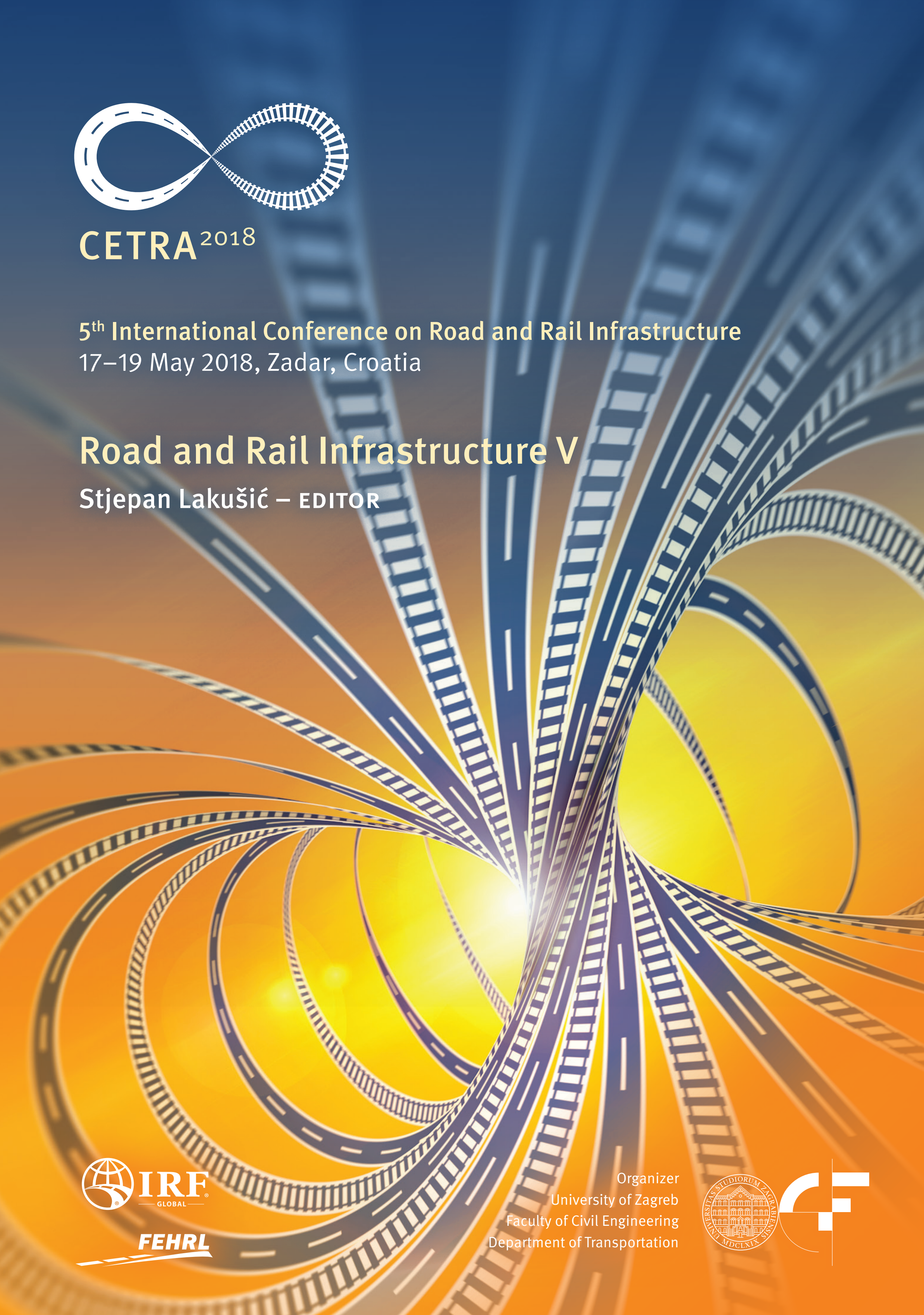

CETRA 2018

5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR

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CETRA^{2018}
5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

TITLE
Road and Rail Infrastructure V, Proceedings of the Conference CETRA 2018

EDITED BY
Stjepan Lakušić

ISSN
1848-9850

ISBN
978-953-8168-25-3

DOI
10.5592/CO/CETRA.2018

PUBLISHED BY
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Kačićeva 26, 10000 Zagreb, Croatia

DESIGN, LAYOUT & COVER PAGE
minimum d.o.o.
Marko Uremović · Matej Korlaet

PRINTED IN ZAGREB, CROATIA BY
“Tiskara Zelina”, May 2018

COPIES
500

Zagreb, May 2018.

Proceedings of the
5th International Conference on Road and Rail Infrastructures – CETRA 2018
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CETRA2018 17–19 May 2018, Zadar, Croatia
5th International Conference on Road and Rail Infrastructure

RAILWAY BUFFER STOPS PLANNING

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Abstract

Paper discusses the methodology of the planning process for railway buffer stops The general procedure to choose the appropriate type of the buffer stop to fulfil demands on kinetic energy absorbing and acceptable risk is presented. The static and dynamic analyses of various structures of buffer stops were performed with the aim to define acceptable velocity and train weight. The rigid buffer stops are usually weak, and movable friction buffer stops are the more suitable choice in most design situations. Friction buffer stops are the favoured structure, mainly due to its high resistance and variety of layout. The manner of deceleration induced upon impact and during the braking what makes it smart solution regarding the railway transport safety. The general approach of designing buffer stops is via usage of the kinetic energy and its conversion into work. Paper describes input parameters such as train velocity or the analysis of buffer stop vicinity which is expressed by the safety coefficient implemented within the calculation. The paper shows the design principles of calculation the friction buffer stop, and its braking jaw arrangement. The results of the analyses were implemented into the national railway regulation.

Keywords: railway buffer stop, static analysis, dynamic analysis, risk analysis

1 Introduction

Buffer stop is a device at the end of a dead-end track or closed track with a purpose of stopping the rolling stocks. Buffers stops can be of different design with different absorption principle. Safety during an impact of the vehicle is the essential requirement. That means that either the buffer stop and rolling stock is not damaged or demand protection of persons. Aforementioned applies both to passengers, train drivers and train crews, and to passengers or other persons in the buffer stop vicinity.

We should consider as necessary design parameters, which define buffer stop and track end arrangement, the impact velocity and the rolling stock mass, i.e. the ability of the buffer stop to absorb the kinetic energy and to stop the vehicle.

We can categorise buffer stops into several groups according to different aspects. Buffer stops can be permanent or temporary, which, e.g. serves during traffic possession and maintenance work. Furthermore, we distinguish between rigid buffer stops (with or without hydraulic or impact-absorbing buffers) and friction buffer stops. The rigid buffer stops are firmly connected to track or its substructure. The disadvantage of the rigid buffer stops is exceptionally high deceleration which occurs during a short time interval and a very short distance.

Friction buffer stops solve this problem since they brake a vehicle for a more extended distance during a longer time. The friction buffer stop (also referred as buffer stop block or frictional buffer stops) absorb the kinetic energy of a rail vehicle by friction of the buffer block along the track. That is why the rigid buffer stops are not installed just at the end of the track but

DOI: https://doi.org/10.5592/CO/CETRA.2018.836

at a certain distance from it. Therefore, the kinetic energy of the vehicle decreases over the braking distance at the moment of an impact. Then the vehicle can be stopped without significant damage both the vehicle and the buffer stop. The deceleration rate during the impact is significantly less than in the case of a rigid buffer stop.
Until recently, only rigid buffer stops, namely steel, concrete or end impact wall, were used in the Czech Republic. Due to the small braking ability of the rigid buffer stops and the requirement on the increased safety at the end of tracks during the impact of the railway vehicle, RIA (Railway Infrastructure Administration in the Czech Republic) has also used friction buffer stops. Friction buffer stops are commonly installed for instance in Belgium, Israel, Germany, Poland, Switzerland or the United Kingdom. RIA's requirements are based not only on the relevant regulations of infrastructure managers in these countries but also on the recommendations and experience of the manufacturers and suppliers of friction buffer stops [1].

2 Static and dynamic analyses of the current buffer stops

2.1 Numerical models of buffer stops

Numerical models were built using the finite element method (FEM) in the ANSYS LS-DYNA software [2] to analyse the behaviour of rigid buffer stops. The models were based on standard design sheets (drawings) of buffer stops. Three types of rigid buffer stops were modelled. The particular complex spatial models are made predominantly from volume elements and completed by elements modelling the substructure, see an example in Figure 1. The models included all significant structural components so they can be subsequently evaluated. Steel components and their joints are assessed in the case of steel buffer stop. The displacement of concrete block embedded in the soil is evaluated for the concrete buffer stops, where inertial properties play the significant role.

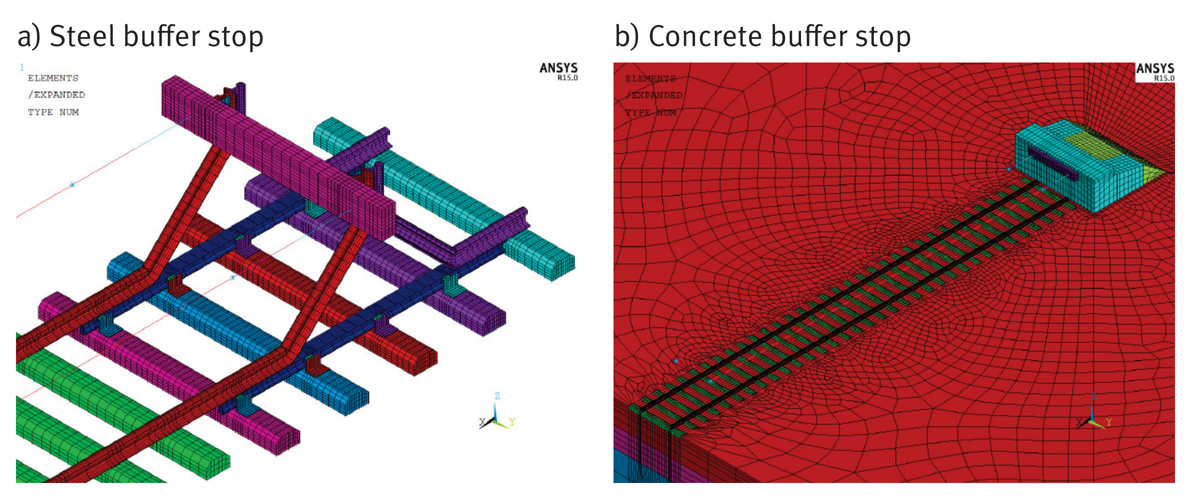


Figure 1 Finite element models of buffer stops

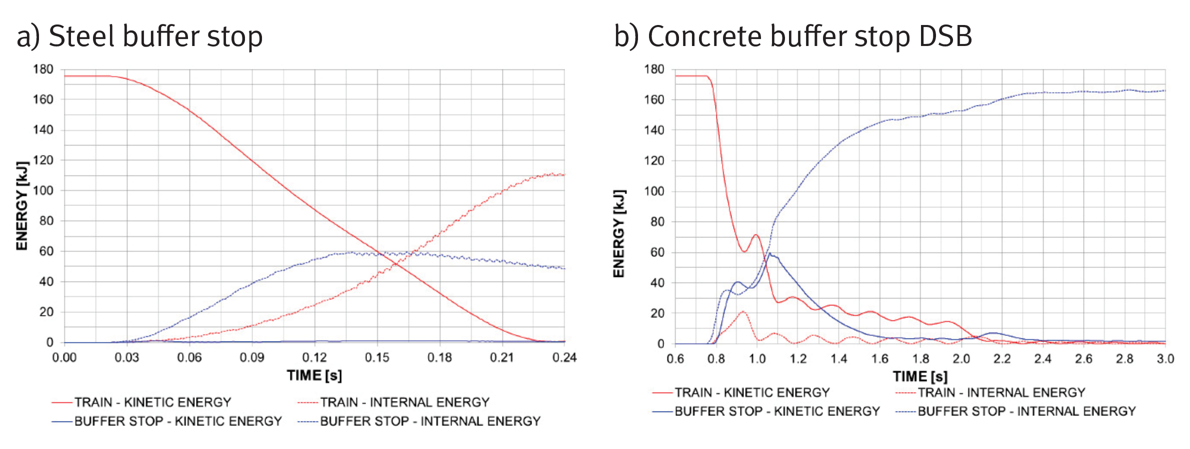
2.2 Vehicle assemblies and their models

Four cases of railway vehicles either a single vehicle or whole train were chosen for analyses:
1) Passenger train, diesel unit – weight 55 Mg
2) Heavy locomotive 100 Mg
3) Passenger train – unit of two engines and two cars – unit weight 180 Mg
4) Passenger train (engine car – interposed car – engine car – interposed car – engine car – interposed car – engine car) – total seven cars – unit weight 385 Mg

Due to the lack of detailed data about particular railway vehicles, these vehicles were modelled by a simplified way using resilient components (e.g. bumper model) and horizontally positioned slabs coupled to beams which represent the stiffness and the weight (without bumpers) of chosen railway vehicles. Railway vehicles were assembled according to requirements a consequently used in the buffer stops analyses.

2.3 Analysed cases, calculations and results

The cases where the movement of railway vehicles during the impact on the buffer stop corresponds to velocities of 0.7; 1.0; 1.6; 3.0 a 5.0 km/h were analysed. The influence of a deceleration of the railway vehicle during the impact was not taken into consideration. There were analysed 4 x 5 cases regarding every type of buffer stop. The theoretical values of kinetic energy of particular railway vehicles or units were calculated respect to input velocities based on the equations valid for the rigid body in the translational movement.
The LS-DYNA software was used for calculations. The extensive database including fields of displacement, strain and stress was received from the calculations. The acceleration in selected points on structures and energy balance during the impact was monitored until either the destruction of the steel buffer stop or the admissible displacement of the concrete buffer stops related to the original position.
The time courses of changes of the kinetic energy of the railway vehicles and the buffer stop and also the internal energy at the deformation of the vehicles and the buffer stop-displayed in the form of the graphs see Figure 2. It shows the zone where the kinetic energy of the railway vehicles is minimal. At the same time, the maximum of internal energy which is accumulated in the buffer stop (energy consumed for the structures deformation and dissipated energy) is reached.


a) Steel buffer stop

b) Concrete buffer stop DSB

Figure 2 Energy changes at the initial impact velocity 5 km/h, weight 180 Mg

Important values are the maximum displacement of the selected points depending on the railway vehicle velocity. Furthermore, the deceleration of the railway vehicle (or whole unit) depending on the impact velocity was checked. The internal structural forces eventually stresses were determined in the exposed points, sections or components, and their extremes were searched for the assessment. The extreme forces in bumpers are important for the evaluation. The state, in which the load carrying capacity of structural components is exceeded, was evaluated when assessing buffer stops. The concrete block displacement was assessed for the concrete buffer stops of the type SUDOP or DSB. The displacement of 100 mm was considered as the limit value. Such displacement usually does not negatively influence the further use of the buffer stop. The displacement 500 mm is considered as the limit value, in which no interaction with surrounding objects occurs. The displacement value greater than 500 mm is considered as inadmissible. The acceptable (A) and limit (L) velocities corresponding to the particular types of buffer stops and the railway vehicles or units are shown in Table 1.

Table 1 Results of analysis

Weight of vehicles [Mg]	**55**		**100**		**180**		**385**	
Type of buffer stop	**Velocity [km/h]**							
	A	**L**	**A**	**L**	**A**	**L**	**A**	**L**
Steel	-	0.7	-	0.7	-	0.7	-	0.7
Concrete SUDOP	1.6	3.0	1.0	3.0	1.0	1.6	0.7	1.6
Concrete DSB	1.6	5.0	1.6	5.0	1.0	3.0	0.7	1.6

3 Risk assessment

The assessment of the risk of a potential threat close to the track end is an essential part of the design of a suitable type of buffer stop and the arrangement of the track end. The assessment of the risk of a potential accident only concerns the track vicinity; it does not concern passengers on board the train. In the case of a replacement of the buffer stop by another type, where no changes in the configuration of the track vicinity are designed (e.g. platforms, structures behind the buffer stop etc.), and the buffer stop type would be the same or better absorption parameters, the design is considered as a change without safety impact in compliance with the codex of good practice and the risk management would not be applied.

The particular parameters and site characteristics (track end arrangement, threats to people in the immediate vicinity and surrounding area, consequences of a potential accident and its impact to adjacent structures, the identification of the cause of an accident) are taken into account to specify values of coefficients listed below when assessing site-specific risks. The resulting level of risk is subsequently specified according to Table 2. The form for infrastructure managers and designers was developed, which serves as a guide for the comprehensive evaluation and specification of the risk level at the particular track end.

The coefficients which express Probability of Occurrence (O), Severity of Consequence (S) and Probability of occurrence of accidental Event (E) are specified based on the assessment described above. The coefficients gain values in the range 1.0 – 2.0. The calculation of the risk level is based on analytical methods using the multiplication of these coefficients, so-called the Risk Priority Number, which is applied in the Failure Mode, Effect and Criticality Analysis (FMECA) or the Risk Matrix method [3, 4, 5].

The track layout, the track length, number of trains or shunting vehicles which go to the track are considered when the probability of occurrence (O) is determined. The assessing the severity of consequence (S) takes into account, in particular, the possibility of severe or even fatal injury of persons in the track vicinity. The consideration should be given to the location of roads, pedestrian path, the occurrence of bridge pillars, platform roof structures, columns, billboards etc. The probability of occurrence of accidental Event (E) is based especially on the command and control system (CCS) by which the track is equipped and also on the way of the interaction between CCS and train. The received values of the coefficients are multiplied according to the following formula:

$$\mathrm{RPN} = \mathrm{O} \cdot \mathrm{S} \cdot \mathrm{E} \tag{1}$$

The risk level connected to the particular track end and the vicinity arrangement is determined by the obtained value of RPN according to Table 2. The level of risk identified is the considered in the general decision-making process for the selection of the buffer stop type, in particular to the decision whether the rigid or friction buffer stop structure should be used.

Table 2 Specification of risk level

Range of the Risk Priority Number	Risk level
RPN > 6	Critical
4.5 < RPN ≤ 6	High
3.5 < RPN ≤ 4.5	Moderate
1.5 < RPN ≤ 3.5	Minor
RPN ≤ 1.5	Insignificant

4 Design process

4.1 General approach of designing buffer stops

The general decision-making process of the buffer stop design and evaluation includes the assessment of the risk level, the specification of buffer stop parameters and their evaluation. The risk assessment is described in Chapter 3 and results in the specification of risk level. If the risk level is "Critical" in the given case, it is necessary to change some parameter of the track or the arrangement of the track vicinity. For instance, the type of CCS, increasing of the threatened structures, the platform arrangement, a modification of adjacent roads or pedestrian path.

If risk level were determined "Insignificant" or "Minor", it would be possible to design a rigid buffer stop. The particular type of the buffer stop is designed especially concerning the supposed operation, and the selection has to be agreed by the infrastructure manager. No additional evaluation or assessment is not required in this case.

If "High" or "Moderate" risk level were determined, it is necessary to design a friction buffer stop. The friction buffer stop is also designed if required by the infrastructure manager. The procedure for designing and evaluation a friction buffer stop includes:

- Specification of input parameters, i.e. determination of the operation character on the track (passenger or / and freight), the weight of railway vehicles or trains, their velocity;
- Calculation of the kinetic energy E_{kin},, which has to be absorbed by the buffer stop;
- Determination of the safety coefficient k and required braking work W;
- Choice of the particular type of the buffer stop, determination of its parameters, i.e. braking length and braking jaws arrangement;
- Calculation of deceleration value a;
- Evaluation of braking work and deceleration rate.

The procedure of the buffer stop design and evaluation is described below.

4.2 Design procedure for the friction buffer stop

The kinetic energy E_{kin} [J] of moving vehicles can be determined using simplified equation without commonly used calculation with rotating parts taking into consideration velocity V [km/h] or v [m/s] and mass m [kg]:

$$E_{kin} = \frac{1}{2} \cdot m \cdot v^2 \cong m \cdot \left(\frac{V}{5.09} \right)^2 \tag{2}$$

The velocities taken into the calculation were defined for the different design cases concerning to the design economy and the real velocities in the track:

- mainline and reginal tracks:
  - 10 km/h for freight trains and shunting;
  - 15 km/h for passenger trains;
- local lines, sidings and special yards:
  - 5 km/h for shunting;
  - 10 km/h pro siding trains.

In the event of an impact of the vehicle or train by a higher velocity, the buffer stop absorbs part of the kinetic energy, reducing the threat for people, structures and equipment in the vicinity of the track end and reducing vehicle damage.

The weight of the heaviest vehicle or train entering the track is taken into account for calculating the kinetic energy. It is necessary to consider the passengers on board of the passenger train or loaded the freight train, depending on the operation character. The rotating masses, the velocity changes due to the track gradient are neglected because of their negligible influence on the kinetic energy.

The buffer stop has to be able to absorb the determined kinetic energy. The maximum brake work W [J] of the buffer stop has to be higher than the kinetic energy E_{kin} [J] of the vehicle or train, multiplied by the safety coefficient k [-]:

$$W \geq k \cdot E_{kin} \tag{3}$$

The safety coefficient k relates to characteristics of the operation or to the track vicinity arrangement and ranges from 1.2 to 2.0.

The braking force acts against the movement of the vehicle after impact. The value of braking work depending on the number n of the braking elements at the constant braking force F_B [N] along the braking length l_w [m] is calculated by the following formula:

$$W = n \cdot F_B \cdot l_w \tag{4}$$

If the braking length is longer than 5 m, the braking length is divided into partial sections for each group of braking elements. The length of the partial sections is determined and consequently braking forces for particular braking elements are calculated. Braking effect of the buffer stop can be increased by installing additional braking elements. The braking work of the group of the braking elements with the same braking force is calculated by the formula:

$$W_i = n_i \cdot \sum_{j=1}^{n} F_{Bi,j} \cdot l_{i,j} \tag{5}$$

in which the index i means the number of the group of braking elements, the index j is the number of the section. The total braking work W is calculated as the sum of braking works W_i. in particular sections. The maximum braking deceleration acting on the vehicle corresponds to the maximum braking force:

$$a_{max} = \frac{F_{B,max}}{m} \tag{6}$$

The recommended value of deceleration for passenger trains is 1 m/s^2, the limit of the braking deceleration is 2.5 m/s^2. The deceleration is not assessed for freight vehicles. The deceleration is also not assessed for rigid buffer stops.

5 Conclusions

Designing a buffer stop depends on many circumstances. Among others, most essential are types of trains running on the dead-end track, impact velocity and the vicinity of the buffer stop. The assessment of level risk was defined as well as the design procedure for the friction buffer stops and criteria to be met. The final design includes all set criteria such as deceleration rate, limited length and the work of all braking elements to stop the variety of trains or shunting vehicles.

Acknowledgment

This paper has been worked out under the project No. LO1408 “AdMaS UP – Advanced Materials, Structures and Technologies”, supported by Ministry of Education, Youth and Sports under the “National Sustainability Programme I” and within implementation of the contract research project supported by RIA.

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