

CETRA²⁰¹⁴

3rd International Conference on Road and Rail Infrastructure
28–30 April 2014, Split, Croatia

Road and Rail Infrastructure III

Stjepan Lakušić – EDITOR

Organizer
University of Zagreb
Faculty of Civil Engineering
Department of Transportation



CETRA²⁰¹⁴

3rd International Conference on Road and Rail Infrastructure
28–30 April 2014, Split, Croatia

TITLE

Road and Rail Infrastructure III, Proceedings of the Conference CETRA 2014

EDITED BY

Stjepan Lakušić

ISSN

1848-9850

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”, April 2014

COPIES

400

Zagreb, April 2014.

Although all care was taken to ensure the integrity and quality of the publication and the information herein, no responsibility is assumed by the publisher, the editor and authors for any damages to property or persons as a result of operation or use of this publication or use the information's, instructions or ideas contained in the material herein.

The papers published in the Proceedings express the opinion of the authors, who also are responsible for their content. Reproduction or transmission of full papers is allowed only with written permission of the Publisher. Short parts may be reproduced only with proper quotation of the source.

Proceedings of the
3rd International Conference on Road and Rail Infrastructures – CETRA 2014
28–30 April 2014, Split, Croatia

Road and Rail Infrastructure III

EDITOR

Stjepan Lakušić

Department of Transportation

Faculty of Civil Engineering

University of Zagreb

Zagreb, Croatia

CETRA²⁰¹⁴

3rd International Conference on Road and Rail Infrastructure

28–30 April 2014, Split, Croatia

ORGANISATION

CHAIRMEN

Prof. Stjepan Lakušić, University of Zagreb, Faculty of Civil Engineering

Prof. Željko Korlaet, University of Zagreb, Faculty of Civil Engineering

ORGANIZING COMMITTEE

Prof. Stjepan Lakušić

Prof. Željko Korlaet

Prof. Vesna Dragčević

Prof. Tatjana Rukavina

Assist. Prof. Ivica Stančerić

dr. Maja Ahac

Ivo Haladin

dr. Saša Ahac

Josipa Domitrović

Tamara Džambas

All members of CETRA 2014 Conference Organizing Committee are professors and assistants of the Department of Transportation, Faculty of Civil Engineering at University of Zagreb.

INTERNATIONAL ACADEMIC SCIENTIFIC COMMITTEE

Prof. Vesna Dragčević, University of Zagreb

Prof. Isfendiyar Egeli, Izmir Institute of Technology

Prof. Rudolf Eger, RheinMain University

Prof. Ešref Gačanin, University of Sarajevo

Prof. Nenad Gucunski, Rutgers University

Prof. Libor Izvolt, University of Zilina

Prof. Lajos Kisgyörgy, Budapest University of Technology and Economics

Prof. Željko Korlaet, University of Zagreb

Prof. Zoran Krakutovski, University of Skopje

Prof. Stjepan Lakušić, University of Zagreb

Prof. Dirk Lauwers, Ghent University

Prof. Zili Li, Delft University of Technology

Prof. Janusz Madejski, Silesian University of Technology

Prof. Goran Mladenović, University of Belgrade

Prof. Otto Plašek, Brno University of Technology

Prof. Vassilios A. Profillidis, Democritus University of Thrace

Prof. Carmen Racanel, Technical University of Civil Engineering Bucharest

Prof. Tatjana Rukavina, University of Zagreb

Prof. Andreas Schoebel, Vienna University of Technology

Prof. Mirjana Tomičić-Torlaković, University of Belgrade

Prof. Audrius Vaitkus, Vilnius Gediminas Technical University

Prof. Nencho Nenov, University of Transport in Sofia

Prof. Marijan Žura, University of Ljubljana



APPROACHES TO SOLVE THE PROBLEM OF PASSIVE SAFETY OF PASSENGER WAGONS

Venelin Pavlov, Nencho Nenov, Veselin Stoyanov

University of Transport 'Todor Kableshkov', Sofia, Bulgaria

Abstract

Railway safety is concerned with the protection of life and property through regulation, management and technology development of all forms of rail transportation. The analytical results of the world modern tendencies and approaches to solve the problem of a passive safety of railway vehicles, in particular passenger wagons are presented. Also, the existing legislation of the European countries that regulates a passive safety of express and high-speed passenger trains is considered. The basic concepts of the design of a passive protection of a high-speed passenger train wagon are determined. The paper analyzes the necessary reconstruction of passenger wagons in Bulgaria to ensure their passive safety.

Keywords: rolling stock, railway maintenance, innovation, vehicle dynamic, passenger wagons (coaches), passive safety

1 Introduction

The problems of passive safety of passenger wagons (coaches) are treated in regard to compliance with the regulations of the EU, mainly with the Technical Specification for Interoperability (TSI) relating to the rolling stock subsystem – “Locomotives and passenger rolling stock” of the trans-European conventional rail system (notified under document C (2011) 2737) [1]. The TSI is applicable to all units except for the units that are not designed to carry passengers or staff during operation and OTMs “On track machines”, which are vehicles designed especially for construction and maintenance of track and infrastructure. Furthermore, the units that cannot reach speeds specified in any of the collision scenarios given below are excluded from the provisions related to that collision scenario. The passive safety measures are intended to be supplement to the active safety ones when all other measures have been exhausted. For this purpose, the mechanical structure of vehicles has to meet the requirements for construction of railway vehicle bodies [2] and ensure the protection to people in case of a collision by providing means for:

- deceleration limiting;
- keeping the survival space and structural integrity of the residential premises;
- reducing the risk of getting the wagons one on another;
- reducing the risk of derailment;
- limiting the consequences of hitting an obstruction on the track.

In order to keep these functional requirements, the units must comply with the detailed requirements set in EN15227: 2008 + A1: 2010 standard [3] to crashworthiness design category CI (according to Table 1 of EN15227: 2008 Section 4), unless something different is stated.

The following four basic collision scenarios will be examined:

- Scenario 1: a front end impact between two identical train units;
- Scenario 2: a front end impact with a different type of railway vehicle (with a freight wagon);
- Scenario 3: a train unit front end impact with a large road vehicle on a level crossing;
- Scenario 4: a train unit impact into a low obstacle (e.g. car on a level crossing, an animal, a piece of rock, etc.).

These scenarios are described in Table 2 in Section 5 of EN15227: 2008 standard. Within the scope of the current TSI, the rules in Table 2 are supplemented with the following:

- The application of the requirements related to scenarios 1 and 2 for heavy haul locomotives used only for freight operations and fitted with central couplers that comply with the principle of Wilson (e.g. SA3) or Jenny (AAR standard) intended for operation on CR TEN track is an open question;
- The conformity assessment of central-cab locomotives with the requirements of Scenario 3 is still an open question.

The current TSI defines the crashworthiness requirements applicable within its scope. Therefore Annex A to EN 15227:2008 standard is not applied. The requirements of Section 6 of EN15227: 2008 standard shall be applied in regard to the reference collision scenarios mentioned above.

2 State-of-the-art in the Bulgarian railways

If we trace the period of 50-60 years backward under the condition of the Bulgarian railways (BDZ), it can be seen that front end impact accidents with fatalities have a clear tendency to decrease. For instance, while for the period of 60 years until now the fatalities caused by front end impacts were over 70, for the past 10 years only one man died – the driver of the passenger train who did not stop at a red signal and crashed into the stopped fast train. The favourable tendency mentioned above is primarily due to duplication and ALS introduction on main tracks, the increase of train braking security as well as to improvements in passenger rolling stock, namely to the substitution of the old-structure coaches (mostly two-axle and three-axle ones) with new four-axle coaches with structures entirely made of metal. The latter meet the requirements of UIC for extra load bearing. Considering the decreased number of collisions, it should be also mentioned the influence of significantly reduced volume of rail freight in the past two decades. Speaking about the front end impact scenarios including No 1 and No 2, one should not neglect the lateral collisions with locomotives or wagons: there were 25 casualties due to such accidents in the period of 25 years but none for the past 10 years. At present as well as in earlier periods the most significant accidents (in number of accidents and number of fatalities) are those that happen at level crossings: about 70 people were killed for the last 35 years and 29 died for five years (2009 -2013). Most of them were in road vehicles and pedestrians. In 2012 there were 30 accidents at level crossings with 7 fatalities and 15 wounded (Table 1). As it can be seen, the increase of this type of accidents is a clear and disturbing tendency. The main reason is indiscipline, aggressiveness, negligence even to the own lives of drivers. Moreover, this disturbing tendency has been increasing regardless of the increasing number of automated level crossings (with electric barriers with or without level-crossing keepers in the area of stations and level crossings with automatic signaling). In Bulgaria only about 22% of all level crossings are with manually-operated barriers and 17% are without any facilities, i.e. only with signs. At that, it is curious and disturbing at the same time that the official statistics show the lowest number of accidents at these particular level crossings, which have only signs (but it is apparently because the frequency of trains and motor vehicles is not considered). It is also interesting that Bulgaria occupies the top position in the EU by the indicator “equipment of level crossings” but contrary to expectations, the country is on the top places also by both the number of level crossing accidents and the number of deaths caused as a result of those accidents.

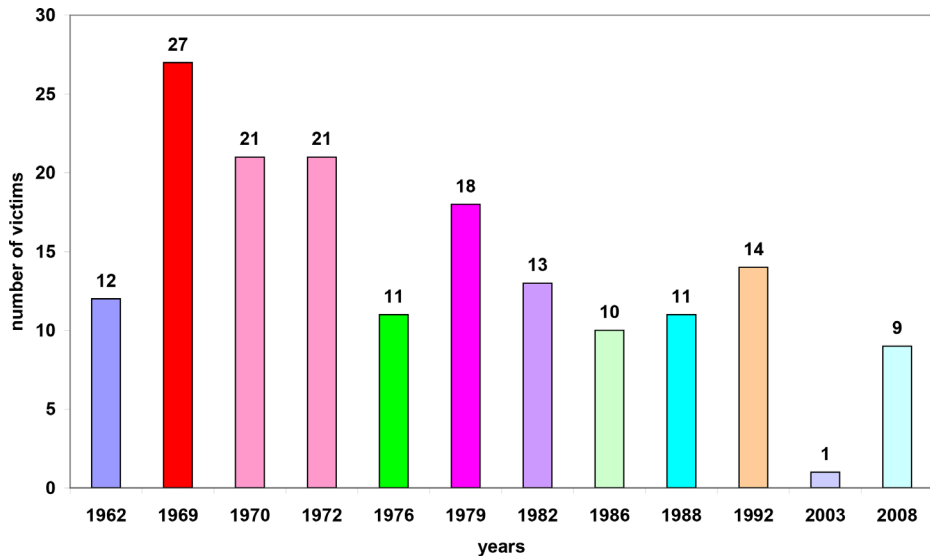


Figure 1 Number of fatalities due to railway accidents in Bulgaria since 1962 (according to the data taken from [4])

Table 1 Number of deaths and injured in 2012 due to railway accidents [4]

Indicators	Accidents	Deaths	Injured
Collision	5	1	5
Derailment	3	-	-
Accidents on level crossings	30	7	15

Of all railway accidents (heavy and light) until now, those with derailment happened most often (over 90% of the total number). Almost all cases of derailment were with freight wagons and locomotives, at low speeds and usually while shunting. However, there were two cases of derailment (in 1974 and 1980) of fast passenger trains at a speed of 90 km/h caused by the loss of stability on the track at high temperature. Although with these accidents the wagons had lost the connection with each other and were scattered over a distances of 50-100 meters and even farther from the track, many of them were turned on their sides (at 90°) and “on their back”, yet their integrity was preserved and the number of fatalities was minimal (one passenger). Apparently, that could be explained by the fact that the wagons were newly-constructed, had passed through all kinds of tests including those under emergency loads with longitudinal and vertical forces as required by the UIC. There are certain reasons to claim that if the wagons had been of old types, the number of passengers killed in such severe crashes would have been at least 10 times bigger.

It is worth analyzing two more severe crashes (in 1969 and 1980): the first one happened to a passenger wagon with many casualties (27 fatalities and 38 seriously injured many of whom consequently died); the second one was with a freight train without fatalities. The first crash (the one of a coach) represents a typical case of extra-loading with passengers and luggage, which caused loss of stability, i.e. violation of the “iron” condition: the metacentric height should be greater than the height of the center of gravity. In fact this led to overturning the wagon side (на 90°) and towing by the locomotive in this state about 250 m where many passengers fell through window openings, which lead to a fatal end. It is also important to note that the overturned wagon was actually a narrow-gauge 760 mm utility cart of Fiat train-set known for its high comfort at the time being: modern furniture, big windows and “soft”

spring suspension, i.e. with springs of large static deflection - f_{st} . Obviously, the overload of wagon resulted in even greater static deflection, hence reduced the metacenter height further (because it is inversely proportional to f_{st}), and on the other hand, to increasing the height of centre of gravity. Thus with divergent changes of these two heights (of metacenter and centre of gravity), they reached their equality, i.e. violation of the above mentioned condition, depletion of wagon stability with fatal consequences. BDZ has accepted that the newly-built passenger wagons should be with advanced features of springs. For example, the coaches produced in 1987 with static deflection of more than 300 mm have rubber pads inserted into the springs of the central level that come into action at high load when sustainability could worsen without them. Of course, it is on the expense of worsened smoothness of running but taking into account that such cases arise quite rarely, the solution in favour of safety is preferred.

The second accident of the ones mentioned above (with a freight train) was caused by a loss of overturning resistance due to large centrifugal force in a curve as a result of speeding. In this case the freight train was “released” in an area of steep slopes and sharp curves, so due to the terrain peculiarities the wagons slid (or rolled) to a deep ravine.

In 2008 there was a fire accident with 9 fatalities. The most important conclusion based on that and other similar accidents (but without fatalities) is that it is necessary to unconditionally meet the requirements for fire-resistance of materials used in wagons furniture.

The statistics of the Bulgarian railways shows that the accidents with derailment are the most frequent ones. The main reasons for derailment are the defects on the track and violation of the signs requiring deceleration. Speeding is a consequence of train driver's errors as well as of vehicles moving uncontrollably on the track (the so-called “released” vehicles). The activities undertaken in regard to derailment belong to the group of active safety.

Taking into account the experience of the Bulgarian railways and international assessments, it is seen that railway collision accidents are still significant due to frequency and damages caused to passengers. However, even with the assumption that the frequency of collisions will be significantly reduced in future but considering the tendency of speed and damage increase with the square grade of speed, it should be concluded that accidents of front end impacts are the most serious problem.

3 Approaches to technical solutions

To solve the problem of passive safety with railway collision accidents, the technical solutions applied can be classified into two groups: active – aimed at preventing the occurrence of emergencies and passive – intended to reduce the possible negative consequences of actual accidents. It is because the analysis of international experience has shown that even the application of all possible means of active safety does not make possible to completely avoid emergency involving death and injury of passengers. Therefore the development of systems and devices to provide passive or structural safety of wagons can be assessed as a priority trend in passenger transport. To minimize the negative effects of emergency collisions is carried out by embedding the so-called crash systems to the bearing structure of the body. These systems contain devices for absorbing the energy of a strong singular impact (this concerns the impact that requires energy-absorbing more than the available We_0 , realized by elastic deformation of the buffer energy absorbing devices.) that emerges random by destruction with irreversible plastic deformation. These destructing devices and components, also known with the definition of “victims”, should meet the following conditions:

- simplified structure;
- small mass;
- low cost;
- easy and convenient replacement after being destroyed.

Due to economic considerations, it is appropriate to build crash systems at least in two stages: First degree: with devices (elements) embedded in crash absorbers (i.e. buffers or automatic couplings), which according to the current possibilities may have energy-absorbing capacity of $We \geq 0,8 \text{ MJ}$). In compliance with the standards, which are in force for in-service modern wagons and newly-constructed ones, the maximum force should be of about $3,2 \div 3,6 \text{ MN}$ (pair number buffers). Second stage: with devices located in the front (transition) parts of the wagons where there might stand only people occasionally passing between them. The minimum value of force, at which the second level becomes active (in order to preserve it in lighter strokes of power up to 3 MN (this value of strength corresponds to the minimum value of the safety coefficient of static loads as well as to the standards of crash loads, which should not cause inadmissible plastic deformations.) and kinetic energy to $\leq We_0 + We_1$), can exceed the strength of the first stage with mean 10% ($4 \div 4,4 \text{ MN}$). The probability of its storage is at least 70 %. On the other hand, this power shall not exceed the threshold, at which inadmissible plastic deformations of the metal structure could occur in the part occupied by passengers. Provided that the safety deformation of the second degree in the front part of the vehicle can not be more than “1m and considering the requirement of power ($4 \div 4,4 \text{ MN}$), it is seen that energy absorption can not exceed 4,4 MJ for the one side of the wagon.

The following requirements have to be met additionally:

- 1 The second stage of the crash system, which according to its purpose should be destroyed and replaced, must be connected to the main structure by bolted joints;
- 2 To determine the boundary conditions of collision (by speed, type and number of vehicles, etc.) where:
 - a derailment of some wagons can occur;
 - b the longitudinal acceleration must not exceed the permissible value for passengers (5g);
 - c the permissible value of the longitudinal acceleration (e.g. the value of 5g, which is assumed as permissible) is precised at what degree of probability preserves life or health of passengers.
- 3 The existing legal framework in the European countries, which regulates passive safety, shall be constantly updated and adapted to increase the passive safety of passenger wagons.

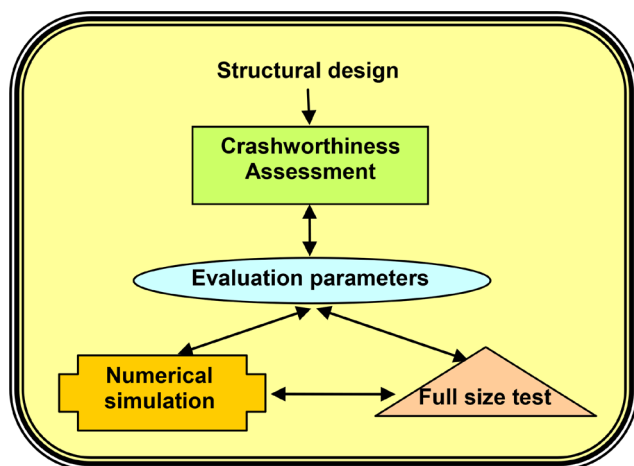


Figure 2 Fig. 2. Elements of the design process of a crashworthiness structure



Figure 3 Fig.3. Crash buffer of a sleeping carriage operated in Bulgaria since April 2013

The design of passenger wagons is an iterative process between the process of design, selection and evaluation of a crashworthiness structure and the assessment methods. Fig. 2 shows the elements of the design process of the crash-resistant structure. The existing evaluation methods, criteria or standards are two: numerical simulation and full tests [5]. The parameters of evaluation are: deformation, energy absorption, material properties, non-linear limitations and contact. Based on the optimized parameters, an algorithm and solution as well as possibilities for structural simplification have been proposed. The crashworthiness structure of a passenger wagon frame is a subject of study carried out at the Todor Kableshkov University of Transport, in Sofia, Republic of Bulgaria. Fig. 3 shows the crash buffer of a sleeping carriage operated in Bulgaria since April 2013.

4 Conclusion

Based on the current regulations in the EU and the global developments in the construction and operation of passenger wagons (coaches) as well as the overall trend of speed increase, it can be concluded that the current priority in passenger traffic is to increase their passive safety by building crash-systems at least in two stages taking into account the established permissible longitudinal loads for in-service passenger wagons with modern structures and the newly-built ones. The main parameters (force and approximate energy absorption) of the 1st and 2nd crash systems of passenger wagons are also determined. A number of questions, which are “hanging” at present but should be made clearer on the basis of consensus and/or research, are also marked.

References

- [1] COMMISSION DECISION of 26 April 2011 concerning a technical specification for interoperability relating to the rolling stock subsystem – ‘Locomotives and passenger rolling stock’ of the trans-European conventional rail system (notified under document C(2011) 2737)
- [2] EN 12663-1:2010: Railway applications - Structural requirements of railway vehicle bodies - Part 1: Locomotives and passenger rolling stock (and alternative method for freight wagons)
- [3] EN 15227:2008+A1:2010: Railway applications – Crashworthiness requirements for railway vehicle bodies
- [4] National Statistical Institute, Republic of Bulgaria, <http://www.nsi.bg>
- [5] Petrović, D.: *Dinamika sudara vagona*, Biblioteka Dissertacio, Zaduzbina Andrejevic, Beograd, 2001