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NUMERICAL ANALYSIS OF THE FRONT IMPACT BETWEEN TWO SHUNTING LOCOMOTIVES

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Abstract

The main aim of this study is to carry out dynamic finite element analysis of a crash between two identical shunting locomotives. Numerical simulations include front-end impact of the running locomotive with a stationary one situated on the track. The first design collision scenario includes such obstacle for railway vehicles operated on national and regional networks. A considered locomotive based on a popular Polish shunting locomotive – SM42. However, the tested locomotive was slightly modernized in comparison with the original one. Finite element model of the locomotive was developed by the authors. FE analyses were carried out according to the PN-EN 15227 standard, which provides crashworthiness requirements for railway vehicle bodies. LESS-DYNA computer code was used for the simulations. The energy balance was initially checked in order to confirm the accuracy of analysis. The paper presents selected results of analyses focused on the locomotive frame behaviour. Contours of effective stress for selected moments of time are presented. Time histories of selected parameters are also depicted. The current study is a part of the project focused on modernization of the SM42 locomotive. Therefore, it is required to evaluate the locomotive behaviour during the impact test. Dynamic numerical simulation is acceptable since the experimental tests on the complete objects under consideration are impractical and impossible at the moment.

Keywords: *finite element method, dynamic analysis, crash test, railway vehicle, LS-DYNA*

1. Introduction

Crashworthiness requirements for railway vehicle bodies are provided in the PN-EN 15227 standard [1]. These requirements are to ensure a high level of passive safety by fulfilling the conditions such as providing controlled energy absorption, reduction of the longitudinal deceleration and minimizing the risk of derailment and the effects of impact infrastructure. Dynamic numerical simulation is acceptable since the experimental tests on the complete objects are impractical or very often impossible. This study is focused on evaluation of the complete locomotive behaviour during the impact with the same type of railway vehicle.

Locomotive under consideration belongs to the C-I crashworthiness design category [1]. It is a railway vehicle designed to operate generally on national and regional networks with mixed traffic. Therefore, it is necessary to take into account the 1st design collision scenario [1] – a front-end impact between two identical train units. According to the mentioned standard a collision speed should be exactly 36 km/h. Numerical simulations include front impact of the running locomotive with a stationary one situated on the track .The paper presents selected results of analyses generally focused on the locomotive frame behaviour.

The current study is a part of the project focused on modernization of a popular Polish shunting locomotive – SM42. Therefore, the tested locomotive is slightly different in comparison with the original one. All components above the locomotive frame could be freely configured according to the operator requirements. A chassis of the locomotive was essentially unchanged. Moreover, parameters of the installed hybrid module may be individually chosen for each locomotive on the basis of the actual power demand resulting from the operation characteristics.

2. Finite element modelling and analysis

Finite element models of vehicles under consideration are presented in Fig. 1. FE model of the locomotive was developed by the authors and it was described in detail in one of the previous papers [2]. The authors expected a significant deformation of the locomotive frame therefore; it was simulated as a deformable body with a fine mesh. Other components of the locomotive FE model were considered as rigid bodies mostly. It allowed the authors to simplify the FE model. Skin plates – as depicted in Fig. 1 – were not modelled.

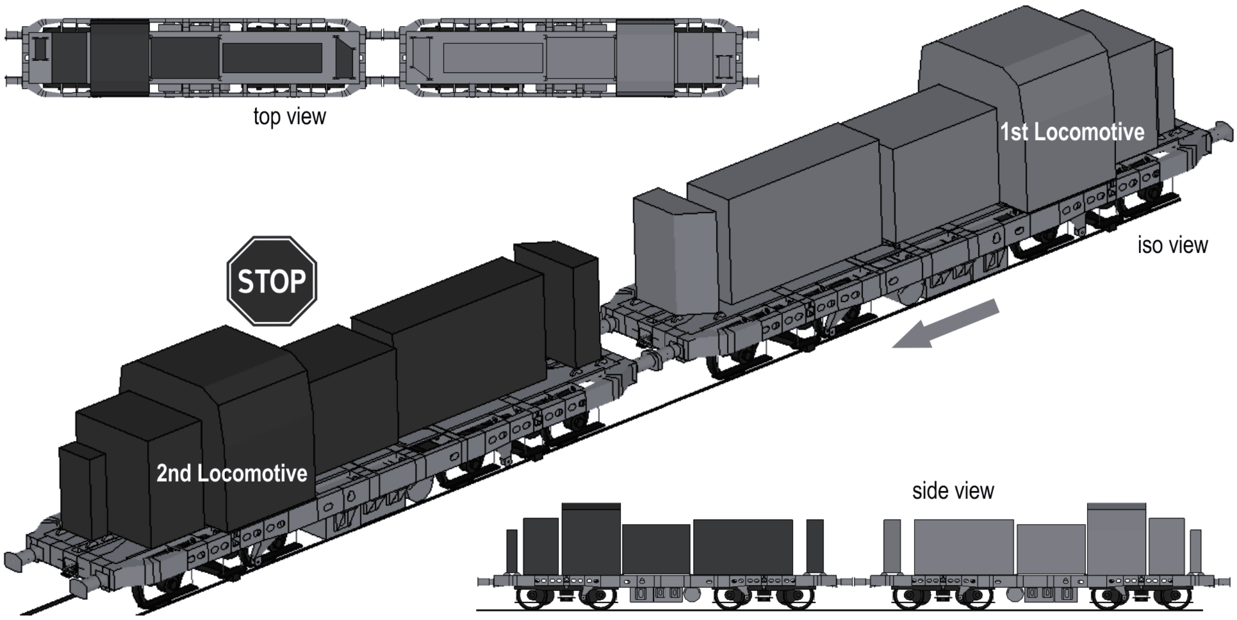

Fig. 1. FE model of two identical locomotives used in the 1st design collision scenario – FE mesh not shown

FE analysis was carried out using the LS-DYNA computer code. Both FE models were merged in HyperMesh software. FE model of the second locomotive was generated using duplicate process. Therefore, it is exactly the same like the considered locomotive. Tested locomotive was running on the track using initial velocity option. Velocity of 10 m/s (36 km/h) was applied to all nodes of the locomotive FE model. Summary of the complete FE model of objects under consideration is provided in Tab. 1. Masses of the FE model correspond to the mass of the designed locomotive – about 74 tons. Therefore, density of some components was modified and some lumped masses were added to the models to ensure their proper masses. Termination of the analysis was assumed at about 230 ms. Total CPU time was about 11 hours for eight computers used.

General conclusion regarding the FE analysis is that proposed numerical model is stable. Analysis was not completed before the termination time and it was completed without errors. The authors obtained a proper balance depicted in Fig. 2 that confirms the correctness of the analysis. The energy ratio oscillates around unity.

Tab. 1. Summary of the complete FE model of the 1st collision scenario between two identical locomotives

	1st Locomotive (moving)	2nd Locomotive (stationary)	Track	Total
Number of nodes	126 391	126 391	40 420	293 202
Number of element	115 677	115 677	16 160	247 514
– shell	96 550	96 550	—	193 100
– solid	19 099	19 099	16 160	54 358
– beam	28	28	—	56

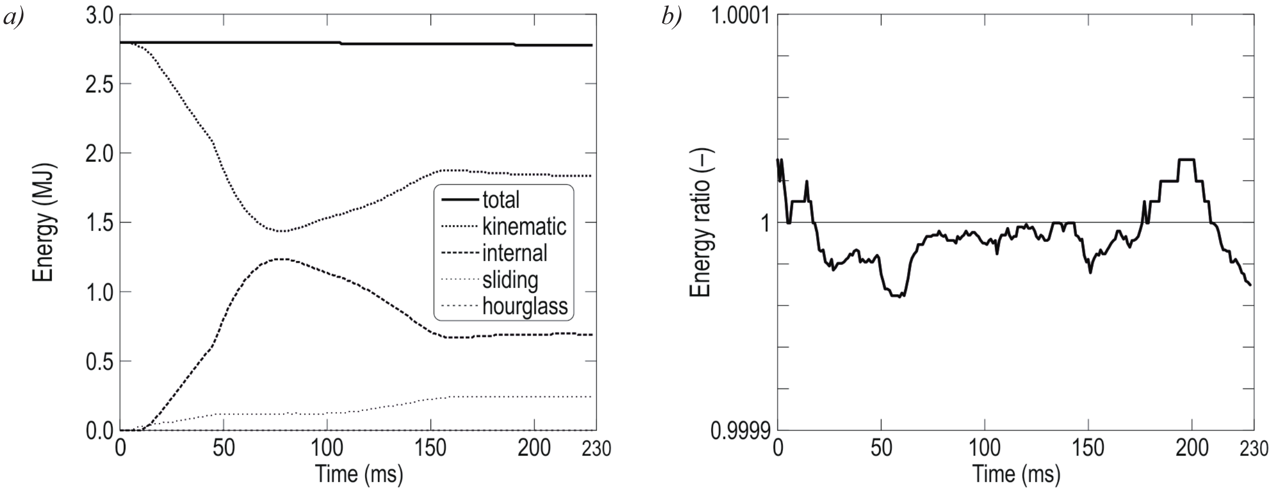

Fig. 2. Energy balance (a) and the energy ratio (b) obtained from the analysis for the complete FE model

3. Results of the FE analysis

Figure 3 shows time histories of velocity and acceleration for both locomotives. These two parameters were measured for the cab during the simulation. The mean longitudinal deceleration in the survival spaces shall be limited to 5 g for the scenario under consideration [1]. Obtained results for the acceleration were filtered using SAE filter available in LS-DYNA postprocessor. Two filer frequencies – 25 Hz and 60 Hz – were assumed on the basis of similar simulation described in [3]. Fig. 3b presents acceleration filtered by 25 Hz SAE filter. It can be noticed that the condition relating to acceptable deceleration is not fulfilled. Deceleration of the cab exceed 5 g. Oscillation on the graph are probably related with the vibration of the cab which was simulated as a rigid body.

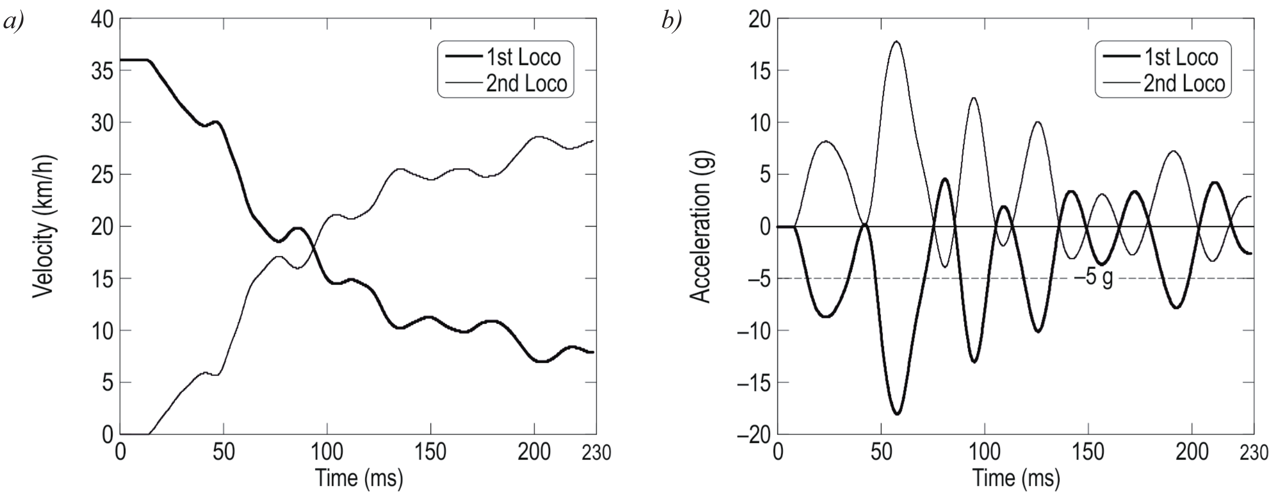

Fig. 3. Velocity (a) and acceleration (b) of the locomotives' cab obtained from the analysis

A process of collision between two shunting locomotives for selected moments of time is presented in Fig. 4. It can be seen that collision is generally symmetric. Behaviour of both locomotives is almost the same since both vehicles are identical. Excessive displacement of the front module was observed as a result of the inertia force caused by the sudden deceleration and acceleration, respectively. Therefore, the connection between this module and the locomotive frame should be reinforced in order to avoid such accidents in regular operation. Snapshots depicted in Fig. 4 show significant deflections of the front suspension and nosedive of the locomotives. Moreover, a separation between wheelsets and the rail is observed in the final analysis stage. Such situation is disadvantageous

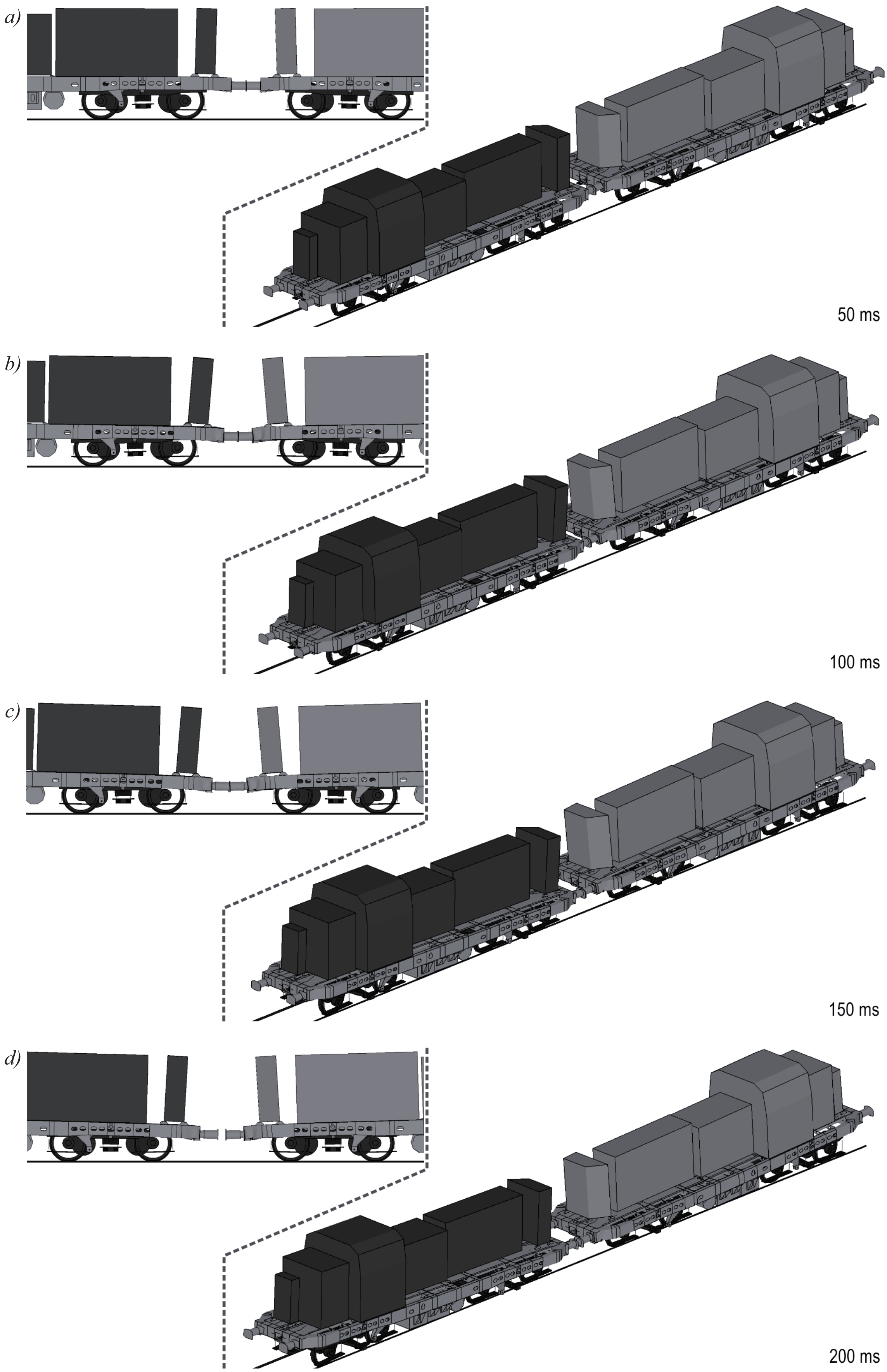

Fig. 4. Views of collision between two identical shunting locomotives for selected moments of time: 50 ms (a), 100 ms (b), 150 ms (c), 200 ms (d)

in addition, it may result in derailment of the locomotive. Fig. 5 presents vertical displacement of the axlebox for the first and the second wheelset of the rear bogie. These results can be interpreted as a distance between the wheel and the railhead.

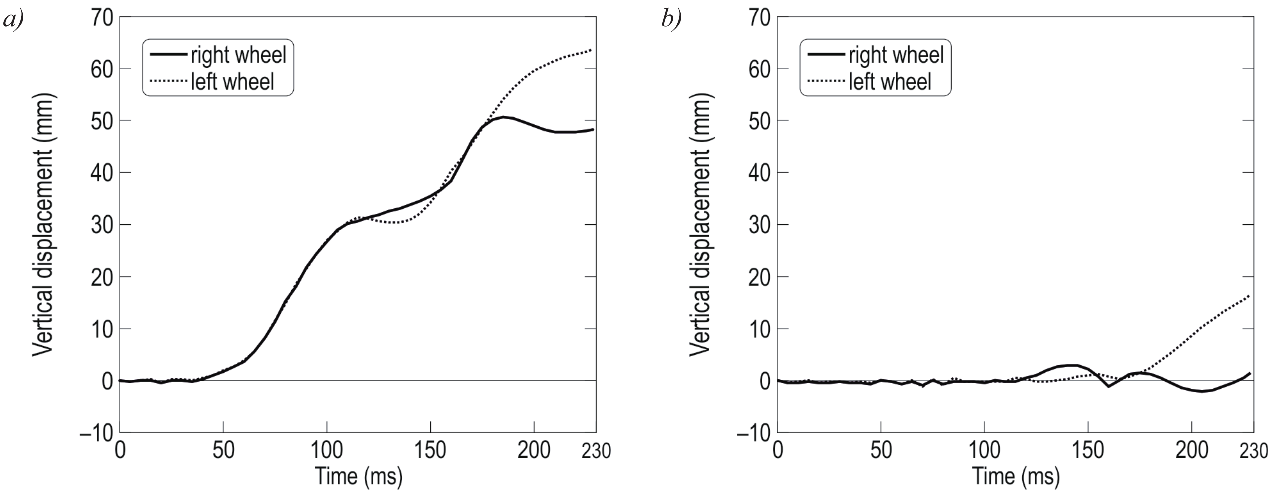

Fig. 5. Vertical displacement of the axleboxes for the first (a) and the second (b) wheelset of the rear bogie confirming a risk of the locomotive derailment

Energy absorbing mechanism for the tested locomotive was also taken into account. Fig. 6a shows buffers compression during the collision. It can be notice that both buffers were gradually reached a full compression after contact with the obstacle and then they were returned to the original size. Time history of the internal energy for the buffers and the frame is depicted in Fig. 6b. In this case, the buffers absorb significant amount of the energy in the first stage of the collision. After 50 ms, once buffers are fully compressed, the impact energy is absorbed by the frame. It may lead to excessive strains and permanent plastic deformations in the locomotive frame.

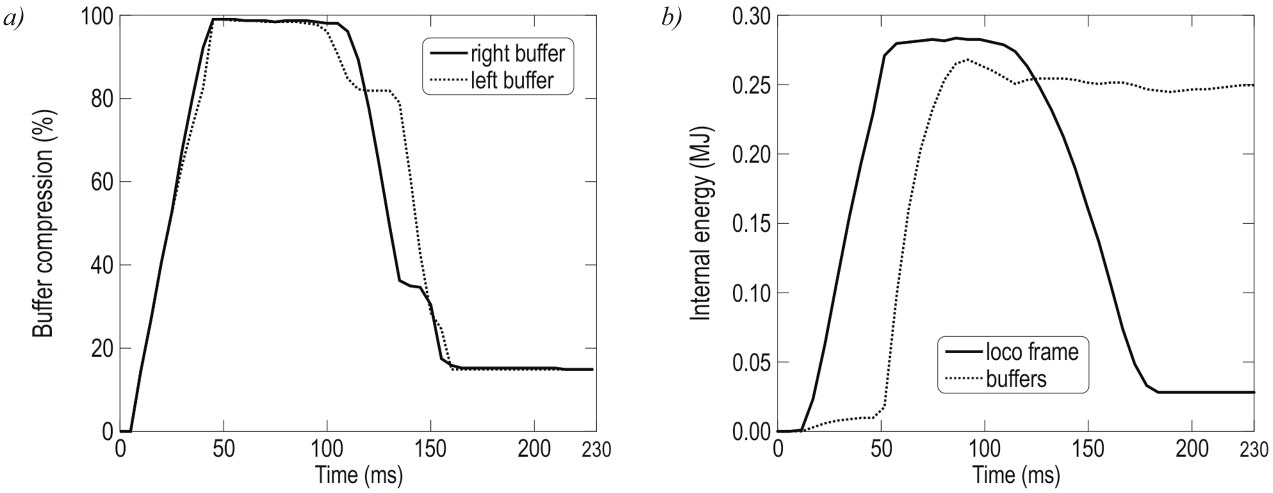

Fig. 6. Time history of buffers' compression (a) and internal energy of buffers and the locomotive frame (b) obtained from the FE analysis

Figure 7 presents contours of effective stress for the front part of the frame. Authors decided to show results for the range 0-600 MPa since the plastic kinematic material model with yield stress of 600 MPa was applied for the frame. Once the stress exceeds the yield, stress material comes into plastic range. Therefore, all areas on the frame FE model in black colour indicate that the area was permanently deformed. It can be noticed that plastic areas appear in the front plate close to the buffer attachments and the frame corners were significantly deformed.

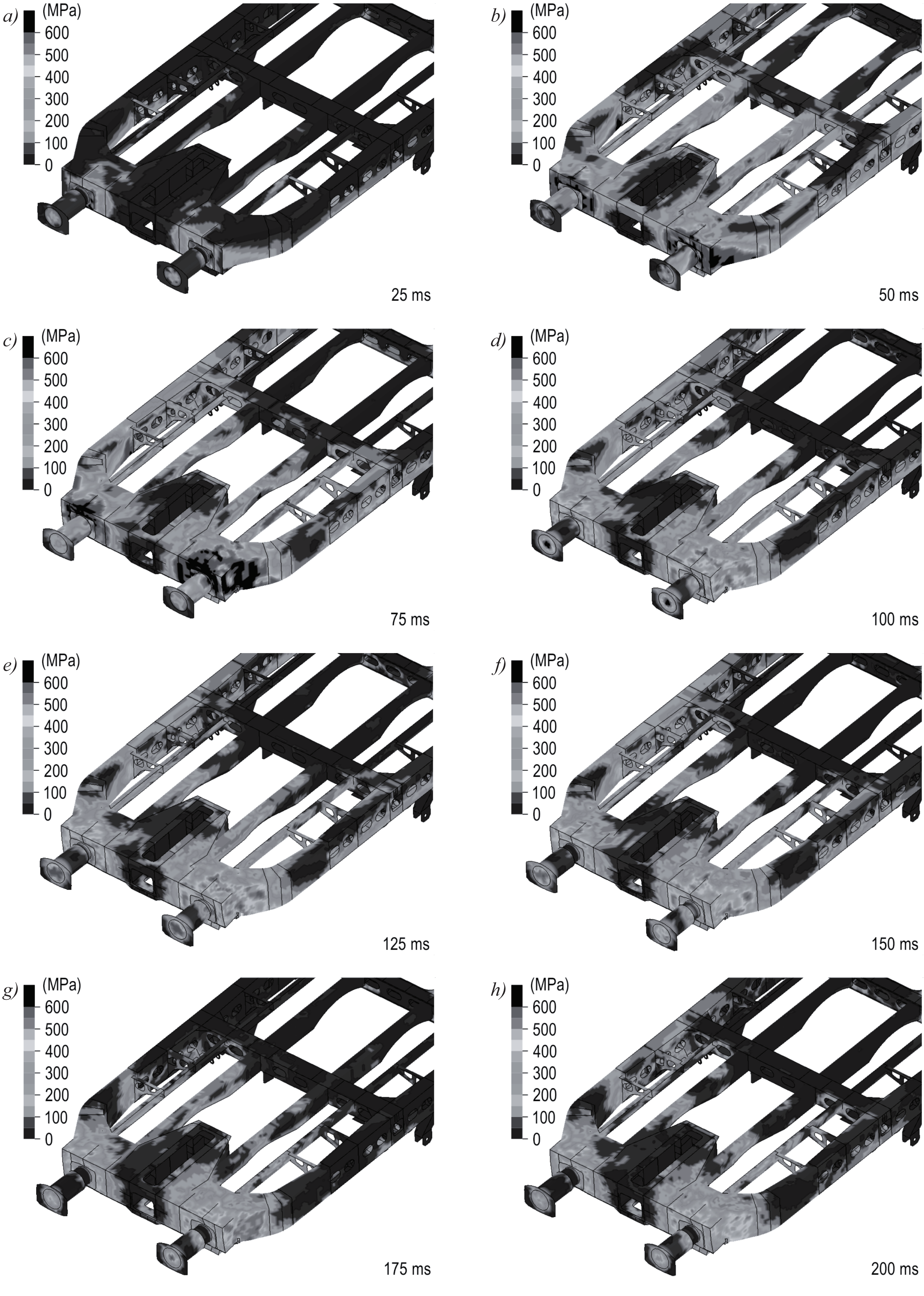

Fig. 7. Contours of the effective von Mises stress for the locomotive frame in selected moments of time: 25 ms (a), 50 ms (b), 75 ms (c), 100 ms (d), 125 ms (e), 150 ms (f), 175 ms (g), 200 ms (h)

Figure 8 presents time history of the relative changes in longitudinal and diagonal distance between buffer attachments. Maximum mean value of the relative change in distance is equal to 4.5‰. It means that base dimension of the frame was changed by about 50-60 mm. A slight asymmetry of the frame deformation is visible – left side is more deformed that may lead to the frame twist.

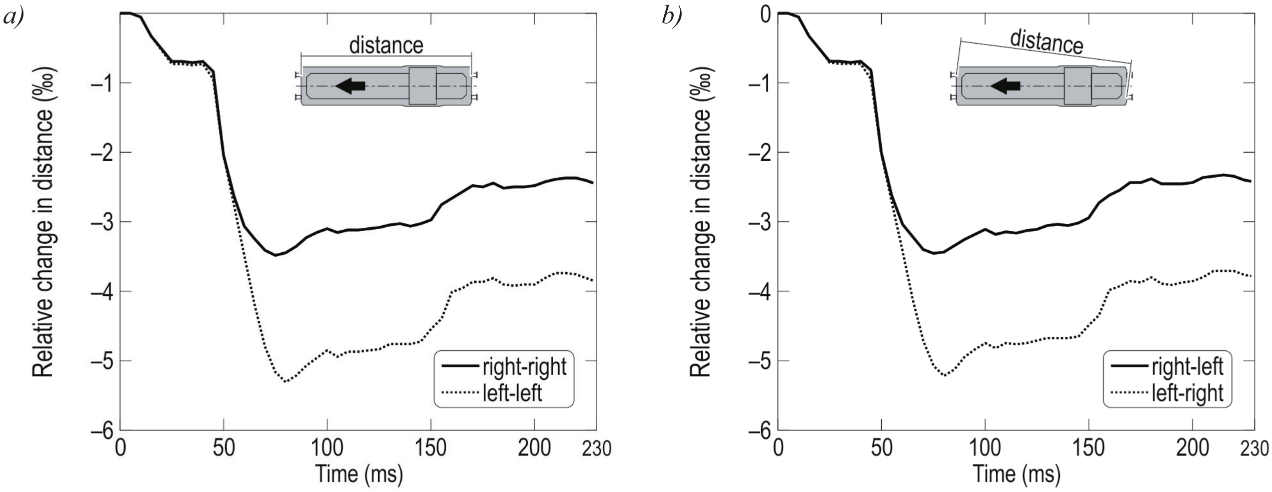

Fig. 8. Relative changes in longitudinal (a) and diagonal (b) distance between buffer attachments

4. Summary and conclusions

The aim of this study was to carry out a dynamic finite element analysis of a crash between to two identical shunting locomotives. Simulation test was performed for the recommended velocity of 36 km/h. Longitudinal deceleration for the locomotive cab exceeds the permissible value of 5 g. The collision processes generally symmetrically, therefore behaviour of both locomotives is the same. Significant deflections of the front suspension and nosedive of both locomotives are noticed. It may be related with the suspension parameters. Primary and secondary suspension systems were simulated by linear spring element without any limit for the spring deflection. It supposed to be corrected in further models. In addition, a separation between wheelsets and the rail is observed in the final analysis stage. It is caused by the load decreasing for the rear bogie due to the inertia forces and it may lead to derailment. However, it may be also related with the possibility of unlimited compression of the suspension systems mentioned above.

Both buffers absorb the impact energy in the first stage of the collision. Once the buffers were fully compressed, the rest of energy must be absorbed by the frame. It leads to excessive plastic deformations in the front part of the frame – especially in the front plate and the corners close to the buffers attachment. Measurements of the longitudinal and diagonal distance between buffers attachments shows that collision caused deformation of the locomotive frame. Base dimension of the frame was changed by about 50-60 mm in length. It is generally caused by buckling of the front plate of the frame where the buffers are attached.

Obtained results provide qualitative and quantitative data related to the locomotive behaviour during the collision with the identical train unit. It may be useful for the designer in further modernization of the considered structure.

Acknowledgements

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