STUDY ON THE SHOCK CAUSED BY COLLISION OF RAILWAY VEHICLES

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Abstract: The paper presents a study on the behavior of the self-unloading SSDT train upon the shock caused by collision. The shock caused by collision of railway vehicles results in the transmission of forces and accelerations of considerable magnitudes. The collision testing of the self-unloading train serves the purpose of testing the resistance structure's capacity to withstand the collisions encountered during use, and to verify the car coupling method and the bogie-chassis relationship. The tests were conducted at velocities up to 7km/h. In conclusion, it is considered that the SSDT train's behaviour during collision testing was good.

Keywords: accelerations, bogie, chassis, plenitude coefficient, residual deformations, shock insulators, stresses.

1. INTRODUCTION

Due to current tendencies to increase travel velocities and car masses by allowing increasingly larger axle loads, railway equipment shows a series of special problems regarding shock loads that appear during collisions [15].

Collision of railway vehicles occurs during use, during car coupling operations, triage maneuvers and during travel, as a consequence of sudden breaking or of a change in coupling systems [2].

The shock caused by railway vehicle collisions results in the transmission of forces and accelerations of considerable magnitudes, which determine:

- strains on the resistance structure of the cars (chassis, body) and bogies [16];
- strains of the internal equipment and facilities of passenger cars;

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- strains of different devices, mechanisms, functional equipment of freight cars;
- accelerations transmitted to the transported freight, which can endanger their integrity and that of the anchoring or packaging systems;
- accelerations transmitted to passenger cars with considerable consequences on the comfort of the passengers.

In order to insulate and protect against longitudinal shocks [11], railway vehicles are equipped with shock insulators [14]:

- bumpers used on locomotives, freight or passenger cars that travel on the European railways or other railway administrations that use this system of protection;
- central coupling dampener, a system which is used by many railway administrations in South America (Brasil) and North America (USA, Canada), Asia (former USSR regions, India, Vietnam), Australia, Africa [19];
- long displacement dampeners which equip platform cars, also used for the protection of the loading platform, where the freight is placed [12].

2. THE COLLISION PROCESS

2.1. Shock occurrence

During the collision of two vehicles, between the time $t = t_1 = 0$, which marks the beginning of the collision, and the moment $t = t_2$, which marks the end of the end of the collision process, there is a time $t = t_{12}$ at which the velocities of the two vehicles are equal $v_{1(t)} = v_{2(t)} = v_{12}$. At that moment the vehicles travel at the same speed v_{12} , the kinetic energy of the vehicles is minimal, a part of the initial kinetic energy being transformed during the interval (0 - t_{12}) in potential energy stored by the vehicles.

The stored potential energy "E_p" at time "t_{12}" is maximum. The deformations and displacements caused by the shock are maximum, implicitly so is the contraction of the shock absorbers (bumpers, central coupling dampeners) "D" [2].

Between the moments $t = 0$ and $t = t_{12}$, considering the laws of conservation of momentum and energy, we have that:

$$m_1 v_1 + m_2 v_2 = (m_1 + m_2) v_{12} \tag{1}$$

$$\frac{m_1 v_1^2}{2} + \frac{m_2 v_2^2}{2} = \frac{(m_1 + m_2) v_{12}^2}{2} + E_p \tag{2}$$

Substituting v_{12} from (1) into (2), the stored potential energy of the vehicle is:

$$E_p = \frac{m_1 m_2}{m_1 + m_2} \frac{(v_1 - v_2)^2}{2} = \frac{m_1 m_2}{m_1 + m_2} \frac{v^2}{2} \tag{3}$$

where: m_1 - mass of the colliding railway car; m_2 - mass of the collided railway car; v - relative velocity between vehicles (collision velocity).

2.2. Motion parameters *a*, *v*, *x* of the vehicles during the collision

Figure 1 shows the time evolution of the kinematic parameters [17], acceleration a, velocity v and displacement x, of the colliding car 1and the collided car 2 during the shock caused by a collision at 12 km/h. The cars had masses of $m_1 = m_2 =$ 80 t. On the figure we have noticed the sum of contractions of the bumpers of the colliding and collided cars $D_1 + D_2 = 196$ mm. Another noticeable element is the moment t_{12} at which the cars have the same velocity and the process of transforming kinetic energy into potential deformation energy stored in the shock insulators (bumpers) ended.

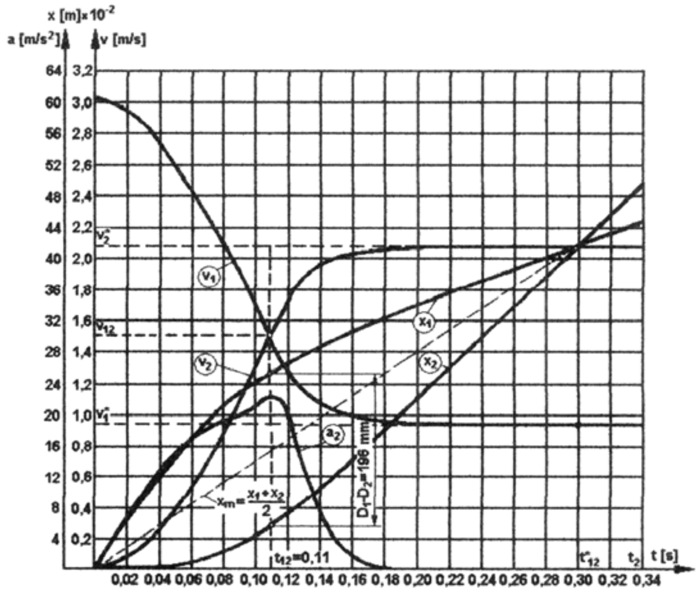


Fig. 1 Time evolution of acceleration $a_2(t)$ of collided car 2, determined experimentally and of the derived parameters $v_1(t)$, $v_2(t)$, $x_1(t)$ and $x_2(t)$ for collision C $\rightarrow$ C

The study of the time variation of the motion parameters of the vehicles, as response functions to the shock caused by collision, leads to the following observations:

1. At each moment "t" of the collision process which occurs on the time interval (0-t_2), the contraction "D" of the shock insulators that equip the vehicles is:

$$D(t) = x_1(t) - x_2(t) = \int_0^t v_1(t)dt - \int_0^t v_2(t)dt \tag{4}$$

2. At the time t_{12}, when the vehicles have the common velocity v_{12} and the stored potential energy of the vehicles is maximum, the difference between the distances traveled by the vehicles represents the maximum contraction of the shock absorbers "D_{max}" and, obviously the surface "S", between the curves v_1 and v_2, [2]:

$$D_{\max} = x_1(t_{12}) - x_2(t_{12}) = \int_0^{t_{12}} v_1(t)dt - \int_0^{t_{12}} v_2(t)dt = S \tag{5}$$

3. Experimentally it is observed that, at time $t = t^*_{12}$, the accelerations transmitted to the vehicles cancel out. Consequently, the vehicles move on the time interval (t^*_{12}- t_2), with constant velocities "v^*_1" and "v^*_2" respectively, while remaining in contact on the whole interval, while the space between the vehicles increases "$D(t)$" = $x_1(t)$ - $x_2(t)$.

This phenomenon occurs due to the fact that at time t^*_{12} the shock absorbers of the vehicles show another deformation (remanent contraction) which, on the interval (t^*_{12} - t_2) cancels out. Thus, the increase of the space between the vehicles at each moment of the time interval (t^*_{12} - t_2) is compensated by the recovery of the contraction of the shock absorbers. At the moment t_2, with marks the ended of the collision process, the shock absorbers (bumpers, central coupling dampeners) return to the initial position, corresponding to the moment $t = t_1 = 0$ (the start of the collision process).

4. The process of transforming stored potential energy into kinetic energy, triggered at $t = t_{12}$, ends at $t = t^*_{12}$, when the vehicles reach velocities v^*_1 and v^*_2 respectively.

Consequently, the values of the maximum contraction "D_{max}" and the surface „S" which represents the value of the maximum contraction are:

$$D_{\max} = \int_{t_{12}}^{t^*_{12}} v_1(t)dt - \int_{t_{12}}^{t^*_{12}} v_2(t)dt = -S \tag{6}$$

2.3. The energetic characteristics of the shock caused by collision, the 2β factor

Using bumpers with superior dynamic characteristics, which store an increased amount of deformation potential energy, leads to the decrease of the effects of the shock caused by collision [13].

For the experimentally studied shock, the energy parameters resulting from the collision of the cars equipped with category C (UIC – 526-1) high capacity bumpers were drawn (figure 2). The experimental determinations comprised $a_2(t)$, the forces transmitted during the collision $F(t)$, the contractions of the bumpers $D(t)$ and the potential energy stored by the bumpers W_e and dissipated W_a [18]. Against shocks that appear longitudinally during the use of the cars [20], the railway vehicles are equipped with shock absorbers (bumpers, central coupling dampeners). The use of bumpers or central coupling dampeners with high dynamic characteristics has the following consequences:

- the spectacular decrease of the maximum transmitted forces to the vehicles, with consequences on the protection of resistance structures by decreasing specific deformations and the stresses caused by the shock of collision;
- the lowering of the level of transmitted accelerations to the vehicles, down to a value that ensures a necessary protection of the freight, vehicle equipment and amenities, as well as an increased passenger comfort.

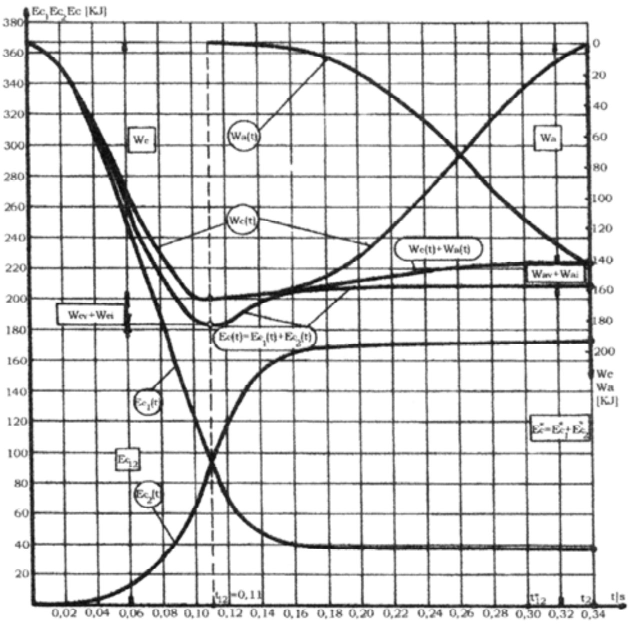


Fig. 2. Time evolution of the energetic parameters

The time evolution of the energetic parameters leads to the following observations on the collision process:

1. At the starting moment of the collision, $t = t_1 = 0$, the kinetic energy of the mechanical system composed of the vehicles, $E_c(t)$ is maximum.

2. On the interval (0 - t_{12}) the kinetic energy of the colliding car, $E_{c1}(t)$, decreases, and that of the collided car, $E_{c2}(t)$ increases. Their sum, $E_c(t)$, considerably decreases on the account of the transformation into stored potential energy by the bumpers W_e, cars $W_{ev} = W_{es} + W_{eb}$ and load W_{ei}.

3. At t_{12}, the kinetic energy of the cars is minimum:

$$E_c(t_{12}) = E_{c12} = \left[(m_1 + m_2) \cdot v_{12}^2\right] / 2 \tag{7}$$

The stored potential energy being maximum:

$$E_p = W_e + W_{ev} + W_{eî} \tag{8}$$

4. On the interval (t_{12} - t^*_{12}) the process of transforming stored potential deformation energy into kinetic energy begins, together with the process of dissipating potential energy.

5. At the moment t^*_{12} the kinetic energy of the cars is equal to the kinetic energy of the cars at t_2:

$$E_c(t_{12}) = E_c(t_2) - E^*_c = E^*_{c1} + E^*_{c2} \tag{9}$$

Furthermore, the sum between stored and dissipated potential energies (by the bumpers W_a, the cars W_{av} and the freight $W_{aî}$) is equal to the dissipated potential energy at t_2:

$$\begin{aligned}(W_e(t^*_{12}) + W_{ev}(t^*_{12}) + W_{eî}(t^*_{12})) + (W_a(t^*_{12}) + W_{av}(\mathrm{t}^*_{12}) + W_{aî}(\mathrm{t}^*_{12})) = \\ = E_c - E_c(t^*_{12}) = E_c - E^*_c = W_a + W_{av} + W_{aî}\end{aligned} \tag{10}$$

6. On the interval (t^*_{12} - t_2) the kinetic energy of the cars E^*_c remains constant, under the conditions of the compensation of the drop in stored potential deformation energy by dissipation of potential energy from the system.

7. At the moment t_2 the energy balance is:

$$E_c = \left(m_1 \cdot v_1^2\right)/2 = E_c^* + \left(W_a + W_{av} + W_{aî}\right) \tag{11}$$

The following specific energy factors are defined, whose variation with the collision velocity $v = v_1 - v_2$ represents the energy characteristics of the shock caused by the vehicles' collision occurring on the time interval (0 - t_2):

1. The $2\beta = f(v)$ factor, which characterizes the shock of railway vehicles, represents the ratio between the potential deformation energy stored by the shock absorbers $\mathrm{W_e}$ and the potential energy stored by the system composed of the two vehicles E_p:

$$2\beta = W_e / E_p \tag{12}$$

2. The $2\lambda = f(v)$ factor is the ratio between the potential deformation energy stored by the bearing structures of the vehicles W_{es} and E_p:

$$2\lambda = W_{es} / E_p \tag{13}$$

If the vehicles are identical from this point of view, then $\lambda_1 = \lambda_2 = \lambda$.

3. The $2\delta = f(v)$ factor represents the ratio between the potential deformation energy stored by the elastic elements of the vehicles' suspensions W_{eB} and E_p:

$$2\delta = W_{eB} / E_p \tag{14}$$

If the vehicles' suspensions are identical, it can be considered that $\delta_1 = \delta_2 = \delta$.

4. The $2\chi = f(v)$ factor represents the ratio between the potential energy stored by the equipment and the freight of the vehicles $W_{e\hat{\imath}}$ and E_p:

$$2\chi = W_{e\hat{\imath}} / E_p \tag{15}$$

If the vehicles are identical from this point of view, then $\chi_1 = \chi_2 = \chi$.

It is obvious that:

$$2\beta + 2\lambda + 2\delta + 2\chi = 1 \tag{16}$$

It is extremely important to take into consideration the fact that the resistance structures, the elastic elements of the suspension, the equipment as well as the nature and quantity of the freight are established by criteria other than that of the response to the longitudinal shock caused by collisions. Thus, the only practical method of reducing the effects of the shock is to increase the potential deformation energy stored by the shock insulators. Hence, it becomes clear why the $2\beta = f(v)$ factor represents the specific energy factor that characterizes the shock phenomenon in railway vehicles. This specific energy characteristic directly influences the unwanted consequences of the shock.

2.4. The generalized expression of the force transmitted during collision[1]

The theoretical expressions of the transmitted force, as previously established by a series of authors, can only be used for vehicles equipped with shock insulators that show a linear dependency between force and contraction [5].

Railway vehicles can be equipped with shock insulators whose elastic elements show a nonlinear dependency (convex or concave) between force and contraction.

The plenitude coefficient p is defined, for shock insulators of any type of dependency between force and contraction. It represents the ratio between the stored potential deformation energy and the product of the maximum transmitted force and the maximum contraction of the shock insulator.

In the case of a collision between two vehicles equipped with different types of shock insulators, the plenitude coefficient is the following:

- for the shock insulators of the colliding vehicle:

$$p_1 = \frac{W_{e1}^{*}}{F_{\max} D_{1\max}} \tag{17}$$

- for the shock insulators of the collided vehicle:

$$p_2 = \frac{W_{e2}^{*}}{F_{\max} D_{2\max}} \tag{18}$$

where: W_{e1}^{*}, W_{e2}^{*} - potential deformation energy of the shock insulators on the colliding and collided car, respectively; D_{1max}, D_{2max} - maximum contraction of the shock insulators on the colliding and collided car, respectively.

It was considered that the bumpers of one vehicle have the same contraction and stored potential deformation energy.

Further on, the conventional rigidity K_T of the bumper is defined as the ratio between the maximum transmitted force and the maximum contraction of the shock insulator for a collision velocity v:

- for the shock insulators of the colliding vehicle:

$$K_{T1} = \frac{F_{\max}/2}{D_{1\max}}; \tag{19}$$

- for the shock insulators of the collided vehicle:

$$K_{T2} = \frac{F_{\max}/2}{D_{2\max}}; \tag{20}$$

Replacing D_{1max} and D_{2max} from (19) and (20), into (17) and (18), the equations of the stored potential deformation energies are obtained for the bumpers:

- of the colliding vehicle:

$$W_{e1}^{*} = \frac{F_{\max}^{2}}{2\,K_{T1}}\,p_1 \tag{21}$$

- of the collided vehicle:

$$W_{e2}^{*} = \frac{F_{\max}^{2}}{2\,K_{T2}}\,p_2 \tag{22}$$

The specific energy factors β_1 and β_2, of the colliding and collided vehicle, respectively, are:

$$\beta_1 = \frac{W_{e1}^{*}}{E_p}; \quad \beta_2 = \frac{W_{e2}^{*}}{E_p} \tag{23}$$

Using (21), (22) and (23), it is obtained that

$$(\beta_1 + \beta_2)\,\mathrm{E_p} = \frac{F_{\max}^{2}}{2}\left(\frac{p_1}{K_{T1}} + \frac{p_2}{K_{T2}}\right). \tag{24}$$

Replacing the expression of the potential energy E_p(3), the maximum transmitted force in a collision is obtained, for the case of vehicles equipped with bumpers:

$$F_{\max} = (v_1 - v_2)\sqrt{\frac{\mathrm{m}_1 \mathrm{m}_2}{\mathrm{m}_1 + \mathrm{m}_2}(\beta_1 + \beta_2)\frac{K_{T1}\, K_{T2}}{p_1 K_{T1} + \mathrm{p}_2 K_{T2}}} \tag{25}$$

In the case of a collision of two vehicles of the same type, with $m_1 = m_2 = m$, $K_{T1} = K_{T2} = K_{T1}$, $p_1 = p_2 = p$, and $\beta_1 = \beta_2 = \beta$, the maximum transmitted force becomes

$$F_{\max} = (v_1 - v_2)\sqrt{\frac{\mathrm{m}}{4} 2\beta \frac{K_T}{p}} \tag{26}$$

2.5. Experimental determination of the parameteres 2β, K_T, *P* and of the force F transmitted during the collision

In order to experimentally determine the parameters 2β, K_T, *P* and the force transmitted to the cars during the collision, over 2500 collisions were conducted, in a specialized stand, for the shock testing of railway vehicles.

The stand is equipped with amenities, mechanical installations, railway cars, transductors, data acquisition, recording and analysis equipment, corresponding and adequate to the purpose of the study.

During the testing, the colliding car, launched from the incline of the stand, collided, at various speeds, the other car which was at rest and unbraked on the flat, level region of the stand. The railway cars used colliding and collided, were 4 axle freight cars loaded up to a total mass of 80 t/car (with sand, gravel, broken rock etc.).

At each shock caused by the collision of the cars, during the collision process, the following parameters were experimentally determined:

- collision speed *v*;
- the forces transmitted through the bumpers $F_1(t)$ and $F_2(t)$;
- the contractions of the bumpers of the collided car $D_1(t)$ and $D_2(t)$.

The forces transmitted through the bumpers were measured with axial force transductors affixed to the frontal beam of the car, using specially designed apparatus.

Force transductors with the following characteristics were used:

- precision class 1;
- measurement range (0 - 500) tf;
- sensitivity 1,5 mV/V.

The contractions of the bumpers were measured with displacement transductors with the measurement range (0 - 200) mm.

The forces transmitted through the bumpers $F_1(t)$ and $F_2(t)$ and the contractions of the bumpers of the collided car $D_1(t)$ and $D_2(t)$, parameters which constitute the response of the elastic system formed by the two cars, to the shock caused by collision, were experimentally determined, their variation in time being recorder throughout the whole collision process.

Figure 3 shows the variations in time of the force transmitted through a bumper, recorded during the testing for the following collision cases:

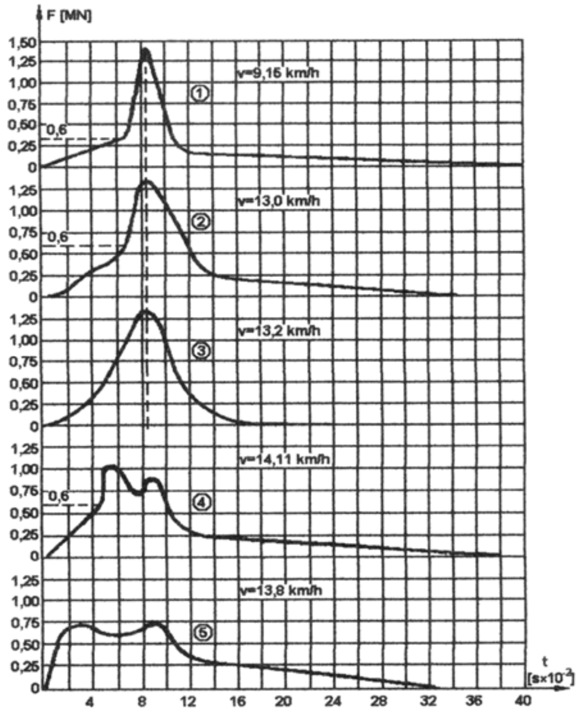


Fig. 3. The variation of the force transmitted through a bumper for different collision cases, depending on the type of bumper equipping the car and the collision speed v: 1 - 75 mm bumpers; 2 - category A bumpers with RINGFEDER rings; 3 - category A bumpers with elastic rubber elements; 4 - category A bumpers on the colliding car and category C bumpers on the collided car; 5 - category C bumpers.

1. Both railway cars were equipped with bumpers that correspond to the UIC 26-2 requirements UIC 526 - 2, meaning that they have a maximum travel of 75 mm. The elastic element was constructed from RINGFEDER type elastic rings;

2. Both cars were equipped with category A bumpers that correspond to the requirements of the UIC 526 - 1, with a maximum travel of 105 mm. The elastic element of the bumper was made from RINGFEDER type elastic rings;

3. Both cars were equipped with category A bumpers that correspond to the requirements of the UIC 526 - 1, with a maximum travel of 105 mm. The elastic element of the bumper was composed of cylindrical rubber elastic elements;

4. The colliding car was equipped with category A bumpers with RINGFEDER type elastic elements and the collided car with category C bumpers that

fulfill the requirements of UIC 526 - 1. The elastic element of the category C bumper was composed of a set of elastic RINGFEDER elements connected in parallel to a hydraulic dampener (a SC ICPVA SA solution);

Fig. 4. The variation of 2β according to speed, for the collision of two cars equipped with 75 mm bumpers

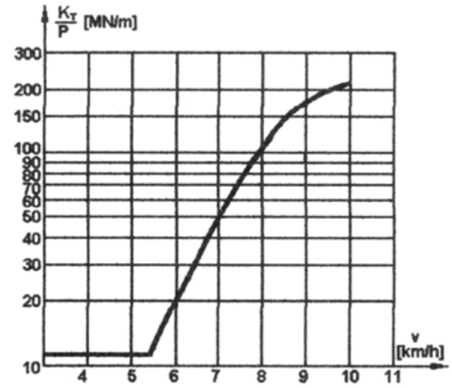


Fig. 5. The variation diagram of the K_T/p parameter according to speed, for the collision of two cars equipped with 75mm bumpers

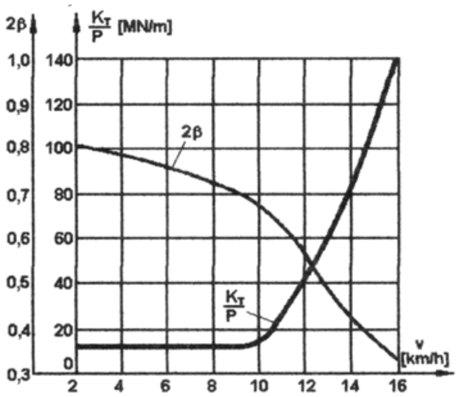


Fig. 6. The variation diagram of the 2β factor and the K_T/P parameter, for the collision of two cars equipped with category A bumpers with the elastic element comprising RINGFEDER rings.

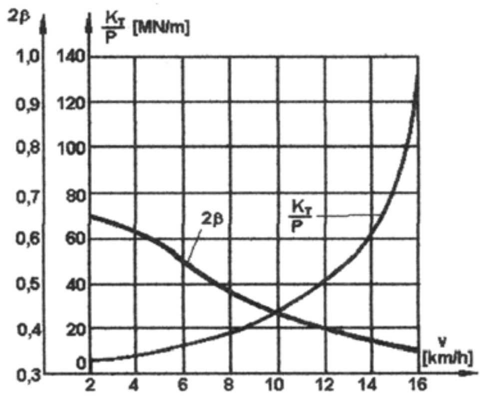


Fig. 7. The variation diagram of the 2β factor and the K_T/P parameter, for the collision of two cars equipped with category A bumpers with rubber elastic elements (bumpers previously subjected to endurance testing)

5. Both cars were equipped with category C, which corresponds to the requirements of UIC 526 - 1 (SC ICPVA SA solution).

From the analysis of the time evolution of the transmitted force, for the cases presented in figure 3, the following conclusion can be drawn:

- the modification of the form of variation of the force for the bumpers with RINGFEDER elastic elements, at the moment when the maximum travel is reached, corresponding to the reaching of a force of 0,38 MN for case 1 and

0,6 MN for case 2;

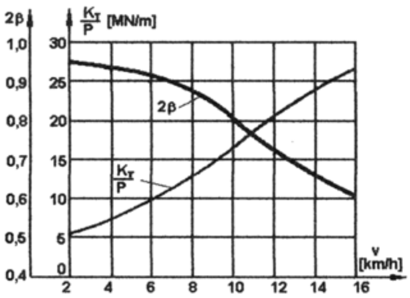


Fig. 8. The variation diagram of the 2β factor and the K_T/p parameter, for the collision of two cars equipped with category A bumpers on the colliding car and category C bumpers (a solution of SC ICPVA SA) on the collided car

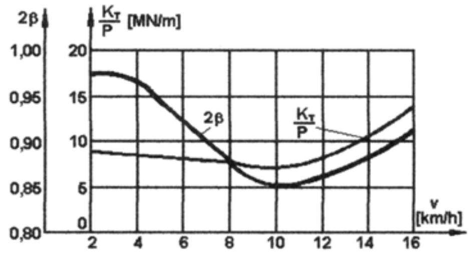


Fig. 9. The variation diagram of the 2β factor and the K_T/p parameter, for the collision of two cars equipped with category C bumpers

- the modification of the form of variation of the force at the value 0,6 MN and in case 4, at the moment when the maximum travel of the bumpers of the collided car is reached, bumpers equipped with RINGFEDER elastic elements;
- the use of bumpers with increased potential deformation energy storage capacity leads to the decrease of the level of forces transmitted upon collision.

3. EXPERIMENTAL STUDY

The paper presents the results of an experimental study conducted on the self-unloading SSDT train, during the shock caused by collision.

The SSDT train was composed of the following cars (fig. 10):

- car type B with chassis serial OO3 B;
- car type A with chassis serial OO4 A;
- car type C with chassis serial OO2 C;
- car type A with chassis serial OO2 A;
- car type A with chassis serial OO3 A;
- car type B with chassis serial OO4 B.

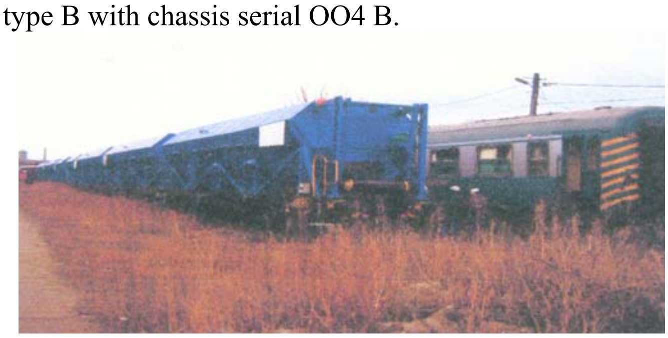


Fig. 10. The SSDT train

The technical characteristics of the train are the following:

- Vehicle gauge	UIC 505-1
- Track width	1435 mm
- Length of train over the bumpers	74640 mm
- Diameter of rolling circle	920 mm
- Maximum axel load	22,5 t
- Bogie type	Y25Ls1-K
- Wheelbase bogie	1800 mm
- Bumper type-hydraulic, category C displacement	105mm
- Maximum travel speed	90 km/h
- Minimum curve radius	75 m
- Maximum ferryboat ramp angle	1º 30'

The train's collision testing with car B loaded were conducted in order to study the capacity of the resistance structure of the car to withstand the collisions encountered in use [10]. The tests conducted with the train unloaded were done in order to verify the car coupling method and the bogie-chassis relationship.

The tests were conducted according to:

- European norm EN 12663;
- UIC 577 methodology;
- ERRI B 12 Rp 17 methodology.

The conditions under which the tests were conducted:

- collisions with velocities of up to 7 km/h;
- the colliding car was a 4 axle, compartmented gondola type car, loaded with sand up to a total mass of 80 t, equipped with category A bumpers, displacement 105 mm;
- the train's cars were equipped with category C bumpers, displacement 105 mm.
- the dynamic collision testing was done in a testing stand by launching the colliding car at certain velocities, from the incline of the stand.

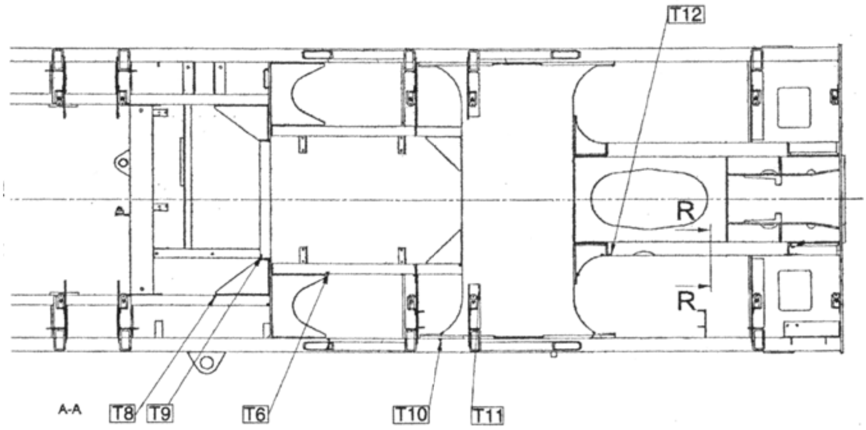


Fig. 11. The positions of the measurement points

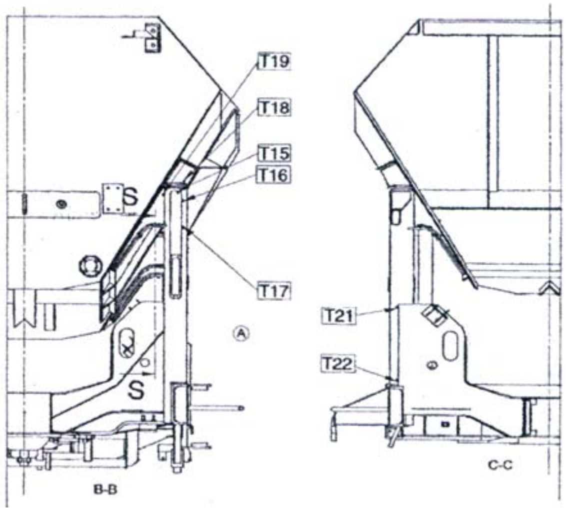


Fig. 12. The positions of the measurement points

As a result of the study of the technical documentation, of the results from the static testing and of the resistance calculations using Finite Element Method, the stress measurement points were determined in the most strained sections during the collision testing, for the concrete loading situation. The positions of the measurement points are shown in figures 11 and 12.

4. CONDUCTING THE COLLISION TESTING

a – SSDT train loaded

With the complete train, specifically: car B (loaded at 90 t), car A, car C, car A, car A, car B (all empty). The collision direction was towards the loaded car B.

The tests were done in the following stages:

- determining the static characteristics of the bumpers;
- equipping car B with electroresistive transductors;
- loading car B with ballast up to 90 t;
- conducting 10 preliminary collisions with increasing velocity;
- conducting 40 collision at 7 km/h;

In order to resettle the load, the train was collided from the opposite direction with another 80 t car at a maximum velocity of 7 km/h.

b – SSDT train empty

The test conducted with the complete train, specifically: car B, car A, car C, car A, car A, car B (all empty).

The collision direction was towards car B, formerly loaded.

A. Stages of the test

- unloading car B;

- conducting 10 preliminary collisions with increasing velocity;
- conducting 5 collisions at 7 km/h;
- At these tests the following parameters were measured [7], [8], [9]:
- v – velocity at impact;
- $F1$, $F2$ - force transmitted to the car, behind the bumpers;
- $D1$, $D2$ - bumper displacements;
- $D3$- displacement of the shock insulator between car B (collided) and car A;
- σ – stresses recorded at the moment of the impact;
- Acc 1. – longitudinal acceleration transmitted to the chassis (measured at the middle of the chassis);
- Acc 2. - longitudinal acceleration transmitted to the hull (measured at the middle of the hull);
- Acc 3. - longitudinal acceleration transmitted to car A (next to car B-collided and measured on the frontal beam).

The preliminary collisions were conducted in order to establish the most strained points, with the aim of studying them in the final series of 40 collisions [3], [6].

B. Result Analysis.

Determining the unit stresses in a linear state of stress is done with the following equation (Hooke's Law):

$$\sigma = E \cdot \varepsilon \tag{27}$$

Measured values.

During the collision testing, the forces were measured behind the bumpers, the bumper displacements, the accelerations transmitted to the chassis and hull, velocity at impact and the stresses in the considered measurement points (for the loaded scenario). The parameters determined during the collision process are presented in:

- tables 1, 2 -stresses, forces, bumper displacements, accelerations;
- figures 13-23-examples of the experimental determinations and transductors used;
- figure 24 - static diagram of the category C bumper used.

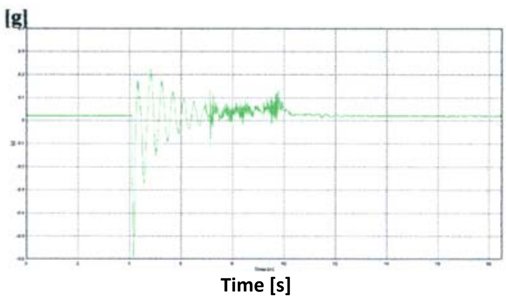


Fig. 13. Acc 1 chassis

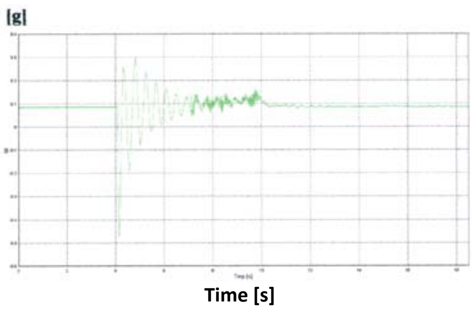


Fig. 14. Acc 2 carbody

Table 1. **Preliminary series**

Nr.crt.	**TER**	**SV**	**Velocity [km/h].**	
			3.15	**7.87**
1	T1	-2	-36	-87
2	T2	-10	-40	-94
3	T3	2	-37	-94
4	T4	-2		
5	T5	-20		
6	T6	-3		
7	T7	-8		
8	T8	4		
9	T9	1		
10	T10	-10		
11	T11	-76		
12	T12	48		
13	T13	-20		
14	T14	-30		
15	T15	-5		
16	T16	-20	-29	-40
17	T17	-41	-50	-57
18	T18	-25	-41	-60
19	T19	-13	-11	-8
20	T20	-51	-57	-66
21	T21	-7		
22	T22	-12	-30	-42
23	T23	-16	-32	-52
24	T24	-5	0	12
25	T25	1	-18	-64
26	T26	28		28
27	T27	29	42	60
28	T28	-41		
29	T29	-51		
30	T30	-46		
31	T31	-32		
32	T32	2	-22	-53
33	T33	6		
34	T34	1		
	F1[KN]		216	591
	F2[KN]		237	624
	D1[mm]		51	94
	D2[mm]		49	95
	Acc1[g]		0.28	0.69

Table 2. **Final series**

Velocity [km/h]		**7.2**		**6.92**	
TER	SV	T1	rezid.	T40	rezid.
T1	-2	-79	0	-74	0
T2	-10	-88	0	-85	0
T3	2	-83	0	-81	0
T4	-2	-87	0	-86	0.01
T5	-20	65	0.01	64	0.01
T6	-3	-128	0	-125	0.01
T7	-8	-129	0	-126	0.01
T8	4	-51	0	-49	0
T9	1	43	0	42	0
T10	-10	-46	0	-45	0.01
T12	48	-25	0.01	-21	0.01
T14	-30	-120	0	-118	0
T18	-25	-60	0	-57	0.01
T22	-12	-30	0.05	-26	0.17
T23	-16	-50	0	-49	0
T25	1	-58	0	-55	0.01
T27	29	52	0	51	0
T30	-46	-61	0	-60	0.04
T32	2	-44	0	-44	0
T33	6	-71	0	-70	0.01
T34	8	55	0.01	53	0.06
F1[KN]	547		532		
F2[KN]	561		562		
D1[mm]	94		92		
D2[mm]	96		92		
D3[mm]	16		16		
Acc.1[g]	0.6		0.54		
Acc.2[g]	0.6		0.54		
Acc.3[g]	0.5		0.46		

	Acc2[g]		0.27	0.64

The stresses from the measurement points presented in tables 1 and 2, are composed of the stresses obtained as an effect of the collision, which are algebraically superimposed on the stresses from the "SV" load corresponding to the vertical load of 90 tons.

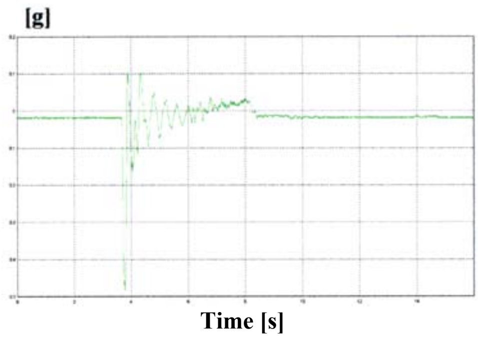


Fig. 15. Acc 3 car A

After finishing the collisions the main characteristics and components of the car were checked as well as the functionality of the mechanisms. The conveyor belt and the hatch opening mechanism were also verified.

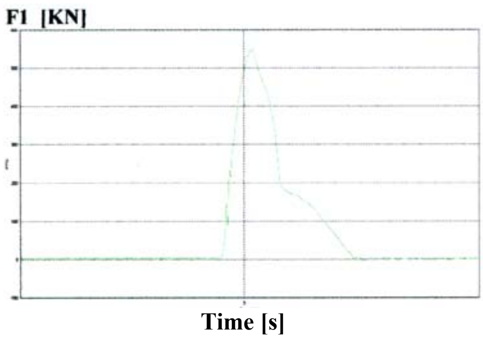


Fig. 16. Force transmitted to the car

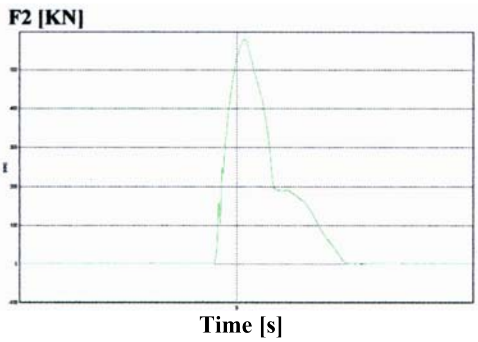
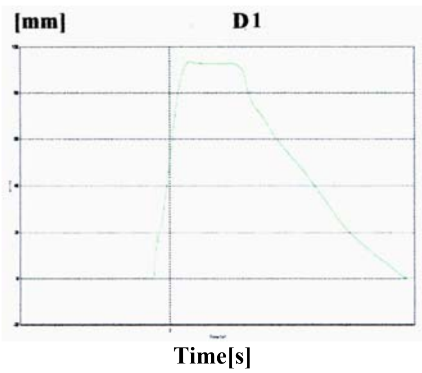


Fig. 17. Force transmitted to the car



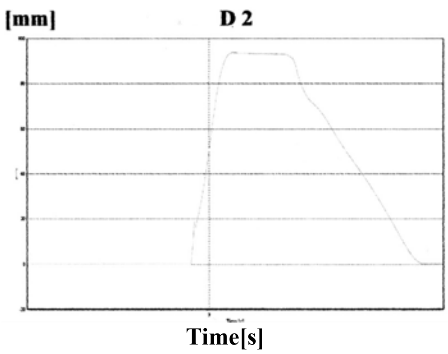


Fig. 18. Bumper displacements

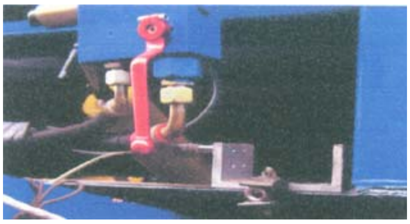


Fig. 19. Bumper displacements

Fig. 20. Acc 1 – chassis

Fig. 21. Acc 2 – carbody

Fig 22. Acc 3 – car A

Fig. 23. D 3 - Coupling system displacement car A/car B

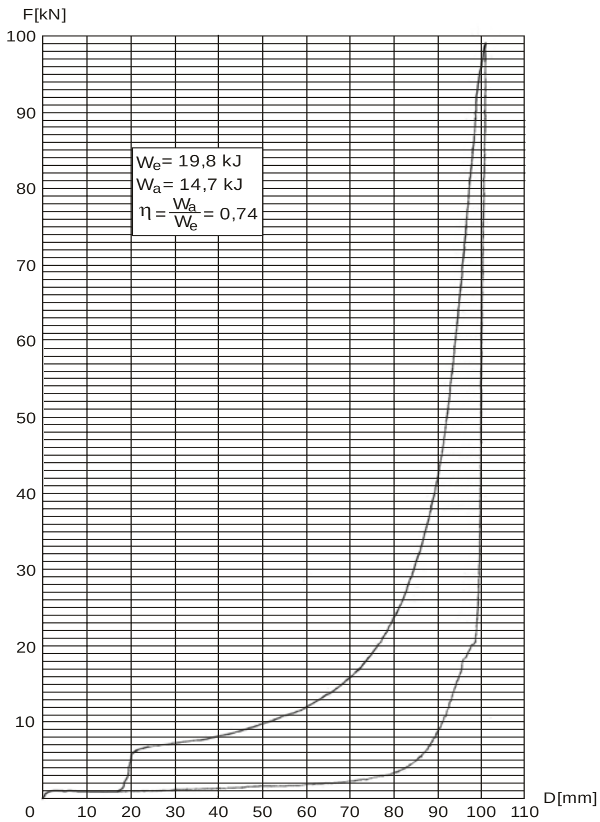


Fig. 24. Static diagram of the category C bumper used.

During the loaded car testing, the following conditions and recommendations were followed:

- cumulated residual deformations from the preliminary tests and the final series of 40 collisions must not exceed 2 ‰ and must stabilize before the 30th collision;
- the difference between forces must be lower than 200 kN.

5. CONCLUSIONS

After conducting the collision testing, it is observed that:

- cumulated residual deformations during the collisions do not exceed 2 ‰ and have stabilized before the 30th collision;
- no visible permanent deformations were found;
- the conveyor belt and the hatch opening mechanism were working properly;
- during the collision testing with the empty car, a good bogie-chassis relationship was found, as well as a good behaviour of the coupling system.

As a final conclusion, we consider that the SSDT train had a very good behavior during the collision testing, while also respecting all the conditions imposed by the European norms and the norms of the International Railway Union (U.I.C.)

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