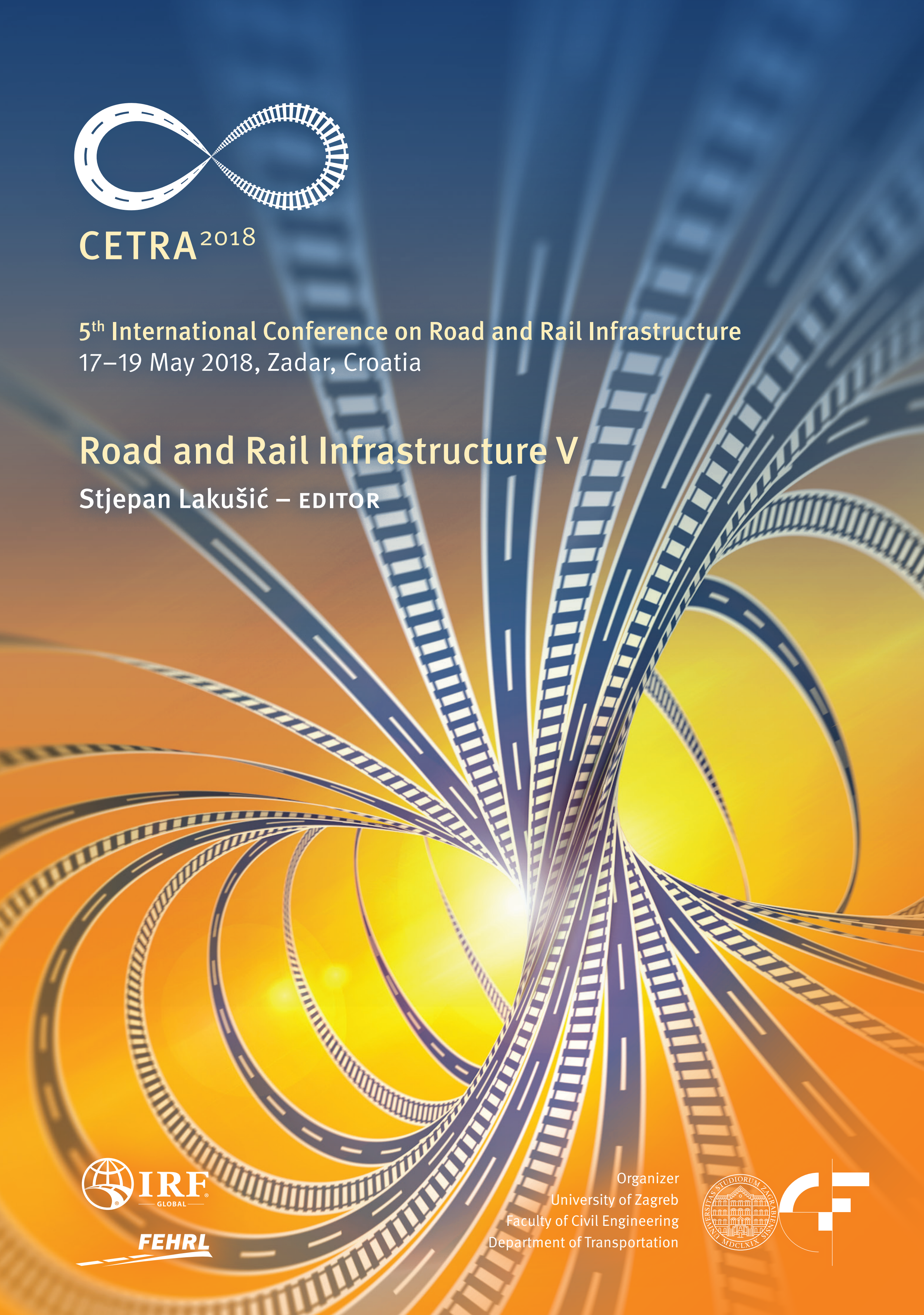

CETRA 2018

5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR

IRF GLOBAL

FEHRL

Organizer
University of Zagreb
Faculty of Civil Engineering
Department of Transportation

CETRA^{2018}
5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

TITLE
Road and Rail Infrastructure V, Proceedings of the Conference CETRA 2018

EDITED BY
Stjepan Lakušić

ISSN
1848-9850

ISBN
978-953-8168-25-3

DOI
10.5592/CO/CETRA.2018

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.
Marko Uremović · Matej Korlaet

PRINTED IN ZAGREB, CROATIA BY
“Tiskara Zelina”, May 2018

COPIES
500

Zagreb, May 2018.

Proceedings of the
5th International Conference on Road and Rail Infrastructures – CETRA 2018
17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

EDITOR
Stjepan Lakušić
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Zagreb, Croatia

CETRA^{2018}
5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

ORGANISATION

CHAIRMEN

Prof. **Stjepan Lakušić**, University of Zagreb, Faculty of Civil Engineering
Prof. emer. **Željko Korlaet**, University of Zagreb, Faculty of Civil Engineering

ORGANIZING COMMITTEE

Prof. **Stjepan Lakušić**
Prof. emer. **Željko Korlaet**
Prof. **Vesna Dragčević**
Prof. **Tatjana Rukavina**
Assist. Prof. **Ivica Stančerić**
Assist. Prof. **Maja Ahac**
Assist. Prof. **Saša Ahac**
Assist. Prof. **Ivo Haladin**
Assist. Prof. **Josipa Domitrović**
Tamara Džambas
Viktorija Grgić
Šime Bezina
Katarina Vranešić
Željko Stepan
Prof. **Rudolf Eger**
Prof. **Kenneth Gavin**
Prof. **Janusz Madejski**
Prof. **Nencho Nenov**
Prof. **Andrei Petriaev**
Prof. **Otto Plašek**
Assist. Prof. **Andreas Schoebel**
Prof. **Adam Szeląg**
Brendan Halleman

INTERNATIONAL ACADEMIC SCIENTIFIC COMMITTEE

Stjepan Lakušić, University of Zagreb, president
Borna Abramović, University of Zagreb
Maja Ahac, University of Zagreb
Saša Ahac, University of Zagreb
Darko Babić, University of Zagreb
Danijela Barić, University of Zagreb
Davor Brčić, University of Zagreb
Domagoj Damjanović, University of Zagreb
Sanja Dimter, J. J. Strossmayer University of Osijek
Aleksandra Deluka Tibljaš, University of Rijeka
Josipa Domitrović, University of Zagreb
Vesna Dragčević, University of Zagreb
Rudolf Eger, RheinMain Univ. of App. Sciences, Wiesbaden
Adelino Ferreira, University of Coimbra
Makoto Fujiu, Kanazawa University
Laszlo Gaspar, Széchenyi István University in Győr
Kenneth Gavin, Delft University of Technology
Nenad Gucunski, Rutgers University
Ivo Haladin, University of Zagreb
Staša Jovanović, University of Novi Sad
Lajos Kisgyörgy, Budapest Univ. of Tech. and Economics
Anastasia Konon, St. Petersburg State Transport Univ.
Željko Korlaet, University of Zagreb
Meho Saša Kovačević, University of Zagreb
Zoran Krakutovski, Ss. Cyril and Methodius Univ. in Skopje
Dirk Lauwers, Ghent University
Janusz Madejski, Silesian University of Technology
Goran Mladenović, University of Belgrade
Tomislav Josip Mlinarić, University of Zagreb
Nencho Nenov, University of Transport in Sofia
Mladen Nikšić, University of Zagreb
Andrei Petriaev, St. Petersburg State Transport University
Otto Plašek, Brno University of Technology
Mauricio Pradena, University of Concepcion
Carmen Racanel, Tech. Univ. of Civil Eng. Bucharest
Tatjana Rukavina, University of Zagreb
Andreas Schoebel, Vienna University of Technology
Ivica Stančerić, University of Zagreb
Adam Szeląg, Warsaw University of Technology
Marjan Tušar, National Institute of Chemistry, Ljubljana
Audrius Vaitkus, Vilnius Gediminas Technical University
Andrei Zaitsev, Russian University of transport, Moscow

CETRA^{2018} 17–19 May 2018, Zadar, Croatia
5th International Conference on Road and Rail Infrastructure

IMPLEMENTATION OF NON-DESTRUCTIVE METHODS FOR THE DETERMINATION OF TRAMWAY EMBANKMENT CONDITION

Mario Bačić, Meho Saša Kovačević, Stjepan Lakušić
University of Zagreb, Faculty of Civil Engineering, Croatia

Abstract

The results of non-destructive investigation works for the 70 years old tramway embankment in Zagreb, located on line 2.7 km long line between Mihaljevac and Dolje stations, are given in this paper. In order to preliminary assess the condition of embankment characterized by several anomalies such as deformation of tracks and tilting of a contact network pole, a non-destructive geophysical methods of Continuous Generation of Surface Waves (CSWS) and Ground Penetrating Radar (GPR) were implemented. While the electromagnetic GPR method was used for the detection of geometrical features such as layer boundaries and man-made or natural anomalies, seismic CSWS method was used for determination of small strain stiffness of the embankment, where classification system based on obtained stiffness values was developed. These values are good indicator of a large strain stiffness of embankment material. A CSWS and GPR results were overlapped with visual inspection findings leading to significant conclusions on current condition along with proposal of further investigation methods.

Keywords: tramway embankment, condition assessment, ground penetrating radar, continuous analysis of surface waves, non-destructive investigation

1 Introduction

In 1950, a tramway line between stations Mihaljevac and Dolje, Zagreb (Croatia), was constructed and open for traffic. The length of this section is 2 711 m and it is the shortest line operated by tram infrastructure manager Zagreb Electrical Tramway (ZET). During its construction, the state-of-the-art technologies were implemented and largest operating speed was 60 km/h. Along the line a special chain suspension of the cables was installed. In this way, a smaller number of electrical poles could be used and the suspension cables could be also used for power supply [1]. A reconstruction and modernization of this line was conducted in 1989. The line, Figure 1, is situated mostly on an embankment with two bridges on the line (first one with 45 m length and the second one with 15 m length).

Along with inhabitants of this part of the town, Mihaljevac – Dolje line also transports numerous hikers to the foothill of Sljeme, a favourite recreational site for inhabitants of Croatia's capital. However, the age of the tramway infrastructure has caused its gradual degradation and rehabilitation measures are necessary in order to satisfy the rehabilitation design criteria of the axle load increase. To increase the level of safety and to reduce overall rehabilitation costs, geophysical investigations were conducted in order to assess the embankment's condition.

A combination of the electromagnetic method of Ground Penetrating Radar (GPR) and Continuous Generation of Surface Waves (CSWS) was applied. The investigations were conducted in length of 2 450 m (last section of 260 m was recently reconstructed so there was no need for investigations in this part).

DOI: https://doi.org/10.5592/CO/CETRA.2018.711

Figure 1 A tramway line between stations Mihaljevac and Dolje

2 Methods of investigation

When using a geophysical method for investigation purposes, a change in the physical characteristics of the soil / rock mass, or investigated structure, for which a method is sensitive must exist. This change clearly determines the scope of method's use. By using methods with different theoretical background and by overlapping of the results, a better insight in tram line condition could be obtained.

2.1 Ground Penetrating Radar (GPR)

Ground Penetrating Radar method is a geophysical method which is based on emission of high frequency electromagnetic pulses in the subsurface by using suitable antennas. In subsurface, generated waves can be attenuated, reflected or refracted. After reflection at boundary between two materials with different dielectric characteristics, wave returns to surface where it is received by antenna [2]. Investigation depth and investigation resolution are directly influenced by the antenna frequency. When higher frequencies are used, lower investigation depth can be achieved, but the image resolution will be higher. Using lower frequencies, investigation will result in lower resolution, but larger depths can be investigated. There are two types of resolution when conducting GPR survey, a vertical and horizontal one. Vertical resolution is, simply put, smallest distance in vertical direction at which two phenomena can be apart in order to see and distinguish them as separate phenomena, while horizontal resolution is the minimum horizontal distance between two phenomena at the same depth before the radar merges them out into one single event [3]. GPR equipment, mounted on custom-made modified cart is shown on Figure 2a, while data acquisition is given on Figure 2b.

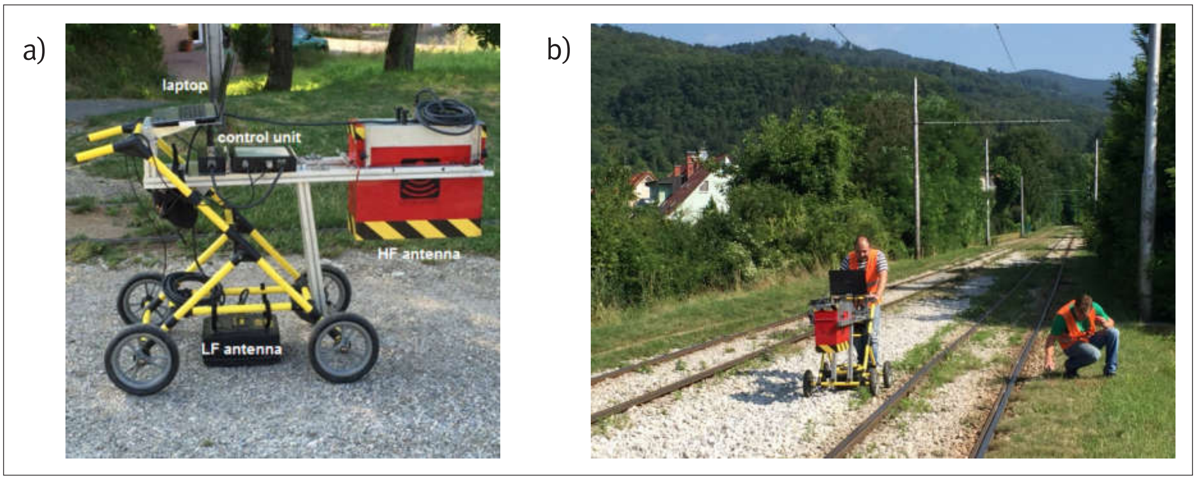

Figure 2 A GPR acquisition equipment (a) and GPR data acquisition (b)

Higher frequency antennas emit electromagnetic wave with shorter pulse wavelength which enables interaction with smaller features. Therefore, these antennas can provide a high resolution profile of the ballast surface and data for analysis of potential ballast fouling. Lower frequency antennas are used to locate potential anomalies in foundation soil, by mapping a range of factors such as boundaries between layers, defects etc. Still, a user of GPR must be aware of certain limitations of method when using them in tramway applications where the main one is the fact that interpretation of collected informations could not be straightforward because those informations are not unique.

Once the data has been collected, a processing phase follows in which filtration is carried out in order to eliminate noise, interference and adverse effects, and highlight the phenomena that are of interest. In many cases it is possible to interpret the test results with very little post-processing. A typical GPR profile is shown on Figure 3.

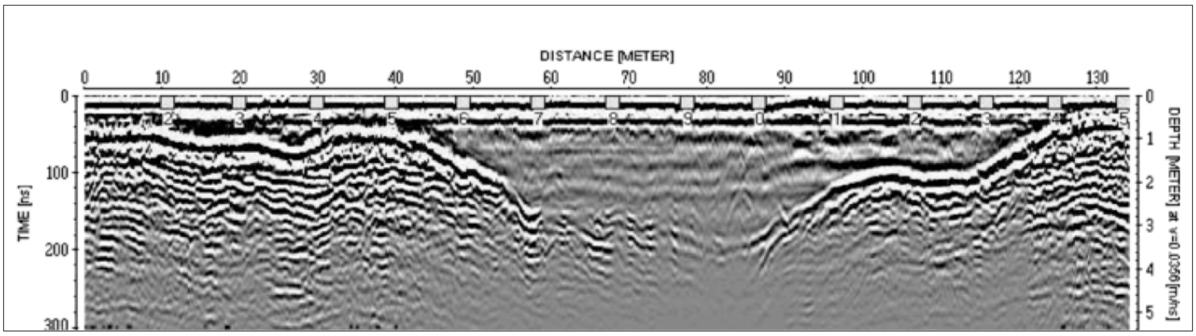

Figure 3 A typical GPR profile [4]

2.2 Continuous Generation of Surface Waves (CSWS)

The Continuous Generation of Surface Waves (CSWS) is a seismic geophysical method which represent a modification of Spectral Analysis of Surface Waves (SASW) method. As the method implies generating and measuring surface waves, the whole process takes place on the surface of the ground, and this method falls into a group of non-destructive seismic measurements. Unlike SASW method (or MASW method) which rely on the frequency spectrum of the energy generator leading to the lack of certain frequencies from the source spectrum, and thus to certain voids in the stiffness – depth profile, the CSWS method uses a vibrator as an energy generator which provides generation of controlled frequencies. The arrival of waves from subsurface is received by geophones situated on the surface at pre-defined array. The acquisition equipment is shown on Figure 4a. The data acquisition resolution in this case was 10 m, with usage of 6 geophones.

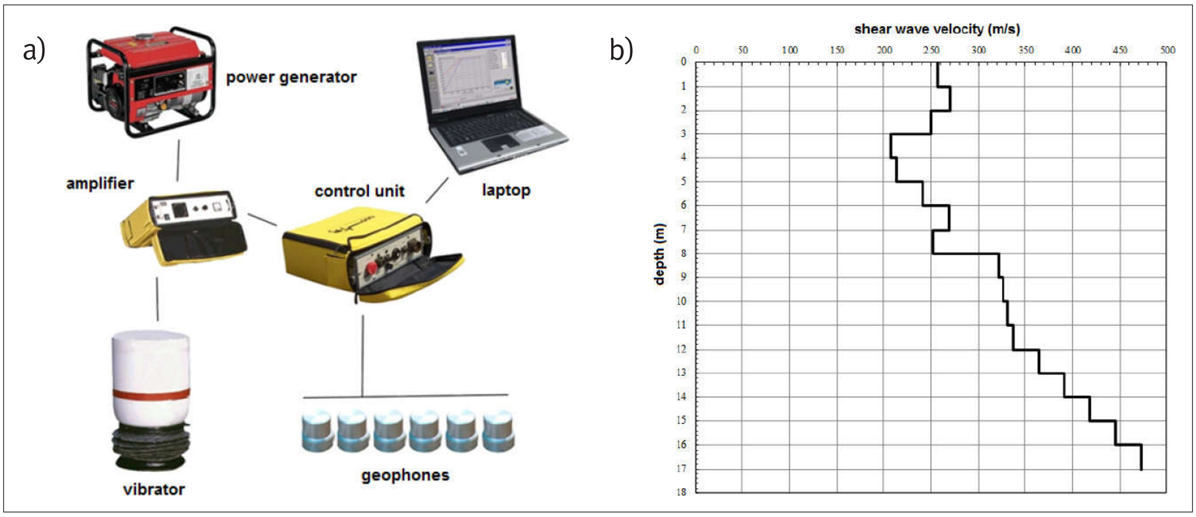

Figure 4 A CSWS acquisition equipment [5] (a) and typical 1D profile of shear wave velocity (b)

The method is based on the dispersive characteristics of Rayleigh R-waves, taking into account the fact that surface Rayleigh R-waves of different wavelengths, or frequencies, penetrate to relatively different depths. Thus waves with lower frequency, and therefore larger wavelengths, penetrate deeper into medium than waves of high frequency, or smaller wavelength. In a layered medium, the wave propagation velocity on the surface depends on the frequency, and on the wave length. This change in wave propagation velocity on a surface with a wavelength is called dispersion of a wave and is closely related to the stiffness characteristics of the layered medium through which the wave passes. Reyleigh's R-waves are generated on the surface by the interaction of longitudinal P-waves and shear S-waves, and they move somewhat slower through the medium than them. By Fourier analysis, the received signal is transformed from time to frequency domain and further spectral analysis is performed on the transformed signal [5]. The acquisition of CSWS data on location of tram line is shown on figure 5.

Figure 5 Acquisition of CSWS data

Using CSWS method, the velocity of the shear waves was determined (Figure 4b), from which the small strain stiffness of the embankment (modulus of elasticity) was determined by following procedure. Based on the obtained values of shear wave velocities, a small strain shear modulus can be obtained using a formula:

$$G_0 = \rho \cdot v_s^2 \qquad (1)$$

where G_0 is a small strain shear modulus, ρ is density and v_s is shear wave velocity. Finally, a small strain modulus of elasticity results from:

$$E_0 = G_0 \cdot 2(1+\upsilon) \tag{2}$$

where E_0 is a small strain modulus of elasticity and υ is Poisson’s coefficient. A small strain modulus of elasticity could be used as an indicator of large strain modulus of elasticity values.

3 Results and Discussion

This chapter gives an overview of results in first 3.5 m of subsurface, since this is considered as influence zone of interest. Therefore, results for each section are shown only for upper portion of CSWS investigation results (even though investigation depth is much larger) and most suitable GPR antenna was the one with 400 MHz central frequency since it gives an optimal ratio of investigation depth and image resolution. Some important features are given here. For CSWS investigations, a custom-made classes of small strain modulus of elasticity were developed, as shown on figure 6.

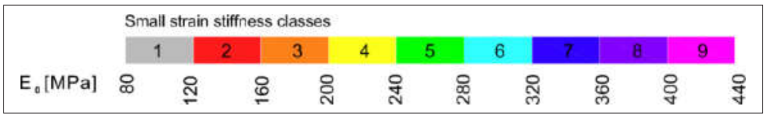

Figure 6 A custom-made classes of small strain modulus of elasticity

3.1 Section 1 (from km 0+000 to km 0+500)

At the beginning of the section (up to km 0+105), the GPR shows (red hatch) the bottom of the ballast to a depth of about 1 m, whereby the small strain stiffness modulus fits into the third class except the smaller part where the stiffness in first meter is somewhat lower, Figure 7. Up to km 0+150, a slightly deeper (more than 1 m) reflection was observed (GPR), indicating the bottom of the ballast with additional reflexes at a greater depth which could represent additionally tampered ballast zones. Here, the CSWS method points to a relatively large stiffness near the surface, below which is material of slightly lower stiffness characteristics (class 2). It is possible that tampering and replacement of the ballast material was conducted in this part with compaction of ballast material into subgrade material up to depth of 2 to 3 m.

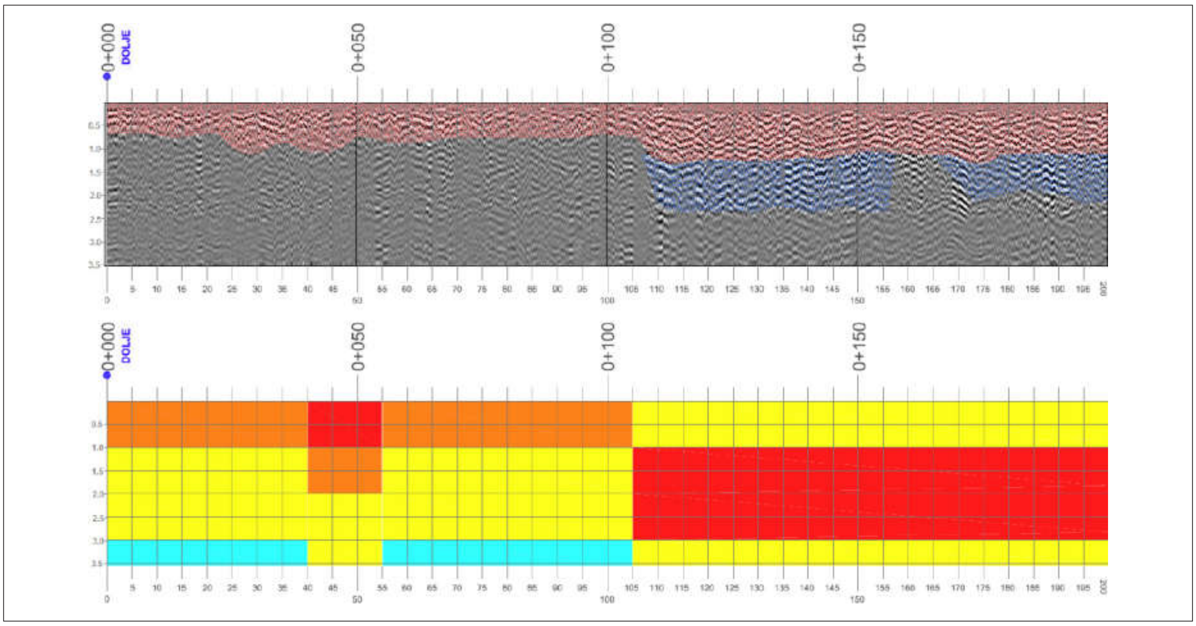

Figure 7 A GPR profile (top) and stiffness determined by CSWS for part of section 1 (from km 0+000 to km 0+200)

3.2 Section 2 (from km 0+500 to km 1+000)

At this section there are visible variations, from GPR profile, in the depth at the contact of the ballast with embankment material (GPR), however in this section CSWS provides relatively high values of small strain stiffness, especially in the part before the bridge, Figure 8.

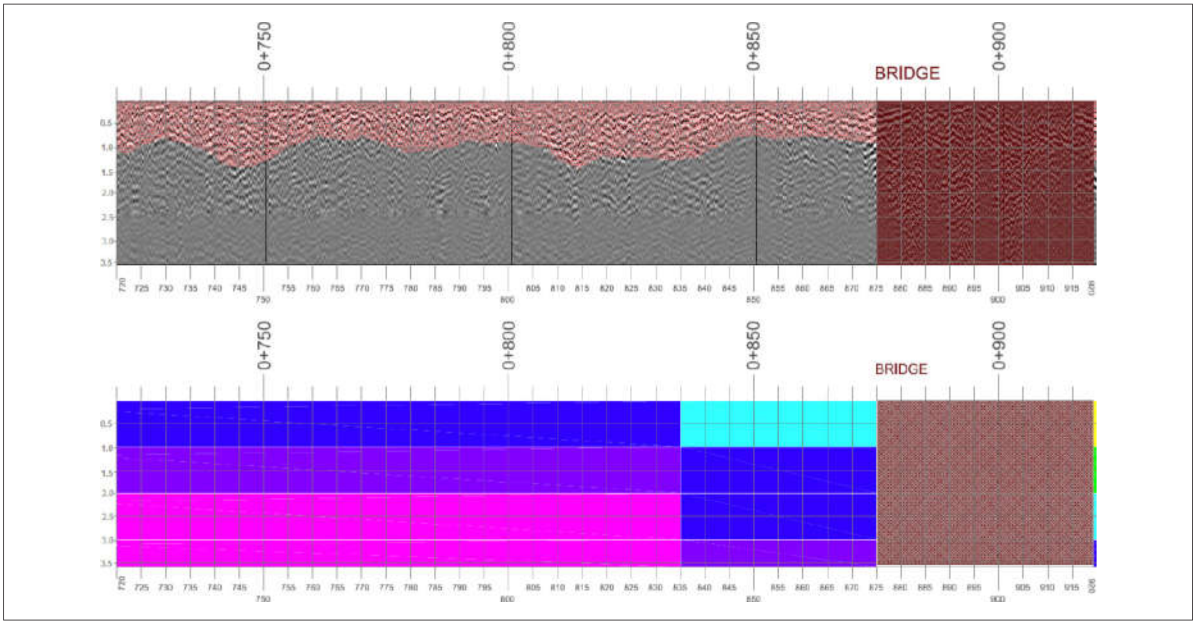

Figure 8 A GPR profile (top) and stiffness determined by CSWS for part of section 2 (from km 0+720 to km 0+920)

3.3 Section 3 (from km 1+000 to km 1+500)

The relatively large values of small strain stiffness stretch all the way up to km 1+145 meters, followed by a cca 85 m zone of extremely small values to greater depths (class 1 stiffness near the surface). The GPR results also point to certain anomalies in this section. In this part of section, anomalies of tram tracks along with tilting of tram poles was noticed through the visual inspection. After km 1+230 the small strain stiffness fits into higher classes, Figure 9.

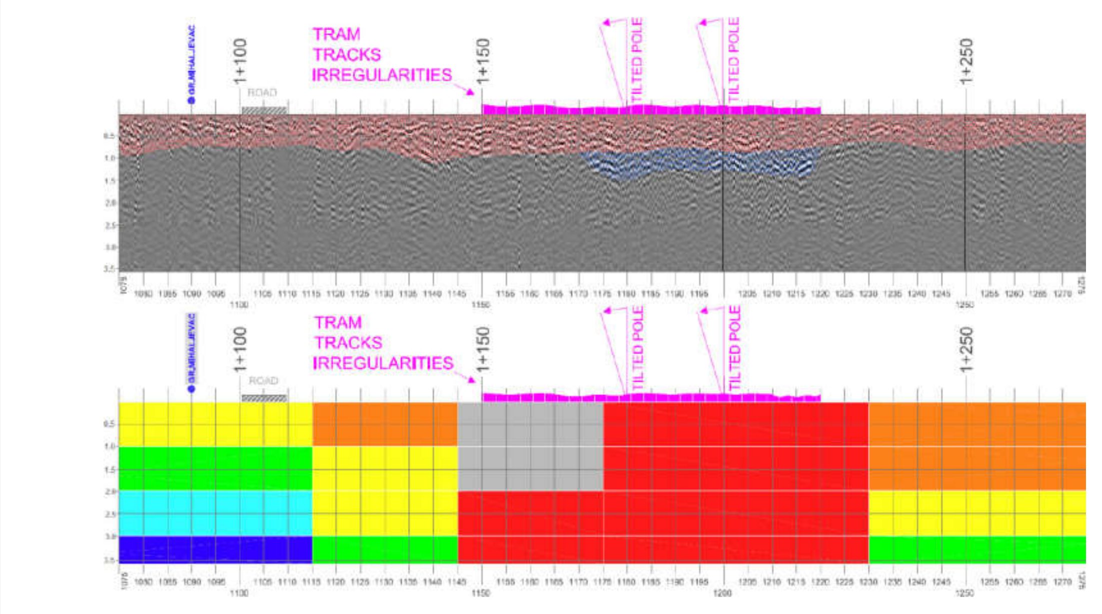

Figure 9 A GPR profile (top) and stiffness determined by CSWS for part of section 3 (from km 1+075 to km 1+275)

3.4 Section 4 (from km 1+500 to km 2+000)

After the initial part where there are visible anomalies in the GPR record that are attributed to the transition zone between the second bridge and the embankment, a deeper zones of balllast material can be noticed. The CSWS method gives relatively higher stiffness values except locally, where the material in the first two meters has slightly lower values of small strain stiffness.

3.5 Section 5 (from km 2+000 to km 2+450)

In this section CSWS gives relatively higher stiffness values, while the contact of the ballast and embankment material is to a maximum of one meter in depth.
It is important to emphasize that the presented stiffness values are not stiffness at 'work strain' but at small strain level, where according to soil mechanics, soil stiffness decreases with increasing strain level. Therefore, the displayed stiffness values with the associated classes can serve as an indicator of large strain stiffness values. From the investigation results, the zones of the poor characteristics could be assessed, but to gain insight into the physical – mechanical properties of the material at the site, it is recommended to carry out additional works involving geotechnical drilling (with SPT) and laboratory testing or CPT testing.

4 Conclusion

The possibility of implementation of non-destructive geophysical methods in engineering practice came to fore in last few decades taking in consideration rapid acquisition and larger investigated volume of soil / rock mass or respective structure. These investigations can be useful in the preliminary stages of the investigation, such is shown in this paper for tram line Mihaljevac – Dolje, in order to obtain a general picture of the condition of the embankment so that number and position of following destructive methods can be optimized. The geophysical GPR and CSWS methods, with different theoretical background, were used and by overlapping of the results, a better insight in tram line condition could be obtained.

References

[1] URL: www.zagrebacki.hr, (02.03.2018.)

[2] Marčić, D., Bačić, M., Librić., L.: Using GPR for detecting anomalies in embankments, 13th International WMHE Symposium 2013, pp. 695-710, Bratislava, 2013.

[3] Alvarez Cabrera, R.: GPR Antenna Resolution, Application notes, http://www.geoscanners.com, (08.03.2018.)

[4] Persico, R., Soldovieri, F., Utsi, E.: Microwave tomography for processing of GPR data at Ballachulish, J. Geophys. Eng. 7 (2010), pp. 164-173

[5] Menzies, B.K.: Near-surface site characterisation by ground stiffness profiling using surface wave geophysics, Instrumentation in Geotechnical Engineering, eds. K.R. Saxena and V.M. Sharma. Oxford & IBH Publishing, New Delhi, pp. 43-71, 2001.