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NUMERICAL ANALYSIS OF IMPACT BETWEEN SHUNTING LOCOMOTIVE AND SELECTED ROAD VEHICLE

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Abstract

The main aim of this study is to carry out dynamic finite element analysis of a crash between shunting locomotive and selected road vehicle. Numerical simulations include side impact of the running locomotive in the vehicle situated across the track. 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 whereas the vehicle FE model was download from the free database of such models. FE analysis was carried out according to the PN-EN 15227 standard which provides crashworthiness requirements for railway vehicle bodies. 15 tons large truck was selected as a representative for the study. One of the design collision scenario includes such deformable obstacle for railway vehicles operated on national and regional networks. LS-DYNA computer code was used for the simulations. The paper presents selected results of analysis generally focused on the locomotive frame behaviour. Contours of stress for selected moments of time are presented. Moreover, time histories of selected parameters are depicted. The energy balance was also checked in order to confirm the accuracy of analysis. 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 are 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]. Dynamic numerical simulation are 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 selected road 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 which have level crossings. It means that such vehicles may interfere with road traffic. Therefore, it is necessary to take into account a following design collision scenario – a locomotive front end impact with a large road vehicle on a level crossing [1]. According to the mentioned standard a collision speed should not exceed 110 km/h. Authors decided to conduct their simulation test for the maximum acceptable speed to consider the most disadvantageous variant. 15-ton large truck located on a level crossing was selected as a deformable obstacle for the test. The paper presents selected results of analysis 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. A locomotive FE model was developed by the authors and described in detail in previous work [2]. A truck model was download from the Finite Element Model Archive available at the National Crash Analysis Center (NCAC) [3]. 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. Numerical model of the truck was dedicated to crash analysis therefore additional modifications were not necessary.

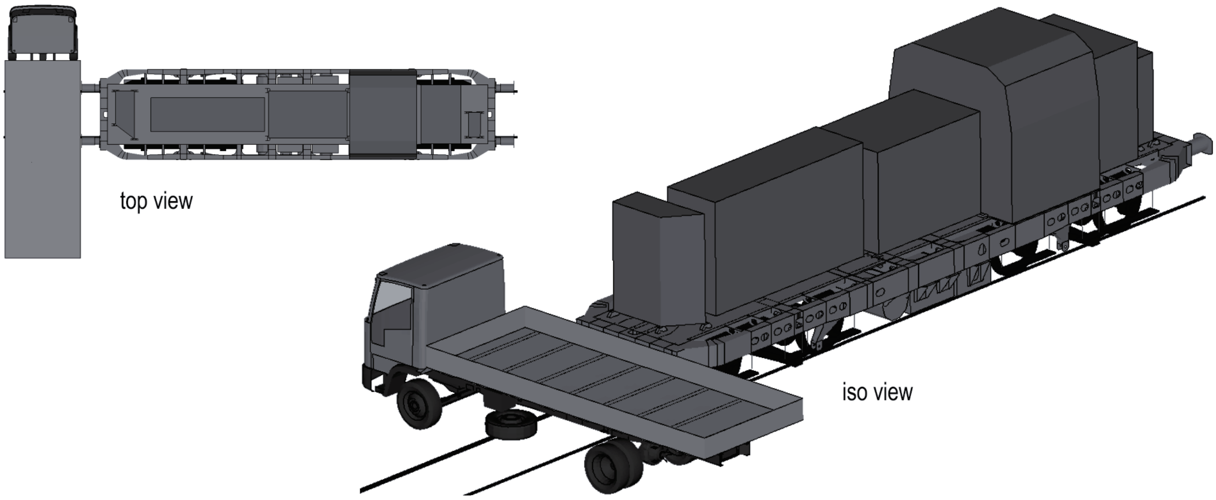

Fig. 1. FE model of the locomotive and the truck located on a level crossing – FE mesh not shown

FE analysis was carried out using the LS-DYNA computer code. Both FE models were merged in HyperMesh software. Truck model was located on a track perpendicularly to its longitudinal axis. Rigid wall was applied to simulate a ground. The friction coefficient between tires and the ground was equal to 0.6. The locomotive was running on the track using initial velocity option. Velocity of 30.555 m/s (110 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 each model correspond to the mass of the designed locomotive (about 74 tons) and the mass of the vehicle (15 tons) required by the PN-EN 15227 standard, respectively. Therefore, density of some components was modified and some lumped masses were added to the model to ensure its proper mass. Termination of the analysis was assumed at about 400 ms. Total CPU time was about 35 hours for two computers used.

General conclusion regarding the FE analysis is that proposed numerical model are 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 collision scenario between a locomotive and the large truck

	Locomotive	15 t Truck	Track	Total
Number of nodes	126 391	29 204	40 420	196 015
Number of element	115 677	27 480	16 160	159 317
– shell	96 550	26 455	—	123 005
– solid	19 099	928	16 160	20 024
– beam	28	97	—	125

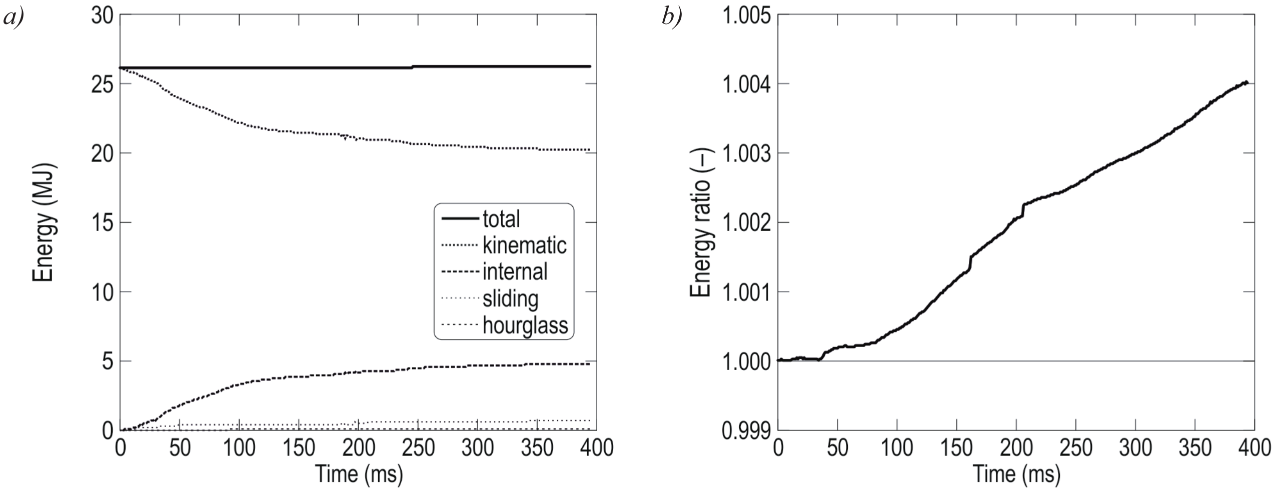

Fig. 2. Energy balance (a) and the energy ratio (b) obtained from the analysis for the complete FE model

3. Results of the FE analysis

Figure 3 shows time histories of velocity and acceleration. These two parameters were measured for the cab during the simulation. The mean longitudinal deceleration in the survival spaces shall be limited to 7.5 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 for acceleration were assumed on the basis of similar simulation described in [4]. It can be noticed that the condition relating to acceptable deceleration is fulfilled.

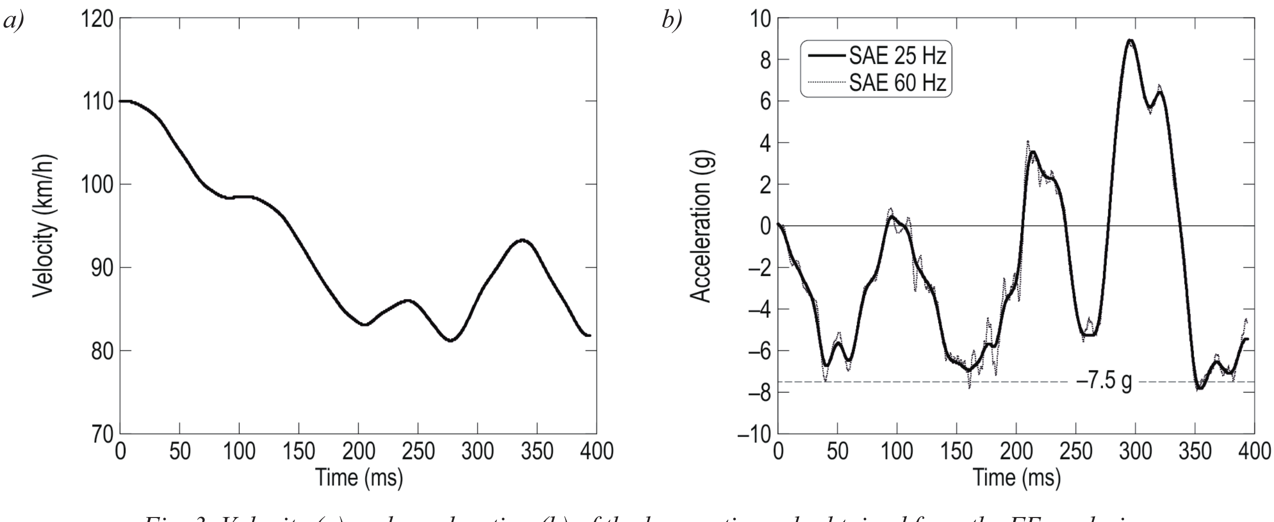

Fig. 3. Velocity (a) and acceleration (b) of the locomotive cab obtained from the FE analysis

A process of collision between a shunting locomotive and the truck for selected moments of time is presented in Fig. 4 and 5. Complete destruction of the centre of the truck is visible. Locomotive practically move the truck and destroy its body frame and flatbed. Front module of the locomotive was detached as a result of the inertia force caused by the sudden deceleration. Therefore, the connection between this module and the locomotive frame should be reinforced in order to avoid such accidents in regular operation. Since the skin plates were not modelled the module simply fly away from the locomotive. Side views of the collision (Fig. 5) show that there is a separation between front wheelsets and the rail. Such situation may result in derailment of the locomotive. Vertical displacement of the axlebox for the first and the second wheelset of the front bogie are depicted in Fig. 6. Presented results can be interpreted as a distance between the wheel and the rail head.

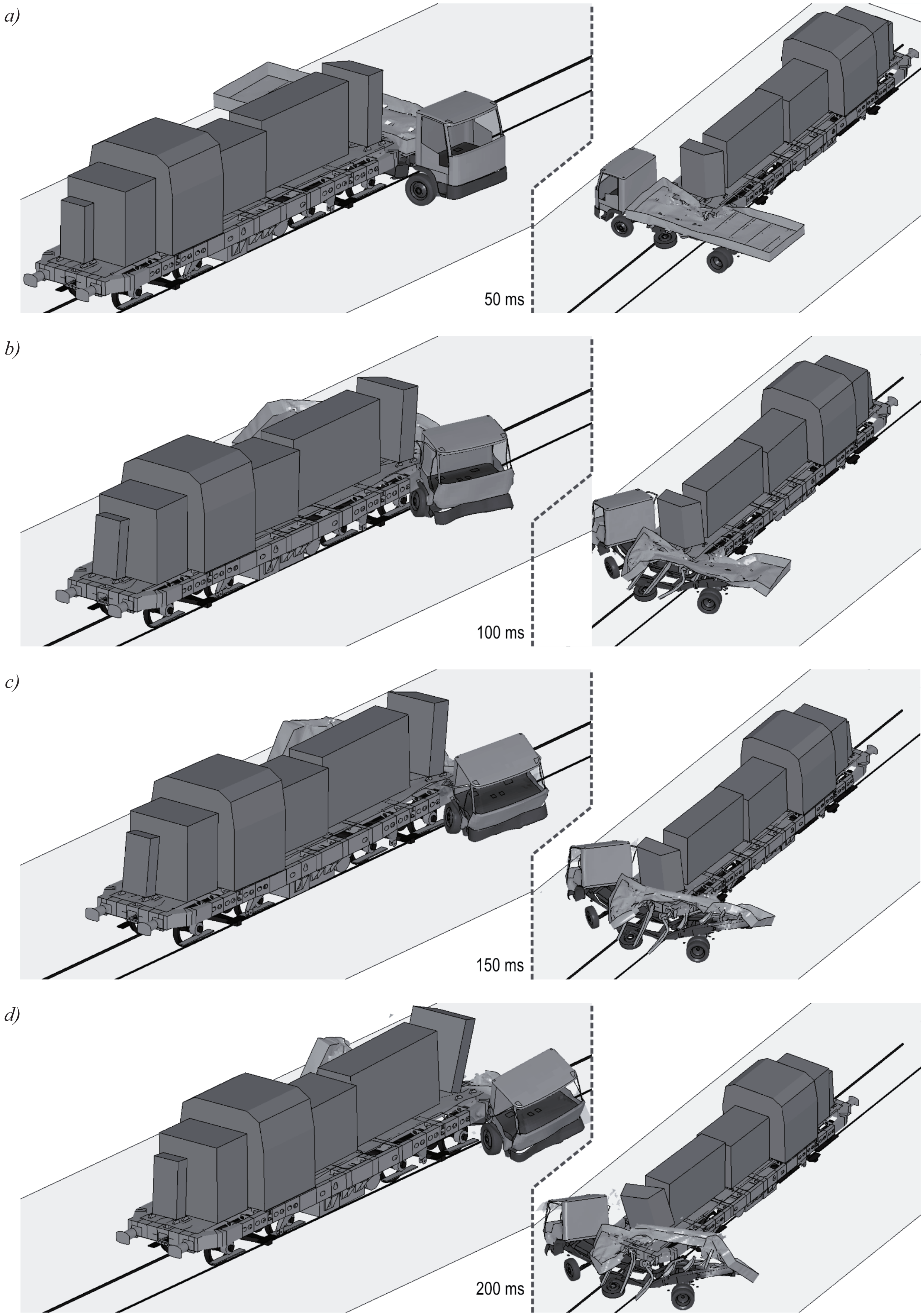

Fig. 4. Isometric views of collision between the shunting locomotive and the 15-ton truck for selected moments of time: 50 ms (a), 100 ms (b), 150 ms (c), 200 ms (d)

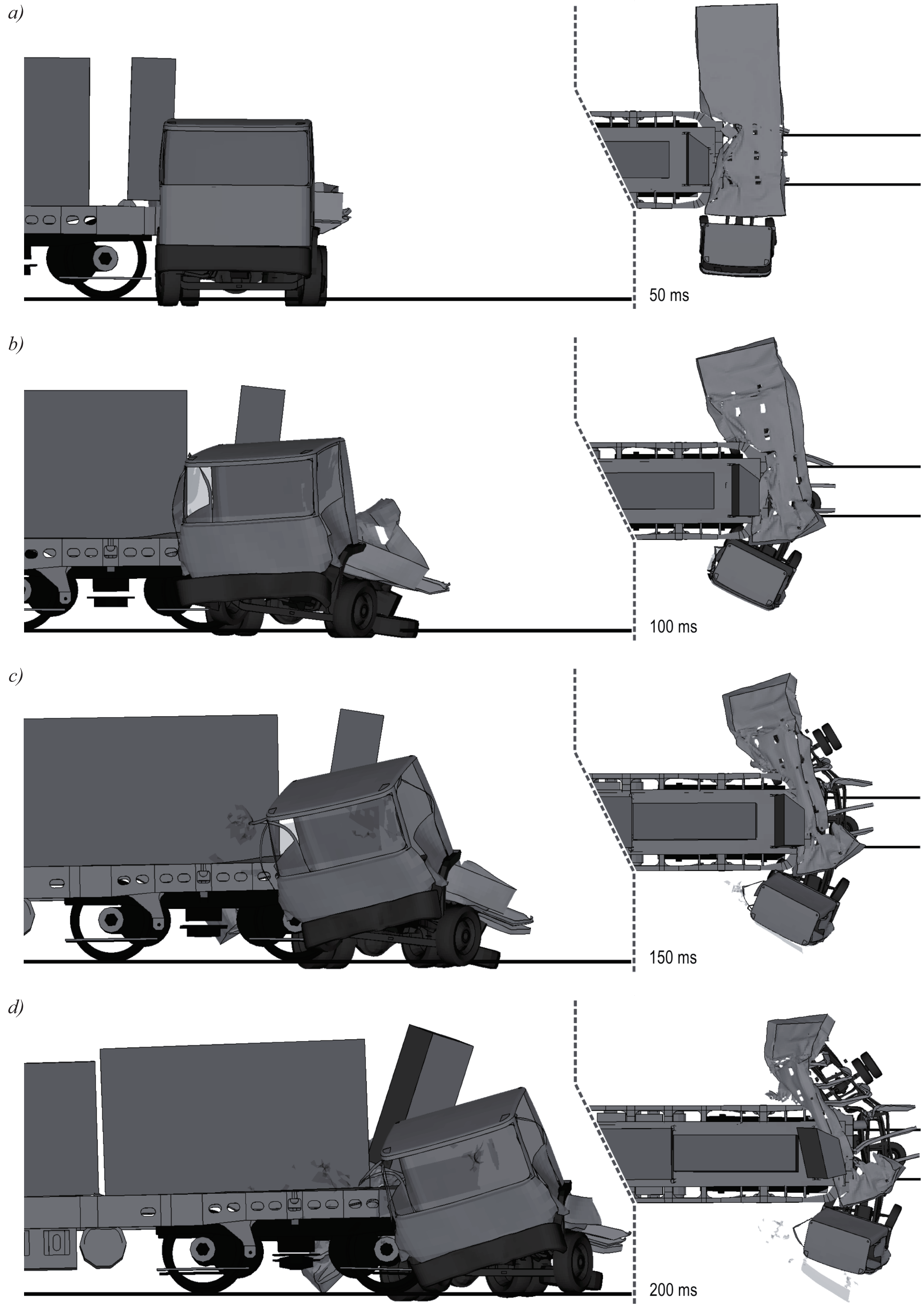

Fig. 5. Side and top view of collision between the shunting locomotive and the 15-ton truck for selected moments of time: 50 ms (a), 100 ms (b), 150 ms (c), 200 ms (d)

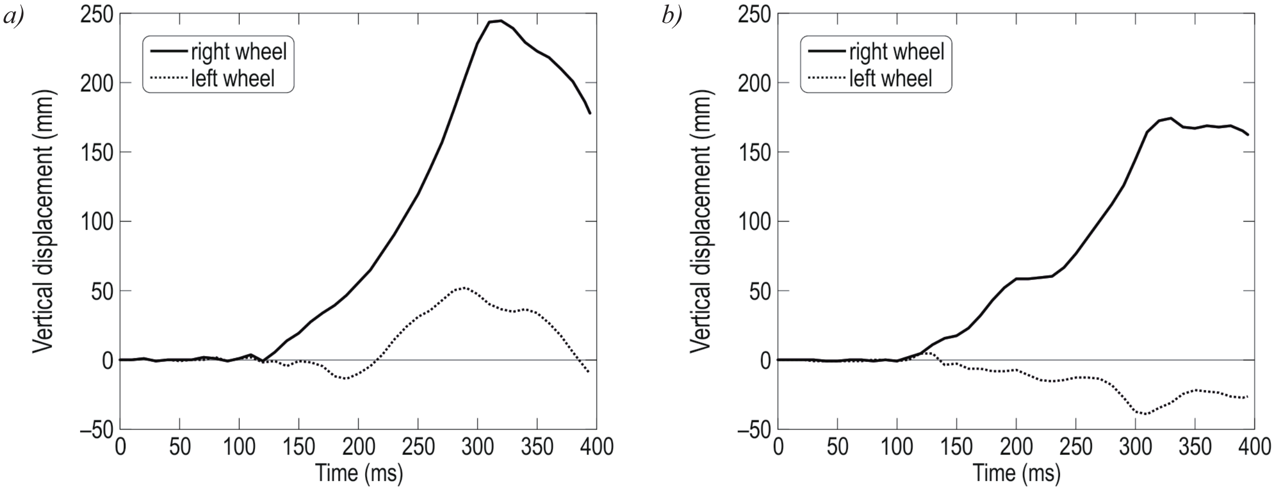

Fig. 6. Time history of vertical displacement of the axleboxes for the first (a) and the second (b) wheelset of the front bogie confirming a serious risk of the locomotive derailment

Energy absorbing mechanism for the tested locomotive was also taken into account. Fig. 7a shows buffers compression during the collision. It can be notice that both buffers were fully compressed immediately after contact with the truck. It is probable that buffers were completely destroyed and the impact energy was absorbed by the locomotive frame. Such situation is not acceptable but it must be remembered that collision was performed for the maximum allowable velocity of 110 km/h. Time history of the internal energy for the buffers and the frame is depicted in Fig. 7b. Frame absorbs significant amount of the energy, which may lead to excessive strains and permanent plastic deformations.

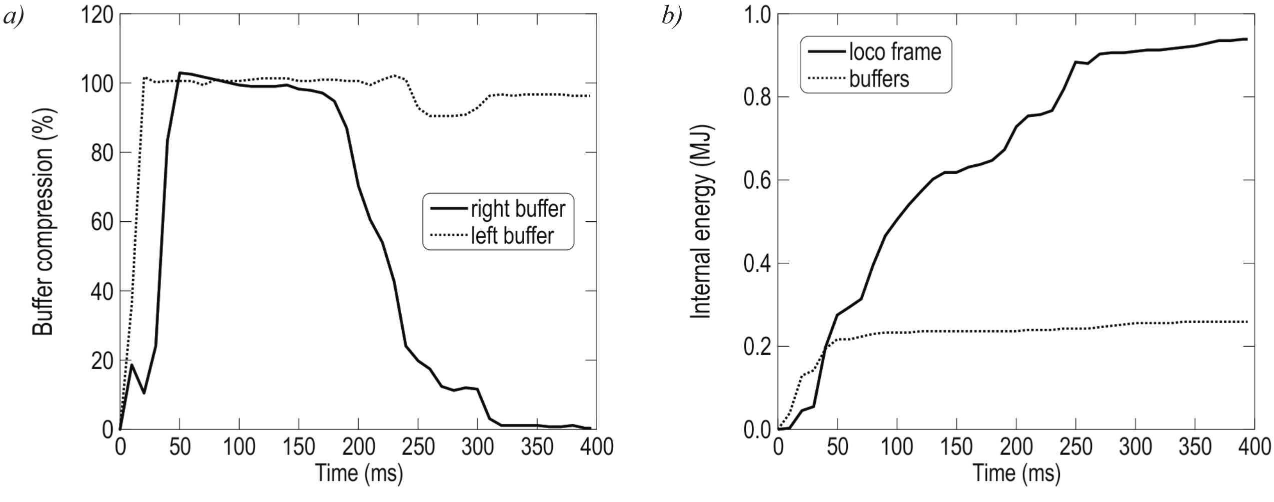

Fig. 7. Time history of buffers' compression (a) and internal energy of buffers and the locomotive frame (b) obtained from the FE analysis

Figure 8 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 noted that plastic areas appear in the front plate close to the right buffer attachment after 40 ms. Later, the plastic areas appear on the left side of the frame. In the final stage, plastic deformation can be observed even in the inner longitudinal members. Such situation in the actual object would lead to the frame twist. Fig. 9 depicts relative changes in longitudinal and diagonal distance between buffer attachments.

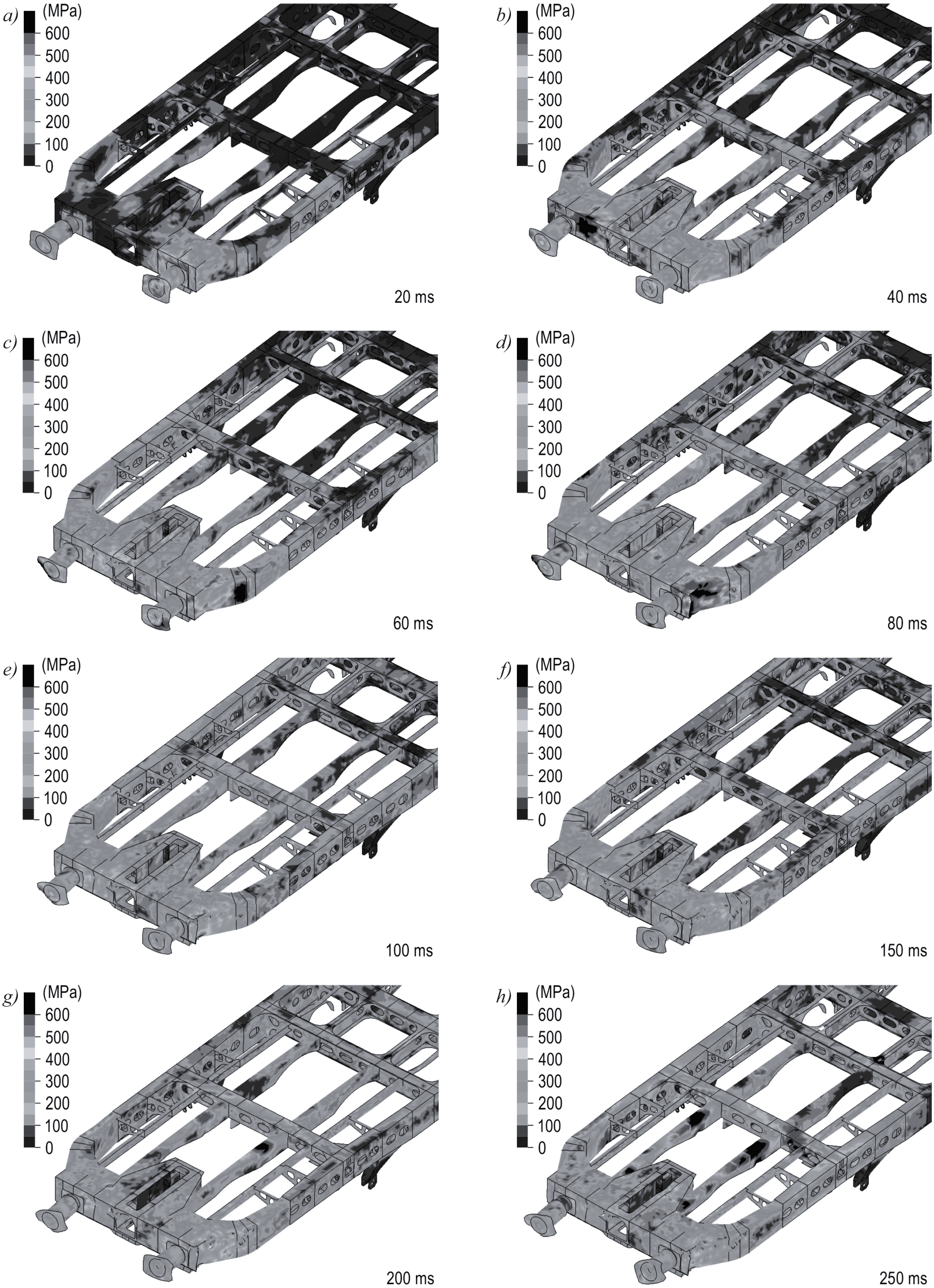

Fig. 8.

Contours of the effective von Mises stress for the locomotive frame in selected moments of time: 20 ms (a), 40 ms (b), 60 ms (c), 80 ms (d), 100 ms (e), 150 ms (f), 200 ms (g), 250 ms (h)

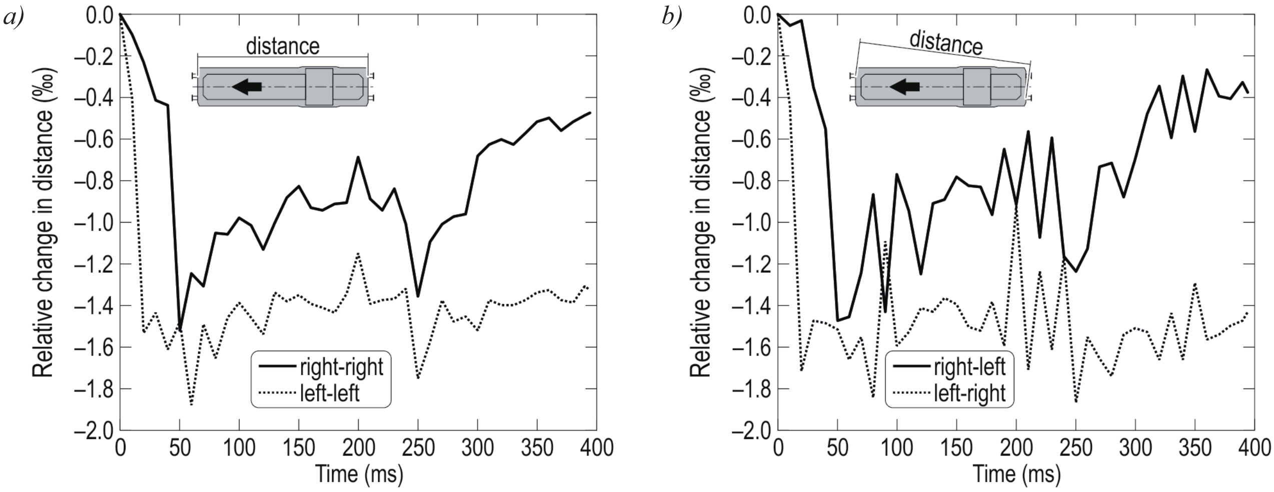

Fig. 9. Relative changes in longitudinal (a) and diagonal (b) distance between buffer attachments

4. Summary and conclusions

The aim of this study was to carry out a dynamic finite element analysis of a crash between shunting locomotive and selected road vehicle. Numerical simulations include side impact of the running locomotive in the 15-ton truck situated across the track. Simulation test was performed for the maximum acceptable velocity of the locomotive (110 km/h) to consider the most disadvantageous variant. Longitudinal deceleration for the locomotive cab does not exceed the permissible values. During the collision locomotive practically move the truck and completely destroy its body frame and flatbed. It should be noted that the locomotive was also affected in the collision. Both buffers were fully compressed immediately after contact with the truck therefore, they could not absorb the energy. Thus, the energy must be absorbed by the frame that may lead to excessive strains and permanent plastic deformations. Measurements of the longitudinal and diagonal distance between buffer attachments shows that collision caused deformation of the locomotive frame. Maximum mean value of the relative change in distance is equal to 1.6‰. It means that base dimension of the frame was changed by about 20 mm. The results provide qualitative and quantitative data related to the locomotive behaviour during the collision with large deformable obstacle. It may be useful for the designer in further modernization of the considered structure.

Acknowledgements

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