CETRA[2012]

2nd International Conference on Road and Rail Infrastructure
7–9 May 2012, Dubrovnik, Croatia

Road and Rail Infrastructure II

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TITLE

Road and Rail Infrastructure II, Proceedings of the Conference CETRA 2012

EDITED BY

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ISBN

978-953-6272-50-1

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.
Katarina Zlatec · Matej Korlaet

COPIES

600

A CIP catalogue record for this e–book is available from the National and University Library in Zagreb under 805372

Proceedings of the
2nd International Conference on Road and Rail Infrastructures – CETRA 2012
7–9 May 2012, Dubrovnik, Croatia

Road and Rail Infrastructure II

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SAFETY MEASURES ON RAIL AND ROAD ENGINEERING STRUCTURES – A COMPARATIVE ASSESSMENT

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Abstract

Safety is one of the key parameters defining the service level of a transportation system. A good safety level makes the system more competitive and attractive to the users and thus contributes to the increase of its potential patronage. Safety is evaluated by the number of incidents that take place during a certain time period which have negative effects on the track, on the rolling stock, on the passengers, on the cargo and on the environment. Incidents occur in all three components of the transportation system (permanent way, civil engineering structures and operational facilities). In particular, the accidents taking place on engineering structures have the worst consequences, including large numbers of fatalities, due to the difficult rescue and escape conditions (on bridges, in tunnels etc) and high cost of the applied mitigation measures. This paper focuses on the rail and road engineering structures applied in high–speed rail and highway networks. In this context, the incidents and their causes are examined and explained. Moreover, the mitigation measures used in order to increase the safety level are recorded and evaluated. The engineering structures under examination are a) tunnels, b) bridges, c) road overpasses, d) embankments, e) cuttings. The approach is based on the comparison between the two transport modes through their engineering structures. The results highlight significant differences in safety measures implemented to the two transport modes due to their different technical and operational characteristics. However, significant similarities are also apparent as the same fundamental safety principles govern rail and road projects. The results of this paper could form the basis of the drawing up of safety recommendations addressing the planning, design, construction, operation, inspection and maintenance, of engineering structures in the rail and road infrastructure.

Keywords: road safety, railway safety, road engineering structures, rail engineering structures, safety measures

1 Introduction

This paper deals with the safety aspects of civil engineering structures applied in high–speed railways and highways networks. In particular the following structures are examined: bridges, tunnels, road overpasses, embankments and cuttings. Incidents taking place in these structures are identified and mitigation measures implemented to increase their level of safety are presented and analyzed. The whole approach is based on a per structure category comparison between the above two transport systems. The results of this paper highlight significant differences in safety measures adopted for the two systems due to their different technical and operational characteristics. However, similarities are also apparent as the same fundamental safety principles govern rail and road projects. This fact is the main motivating factor initiating this paper. The findings of this paper could form the basis of the drawing up of safety recommendations addressing the planning, design, construction, operation, inspection and maintenance, of engineering structures in rail and road infrastructure.

2 The safety parameter in rail and road civil engineering structures

Engineering structures in rail and road transportation systems are taken to be all the constructions built–in along the track or the road aiming to achieve their layout insertion into areas with difficult topography and sensitive environment. They must ensure the safe movement of trains and road vehicles and they must be harmoniously integrated in the environment.
The safety provided by a transportation system is evaluated by the number of specific incidents (derailments, collisions, etc) that take place during a certain time period (for example a year) which have specific negative effects on the track, on the rolling stock, on the passengers, on the cargos and on the environment.[1] According to another definition, the safety of a transportation system is the assurance that the provided risk level (combination of frequency and severity of incident factors) is not characterised as 'non–permissible'.[2]
Measures taken by the system operator to reduce the likelihood of incidents are characterised as preventive measures. Measures aiming at reducing the consequences of the incidents (measures to reduce the consequences) so that the actions taken following the incident are performed rationally (escape and rescue measures), are characterised as management measures. In the engineering structures virtually all the incidents taking place on the 'open' track can also occur. Table 1 shows the incidents which occur and require special handling for the two transport systems under examination for each individual engineering work.
As a transportation system, the railway differs from the road vis–à–vis in three components, that is, infrastructure, rolling stock and operation.[3] As a consequence, there are marked differences in terms of safety between the road vehicle and the train concerning both the characteristics of the incidents (type, severity) as well as the safety measures taken for the prevention and management of incidents. .

Table 1 Incidents on rail and road engineering structures requiring special management

Engineering structure	Railway track	Highway
Bridges	Train derailment and falling from the bridge (for various reasons) Pedestrians dragged along by rolling stock Train derailment due to strong cross winds and falling from the bridge Workers dragged along by rolling stock (due to aerodynamic phenomena) Immobilisation of a train on a bridge	Road vehicle falling from the bridge(for various reasons) Pedestrians dragged along by road vehicle Road vehicle hits a parapet due to different reasons (poor driving behaviour, misreading of road design and layout)
Tunnels	Fires or emission of toxic gases and smoke inside the tunnels Work accidents Passengers' discomfort in terms of noise Shattering of window pane in train carriage Immobilisation of a train in a tunnel	Fires or emission of toxic gases and smoke inside the tunnels Work accidents Collision of road vehicles Loss of road vehicle control for various reasons (poor driving behaviour, misreading of road design and layout)

Road Over passes	Loss of road vehicle control and falling from the road to the track Object falls from the road to the track	Loss of road vehicle control and falling from the road overpasses to the highway
Embankments	Train derailment due to strong cross winds and falling from the embankment Appearance of non permitted limits of track defects due to embankment subsidence – Train derailment Immobilisation of a train on a high embankment	Loss of road vehicle control and running off the road Collision of road vehicles with fixed obstacles
Cuttings	Collision between train and obstacle on the track Accident due to landslide Rock fall Immobilisation of a train on deep cuttings	Collision between road vehicle and obstacle on the road Accident due to landslide Rockfall Collision of road vehicles with fixed obstacles

Indicatively:

- The railway has only one degree of freedom. Due to the impossibility of a train to perform manoeuvres while moving, braking is the only option when faced with the risk of two trains colliding or a train crashing into an obstacle. However, during braking, as a result of the low adherence between wheel and rail (steel/steel contact) and the greater braking load, the braking distance of a train is much greater than that of a road vehicle. Given this fact, since braking seldom prevents a collision, it is of great importance that the railway can 'prevent' such accidents by taking those measures necessary in order to avoid collision conditions.
- Trains possess operational and constructional features which increase the aerodynamic phenomena as they move (high speed, great length, large frontal cross section). These phenomena may have negative consequences for rolling stock, passengers, system users who are on the platforms and staff working near the track. At the same time, due to the train's large lateral surface, it receives greater transversal wind loading, thereby making it more susceptible to being overturned as a result of cross winds.
- The railway moves along the railway track which, because of its construction (rails/sleepers/ballast) cannot be used by the usual road transport. Also, in many instances the layout of the track is integrated into the topography of the ground which is inaccessible to road transport. Given this fact, if a train is immobilised on the track, either due to a fault or an accident, the evacuation of passengers from the site of the incident and the provision of first aid is a particularly challenging operation.
- The rolling surface of roads in contrast to that of the railway track is impermeable to water, meaning that driving in icy conditions or following heavy rainfall is hazardous (risk of sliding or aquaplaning).

In particular, in regard to engineering structures, the two systems, railway and road, differ in terms of design, construction, operation and maintenance.[3]
As far as design is concerned, the differences are generally to be found in the alignment, loading and typical cross–section of the structures. The railway requires greater horizontal curvature alignment and smaller longitudinal slopes. The static loads used for dimensioning of the structures are much greater, while special attention is needed for dynamic loads which might produce resonance phenomena.
Great importance is placed on differential settlements as any exceeding of the allowed limits will lead to derailments. The track gauge of a double railway track has less than a 2X3 road (ratio of

1:3) while the clearance gauge on the railway is greater, particularly in the case of electrification because of the traction system installations.
The most significant differences as far as the operation is concerned relate to the aerodynamic impact, the ground–borne noise and vibrations and acoustic nuisance. Problems concerning aerodynamics, particularly in high–speed tunnels, impact on passengers' health (sudden changes in pressure) can create feelings of insecurity in those living adjacent to the track. Vibrations are felt in the embankments resting on loose and soft soil, which could affect the nearby buildings. Lastly, railway engineering structures require greater maintenance in comparison with those of the road due to increased static and dynamic loads and the very small room for track defects.

3 Safety on bridges

3.1 Railway bridges

The main cause of accidents on railway bridges is cross–wind. It has been proven that when the speed of 25 m/s is exceeded, the transversal and vertical acceleration of the bridge body increases dangerously, thus reducing the safety of its passage. The thicker the bridge body, the greater the transversal force coefficient is. In the event of an untoward incident (collision of trains, derailment, immobilisation of train on a bridge) due to construction of the specific structure above natural ground level or above a water hazard, together with the narrowness of the space, increases the severity of the incident while at the same time making the evacuation of the passengers and access of the rescue services more difficult. In all cases the placement of anti–derailment protective checkrails along the track should be envisaged.

3.2 Road bridges

Road accidents at bridge locations are common and usually very serious in nature. The characteristics of the design of the road alignment and cross–sections providing the safe sight distance affect the appearance of the incidents. The installation of adequate safety barriers on the approach holds the vehicles on the road.
Table 2 presents the safety measures used on bridges for the two systems in question.

Table 2 Mitigation measures implemented on railway and road bridges

Category of measures	Rail bridges	Road bridges
Preventive measures	Wind barriers and drapes Harmonic buffers Anemometers Footways for workers	Signing and road markings Pedestrian facilities Footways for workers
Measures to reduce the consequences	Anti–derailment protective checkrails	Safety parapets and barriers
Escape and rescue measures	Footways for pedestrians Construction of steps for evacuation to safe place Safety Manholes	Footways for pedestrians

4 Safety in tunnels

4.1 Railway tunnels

Accidents common on the rest of the railway line such as collisions on level crossings, collisions with impediments, derailments caused by wind or landside cannot occur in tunnels. The most serious accidents to have occurred inside tunnels have involved fire, the release of smoke and toxic gasses. Additional problems are created by increased aerodynamic pressures or reduced ventilation (in the case of diesel locomotives). In tunnels servicing high–speed trains, a sudden reduction in the passenger's acoustic comfort and cracking of window panes may be experienced due to the sudden change in pressures. In cases of such incidents (train collisions, fire, immobilisation of the train inside a tunnel etc), due to the construction the specific structure below ground, the severity of consequences increases especially in long tunnels as does the need for fast evacuation from the incident site, while access for the rescue services becomes more problematic.
Two construction types for railway tunnels have prevailed internationally: the standard single–track tunnel and the single tube double–track tunnel. The main advantage of the twin–tube is zero collisions with passing trains (and the avoidance of aerodynamic problems occurring from the crossing of trains moving in opposite directions) and the high degree of protection in case of a fire event. The single–tube tunnel has respectively the major advantage of lower construction costs and clearly reduced aerodynamic problems

4.2 Road tunnels

Road accidents in tunnels are characterized by their importance in human, economic and cultural terms. Special consideration has to be given to safety in the design of the horizontal and vertical alignment of a tunnel because these parameters have a significant influence on the probability and severity of accidents. Safety measures should enable people involved in incidents to rescue themselves, allow road users to act immediately so as to prevent more serious consequences and ensure that emergency services can act effectively and protect the environment as well as limit material damage. However, the probability of an accident occurring and of being injured is lower in tunnels than on open stretches of roads, but the severity of injuries is significantly higher. [4]
Table 3 presents the safety measures used in tunnels for the two systems in question.

5 Safety on road overpasses

5.1 Passage of the rail track under a road bridge

Accidents on road overpasses– railway underpasses usually occur as a result of objects falling from road bridges.

5.2 Passage of highway vehicles under a road bridge

Road accidents on road underpasses are due to loss of road vehicle control and falling from the road bridge. The installation of adequate safety barriers, on the approach, holds the vehicles on the road. However, when the road overpasses supporting columns have no protection it results in their crashing onto the trains.
Table 4 presents the safety measures used on road overpasses for the two systems in question.

Table 3 Mitigation measures implemented in railway and road tunnels

Category of measures	Rail tunnels	Road tunnels
Preventive measures	Control centre for surveillance of tunnels Hot–box detection devices placed at tunnel entrance Avoidance of turnovers and crossings in tunnels	Control centre for surveillance of tunnels Video monitoring systems Road signs and panels Special lighting
Measures to reduce the consequences	Fire resistant structures Automatic fire, smoke and toxic gas detection systems, Installation of fire extinguishing system Ventilation system to control heat and smoke Water supply Emergency power supply Measures to reduce aerodynamic problems	Fire resistant structures Automatic fire, smoke and toxic gas detection systems, Installation of fire extinguishing system Ventilation system to control heat and smoke Water supply Emergency power supply Ventilation system to control pollutants Drainage system for flammable and toxic liquids Equipment for emergency closing of tunnel
Escape and rescue measures	Escape routes and emergency exits Safety and evacuation lighting Emergency exits leading to ground surface Emergency contacts Auxiliary tunnel for single–tube. double–track tunnel. Cross connections between tunnel tubes Staff refuge area	Escape routes and emergency exits Safety and evacuation lighting Emergency exits leading to ground surface Emergency contacts Cross connections between tunnel tubes

Table 4 Mitigation measures implemented on road over–passes

Category of measures	Rail underpasses	Road underpasses
Preventive measures	Proper design of alignment and cross–section of the road. Pedestrian facilities on the road bridge. Signing and road markings on the road.	Proper design of alignment and cross–section of the road Pedestrian facilities on the road bridge Signing and road markings on the road.
Measures to reduce the consequences	Safety parapets and barriers Protective wall for road bridge supporting columns Horizontal protective nets on the road bridge	Safety parapets and barriers

6 Safety on embankments

6.1 Railway embankments

In the construction of embankments for engineering structures, particular attention must be paid to their height (lower height relative to road embankments) and to their compactness so as to avoid subsidence and by extension the geometrical defects of the track panel. When subsidence of an embankment does occur, the difference in elevation which may be produced in the two rails on the track becomes particularly hazardous for train movements and certainly detrimental to the operation of the system.

6.2 Road embankments

The terrain along the roadside may affect the number of accidents and the severity of injuries. Steep slopes increase the probability of a vehicle falling from the embankment in the event of running off the road. Moreover, permanent obstacles close to the road can increase the number of accidents and leave a smaller margin for regaining vehicle control when it has been lost.[5] Table 5 presents the safety measures used on embankments for the two systems in question.

Table 5 Mitigation measures implemented on rail and road embankments

Category of measures	Rail embankments	Road embankments
Preventive measures	Protection from groundwater and rain water Strengthening of embankment foundation soil Monitoring of movements by optic fibres Wind barriers and anemometers	Proper design of alignment and cross–section Signing and road markings Flattening of side slopes Removal of fixed obstacles Increasing distance between the edge of the road and fixed obstacles
Measures to reduce the consequences		Safety parapets and barriers
Escape and rescue measures	Separating of the railway track into 'safety zones'. Linking up of 'safety zones' with road network. Construction of steps for evacuation to safe areas	

7 Safety on cuttings

7.1 Railway cuttings

The most common accidents occurring at cuttings are caused by rocks falling on the track or by landslips. When rocks fall onto the track, there is a high risk of the train colliding with the obstacle on the track, since it cannot be avoided by braking, while usually falling rocks are not identified in time. Often such collisions can lead to derailment. A high water table and poor drainage contribute to the breaking up of the superstructure and substructure of the track, thus particular attention must be paid to them. **Road cuttings**
Road crossings of mountainous terrain in zones with steep gradient may provoke rockfall or a landslide. Sliding soil masses or sudden displacement or collapsing rocks reduce the safety and increase the need of operational expenses. Controlled release of landslides or periodic closure of roads may be used as preventive measures.[5]
Table 6 presents the safety measures used on cuttings for the two systems in question.

Table 6 Mitigation measures implemented on rail and road cuttings

Category of measures	Rail cuttings	Road cuttings
Preventive measures	Protection from rockfall (fences and catch nets, protective gullies, rock–trap ditches, retention walls) Protection against slope slip Track guard presence	Protection from rockfall (fences and catch nets, protective gullies, rock–trap ditches, retention walls) Protection against slope slip
Measures to reduce the consequences		Removal of fixed obstacles Increasing distance between the edge of the road and fixed obstacles
Escape and rescue measures	Separating of the railway track into 'safety zones'. Linking up of 'safety zones' with road network. Construction of steps for evacuation to safe areas	

8 Conclusions

Incidents which take place in both engineering structures of high–speed railway lines and highways have many similarities as already shown but also a number of significant differences. The differences result from different technical and operational characteristics of the two transport systems, and are related both to the kind of incidents taking place and to the measures used to deal with them. In Table 1, incidents which differ between the two systems are shown in italics, while those which are the same appear in regular characters. Tables 2 to 6 present the measures used to combat the incidents. More analytically:

On the railway

- Embankments must have the lowest height possible and the greatest possible degree of compactness
- Horizontal protective netting must be placed on road overpasses
- Provision must be made for appropriately designed steps on high embankments, deep cuttings and bridges for the evacuation of passengers to safe areas in the case where a train is immobilised on the track
- Falling rocks at cuttings must be avoided at all costs while such events must be identified and managed at the earliest possible time.

On highways

- Lighting in tunnels needs to be designed especially for the purpose
- Barriers must be placed along all engineering structures
- Good design and road signs are particularly important on all engineering structures

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