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17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

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Road and Rail Infrastructure V

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IN-SITU TESTING OF RC TRACK SLAB IN TUNNEL IVAN AND NUMERICAL MODELLING

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Abstract

Institute for Materials and Structures of the Faculty of Civil Engineering in Sarajevo conducted static and dynamic testing of the RC track slab in the railway tunnel Ivan. Due to the tunnel age, traffic in the tunnel was impeded so that the reconstruction of the complete track bed structure was executed. A so-called integrated structure in which the prefabricated sleepers are connected to a stiff concrete slab by using reinforcement was applied for the first time in Bosnia and Herzegovina. The track slab was founded on heterogeneous material which includes weathered marl, granular material as well as amphibolite or schist rocks. The deflections measured under service load simulated by a locomotive and eigen frequencies indicate that the structure is quite rigid. Experimentally obtained data was used for numerical modelling of short-term settlement assuming Mohr-Coulomb material model in Plaxis and the results match quite well.

Keywords: tunnel Ivan, integrated track slab settlement, experimental testing, numerical modelling

1 Introduction

Tunnel Ivan is located on the railway section Blažuj-Konjic within the so-called “Southern railway” which links Sarajevo with Ploče port. The railway line was first planned and built as a narrow-gauge line between 1879 and 1891, and as a part of it, 648 m long tunnel Ivan was drilled. Due to high altitude difference on this section, the line was designed with large longitudinal slopes (35 ‰ on Pazarić-Tarčin section, and 60 ‰ on Podorašac-Raštelica section) and constructed as a rack railway (Abt rack system after Swiss engineer Roman Abt). In 1931 the railway route was changed and a new tunnel Ivan 3223 m long was built with a slightly wider profile than the usual narrow-gauge line. This was used when constructing a normal-gauge line (1435 mm) in 1966, so that the railway passed through the same tunnel without making any significant changes on the tunnel profile itself. In 1976 a major reconstruction was planned. However, only in 2016 (after 50 years), the tunnel overhaul and repair of the tunnel lining had begun (Fig. 1). Due to the tunnel age, traffic was impeded so that the reconstruction of the complete track bed structure was executed. In addition to poor maintenance, major defects were caused by inadequate drainage system and weak connection between the rails and steel sleepers. A so-called integrated structure in which the prefabricated prestressed sleepers are connected to a stiff concrete slab by using reinforcement, hence making a monolithic unit, was applied for the first time in Bosnia and Herzegovina. In order to assess the state of the executed RC integrated slab, it was tested under static and dynamic loading. The structural solution was developed by contractors GCF S.p.A. (Italy) and Hering d.d. (BH).

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Figure 1 Tunnel Ivan – before (left) and after overhaul (right)

2 Description of the RC track slab

In order to achieve the minimum free profile of 5.05 m (contact network-top of rail), instead of the classic gravel bed, an integrated track bed structure was executed. Prefabricated pretensioned sleepers and rails make a truss that is integrated with the RC slab using reinforcement. This conception has its origin in negative experiences of German and Japanese railways with gravel bed (Fig. 2, Fig. 3).

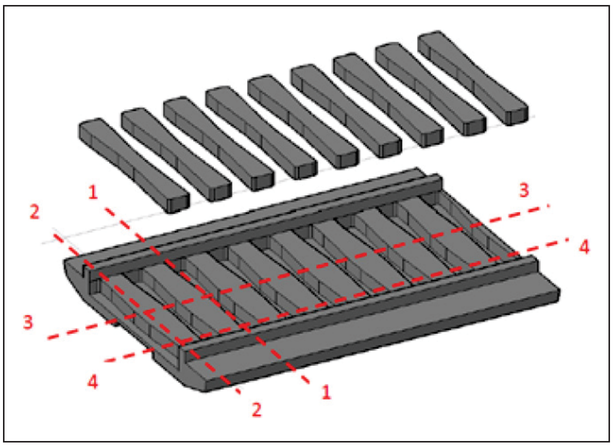

Figure 2 3D view of the track bed structure

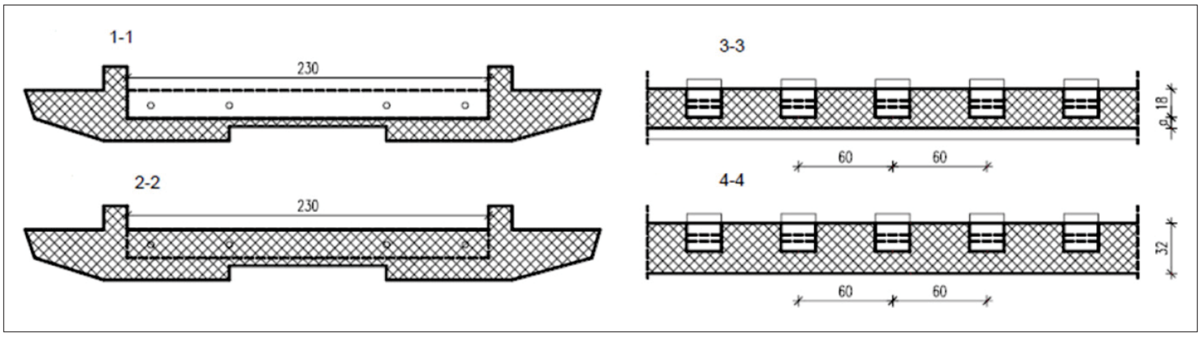

Figure 3 Cross and longitudinal sections of the track bed

Reinforced concrete slab 320 cm wide, min. 14 cm thick below sleepers (29 cm together with sleepers) is connected to sleepers by means of 4 reinforcement bars Ø20 mm. The bars were introduced into the sleeper at a distance of 0.5 m through pre-prepared Ø40 mm holes which were subsequently grouted. The slab was concreted in 5.99 m long sections, and the 10 mm wide gap was cleaned with compressed air and grouted. The required concrete class for the slab was C25/30 (MB30). Part of the slab below and between the sleepers was reinforced with BSt500S, Ø10/15 (bottom zone, X direction), Ø8/20 (lower zone, Y direction), 3Ø12 (between sleepers, direction X) and 2Ø20 (rail axis, direction Y). Distance between the rails is 1435 mm and the spacing of sleepers is 60 cm. The sleeper length is 2300 mm, the width varies from 220 mm to 300 mm and the height is 175 mm up to 234 mm (BH70-230). The sleeper was made of concrete MB 60 (PBAB 87) or C50/60 (EC 2) and reinforced with 4 pre-tensioned wires Y1570C, 4 Ø9.5 mm (St 1375/1570). According to the available data and the geological map of Ivan Mountain between Raštelica and Bradina, the subsoil is composed of solid rock mass. The actual geological situation has not been confirmed by execution of boreholes, and there is a possibility that rock masses may have been degraded on a certain stretch. At these locations, the material was removed to provide a good base for reinforced concrete slab.

3 Static and dynamic testing of track bed structure

Testing of the track slab was performed at three locations in the tunnel. As a test load, the Deutz 2000 CV locomotive (total mass of 80 t) was used. The vertical and horizontal displacements of the track slab were measured at three locations in the tunnel designated by the tunnel consoles TK 15, TK 69 and TK 110. Test locations were determined following the instructions of the Supervisor in order to investigate the structural behaviour in three different geological environments through which the tunnel passes. Visual inspection and laboratory tests were made as a part of the design and geological survey. Hence, the rock layers in which the slab was founded were classified as follows:

- Location TK 13: marl
- Location TK 69: amphibolite, schist, sandstone
- Location TK 110: debris, gravel, sand (soil replacement, 0.5 m in depth)

Displacements at each location were first measured due to static load induced by both locomotive axles. Since a typical slab section is cca. 6.0 m long, and the length of the test locomotive amounts to approx. 16.5 m, only a half of locomotive weight acts on the section. Then the displacements due to nonstationary dynamic load generated by the locomotive passing through at speeds v = 30 km/h and v = 70 km/h were measured in order to determine the dynamic amplification factor. Vertical vibrations caused by the impact of a heavy hammer were measured at two locations (TK 69 and TK 110) in order to determine eigen frequencies of the investigated structure. The following measuring equipment was used for the test: HBM type WA/100mm-L and HBM type WA/50mm-L deflectometers; HBM 160 and HBM 208 accelerometers. Layout of instruments is shown in Fig. 4.

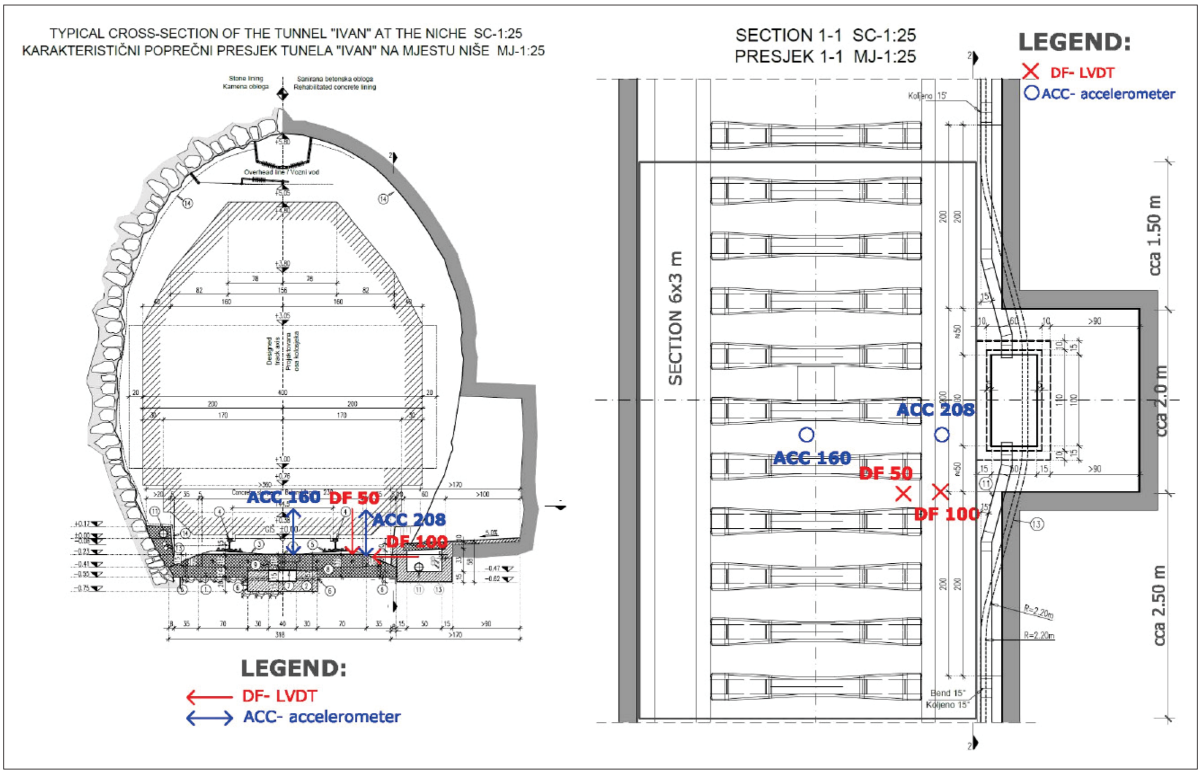

Figure 4 Location of measuring instruments (cross section and top view of typical section)

In Table 1 comparison of experimentally and numerically determined static displacements (see Chapter 4) is given. Also, maximum displacements due to dynamic load and dynamic amplification factors are provided.
In Fig. 5 dynamic displacements measured at TK 69 and TK 110 are shown. In Fig. 6 and Fig. 7 the measured accelerations and power spectra of vertical vibrations at TK 69 and TK 110 are respectively given.

Table 1 Experimentally and numerically determined displacements

Location	Experimental displacement [mm]	Numerical displacement [mm]	Dynamic displacement [mm]	Dynamic amplification factor
TK 13	0.20	0.19	0.28	1.40
TK 69	0.08	0.069	0.11	1.35
TK 110	0.15	0.18	0.22	1.45

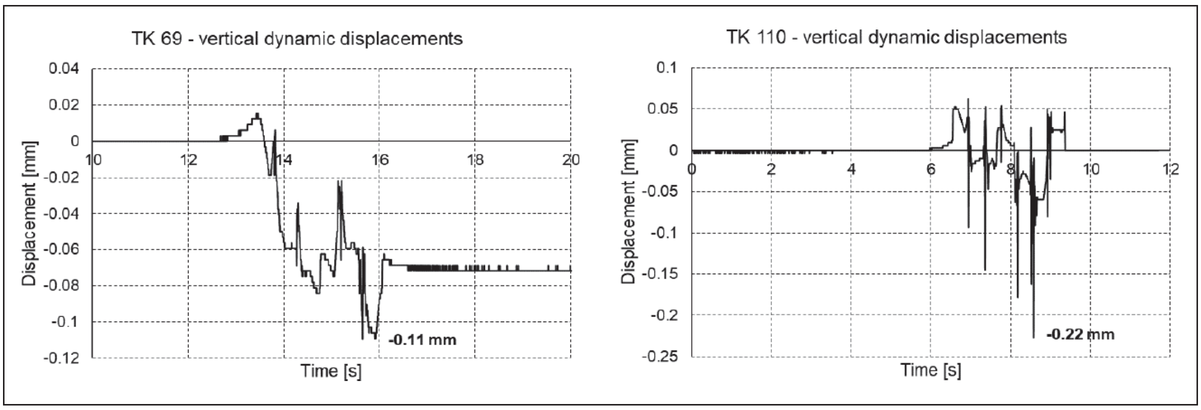

Figure 5 Dynamic displacements at TK 69 (left) and TK 110 (right)

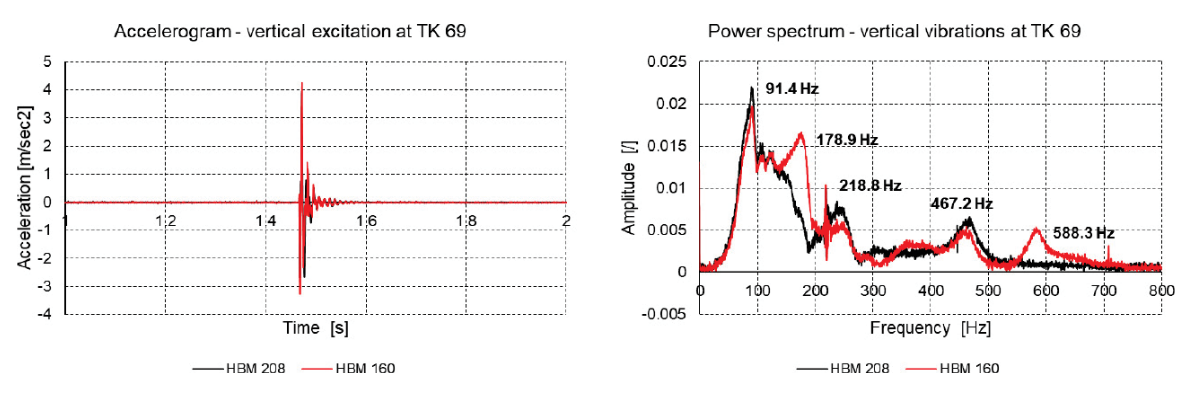

Figure 6 Measured accelerations (left) and power spectra of vertical vibrations (right) at TK 69

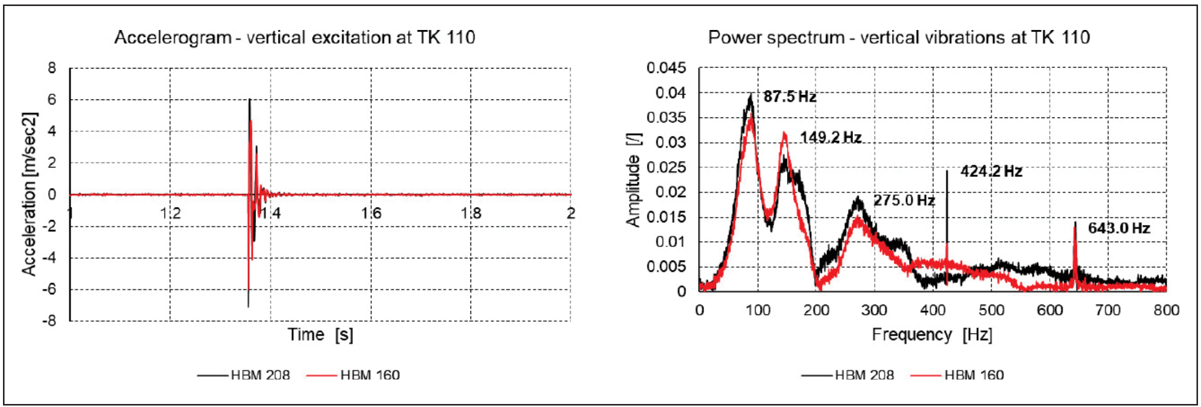

Figure 7 Measured accelerations (left) and power spectra of vertical vibrations (right) at TK 110

4 Numerical models

Two-dimensional plane strain analysis was performed using Plaxis 2D software [1]. A numerical model is shown in Fig. 8. Surcharge load equal to 34.0 kN/m' and structural elements characteristics are indicated along with the geometry of the numerical model.

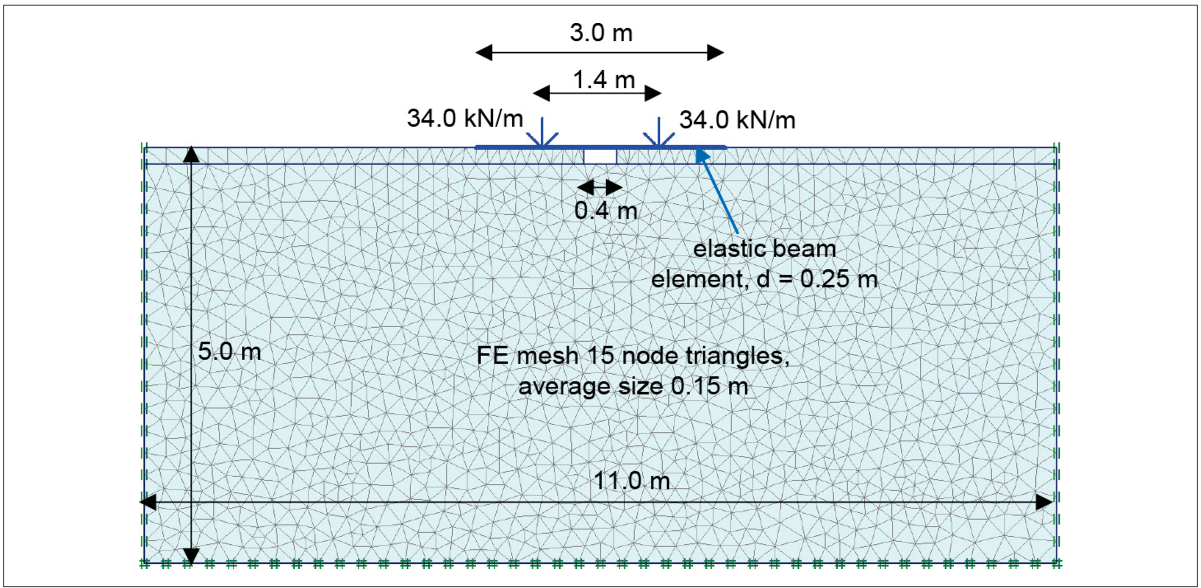

Figure 8 2D numerical model

Three characteristic cross sections were analysed. The difference between cross-section is related to geotechnical characteristics of foundation soil which can be assumed as weathered marl rock (TK 13), solid schist and sandstone rock (TK 69) and compacted granular material laid on solid rock (TK 110).
Geotechnical parameters of compacted granular material (thickness 0.5 m) were determined according to gradation curve and in-situ compaction controlled by static plate load tests after compaction in 2 layers of 0.25 m thickness. The parameters of weathered and solid rock layers were determined by using Hoek-Brown failure criteria, implemented in RocLab software [2]. Input parameters were selected as characteristic values of laboratory test (uniaxial strength and deformation modulus of intact samples), in-situ observations (GSI value) and stress range typical for the analysed problem. This approach for selection of rock mass strength and deformation parameters is conventional in geotechnical engineering practice and it can be considered as appropriate for the analysed problem. Namely, comparing the structure dimensions (linear structure approx. 3.0 m in width) with a discontinuity spacing (weathered rock with extremely small discontinuities spacing and solid rock with practically no discontinuities) it can be concluded that foundation medium can be considered as quasi-homogeneous rock mass. Geotechnical parameters that pertain to characteristic cross sections are listed in Table 2.

Table 2 Geotechnical parameters

Material	Cohesion [MPa]	Friction angle [°]	Dilatancy [°]	Deformation modulus [MPa]
Weathered marl	0.1	29	0	300
Schist	0.3	39	9	1000
Compacted granular	0	37	7	80

The results of numerical simulations are represented by vertical settlements (s_v) due to surcharge load applied at the top of the beam element. Typical displacement field for solid rock is shown in Fig. 9, with maximum settlement equal to 0.069 mm. The maximum vertical displacement for weathered rock and compacted granular backfill (depth 0.5 m) amounts to 0.16 and 0.19 mm respectively. The response of foundation soil lies in the linear elastic range due to relatively large strength parameters. Predicted settlements comply well with the measured static displacements (Table 1).

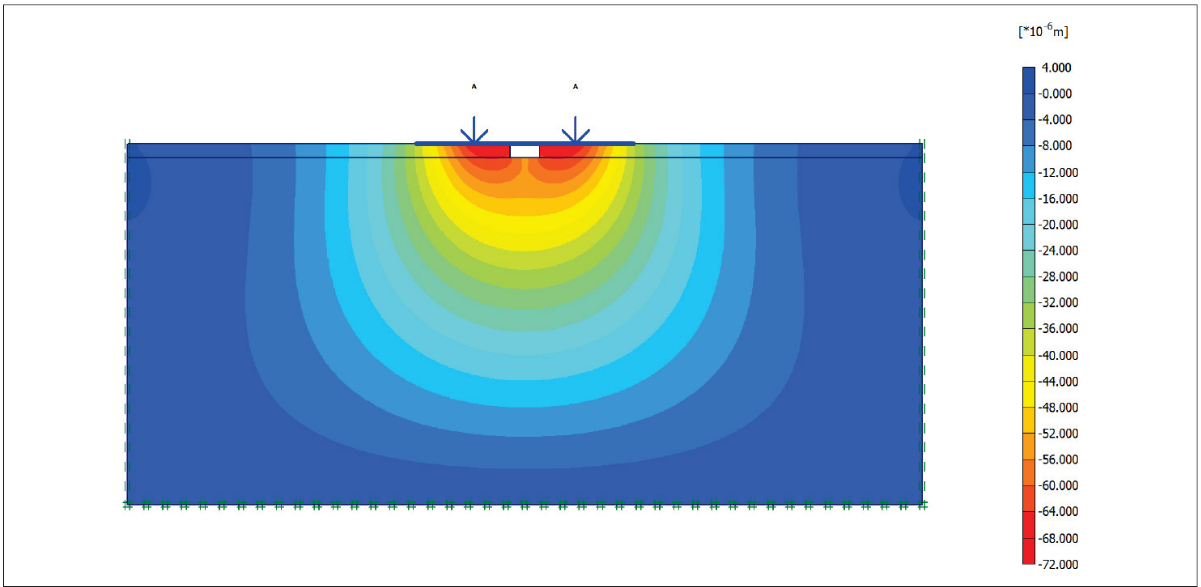

Figure 9 Displacement field for solid rock ($s_{v,max}$ = 0.069 mm)

Linear elastic model of the track slab was created in order to compare the measured eigen frequencies with the numerical ones. The slab was modelled using shell elements and the soil was considered employing subgrade modulus coefficient k (Fig. 10). Subgrade stiffness was obtained by dividing the half locomotive weight by the slab area and the measured settlements. It was assumed constant equal to 300 000 kN/m^3 for section TK 69 and 150 000 kN/m^3 for TK 13 and TK 110. The first eigen frequency amounts to 93.7 Hz for TK 69 (experimentally determined 91.4 Hz) and the corresponding eigen mode is shown in Fig. 10. One can notice quite good matching between the measured and the numerically obtained results.

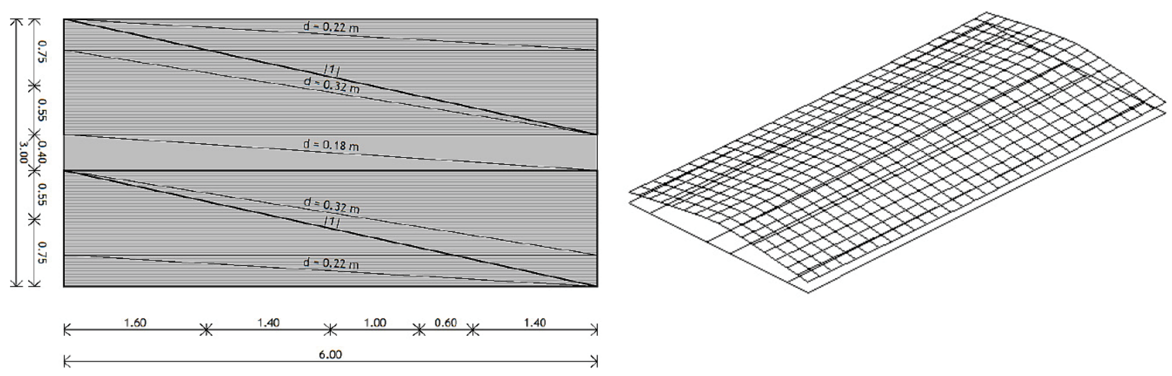

Figure 10 Model geometry (left) and the first eigen mode with f = 93.7 Hz (right)

5 Conclusion

An integrated superstructure in which the prefabricated sleepers are connected to a stiff concrete slab by using reinforcement was applied for the first time in Bosnia and Herzegovina. The track slab was founded on heterogeneous material which includes weathered marl, granular material as well as amphibolite or schist rocks.

The measured displacements under service load simulated by a locomotive and frequencies of the investigated track slab sections indicate very stiff behaviour. Considering all foundation soil conditions, the static displacements amount to maximum 0.20 mm and the first eigen frequency lies in the region around 90 Hz. Dynamic factors obtained by comparing static and dynamic deflections are less than 1.5. Results of numerical modelling regarding settlements and eigen frequencies are in the range of the measured values. Cracking in the track slab was not observed and the response of both the slab and the foundation soil is linear elastic. Considering the future application of this construction system, especially in tunnels, it is recommended to perform laboratory tests and certify the selected structural system.

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