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SIMULATIONS OF FRONT IMPACT BETWEEN TWO SHUNTING LOCOMOTIVES AT DIFFERENT VELOCITIES

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Abstract

The main aim of this study is to carry out dynamic simulations of a crash between two identical shunting locomotives running at different velocities. Numerical analyses using a Finite Element Method (FEM) include front-end impact of the running locomotive with a stationary one situated on the track. Such collision scenario is required for railway vehicles operated on national and regional networks. A considered locomotive based on a Polish shunting locomotive – SM42, however the tested locomotive was slightly modernized. Finite element model of the locomotive was developed by the authors. FE analyses were conducted according to the PN-EN 15227 standard, which provides crashworthiness requirements for railway vehicle bodies. LS-DYNA computer code was used for the simulations. The paper presents selected results of analyses focused on the locomotive frame behaviour. Simulations were performed for the vehicle between 20 and 90 km/h. An influence of the impact velocity on some output quantities was determined. Contours of effective stress for selected moments of time as well as time histories of selected values are depicted. For modernized locomotives, it is required to evaluate their behaviour during the impact test. Dynamic numerical simulation is acceptable since the experimental tests on the complete objects under consideration are impractical and impossible sometimes.

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

1. Introduction

Characteristics of locomotives change with the technological advances. Currently, locomotives reach higher velocities, which may lead to an increase in collisions due to i.e. the amount of rail vehicles, their multitude applications, the human factor, a braking distance or a faulty equipment. Engineers using modern software for numerical analysis try carefully investigate the current railway vehicles that may be involved in a collision in order to improve efficiency or to introduce a new type of solutions. All of this is to minimize the consequences of an accident and to increase the chances of survive for passengers and road users.

Crash zones are an essential element of rail vehicles. Their main aim is to absorb an impact energy in such a way that the parties involved in the collision avoided death and injury. Collisions between railway vehicles are most often held in the direction of the vehicle longitudinal axis. However, each collision is different due to many factors, i.e. the difference in velocities of the individual vehicles.

Crashworthiness requirements for railway vehicle bodies, provided in the PN-EN 15227 standard [1], 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. An influence of the impact velocity on some output quantities was determined, because the tests were carried out for different impact velocities, and not only for the one recommended in the standard [1].

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 velocity should be exactly 36 km/h. However, numerical simulations were performed for the velocity between 20 and 90 km/h. It allows Authors to determine an influence of the impact velocity on some output quantities e.g. a deceleration and an internal energy. The paper presents selected results of analyses generally focused on the locomotive frame behaviour.

The current study is related to the research carried out within an already completed project, focused on modernization of a popular Polish shunting locomotive – SM42. The tested locomotive is slightly different in comparison with the original one; however, a chassis of the locomotive was essentially unchanged. All components above the locomotive frame could be freely configured according to the operator requirements.

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 within the earlier works and described in detail in [2]. The locomotive frame was simulated as a deformable body with a fine mesh due to the expected significant deformation. Other components of the locomotive FE model were considered mostly as rigid bodies. It allowed simplification of the FE model. Skin plates – as depicted in Fig. 1 – were not modelled.

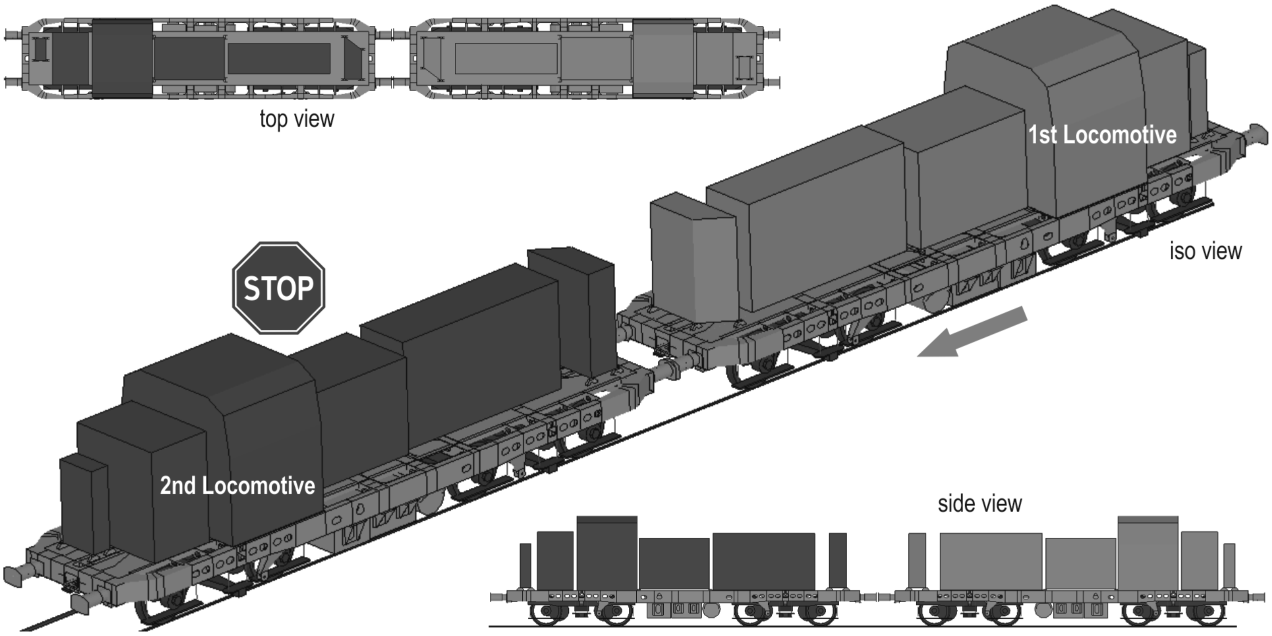

Fig. 1. FE model of two identical locomotives used in the 1st design collision scenario – FE mesh not shown [3, 5]

Numerical analysis includes front impact of the running locomotive with a stationary one situated on the track. FE analysis was carried out using the LS-DYNA computer code. Tested locomotive was running on the track using initial velocity option.

Different variants of the impact velocity from the range of 20-90 km/h stepped by 10 km/h were taken into consideration (Tab 1). The first one (#1) corresponds to the velocity of 36 km/h required by the standard [1]. The last one (#9) is limited to 90 km/h due to the design velocity of the locomotive. Termination time varies from 550 to 125 ms, whereas the total CPU time for 8-node unit is between 18 and 5 hours, respectively.

Tab. 1. Impact velocities and termination times of analyses considered in this study [5]. Velocity of 36 km/h is required according to the standard [1]

	Variant	#1	#2	#3	#4	#5	#6	#7	#8	#9
Velocity	[km/h]	36	20	30	40	50	60	70	80	90
	[m/s]	10	5.(5)	8.(3)	11.(1)	13.(8)	16.(6)	19.(4)	22.(2)	25.0
Termination time [ms]		300	550	350	275	225	200	175	150	125

3. Results of FE analysis

Results of the FE analysis are limited to the following output values: a longitudinal deceleration of the cab, a decrease in a velocity of the locomotive due to a collision, and an internal energy of buffers and a frame. Internal energy for these components determines an energy absorbed by them.

Figure 2a shows maximum values of a longitudinal deceleration of the cab as a function of the locomotive velocity. A decrease in the locomotive velocity as a result of a collision is depicted in Fig. lb. The mean longitudinal deceleration in the survival spaces shall be limited to 5 g for the scenario under consideration [1]. The condition relating to acceptable deceleration is generally not fulfilled. A percent decrease in velocity increases with the impact velocity.

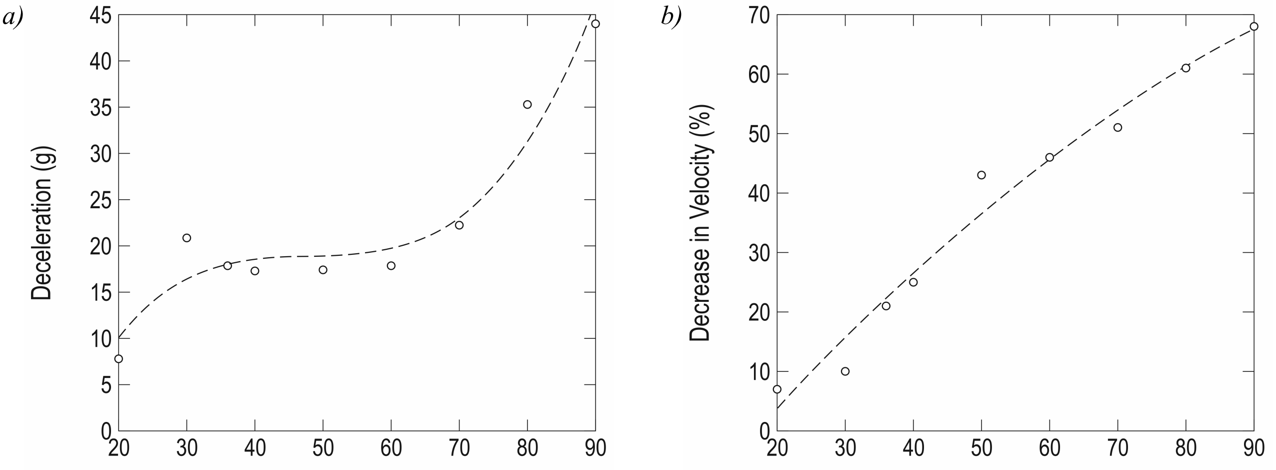

Fig. 2. Maximum values of a longitudinal deceleration of the cab (a) and decrease in the locomotive velocity (b) as a function of the impact velocity [5]

Internal energy for the buffers and the locomotive frame is summarized in Fig. 3a. It can be notice that the internal energy of buffers is practically constant as a result of their full compression. Internal energy of the frame increases with increasing the impact velocity. It means that the impact energy is absorbed mostly by the frame leading to its high and permanent deformations. Percentage distribution of the absorbed energy between buffers and the frame varies from about 85:15 for the velocity of 20 km/h to about 15:85 for the maximum velocity under consideration (Fig. 3b).

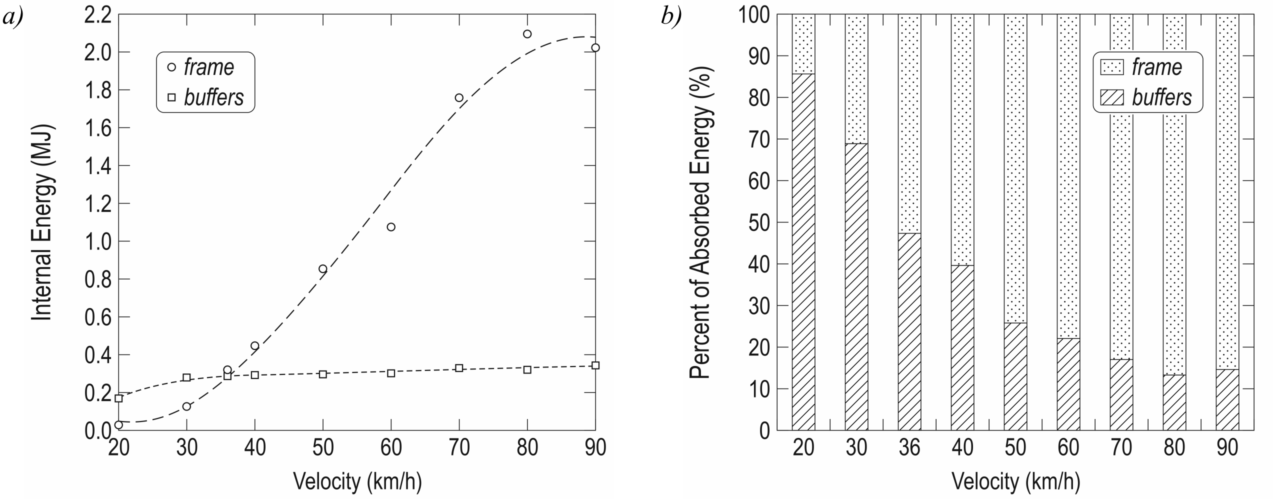

Fig. 3. Internal energy for the buffers and the locomotive frame (a) and the percentage distribution of the absorbed energy between these components (b) [5]

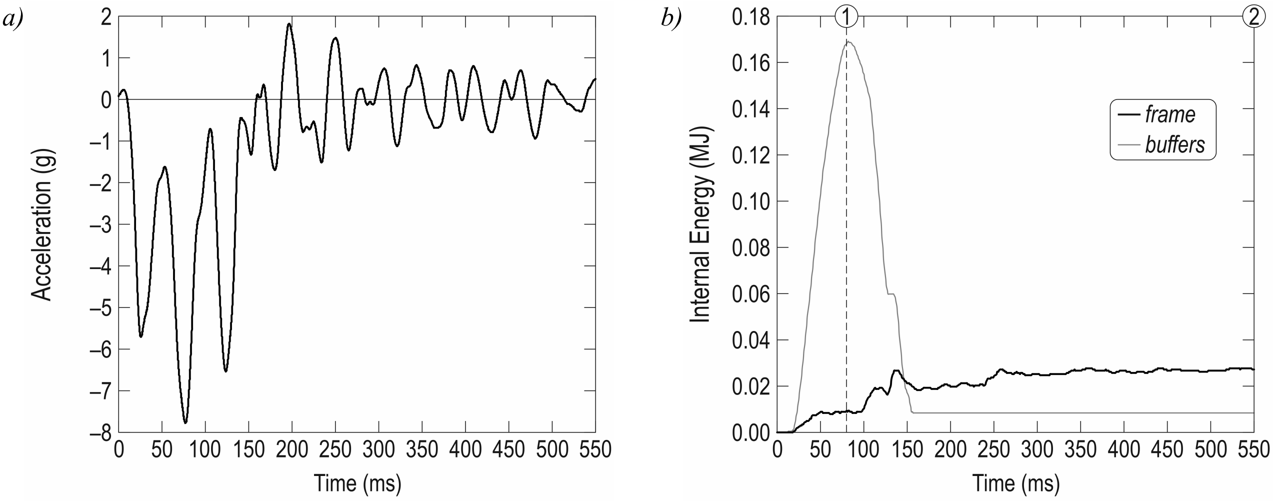

Fig. 4. Time-histories of an acceleration of the locomotive cab (a) and an internal energy for the buffers and the locomotive frame (b) for a velocity of collision equal to 20 km/h [5]. Characteristic points of analysis ① and ② are marked

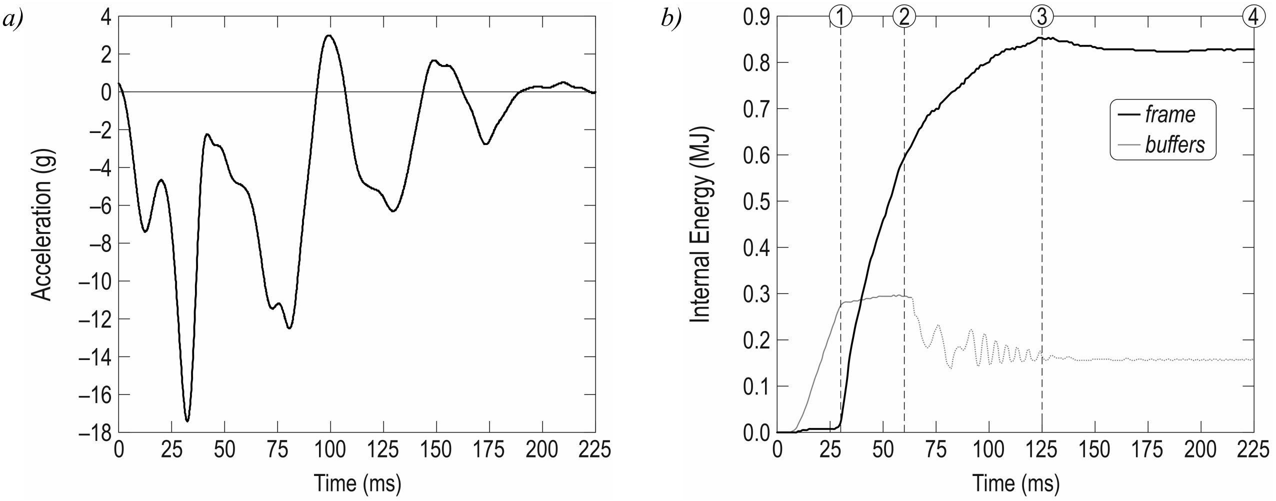

Fig. 5. Time-histories of an acceleration of the locomotive cab (a) and an internal energy for the buffers and the locomotive frame (b) for a velocity of collision equal to 50 km/h [5]. Characteristic points of analysis ①, ②, ③ and ④ are marked

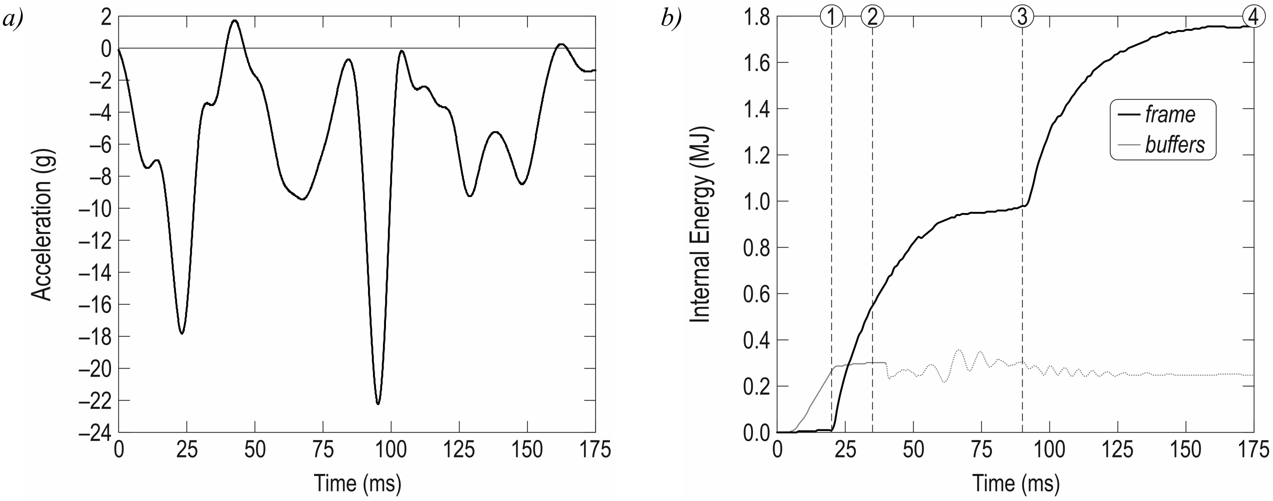

Fig. 6. Time-histories of an acceleration of the locomotive cab (a) and an internal energy for the buffers and the locomotive frame (b) for a velocity of collision equal to 70 km/h [5]. Characteristic points of analysis ①, ②, ③ and ④ are marked

Results in the form of time-histories of selected values are limited only to the specific impact velocities at which some significant changes in behaviour of the model took place. A case for a velocity of 36 km/h was presented and discussed in detail in [3]. Results for three specific velocities of collision – 20 km/h, 50 km/h and 70 km/h – are shown in Fig. 4, 5 and 6, respectively.

Obtained results of acceleration were filtered using SAE filter available in LS-DYNA post-processor. Filer frequency of 25 Hz was assumed on the basis of similar simulation described in [4].

Contours of effective stress for the front part of the frame are presented in Fig. 7, 8 and 9 for selected moments of time (①, ②, ③, ④). Authors decided to show results for the range of 0-600 MPa since the plastic kinematic material model with yield stress of 600 MPa was applied for the locomotive 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.

At the lowest velocity of collision, a maximum deceleration appears in the initial stage and corresponds to the maximum – but not complete – compression of the buffers. Internal energy of the locomotive frame is very low which means its slight deformation. Stress concentrations appear in the front plate close to the buffer attachments. Permanent plastic deformations of the frame do not occur (Fig. 7). After a collision, buffers expand and return to the initial configuration. At the end of collision, an effective stress in the locomotive frame is significantly below the yield stress.

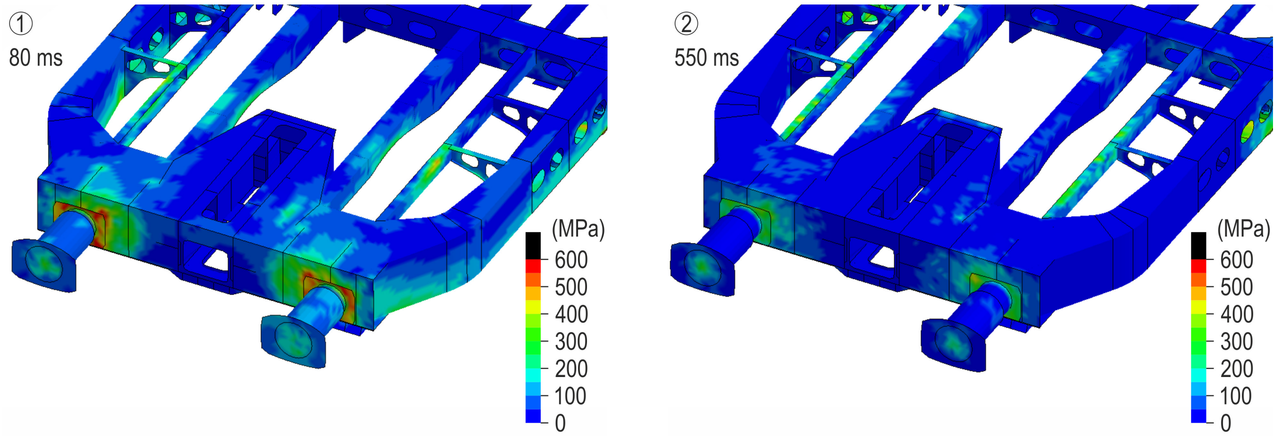

Fig. 7. Contours of effective von Mises stress for the front part of the locomotive frame in selected moments of time. Collision at a velocity of 20 km/h

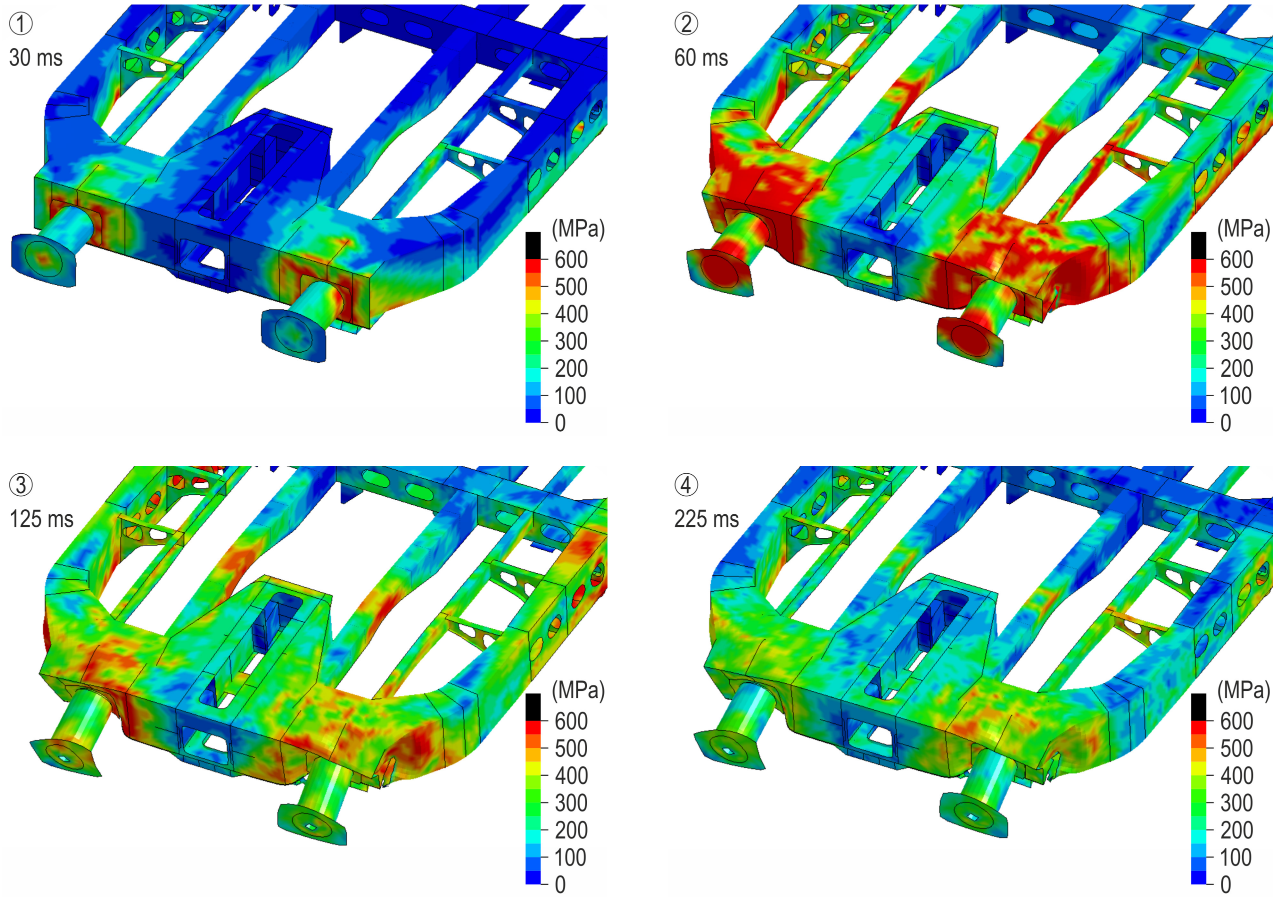

Fig. 8. Contours of effective von Mises stress for the front part of the locomotive frame in selected moments of time. Collision at a velocity of 50 km/h

Collision at a velocity of 50 km/h (Fig. 8) leads to significant and permanent deformations of the front part of the locomotive frame. Both buffers are fully compressed; therefore, the impact force is transferred into the end sill. Buffer attachments strongly penetrate a buffer beam, whereas the buffers tend to tilt down. After about 60 ms, buffers do not fulfil their function, which is manifested in the graph oscillations (Fig. 5b). At final stage, the end sill of the locomotive frame is permanently deformed. Erosion of some elements occurs. Maximum deceleration of the locomotive cab appears in the initial stage.

Collision at a velocity of 70 km/h (Fig. 9) and higher leads to extremely significant and permanent deformations of the front part of the locomotive frame. Impact force is transferred into the end sill. Buffer attachments strongly penetrate a buffer beam, whereas the buffers tend to the completely vertical position and do not fulfil their function. Moreover, high deformations appear in a skid rail. The end sill tends to tilt down resulting in bending of the longitudinal profiles. Erosion of elements close to the buffer attachments occurs (Fig. 9). Maximum deceleration of the locomotive cab appears in the middle phase of the collision. It is probably related to the initiation of bending of the skid rail. It can be notice that the graph of internal energy of the locomotive frame is divided into two distinct ranges graph corresponding to the destruction of successive components.

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 for different velocities of collision. Longitudinal deceleration for the locomotive cab exceeds the permissible value of 5 g for all cases under consideration. The collision processes symmetrically, because behaviour of both locomotives is the same. Significant

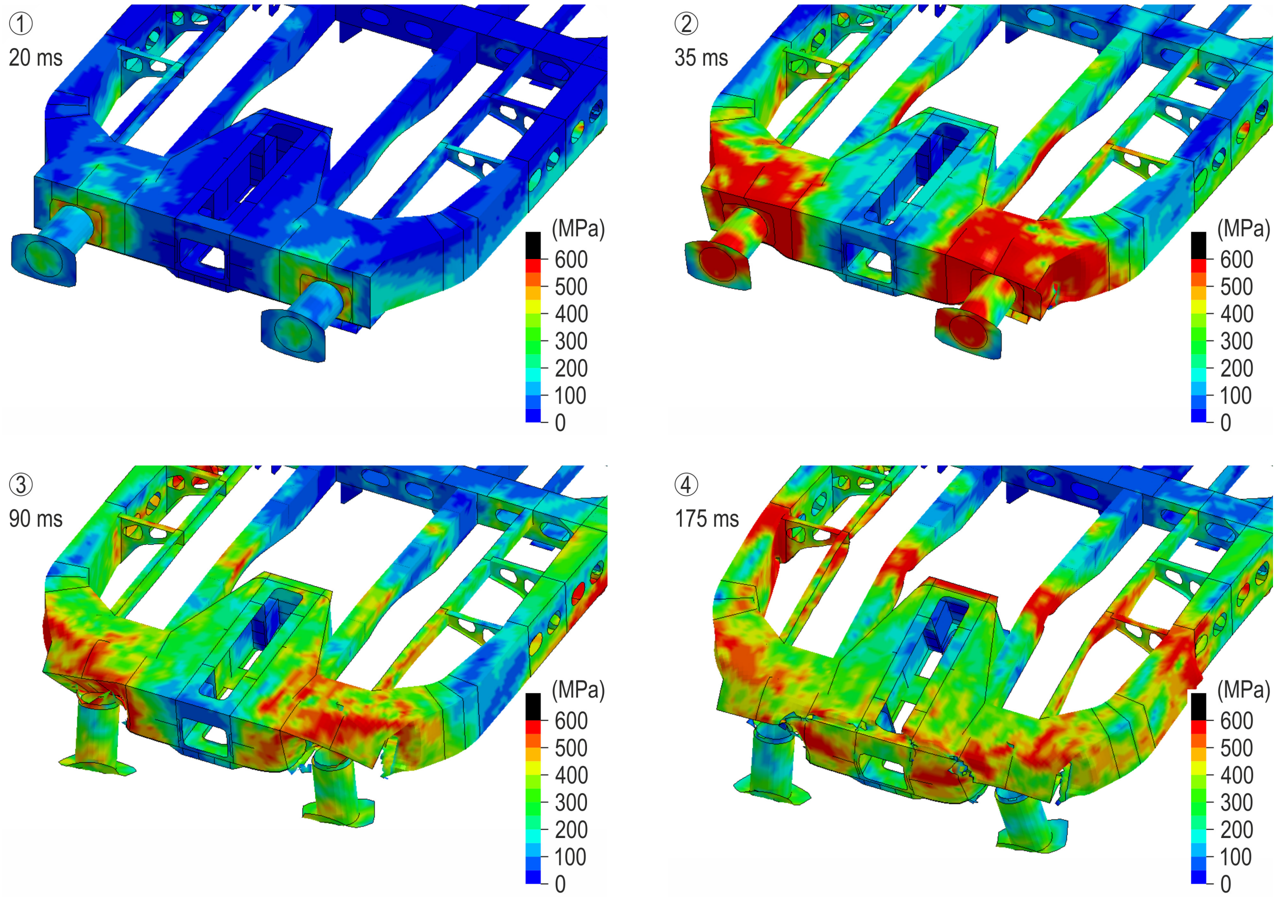

Fig. 9. Contours of effective von Mises stress for the front part of the locomotive frame in selected moments of time. Collision at a velocity of 70 km/h

deflections of the front suspension and nosedive of locomotives are noticed, especially for the cases at high velocities.

Both buffers absorb the impact energy in the first stage of the collision only. Once the buffers are fully compressed, the rest of impact energy must be absorbed by the frame. It leads to excessive plastic deformations in the front part of the frame – especially in the end sill and the corners close to the buffers attachment. For higher velocities, strong deformations appear also in a skid rail. Obtained results provide qualitative and quantitative data related to the locomotive behaviour during the collision with the identical train unit according the 1st design collision scenario described in the Crashworthiness requirements for railway vehicle bodies. It may be useful for the designer in further modernization of the considered structure.

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References

[1] PN-EN 15227+A1:2011 Standard, *Railway applications – Crashworthiness requirements for railway vehicle bodies*, Polish Committee for Standardization, Warsaw, Poland 2011.

[2] Dziewulski, P., Szurgott, P., *Development of finite element model of shunting locomotive applicable for dynamic analyses*, Journal of KONES, Vol. 21, No. 4, pp. 95-102, 2014.

[3] Dziewulski P., Konarzewski M., Szurgott P., *Numerical Analysis of the Front Impact Between Two Shunting Locomotives*, Journal of KONES Powertrain and Transport, Vol. 21, No. 3, pp. 81-88, 2014.

[4] *Full-scale locomotive dynamic crash testing and correlations: locomotive consist colliding with steel coil truck at grade crossing (Test 3)*, Final Report, U.S. Department of Transportation, Office of Railroad Policy and Development, Washington, United States 2011.

[5] Kozioł, Ł., *Numerical simulation of crash test of two shunting locomotives* [in Polish], Master thesis, Faculty of Mechanical Engineering, Military University of Technology, Warsaw, Poland 2016.