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APPLICATION OF MODERN BALLASTLESS TRACK SYSTEM ON BRIDGES OF THE HIGH PERFORMANCE RAILWAY LINE "STATE BORDER – ZAGREB – RIJEKA"

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Abstract

Railway Transport Development Strategy of Croatia and its integration into the European railway transport corridors marked the beginning of design development for the High Performance Railway line that runs from the Croatian Borderline in Botovo, through Zagreb up to Rijeka. The section Skradnik – Krasica, sub-section Skradnik – Ledenice, has three viaducts on the route, which are positioned immediately next to the tunnel portals. According to the design, the track in the tunnel is modern ballastless track. Therefore, in order to unify the structural, financial and durability parameters, the same track system is also planned on the viaducts. Until now, the railway infrastructure design in Croatia always used ballast. This paper tries to present an impartial comparison of the influence of two different types of track system on viaducts from the aspect of safety, durability and serviceability. Several static models of the structure were prepared for this analysis, track system being represented by springs of respective stiffness. Opinions of the designers are also given regarding the two track systems, as well as possible influences that the choice of a particular track system can have on the overall superstructure.

Keywords: ballastless track, ballasted track, railway bridge, simply supported girder

1 Introduction

The new double track railway line, Botovo – Zagreb – Rijeka, is intended for mixed railway traffic with emphasis on transporting large amounts of cargo whose starting point, i.e. end destination in the Port of Rijeka. The railway line should also be able to withstand freight trains at 120km/h (speeds of up to 160km/h are expected in the future), and passenger trains at up to 200km/h (speeds of up to 250km/h are expected in the future), as recommended by the UIC organisation. Since the part of the terrain from Karlovac to Rijeka is mountainous, a greater portion of the route runs over viaducts and through tunnels.

In the design process, tunnels proved to be more cost-effective when constructed separately for each direction, thus placing the track centerline in plan view at 25,0m from each other inside the tunnels and the immediate vicinity. Since viaducts are placed immediately next to tunnel portals, they are also designed separately for each direction. Due to quite even elevation of grade lines crossing over valleys, it was possible to choose the same type of base course for all structures. The tendency was to build in a cost-effective, uniform and fast construction, at the same time meeting all safety and durability requirements.

Three structures have been designed within the railway tracks in Sector III, Zagreb – Rijeka:

- Donji Puškarići Viaduct (km 5+522.5 (R); km 5+540.00 (L)), 200m long,
- Drežničko polje Viaduct (km 16+430.00 (R); km 16+445.00 (L)), 800m long,
- Pađeni Viaduct (km 6+390.00 (R); km 6+415.00(L)), 390 long.

Since the design proposes the rails inside the tunnels to be placed on a ballastless track, the same type of track system has been proposed for the above mentioned viaducts. This is a novelty, considering that the classic ballast has been used in Croatia until now. This is why the two different types of track systems came into question. Preliminary analysis has been developed to compare the impact that this two systems have on viaducts in terms of safety, durability and usability.

2 Track system and bridge structure

2.1 Track system

While developing the preliminary design, two types of track system were considered. The first type is the ballasted track (Fig. 1). The rails are connected to the reinforced-concrete sleeper via fastening system at 65cm (or 60cm) spacing. The reinforced-concrete sleepers are placed into the 50cm thick ballast. In order for water to be drained from the permanent way, and in order for it to be durable, a 6cm thick concrete protection layer has been proposed to be placed between the ballast and the superstructure, with a 1cm thick waterproofing course to be placed underneath it.
The other type is a ballastless track (type Züblin, Rheda 2000). In this system (Fig. 1) the rails are laid onto reinforced-concrete sleepers embedded in a 24cm thick slab with reinforcing steel of Φ20. A ballastless track system is adjusted in its exact position before concreting. The slab leans against a 13cm thick positive cam plate, which transfers shear force through the permanent way. Elastic bearing is inserted between the concrete slab and the protection concrete layer which facilitates vibration damping.

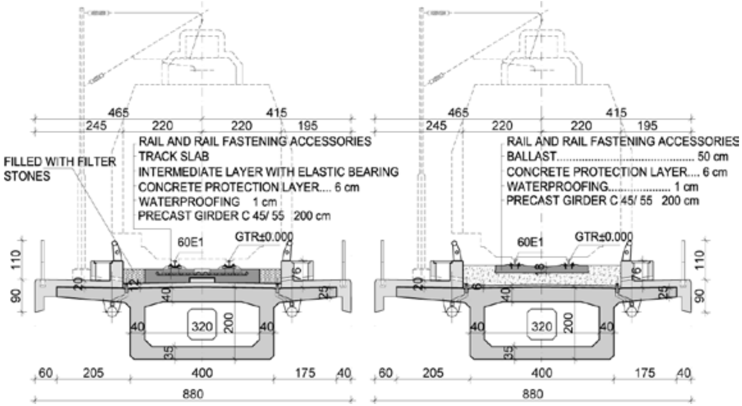

Figure 1 Two types of cross section

2.2 Advantages and Disadvantages of Both Track Systems

By using a ballastless system instead of a classic track system, the specific loads onto the formation level are very low (≈ 4 N/mm^2). Advantages of a ballastless track in comparison with a ballasted track are: excellent riding comfort with reduced strain on the tracks and vehicles, very high lateral and longitudinal track stability, reduced height and weight of the ballastless track, durability of high geometrical track quality – significantly increased, reduced maintenance cost (ballast has to be replaced every 30 years, while ballastless track has a duration period of up to 60 years), vertical adjustability up to +76mm for isolated defects (caused by settlements), no ballast swirling or flying ballast, increased damping against vibration. The main disadvantage of a ballastless track is that the initial investment cost is higher than with ballasted track. However, through the life cycle cost analysis, when maintenance costs and decommissioning are taken into account, a much lower total cost of the entire railway line during its lifespan is arrived at. Also, the noise emissions of the ballastless are much higher than of the ballasted track (5 dB) and may require extra sound barriers.

2.3 Viaducts

Due to possible standardization of structures, viaduct consists of a series of identical upper structures, i.e. in terms of statics, it consists of simply supported beams. These are prestressed box girders, 4.0m wide x 2.0m high, with cantilevers on both sides, with lengths 1.75m and 2.25m. For a 25.0m span, the thickness of vertical walls and top slab is 40cm, where as the thickness of the bottom slab is 35cm. Concrete class of the prestressed girder is C45/55. Post-tensioning tendons of total surface of 198cm2 are used. Transverse 80cm thick RC girders are placed above piers and abutments. The superstructure is supported at each pier (by abutments) on two pairs of pot bearings, one of which can be moved in all directions, one is immobile, and of the other two, one can be moved longitudinally and the other transversally. Pot bearings are of a nonstandard make since they have to be able to bear lateral forces greater than standard ones, i.e. greater than maximum 7% vertical force. The piers are rectangular in shape and hollow in cross section, 2.10 x 4.50m. Walls are 40cm thick. The piers are approx. 6.2m to approx. 28m high. Plan dimensions of the pier pad foundations are 6.2 x 8.5m for piers up to 12m high, i.e. 8 x 9m for piers up to 21.5m high. For piers over 21.5m high, the foundations are 8.5 x 11m. The height of the footing is 2m. The concrete strength of piers and abutments is C 30/37, reinforcement is deformed, B500B. Massive abutments have wing walls of up to 10m long (Fig. 2).

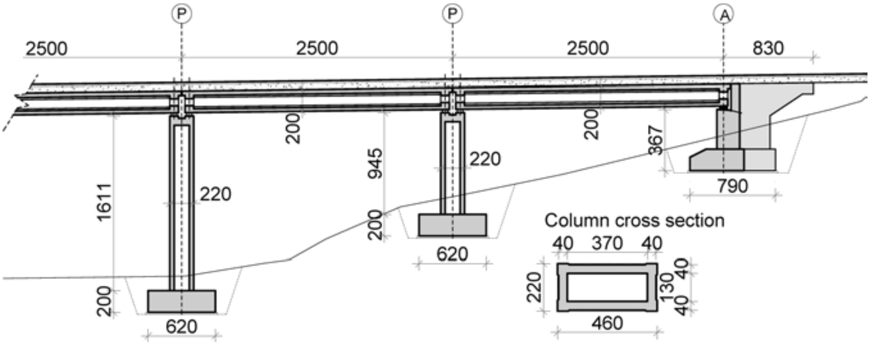

Figure 2 A part of typical longitudinal section of viaducts

3 Valid regulations

In developing the preliminary design valid Croatian regulations have been applied (EN 1991-2). Regulations for railway loads have basically not changed much, but differences do exist. A new, larger dynamic factor of Φ_3 has been introduced for normal track maintenance, whereas the factor for careful track maintenance of Φ_2 is still used in accordance with German regulations. Certain differences in defining relevant lengths of structural elements lead to different dynamic factor values as well. Since the speed of trains has recently increased, more attention has been paid to the possibility of resonance and dynamic vibration under moving loads. Valid standards introduce stricter criteria for limit values in terms of deformation and vibration of the bridge, depending on the type of track system. If a dynamic bridge analysis should prove to be necessary, there are differences in values of bridge deck acceleration for ballasted track and for ballastless track (EN 1990-prAnnexA2). The maximum permitted peak values of bridge deck acceleration calculated along each track shall not exceed the following design values:

- for ballasted track $\gamma_{bt} = 3.5 m/s^2$
- for ballastless track $\gamma_{df} = 5.0 m/s^2$

An unwanted occurrence on railway bridges is also track uplifts due to exceeded compressive stress. Unrestrained uplift at any bearing is not permitted to avoid the resultant vertical displacement of the track and to avoid premature failure of the bearings. Uplift is limited to avoid destabilizing the ballast and limit uplift forces on track components and ensure acceptable additional stress in the rails. Valid regulations - EN 1991-2, limit the additional compressive stress allowed for both types of track systems at the same value of 72.0 N/mm², whereas German guidelines (DB Netz AG) limit exactly the peak values of compressive, i.e. tensile stress in the tracks, depending on the track system.

Max. allowed compressive stress:

- for ballasted track 72.0 N/mm²
- for ballastless track 92.0 N/mm²

Max. allowed tensile stress:

- for ballasted and ballastless track 92.0 N/mm²

One of the benefits of a higher additional compressive stress allowed is greater freedom in laying the rail expansion devices onto bridges. In terms of railway bridge specifications, ballasted track and ballastless track are the same, except for the greater bridge deck accelerations and additional compressive stress in rails allowed in German specifications.

4 Vertical loads

One of the advantages of the ballastless track as opposed to the ballasted track is reduced construction height and weight. However, when analyzing additional permanent load for a bridge with ballastless track and a bridge with ballasted track, the difference between them is about 10% (additional permanent load for the bridge with ballastless track is 108.51 kN/m, and additional permanent load for the bridge with ballasted track is 120.67 kN/m). In the preliminary design the applied vertical rail traffic loads are load model UIC 71 to represent normal rail traffic and load model SW/2 to represent heavy traffic.

If a bridge does not meet the requirements shown in Fig. 3, a dynamic analysis is necessary.

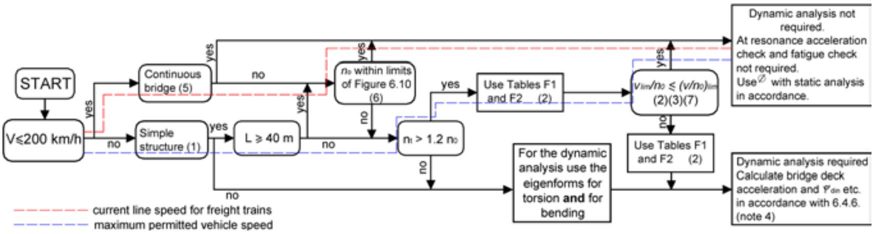

Figure 3 Flow chart for determining whether a dynamic analysis is required

Freight train speeds of up to 160km/h are expected. The viaducts consist of successive box girders with noticeable torsional and flexional stiffness placed on pot bearings. The first natural bending frequency is $n_o = 5.640$ Hz, the span of the girders is 23.6m. Bridge structure is within limit values of upper and lower natural bending frequency (as a span function), so the dynamic analysis is not required. Passenger train speeds are expected to be up to 250km/h, and speed range for freight and passenger trains is expected to increase in the future. For speeds greater than 200km/h, bridge structure is simple, the span is less than 40m, and the first natural bending frequency is more then 1.2 times higher than the first natural torsional

frequency. The requirements in EN 1991-2, Annex F for the ratio between the maximum line speed and the first natural bending frequency have been met. Therefore, the dynamic analysis is not required and static analysis with loads LM71 and SW/2 multiplied by the dynamic factor Φ can be carried out. Ballastless track bridges are considered to be carefully maintained, due to permanently high track accuracy, so the dynamic factor Φ is reduced when compared to ballasted track bridges (EN 1991-2:2003-6.4.5.2.). For this particular bridge structure Φ_2 = 1.129 for ballastless track, and Φ_3 = 1.194 for ballasted track, so the difference is about 5%.
To avoid decompression and fatigue problems of a prestressed box girder, the bridge superstructure is placed in class A – fully prestressed girder for serviceability limit state. This dictates that there is no tension in the concrete box girder under a rare combination of loads, particularly in the edge which is closest to prestressing cables. Rare load combination includes both permanent and traffic loads. As a result of the difference in permanent and traffic loads, the box girder of a ballasted track bridge requires additional 176.6 kg of prestressing steel when compared to the box girder of a ballastless track (about 5% more).

5 Horizontal loads

Considering the valid regulations, there are no explicit differences in ballasted and non ballasted track for horizontal loads on bridges. Eurocode requires a control of track–bridge interaction for bridges with expansion length grater then 40m. Track-bridge interaction originates from the fact that longitudinal forces in long welded rail are transmitted both by the structure and the rail to the fixed points at piers or abutments.
Deformations of bridge structure due to traffic loads, temperature loads, creep and shrinkage of the bridge can cause a significant rise in rail stress and modify the geometry of the track. Eurocode recommends a model for track – bridge interaction which consist of bridge elements with their characteristics, track, rail expansion devices and nonlinear longitudinal springs that represent load/displacement behaviour of track. Longitudinal shear resistance of the track per meter q (kN/m) depends mostly on the type of track and vertical load and has a bilinear law diagram (Fig. 4).
For ballasted unloaded track q is expected around 20.0 kN/m of track, and for ballastless track q value is about 40.0 kN/m. Some regulations dictate the use of special rail fastening systems on the bridge and up to 40.0m outside of the bridge to reduce longitudinal shear resistance to a value from 20.0 to 30.0 kN/m. The difference between the ballasted track and ballastless track is obvious (Fig. 5). Unloaded ballastless track bridge is submitted to grater rail stress and pier bending.
However, for the loaded track the value of recommended longitudinal shear resistance is the same for both types of track. These loads are much higher then those for unloaded track. During these considerations another problem emerged. Rail stress above two consecutive box girders is highly dependant of pier stiffness. In case of rough terrain and significant difference in height of two adjacent piers, the bridge may require a large number of rail expansion devices. Therefore, application of continuous girders should be investigated. One of the advantages of simply supported beams is that the replacement of damaged girders is done with no disruptions of the rest of the bridge. In reality, such vast defects rarely occur, and a large number of bridge joints represent weak points from durability aspects.

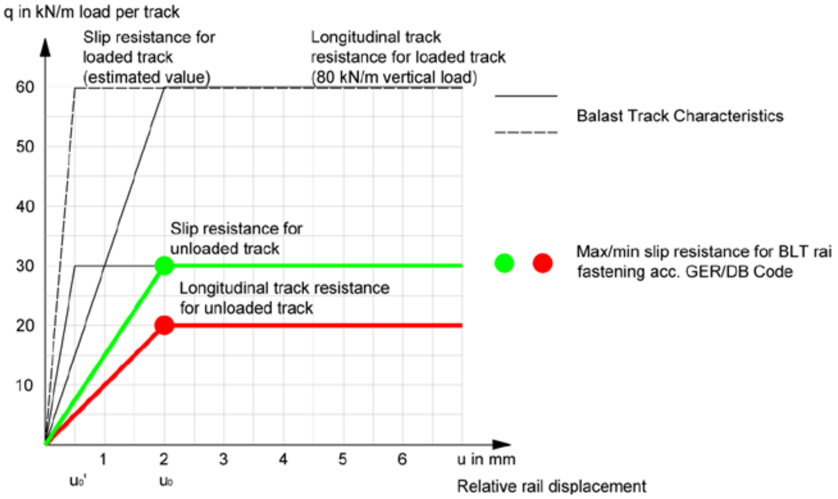

Figure 4 Load/displacement behaviour of track

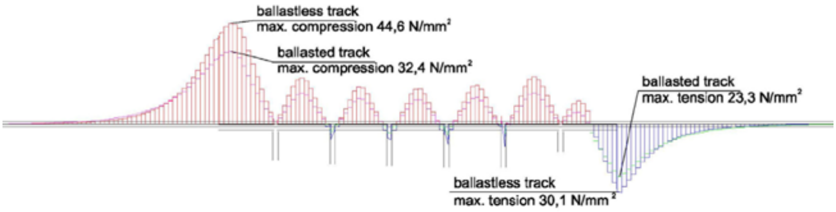

Figure 5 Comparison of stress in rails for unloaded ballastless track and ballasted track due to creep and shrinkage of the bridge and temperature loads

6 Conclusions

Preliminary design shows that both type of track systems don't have significant differences considering the bridge structure. Viaducts with ballastless track require a little less prestressing steel and viaducts with ballasted track perform slightly better under some horizontal loads. Also, the use of continuous girder opposed to system of successive simply supported beams should be investigated.

References

[1] Pfeifer, R.H. & Mölter, T.M.: Eisenbahnbrücken, Grundsätze für Planung und Konstruktion sowie auf Bauverfahren, Hamburg, 2008.

[2] Goicolea J.M., Gabaldón F.: Design issues related to dynamic effects for high-speed railway bridges in Spain, Computational Mechanics Group, Dept. of Mechanics and Structures, E.T.S. Ingenieros de Caminos, Universidad Politécnica de Madrid

[3] Kleeberg, J., RHEDA 2000® Slab Track Technology on Viaducts, Madrid, September 2007.

[4] HSL Rail Track Technology for Croatian Railways, Presentation and Discussion, The Proposed Track: RHEDA 2000® Slab Track Technology, Coswig, April 26th, 2008.

[5] Goicolea-Ruigómez, J.M., Service limit states for railway bridges in new design codes Iapf and Eurocodes,

[6] EN1991-2 (2003). European Committee for Standardization. EN1991-2: EUROCODE 1-Actions on structures, Part 2: Traffic loads on bridges. European Union, 2003.

[7] EN1990-A1(2005).European Committee for Standardization.{EN1990-A1}: EUROCODE 0—Basis of Structural Design, Amendment A1: Annex {A2}, Application for bridges, European Union, 2005.

[8] Railway bridges today and tomorrow, Marriott Hotel City Centre, p.p. 61-64, Bristol, 22-23 November 2006.

[9] Carvalho Santos Henriques J.F., Dynamic Behaviour and Vibration Control of High Speed Railway Bridges through Tuned mass dampers, Dissertation for the degree of Master of Science in Civil Engineering, Instituto Superior Tecnico, Universidade Tecnica de Lisboa, p.p. 1-60, November 2007.