Applications of unconventional construction of the railway superstructure on the railway infrastructure of the Slovak Republic

Introduction

A track with the standard structure of railway superstructure is marked such railway track where track skeleton is stored in the gravel ballast. In the case of high operating and axle load and introducing higher speeds there are proved limit possibilities of standard structure of superstructure, particularly in its ability to guarantee the long-term moving rail vehicles operationally safe, reliable and easy-to-maintain track.

The standard structure of railway superstructure is characterized by "floating" placing of track skeleton, which causes the growth of dynamic forces during each passage of a rail vehicle or train that cause gradual degradation of track geometry, which leads to turbulent ride of rail vehicles. This phenomenon increases with increasing track speeds and thus increases the cost of maintaining and share of closure of traffic tracks, which reduce the attractiveness of rail infrastructure for its users - goods and passengers. It is sufficient, however, if there is only replaced the weakest element of standard railway superstructure in the track, and this is the gravel, with other more appropriate component which does not show particular plastic behaviour. Such substitute is a structure, where the track skeleton is concreted (monolithic structure) or fixed on a concrete or asphalt supporting layer (layered structure); structural solution, which is referred to as unconventional railway superstructure. This concept of track is currently referred to as a slab track (hereinafter referred to as "ST"), in which the required flexibility of the superstructure for the system wheel / rail is secured using elastic elements disposed between a rail and rail support or under a rail support. The term "ST", as defined in [10], represents the structure of railway superstructure, in which a spread function of railway ballast is replaced by reinforced materials, and which is placed on a concrete or asphalt supporting slab. The term slab track is also often replaced by the term ballastless railway superstructure. This concept, however, is useful only if the track ballast is replaced with a material which is resistant to deformation, but not if ballast for slab track can be used for other tasks, for example, as protection against UV radiation, required resistance against longitudinal movement of sleepers, etc.

The possibility of applying the structure of slab track

The essential reason for building unconventional structure of railway superstructure – a slab track – is the fact that it was set up to give high stability of the track, which is associated with the peaceful movement of vehicle and thus simultaneously driving comfort for the passenger and the operator with significantly lower maintenance requirements for the track hence lock-out and finance. This driving comfort can be obtained, in case of standard structure of railway superstructure, only with very high operating costs [2].

Besides these principal profits, there are still other additional profits of unconventional structure of railway superstructure, including [5]:

- lower investment costs using more suitable parameters (possible higher elevation), which are associated with smaller radii, which can promote the ideas of a parallel routing of highways, smaller geometric cross sections of ground body, bridges and tunnels
- smaller loads of the structure of earthwork due to a better distribution of loads of supporting layer; misconception that the construction of slab track in the earthwork must be made ,,something more“ com-

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pared to standard structure of superstructure is not confirmed, it is exactly the opposite
- two to three times longer service life compared with the standard structure of railway superstructure, which is associated with the life cycle costs of the track
- greater operational safety by increasing cross-resistance, no effects of track temperature are expected
- easy deployment of linear brakes with vagabond currents as operational brakes and the greater cost savings for braking train sets
- less wear of vehicles by permanently maintaining the required track position
- no dangerous swirling gravel
- no problems arising with the need for removal of undesirable vegetation
- there is an increase of operational capacity and reduction of potential accidents by less maintenance.

As every engineering structural system, as the so-called slab track has not only its advantages, but disadvantages which we calculate:
- higher investment costs
- longer construction period
- limited possibility of adapting to changed operating conditions
- higher noise emissions
- expensive and time consuming renewal of track

According to current experience it can be stated that the costs of maintenance and renewal of railway track with inbuilt structure of ST have been decreasing over a long period since the revision, as well as the cleaning of ballast can be omitted and renewal of the track can be carried out in longer intervals. Building a railway track with the structure of ST can reduce the following cost items during its operation [7]:
- track geometry revisions
- elimination of errors and deficiencies of projected track geometry
- vegetation in the track
- revision of the track – it is not necessary to implement
- cleaning of track ballast – it is not necessary to implement
- renewal of the track – implemented in a significantly longer time interval.

It means that it is not necessary to perform more than two thirds of annual maintenance costs on the railway track with the ST structure! At the same time the service life of ST is considerably higher compared to standard structure of superstructure. In contrast, however, a better quality ST requires higher initial investment costs than ballasted track. From an environmental perspective, further development and precise structure of ST should focus to be:
- less noisy
- emit less vibration in the track environment
- environmentally friendly
- capable of recycling

The structure of ST requires common concentration of legislators, operators and developers. Although the qualities of ST structure do not currently match capacities of ballast in terms of noise emissions and vibrations, the structure of ST disposes of unique quality characteristics that must be taken into account in the decision-making process for the application of railway.

In general, the present structure of ST applies mainly to high-speed lines and lines that have high operating load, where the cost of track maintaining with the standard structure of superstructure grows strongly. At the same time, however, this structure also promotes the upgraded sections of the standard tracks (track speed up to 160 km/h); mainly to the sections in tunnels, as a rule, there are the required properties of subgrade that does not show subsidence. Furthermore, the use of the ST has a positive impact on the size of the investment costs for setting up the tunnel, given the smaller cross-section, in the case of its new building, or excluding freight tunnel extension, in the case of its electrification on the existing tracks. Subgrade without a drop is offered for application of the ST structure and bridges and therefore the application of this structure is also possible in these track sections. The reflections, as regards the temperature expansion of the structure and creation of closing tangential angle during its load, however, lead only to its gradual use so far. The structure of ST is, however, increasingly applied for urban tracks – trams or subway lines.
The existing applications of slab track in Slovak railway infrastructure

Unlike the developed railway administrations, the structure of ST was not ever applied in administration of Slovak Railways for many years. Historically, the first section of ST on the Slovak railway tracks was built in Bratislava Tunnel no. 2, located in the track section Bratislava – Lamač – Bratislava main station. The second section of ST was built also in connection with the construction of the tunnel, and new tunnel Turecký vrch, which is located on the modernized section of track Nové Mesto nad Váhom – Púchov. While last application of ST structure on the Slovak railway track is section in Bratislava Tunnel no. 1 (in operation since the end of 2014).

The structure of slab track in Bratislava Tunnel no. 2

The ST structure of SATO type was built in Bratislava Tunnel no. 2 (Fig. 1) in the period from 09/2007 to 02/2008, in the second track of railway section Bratislava - Lamač - Bratislava city railway station according to project documentation developed by company PRODEX Ltd. and ThyssenKrupp, Road Construction Slovakia Ltd. [9]. Both Bratislava (Lamač) railway tunnels are the oldest tunnels in Slovakia and, moreover, they are located in important railway line to Vienna, or Kúty. The section of Bratislava Tunnel no. 2, the operation of which was started in 1902 and whose length is 595.870 m, is apart from Bratislava Tunnel no. 1 directionally led in two right curves of transition curve R = 525 m (with an elevation of 49 mm) and R = 600 m (with an elevation of 43 mm) with inter-line of 315.805 m, while its longitudinal gradient is 6.7 ‰. The reason for the reconstruction are the results of the technical assessment made in 2006, in which it was stated that its isolation is significantly disturbed, what causes water penetration and due to moisture loss of the insulating ability of the track, and at the same time, considering the age of railway superstructure, the fastening of rails to wooden sleepers is also in unsatisfactory condition.

Fig. 1. Bratislava Tunnel no 1. (on the left) a č. 2 (on the right) – portal Bratislava main station

Source: authors

In connection with the reconstruction of the tunnel, in terms of horizontal and vertical alignment, there have been no substantial changes to the original state. These were only specified in the ST draft on the basis of detailed geodetic survey and subsequently directional conditions with respect to vertical track no. 2 were designed for speed V = 60 km/h. In order to keep the values projected within standard tolerances allowed, after laying tracks on the asphalt roadway, there were used polyethylene pads and angled inserts in the tunnel. The original structure of superstructure and its fastening in the tunnel was replaced with ST on the steel sleepers of shape "Y" ThyssenKrupp and length of 599.570 m, with new rails 60 E1 and flexible fastening using clips Vossloh Skl 15 (Fig. 2). Continuous steel sleepers are of type St 98 Y FF-No-650-60 and transition sleepers at the point of connection to transition reinforced concrete slabs before and after the tunnel are type of St 98 Y FF-Üre-650-60, or St 98 Y FF-Üli-650-60. Steel sleepers of shape "Y" are embedded in the underlying asphalt slab of thickness 150 mm and provided with corrosion-proofing.
Transitions from asphalt ST placed in the tunnel to ballast before and after tunnel are realized by two reinforced concrete slabs of length 15 m, width 3.20 m and thickness of 0.400 m. Total structural height of these slabs, including tracks and inbuilt sleepers, is 0.632 m; axial distance of reinforced concrete sleepers embedded in the slabs is 0.650 m. To ensure a smooth transition to ballasted track, there were used additional bracing rails 60 E1, which are attached to the sleepers embedded in reinforced concrete slabs of length 5 m and modified sleepers B93 stored in the ballast of length 10 m. After transition slabs, there follows standard ballast, first with modified reinforced concrete sleepers B93 then reinforced concrete sleepers B 91 S/1 and finally wooden sleepers - all divided to UIC. New rails (excluding transition) are of shape 60 E1; they were delivered in the length of 120 m and welded to double length of the resistance and after assembly to spot of termite. Finally, the track is welded to the contactless track using closing welds in the whole section. New railway ballast, of fractions 31.5/63 mm of thickness about 0.300 m below the bearing surface of sleepers, is embedded throughout the section; banquets are of stone grit of fraction 4/16 mm.

The structure of slab track in Bratislava Tunnel no. 1

Construction of ST ÖBB-PORR (Fig. 3) was built in the period from 10/2014 to 12/2014. The aim of modernization of track no. 1 in Bratislava Tunnel was to improve technical condition of railway superstructure. Unsatisfactory condition of the superstructure resulted from complicated maintenance of fastening on wooden sleepers in poor condition (cracks and rotten material of sleepers). There were also reconstructed all associated parts of the tunnel tube. The modernization involved elimination of leaks in the tunnel where water percolating through arch caused disturbances of catenary and icicles during winter.

Project documentation was prepared in 2012 by Prodex, s.r.o., changes in order to optimize technical solutions and technological processes due to changes in regulations and standards was carried out by TAROSI c.c., s.r.o. The construction of superstructure consist of prefabricated reinforced concrete slabs ÖBB-PORR, which are monolithically jointed with the invert of the tunnel. Reinforced concrete slab have dimensions of 4 760 x 2 400 x 160 mm and each have eight fastening points at a distance of 600 mm. Fastening points are made for system UIC 60 E2 in inclination of 1:40 and fastening Vossloh W 300-1. There are 124 slab boards fitted on invert of the tunnel. The construction is equiped with steel mandrels with a diameter 20 mm and length of 300 mm to connect levelling concrete layer and invert of the tunnel [1].

Transition areas between ST construction and ballasted track is according to present state (max. speed up to 60 km/h) consist of a combination of ballast glueing and track skeleton with concrete sleepers of type ŽPSV. Tranistion area around portal Lamač (Fig. 3) with a length of 18.020 m is made of 30 sleepers BV
08. In the area of Bratislava main station portal ST structure is located near to switches of station head and according to spatial conditions and high rigidity of the superstructure is realized by length of 5.592 m with 7 concrete and 2 wooden sleepers. Ballast (friction 32/63 mm) has been glued by two-component resin – the first phase was realized during maintenance works (underneath surface of the sleeper), the second phase will be realized after year of operation (sleeper crib and by the end of sleeper) [1].

Fig. 3. Construction ÖBB-PORR in Bratislava Tunnel no. 1 (on the left) and transition area near portal Lamač (on the right)

Source: authors

The structure of slab track in the tunnel Turecký vrch

In connection with the modernization of the V. trans-European corridor Venice – Trieste / Koper – Ljubljana – Budapest – Chop – Lvov; wit the branch Va passing through the Slovak Republic in the section Bratislava – Žilina – Košice – Číerna nad Tisou – Chop, there was proposed by the project contractor (REMING Consult, a.s.) and approved by the client (GR ŽSR) the structure of ST of type RHEDA 2000® within the construction of Slovak Railways, Modernization of railway track Nové Mesto nad Váhom – Púchov, km 100.500 – 159.100, object 24-32-01 Nové Mesto nad Váhom – Trenčianske Bohuslavice. The reasons why the subjects in question decided to build unconventional structure of superstructure, although it is not the application to the speed or high speed track, where such structure has a priority use, there was the fact that there was designed new railway tunnel Turecký vrch in terms of Slovak Railways after more than 50 years. The location of the tunnel, together with the structure of portals and retaining walls addresses the issue of inevitable conflict of spatial interests between the modernization of the track and Protected landscape area (PLA) Turecký vrch. After analyzing alternative solutions of the track alignment around Turecký vrch in the current railway track and new route – tunnel variant – the builder decided for tunnel variant. It is considered that the change of track alignment through the tunnel will increase the track speed and minimize negative impacts on PLA. Another advantage of tunnel variant is that the construction of tunnel did not restrict rail transport, because the tunnel was dug outside the original track [4].

In view of the fact that in the case of necessary maintenance, or future repair of reconstruction works, the implementation of these works is complicated in the tunnel and also due to the reduction of the amount of rock excavated from the tunnel portal, which did not have further use; the structure of ST, which has a lower structural thickness as it would be when using a standard structure of railway superstructure, would
be the appropriate solution.

Modernisation of already mentioned track section started in September 2009 and was completed in May 2013. The railway tunnel, which is part of the track section, is the first tunnel in Slovakia, which is designed and implemented according to the technical specifications for interoperability for conventional tracks, it corresponds to the latest trends in tunnel and railway construction and should become a model for all future tunnels that will be built in Slovakia within the modernization of railway tracks. Double-track tunnel is designed to passable diameter of UIC C with axial distance of tracks 4 200 mm. The total length of the tunnel Turecký vrch in the axis is 1 775 m. Tunnel tube of the section excavated has a length of 1 738.5 m and is followed by excavated sections of the south portal of length 25 m and the north portal in the length of 10 m. The entire length, including the portal sections, includes integrated cross-section of double-track tunnel with light radius of tunnel tube of 6.1 m, there are just two chambers for stretching traction supply with extended cross-section in the middle of the tunnel. Double-track in the tunnel is designed for the speed of 200 km/h with reverse arcs with a radius of 2 000 m.

The structure of ST was designed, as already mentioned, due to the reduction of the area of cutting and also durability and fixation of the track position and its minimum maintenance during the operation. The structure of ST of RHEDA 2000® system passes through different types of track subgrade. It begins before the south portal and passes through the entire tunnel. Then, the ST structure continues on bridges and ground body behind the north portal. The structure of ST itself also includes transition areas on both ends, which ensure smooth transition (smooth change of stiffness) of rigid structure of ST, whose total length is 2 280.145 m (it starts in new km 102.459 825 and ends in new km 104.740 000), where its particular parts are: transition area – 45.175 m, tunnel – 1 775.000 m, bridges – 34.770 m and ground body – 425.200 m.

The structure of ST of RHEDA 2000® system is has been verified by years of smooth operation on the German railways. Due to the complex directional conditions and bridges located immediately behind the north portal, the structure of ST is established not only in the tunnel itself, but it almost continues to the railway station Trenčianske Bohuslavice on the north side of the tunnel. Total length of the ST structure is up to 4 480 m. Due to the diversity of subgrade stiffness (tunnel bottom, bridge and railway substructure of ground body), the system of the ST structure is modified, which is reflected in the thickness of concrete structure and also in its reinforcement.

The structure of ST of RHEDA 2000® system is made up of its own monolithic structure of ST, which is divided in its track section in question into 3 basic types [8]:

- in tunnel – Fig. 4: monolithic reinforced concrete slab of variable thickness (according to track elevation) – concrete class C 35/45 with concreted twin-block sleepers, lying on the concreted bottom of the tunnel tube (anchored with the underlying slab of the tunnel bottom in the place near portals)
- on earthwork – Fig. 5: monolithic reinforced concrete slab of constant thickness 240 mm - concrete class C 35/45 with concreted twin-block sleepers (also called TCL), lying on a monolithic slab of plain concrete class C 12/15 of constant thickness of 300 mm (also called HBL). Track elevation in arcs consists of an inclined plain of railway substructure. There is a TCL slab anchored to HBL slab in the place between the northern portal of the tunnel and bridge over the brook Bošáčka
- on bridges – Fig. 6: monolithic reinforced concrete slab of variable thickness (according to track elevation) - concrete class C 35/45 with concreted twin-block sleepers, lying on the separation layer Styrodur + foil on the construction of the bridge
Rails used in the system of the ST are the same as in the case of standard superstructure, and the shape of 60 E2, welded into countinuously welded rail track. The rails are fastened to the structure of ST using the system Vossloh 300-1U. It is non-sole-plate flexible fastening system, similar to the normal rails on railway sleeper. Standard distribution of double-block sleepers, which were concreted in monolithic slab, has a value of 650 mm. This value was adjusted as necessary (reduced) only on bridges and areas where the location of dilatation cracks in the inter-sleeper spaces is needed. Double-block sleepers are a type of B 355.3 U60M of manufacturer ŽPSV a.s. The transition of the structure of ST to standard structure of railway superstructure with ballast consists of reinforced concrete tubs of length of 20 m, filled with ballast of variable thickness below the bottom edge of the sleeper BP-3 (250-350 mm), lined with sub-gravel elastic mat. The space between the tracks in the tunnel and the bridge consists of infill concretes, outside side of the structure of ST on earthwork is filled up with ballast of fraction 31.5/63 mm.
The critical place of the ST structure is transition area between standard structure of superstructure and ST. In terms of dynamic effects it is a place with a change in stiffness and thus there was paid a special attention to this place. There was used a new type of transition area using standard components of railway superstructure, while without the need for stabilization of the superstructure within the transition area of bonding. The structure consists of reinforced concrete tub of concrete C 30/37 of length 20 m. Thickness of ballast under the sleepers decreases in the direction to the structure of ST, thus stiffness of the subgrade gradually increases. The bottom and walls are lined with elastic mat, whose task is to simulate the deformation properties of the soil of earthwork. There is water and moisture isolation below the elastic mat. Draining rainwater ensures both the longitudinal tub gradient and drainage facilities.

Conclusions

The increasing population mobility and economic competition between different transport system put higher and higher requirements and objectives even before the railway. An essential precondition for the competitiveness of rail transport is, however, a reliable operation of the railway lines; it means a safer and more stable movement of vehicles on the track – rail.

Development and validation of a number of technical solutions of ST in terms of Slovak Railways have demonstrated a willingness to optimize the structure of superstructure, which would allow to ensure the quality of the track geometrical parameters, reduce maintenance costs, extend the service life of structures and increase the competitiveness and attractiveness of railway lines in the territory of Slovak Republic in longer term. The issue of modernization of railway infrastructure is an ideal opportunity for further application of advanced systems and structural elements of railway lines, where the ST undoubtedly belongs to.
Abstract
Modernization of railway infrastructure in the Slovak Republic is still very current topic and is an ideal opportunity for the application of advanced systems and structural elements of railway track construction, such as slab track construction. The paper deals with application of slab track construction in the ongoing modernization of the railway infrastructure and potential for further use on the railway infrastructure of the Slovak Republic.

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