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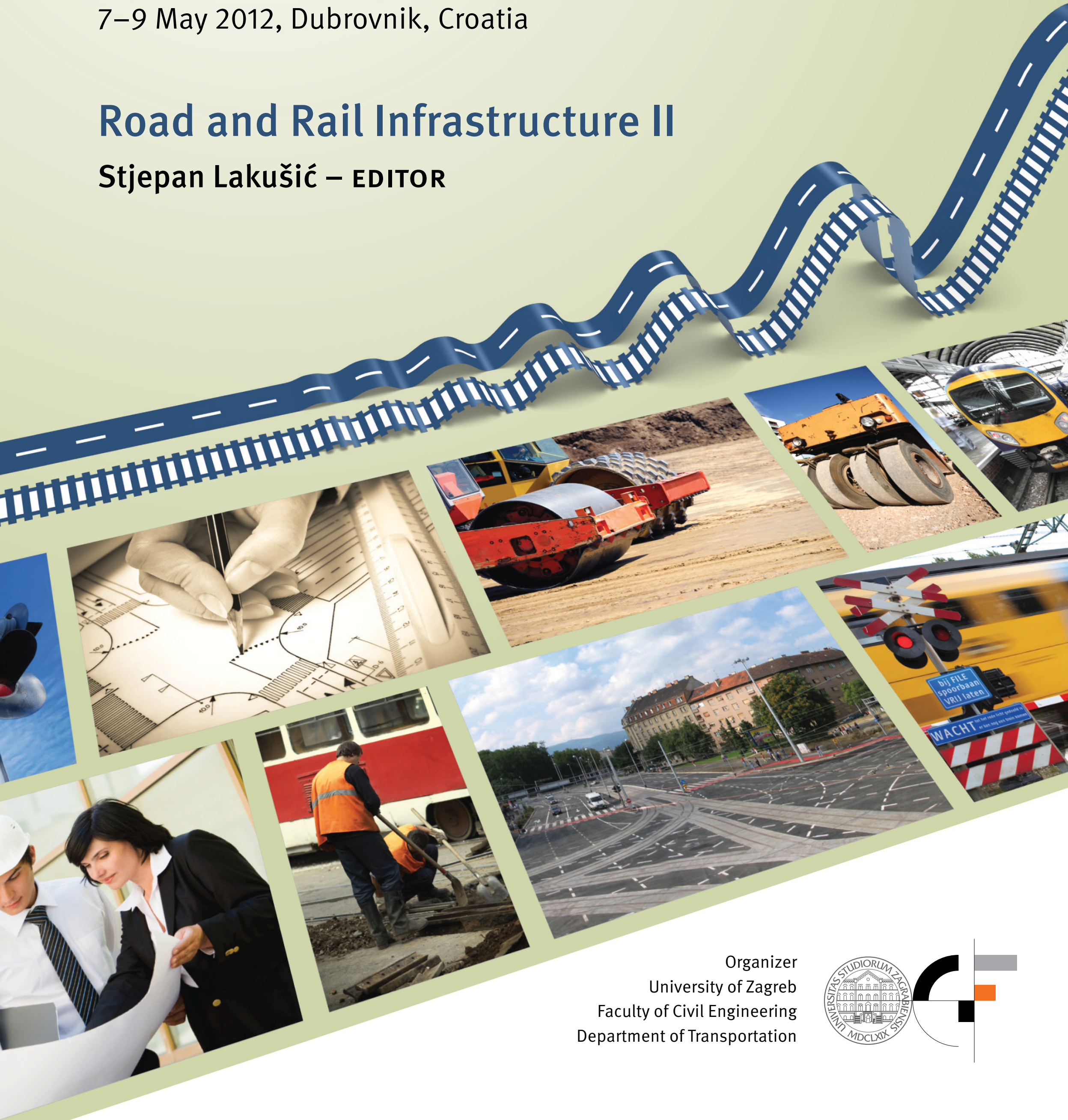
2nd International Conference on Road and Rail Infrastructure

7–9 May 2012, Dubrovnik, Croatia

Road and Rail Infrastructure II

Stjepan Lakušić – EDITOR



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TRANSITION ZONES ON THE RAILWAY TRACK – OVERVIEW

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Abstract

Transition zones between bridges, tunnels, artificial and earth structures, including transitions between ballast and non–ballast permanent way (slab track), are a part of the railway track structure where the abrupt change in the rigidity of the track structure and track settlement occurs between individual transverse profiles, as a result of the change in the structural elements and the foundation. Variation in the rigidity of the rail structure is the basic parameter influencing the generation of new impulse mechanisms during interaction between the vehicle and the structure. This causes additional dynamic loads, resulting in further degradation of the track structure and indirect decrease in the level of safety and comfort of railway traffic. Due to foregoing, the transition zones are defined as exceptionally problematic parts on the railway track. In order to limit additional and frequent costs of rehabilitation of these track parts, the degradation mechanisms are analyzed within EU funded research project (SMART RAIL), with the aim to find a high–quality, economically and environmentally acceptable solution for existing older railways.

This paper presents the mechanisms influencing the degradation of tracks in the transition zones, as well as structural measures presently known and used for rehabilitation of existing railways.

Keywords: transition zones, degradation of the railway track, structural measures

1 Introduction

One of the basic objectives of the present railway authorities refers to the reduction of maintenance costs allocated for maintaining the railway infrastructure. Due to the frequent need for conducting additional maintenance and reconstruction, which are disproportional compared to other sections of the railway track, several European railway authorities define the transition zones between the 'normal' open tracks and 'rigid' track systems or substructure such as bridges/ tunnels/ culverts as problematic parts on the track. In the Netherlands, intervention frequency at transitions is up to 2–4 times those on the open track, [1].

Frequent repairing of the places like these has resulted in reduction of the track capacity and traffic continuity, which generates additional costs to the railway authority.

With the aim of reducing both direct and indirect costs of maintenance of such places to an optimal level, taking into account the increase in safety and comfort of rail services, the issue of transitional zones demands more attention, which was recognized within SMART RAIL consortium and set up as one of the main goals.

2 Transition zones

Transition zones are defined as parts of the railway track where a change of basic characteristics that define a railway structure in its entirety takes place.

Under the basic characteristics following parameters are considered: substructure and superstructure stiffness, deformation of each substructure layer and each superstructure part, overall value of track deformations, geometric restraints.

The transition zones in general represent the appearance of discontinuity in the track structure, as shown in Fig. 1.

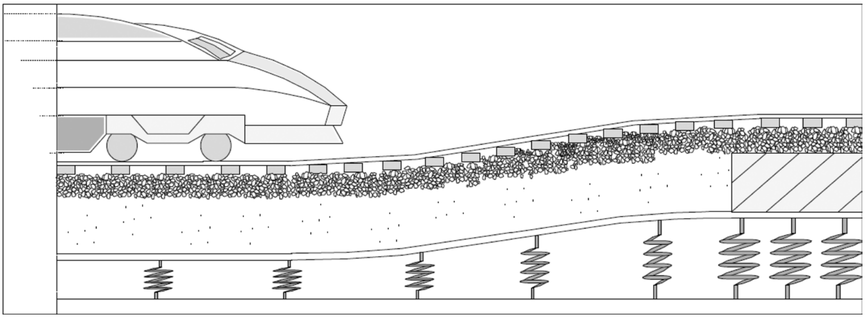

Figure 1 Transition zones – discontinuity in the track structure, [2]

Type of the transition zone depends on where it is located, [3]:

- transition between different types of superstructure (from slab track to ballasted track or reverse)
- transition from one type of substructure to another:
  - transition between embankments and bridges/viaducts
  - transition between embankments and tunnels
  - the track above the shallow built culvert
  - transition between different types of embankments
- direct transition between two different types of rigid substructures:
  - transition from tunnel to bridge/viaduct
  - transition between two different types of bridge structures

3 Negative mechanisms that occur in the transition zones

Poor condition of the transition zones is a consequence of numerous complex and interrelated mechanisms. In order to find the best possible solution for solving the problems that happen in the transition zones, all the negative mechanisms which influence the behaviour of the track structure should be taken into account and analysed.

Analysis and identification of the basic causes of degradation of the track structure in the transition zones have been performed in this decade only, as a result of constant efforts to reduce maintenance costs, with transition zones representing a significant potential and opportunity for contributing to this reduction of both direct and indirect cost (e.g. resulting from train delays and loss of capacity) of maintenance. [1]

3.1 Discontinuity in the stiffness of the track structure

The basic negative attribute which is characteristic for the transition zones is the discontinuity in the stiffness of the track structure.

The diagram in Fig. 2 shows the deflection profile of measured results which were obtained with the help of the measuring vehicle. The results were obtained after a surfacing maintenance operation, when the unloaded track profiles were impeccable. Nevertheless, as illustrated in Fig. 2, in the transition zones we still have large and variable track deflections under load, indicating an apparent factor contributing to poor vehicle/ track interactions. Deflection results shown in Fig. 2 include not only contribution from the ballast, subballast, and subgrade layers, but also contribution of possible gaps and slacks between sleepers and ballast, which would close under the loaded condition, [4].

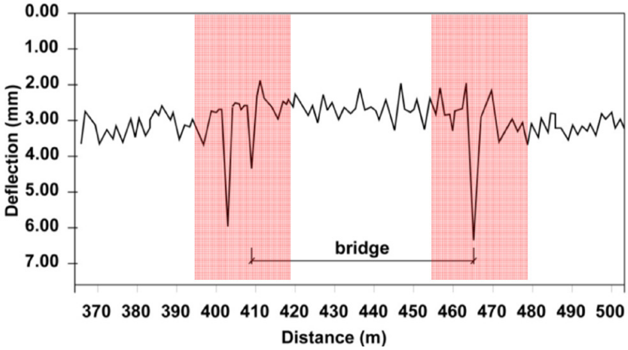

Figure 2 Loaded track deflection profile, [4]

The diagram in Fig. 3 shows the measured results of track modulus which are obtained on the concrete bridge with ballast deck and their transition zones (from both sides). As shown, the track structure on the concrete bridge has high stiffness characteristics compared to other parts of the track. On average, the measured track modulus on the bridge was 68.95 N/mm2, which is too high to accommodate desirable vehicle/track dynamic interaction. In addition, the change of track stiffness between bridge and approach was also too high (almost double on average), [4].

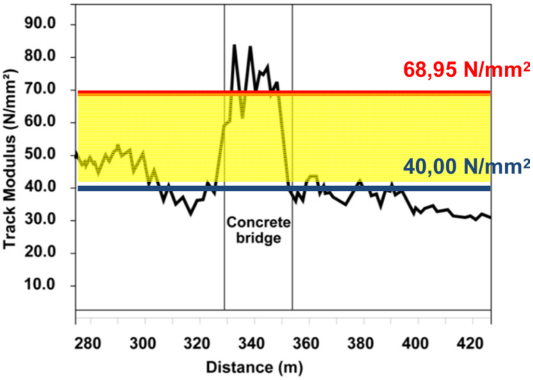

Figure 3 Track modulus test results, [4]

3.2 Differential settlements of the rail track structure

Studies have shown that the settlements of the rail track at the transition zones are much larger than those on the open track, or the one on the bridges and in the tunnels, [1].
Track settlement on the open track section can be very variable due to variety of the geotechnical parameters. Geotechnical disadvantages such as poor bearing capacity of the foundation soil, poor initial compaction/consolidation of the embankment and foundation soil, erosion

as a result of poor solutions of the drainage system and inadequate drainage system of the foundation soil further contribute to negative occurrences of differential settlement. Natural factors such as wet/dry and cold/ warm cycles also affect the level of settlement of the substructure.

In addition to geotechnical imperfections, the settlements can occur also because of poor performance, inadequate application of fill material, as well as bad judgment or a sudden increase of traffic load.

For the foregoing reasons, the differential settlement is considered to be the following negative characteristics typical for the transition zones.

Fig. 4 shows comparative test results of average track settlements on four different railway bridges and their approaches. As may be read out from the diagram, the track segment right before and right after the bridge is affected by most intense track geometry deformations in comparison with track structure on the bridge itself or the one on the open part of the route. Track structure settlements on a bridge are about 25% less severe than settlements which appear in transition zones, [4].

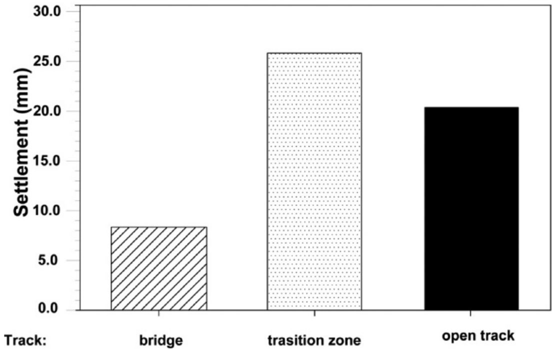

Figure 4 Test results of average track structure settlements on four different railway bridges and their approaches, [4]

3.3 Influence of rail services speed

The impact zone of the above mentioned negative mechanisms depends also on the trains operating speed. As the train speed increases, the zone of negative dynamic effects becomes longer. It is recommended that the minimum length of the transition zone is, [5]:

$$L_{min}(m) = v_{train}(m/s) x 0,5(s) \qquad (1)$$

3.4 Influence of the direction of the train

A sudden change in the vertical track structure rigidity causes the wheel of the vehicle to go through the same sudden change along its height due to uneven deflection. This change in elevation causes vertical acceleration of the vehicle mass, which generates an increase of the existing load by the value of the newly–formed impact dynamic load, [2].

This is why each track degradation mechanism is different, depending on the direction of the trains.

3.5 Mutual interaction of negative mechanisms

The above–mentioned degradation mechanisms, which in fact act each on their own, may also be conditioned by each other. For an example, geotechnical deficiencies may cause differential settlements of the ballast or subgrade, which reduces the structure rigidity and as a consequence generates larger dynamic impact loads, which in turn intensifies ballast degradation and settlement of the track substructure.

Cyclic repetition of these processes accelerates degradation of track geometry, with reduced quality and safety of driving as an immediate consequence.

4 Transition zones

A certain structural solution is in fact hidden behind the term 'transition zones'.

The main task of transition zones is to prevent sudden changes in stiffness of the load–bearing structural elements of the track. The aim is to minimizing/ or prevent the occurrence of additional negative dynamic loads over a part of a transition zone, which additionally accelerate the track geometry degradation, with reduced quality and safety of driving as an immediate consequence. This can be achieved by linearly changing certain properties of the surrounding structures at a reasonable distance by dividing one differential change into smaller steps, i.e. dynamically irrelevant intervals.

Ideally these inconsistencies occurring in parts of transition zones do not influence the performance of a passing train in terms of safety but rather they more often reflect upon the quality and comfort of rail services and other dynamic occurrences, [6].

Different railway authorities have approached the solution to the transition zones issue differently. The reason for this lies in the fact that there is no single unique solution which would adequately solve every problem. Transition zones are complex constructions which require an individual approach in design engineering in terms of their location and type.

Various approaches to solving this issue have been proposed, with emphasis either on increasing track structure stiffness in a transition zone or on reducing track structure stiffness on a bridge/tunnel/culvert/modern slab track. All the proposed solutions are based on gradual linear adjustment of stiffness of the load–bearing base in the transition zone in order to avoid discontinuity in track structure rigidity, [7].

4.1 Design of transition zones

Two characteristics are commonly considered when designing a transition, which are, [6]:

- Differential Settlements – Settlements are slowly but continuously emerging plastic deformations of a structure, usually resulting in small but dynamically relevant changes in a structure's dimensions.
- Differential Stiffness – Stiffness is a value of a structure's deformation under live loads. A train (representing a live load, thus causing a certain deformation) when passing structures of differential stiffness is exposed to a dynamic reaction, usually resulting in a noticeable acceleration of the coach.

Transitions shall be designed by making variations gradually in both the settlements and the stiffness, so that both safety and comfort conditions are achieved. Furthermore, transitions shall not be subject of increased maintenance requirements but should ideally be coordinated with the rest of the tracks.

Design of the transition zone is performed separately for the substructure and for the superstructure of the track, [6].

In recognition that the installation of good quality rails, fastening systems, railway sleepers and ballast will have little effect if the substructure of track does not have adequate bearing capacity and stiffness design, maintenance and reconstruction planning of the sub–structure must be given equal importance as to the superstructure.

4.2 Compensation of differential settlements

Structural parts of the track structure on the open part of the route, such as embankments and ballast, are most often prone to settlements.

4.2.1 Compensation of differential settlements of the ballast

Stabilization of the ballast may be conducted by applying various structural solutions:

- application of different types of sleepers, [2,4,6,11]
- application of additional rail, [2,3,6,11]
- application of ballast 'glue', [15,16]
- application of the ballast and sub–ballast mats, [20,21]
- application of the concept of lateral reserved ballast – ballast casing, [4]
-

4.2.2 Compensation of differential settlement of the embankment

With structures such as tunnels, bridges and viaducts there are usually no problems with settlements, and it may therefore be assumed during the design phase that indeed no settlements will occur.

In case of earthen structures, such as embankments, the occurrence of differential settlement cannot be completely ruled out and therefore certain predictions shall be made, most often based on rough estimates.

The measures most often taken are as follows:

- stabilization of the embankment (in compliance with the recommendations from UIC CODE 719R), [8],
- separation of the tunnel/bridge/viaduct structures from the embankment, and
- securing of their free ends.
-

The last two measures are implemented with the aim to prevent transfer of negative impacts from one structure to the other.

Each railway authority approaches the embankment differential settlement compensation issue independently. The Figures in UIC CODE 719R illustrate the exact diversity in structural solutions for transition zones divided into particular railway authorities in Europe, [8].

In case of embankments elevated on foundation soil with low bearing capacity, the issue of the foundation soil bearing capacity should be solved first, using standard geotechnical solutions for improving its mechanical properties, [9]:

- gravel piles – vibratory compaction
- vibrated concrete columns
- soilfrac process
- micropiles, [4]
- jet grouting, [19]
-

A properly designed and constructed base shall have nominal stiffness's adequate for the proposed traffic loads, and it shall fulfill its task equally well under wet and dry conditions, so it would not be prone to differential settlement.

In case of a transition zone between two different permanent way systems, a standard ballasted one and a modern ballastless one, on a particular embankment with a particular structure, it may be assumes that the traffic load, as well as its distribution through structural load–bearing layers of certain track structure systems, are similar or nearly identical, which leads to the conclusion that embankment settlement is the same in both track structures, and it doesn't need to be compensated for, [6].

4.3 Compensation of differential stiffness

A linear change in rigidity between two different track structures may be achieved by performing the following:
· application of fastening systems with different stiffness properties, [22]
· adjusting of the stiffness in the track bearing layers, [3,6,11]
Due to modern fastening systems and a variety of elastic mats intended for track structures on a rigid base, the overall rigidity of the ballast track structure and track structure on a rigid load–bearing base become mutually comparable and similar, meaning that the difference in stiffness doesn't need to be compensated any longer by certain additional construction measures.

5 Future efforts – SMART RAIL Project

A first step towards efficient and optimized design and maintenance is the modeling of track settlement and track/ foundation stiffness. In both cases, the models will be integrated with existing and new methods of monitoring current condition.
Simulation of nonlinear behavior of track structure elements in a transition zone is attempted by applying the finite element method.
A train–track interaction model will be developed to consider the response of railway infrastructure to loading. The objective is to find a way towards a structural solution of the transition zone issue by developing 3D models, integrating the time variable and specifying realistic boundary conditions in order to simulate the behavior of a track structure.
Development of a 3D model is preceded by an adequate and comprehensive monitoring of on–site activities. It is necessary to collect proper input parameters in order to calibrate the model as well as possible, and thus adjust it to a particular micro–location.
The results of such analyses will improve the existing models and determine specifications for new structural solutions for transition zones. Within SMART RAIL project researchers are focused on the transition zone problem areas, and based on several typical case studies will try to develop unique recommendations for the design and rehabilitation of the transition zone on the existing railway lines, [12].

6 Conclusion

Transition zones represent discontinuity in track structures. Many studies have indicated that sudden changes in track structure stiffness in transitions over culverts or transitions from an open part of the route onto a bridge/ viaduct/ tunnel is the main reason for the degradation of track structure in those sections.
The higher the axle load is, as the traffic load increases and as the train speed is higher, the more urgent is the transition zone issues.
When designing a new route, the transition zone issue is in most cases considered tough problem, where typically following questions are occurring: What is the required length of the transition zone, and which transition zone system to apply? There are many different solutions to this problem available in expert reading materials. However, there are currently no specific recommendations for dimensioning and designing of the transition zones in Croatia where many projects for the rehabilitation and improvement of existing railway are planned or already on going. Based on the experience from the road construction, research results, laboratory and on–site measurements, case studies where new solutions will be implemented, guidelines for the rehabilitations of transition zones on the existing railways will be developed, [12, 18, 23, 24].
In order to reduce costs generated through frequent rehabilitation of such parts of the route, all mechanisms which impact track structure degradation in transition zones should be

analyzed in detail in order to find an adequate solution in terms of special construction measures for solving this issue, and in order to develop the required technical conditions for dimensioning and designing.
Rehabilitation designs for the existing structures as well as designs for the new structures should take transition zones into account and offer a solution for them, namely transition zones should become an integral part of a structure's design documents.

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