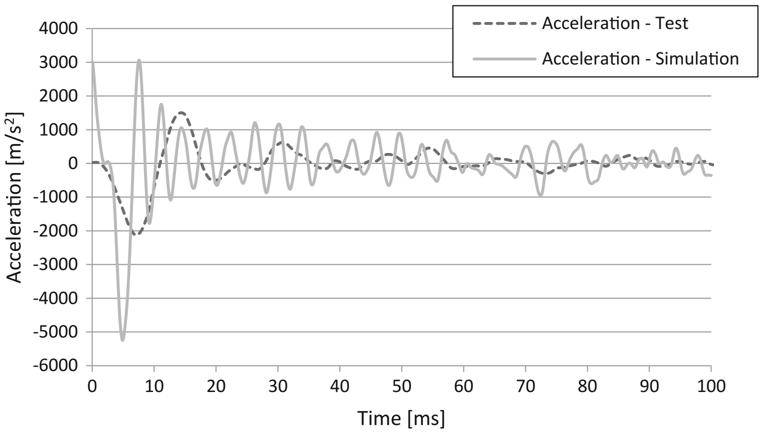


Fig. 16 Comparison of acceleration at the driving position

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