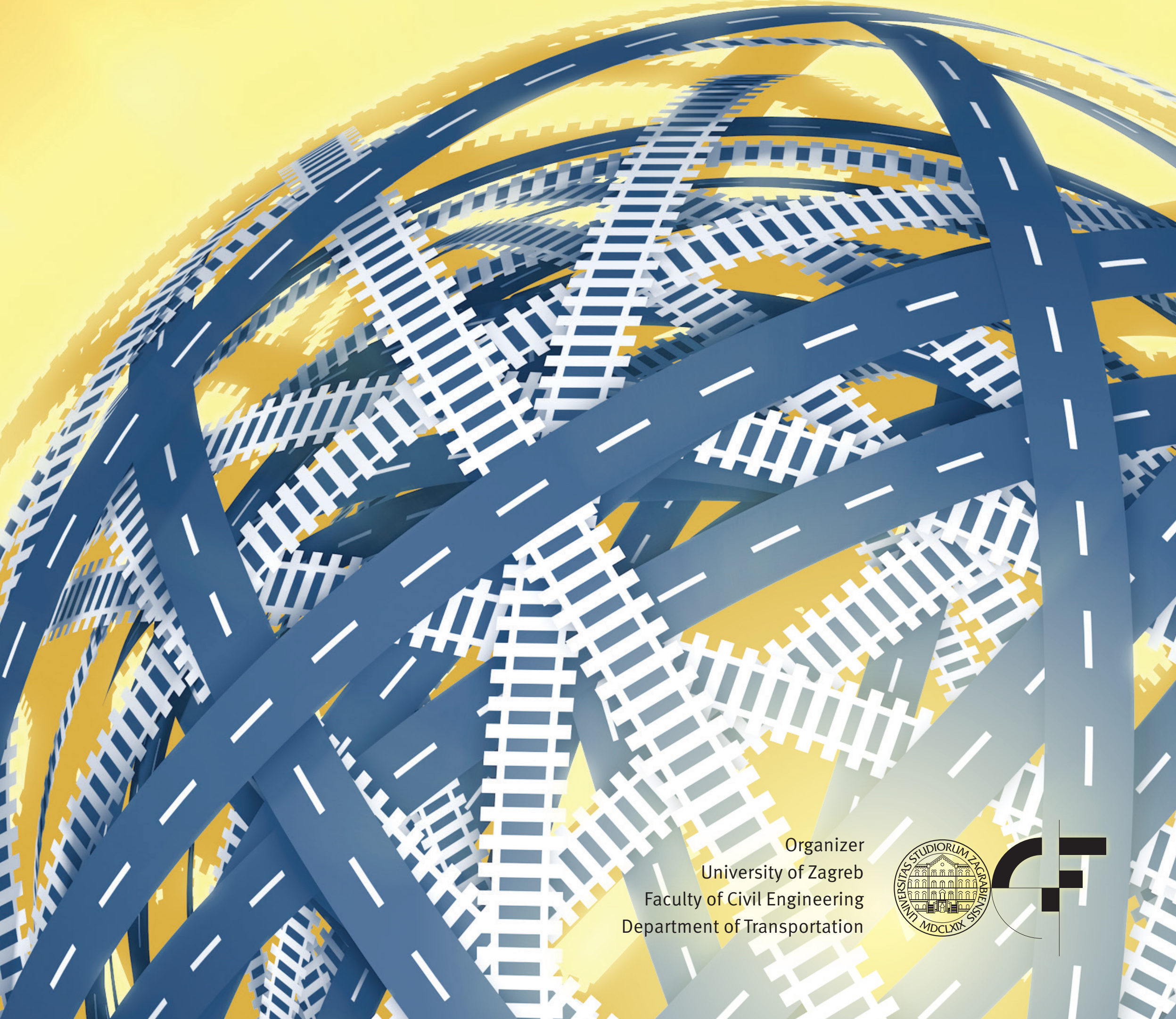
CETRA 2016

4th International Conference on Road and Rail Infrastructure
23–25 May 2016, Šibenik, Croatia

Road and Rail Infrastructure IV

Stjepan Lakušić – EDITOR



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Road and Rail Infrastructure IV

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REMEDIATION OF KARST PHENOMENA ALONG THE CROATIAN HIGHWAYS

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Abstract

More than 50 % of Croatia's area is situated in karst terrain which is characterized by dissolution of limestones, dolomites and other soluble rock masses under the influence of water, CO_2, temperature etc. As a consequence of this process, often referred to as 'karstification', a large number of karst phenomena is linked with engineering activities and directly influence existing infrastructure, especially national highways and roads. Since many highway sections, out of 1 300 km in total, are constructed in karstification susceptible terrain, phenomena such as faults or caverns can have large impact both on construction works as well as on structure behaviour during exploitation. The latter became more obvious in last few years since number of exploitation issues have been reported. Few of these phenomena are presented in this paper, including cavern near Bosiljevo exit, suffosion sinkhole near tunnel Sv. Marko and bulging of pavement near tunnel Veliki Glozac due to karstificiation of bottom layers. Besides describing the nature of these phenomena, this paper presents a methodology for their remediation combining different non-invasive geophysical methods whereas method of seismic refraction will be shown in this paper since it yields best results for fulfilment of task. The main advantage of this methodology is to obtain relatively precise information about presence, distribution and size of karst features in fast and simple manner. Based on these data, a technical documentation including remediation measures was prepared and the remediation works were conducted, or will be conducted, accompanied by detailed quality control program.

Keywords: karstification, highways, cavern, suffusion sinkhole, seismic refraction

1 Introduction

Croatia is situated in south-east Europe and, according to Kovačević et al. [1], more than half of the its area of (or over 70% if taking into account the Croatian Adriatic seabed) is situated in karst terrain, Figure 1. Field [2] explains that the karst is 'the result of natural processes on and in the earth's crust caused by the dissolving and rinsing of limestone, dolomites and other soluble rock masses'. Dissolution of limestones and dolomites, which are dominant rock masses in Croatia, is under influence of many factors such as water presence, CO_2 content, saturation level, temeprature etc. The process of carbonate rock dissolution is often called karstification. Regarding their morphology, karst phenomena can roughly be divided on surface features and underground features. Jurić-Kaćunić [3] gave an extensive description of all karst features. Surface features may be small scale such as flutes, runnels, clints and grikes, medium-scale such as sinkholes, vertical shafts, foibe, disappearing streams, and reappearing springs or large-scale such as polje and karst valleys. As a consequence of karstification, a large number of karst phenomena is linked with engineering activities and directly influence existing infrastructure, especially national highways and roads. These features can impact physical-mechanical behaviour of rock and can have large impact both on construction works and behaviour of structure during its exploitation. One of most interesting examples of karst-related issues during construction of Croatian highways is the cavern which was found during construction work of tunnel Vrata [4], Figure 2.

Figure 1 Karst regions in Croatia [1]

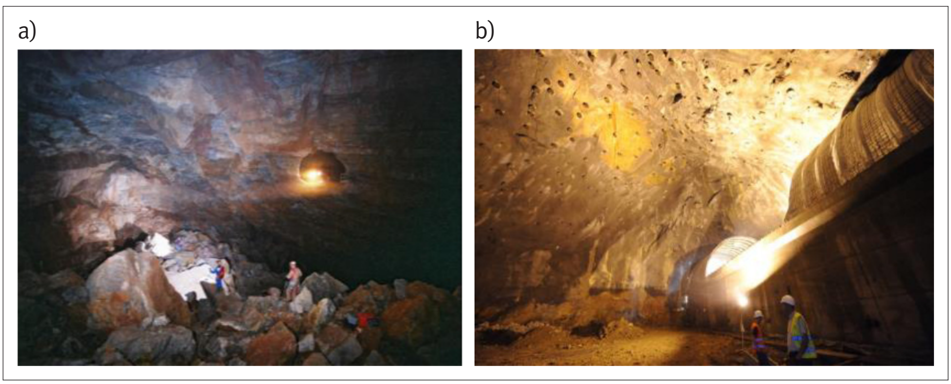

Figure 2 Cavern in tunnel Vrata: a) after detection, b) after remediation [4]

During tunnel mining, a 50 000m^3 cavern was discovered, Figure 2a, and fast and effective remediation measures needed to implemented. Remediation measures therefore included an innovative solution of constructing a bridge inside tunnel pipe, Figure 2b.
However, in recent years, problems regarding exploitation of highways and roads in karst terrain became more obvious with large number of number of exploitation issues being reported. Some of these phenomena are presented in the paper, and include cavern near Bosiljevo exit, suffosion sinkhole near tunnel Sv. Marko and bulging of pavement near tunnel Veliki Glozac due to karstificiation of bottom layers.

2 Methods for detection of karst phenomena

The basic method for detection of karst phenomena is most certainly method of visual inspection. However, the main issue regarding visual inspection is that hidden effects can be overlooked and that visual inspection is very susceptible to subjective assessment. This is especially significant when it comes to underground karst phenomena. Besides visual inspection, an invasive method of borehole drilling is traditionally used as main method for engineering – geological interpretation of underground. Even though borehole drilling gives unique information about is expensive and although it gives about geotechnical parameters, those information are obtained in discrete area (point information) and as such drilling is ineffective tool for detection of extent and scale of underground anomalies.
To overcome issues posed by invasive methods, non-invasive geophysical methods have been applied extensively in civil engineering in last few decades. Even though the main advantage of these methods is in considerable savings of time and financial resources, there is still a lack of information on selection of suitable methods and measurement parameters when using geophysical methods for investigation of karst phenomena [5]. Another disadvantage of geophysical methods is that they cannot directly (without correlation) provide information about some important physical-mechanical characteristics of rock, but this is not of great importance when it comes to simple mapping of subsurface. Generally, non-invasive geophysical methods can be divided to geoelectric, seismic and electromagnetic methods. Each of these groups consists of large number of methods and few of them have been used for detection of karst phenomena along Croatian highways. These methods include seismic refraction method, multichannel analysis of surface waves and electromagnetic method of ground penetrating radar. However in this paper, results of seismic refraction method will be presented since it was shown that, out of mentioned, this method yields best results when it comes to mapping of karst phenomena.
The main objective of the seismic methods is to define the profile of the elastic waves velocities in depth which are in direct contact with the elastic stiffness properties of the material through which they travel. Such elastic waves spread through the soil or rock after they were generated by impulse or controlled vibration on the surface. When they arrive at the border of layers of different seismic velocity, waves are reflected or refracted after which they travel back to the surface. Refraction waves are longitudinal (P) waves and they are conducted according to Snell's optics law of spreading rays in stratified medium. The method is based on the analysis of artificially created seismic waves that are generated from the surface and which are detected by measuring sensors – geophones, placed on pre-defined positions. After analysis, the final output is profile of longitudinal waves of investigated subsurface.

3 Examples of karst phenomena along Croatian highways

Even though large number of different issues have been reported and consequently treated, this paper presents only few of them.

3.1 Example 1: Cavern in 9th kilometer of the Rijeka-Zagreb highway, near Bosiljevo exit

In February 2014, on the 9th kilometer of the Rijeka-Zagreb motorway (red dot on Figure 1), in the direction of Zagreb, an opening with depth of approximately 3 m and aperture area of 10 m^2, appeared between the two lanes, Figure 3a. Detailed geological mapping, Figure 3b, indicated that the reason for this is due to so-called 'reverse' karstification where the rock mass dissolves from bottom layers to top layers. After significant degree of karstification, the collapse of surface material in the cavern located at greater depth was inevitable.

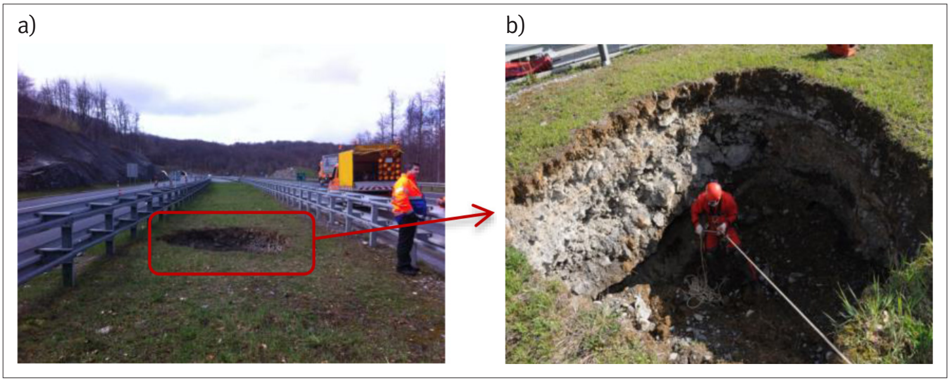

Figure 3 Opening in 9th km: a) Position of opening, b) geological mapping

Besides conduction of geological investigation, a geophysical investigation was carried out where the methods were chosen according to the geological structure of the ground and geotechnical nature of the problem related to the design requirements. Two investigation geophysical methods were therefore chosen. Ground penetrating radar profiling was used to identify potentially karstification-caused anomalies beneath the road which could endanger its functionality, while seismic refraction geophysical surveys were carried out in the area between the lanes and it was used to determine the volume and position of the cavern. After interpretation of refraction data, a longitudinal velocity profile was obtained and it is shown on Figure 4. A feature which can be easily seen is an area of reduced velocity of seismic waves between 30th and 45th meter of profile and on 6th to 14th meter in depth. This area is assigned to cavern which caused collapse of material on surface.

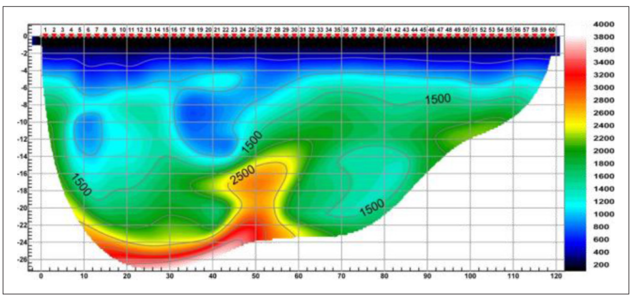

Figure 4 Refraction profile on 9th kilometer of the Rijeka-Zagreb highway

The remediation of cavern [6] consisted of two phases where, in the first phase, cavern was filled with fine-grained concrete. In second phase, a stabilization of the cavern surrounding area was done with 'contact grouting' method. After completing these phases, a surface hole was filled with gravel and reinforced slab was constructed on surface. By conducting seismic refraction investigations, a volume of cavern was estimated to be 160 m^3, while during remediation works total amount of fine-grained concrete which was used for filling of cavern was 130 m^3. This can be considered as good estimation.

3.2 Example 2: Suffosion sinkhole on the Rijeka-Zagreb highway, near Sv. Marko tunnel

During rainy period of winter 2014/2015, an opening of unknown genesis and morphology appeared near electrical substation in km 46+300 of Rijeka-Zagreb highway, next to the entrance to sv. Marko tunnel (blue dot on Figure 1). The aperture area of 13 m^2 was located next to western part of highway security fence. Also, extensive bulging of terrain was observed in area around opening, Figure 7a. It is significant that these phenomena occurred at the very end of drainage system of tunnel cutting slopes.

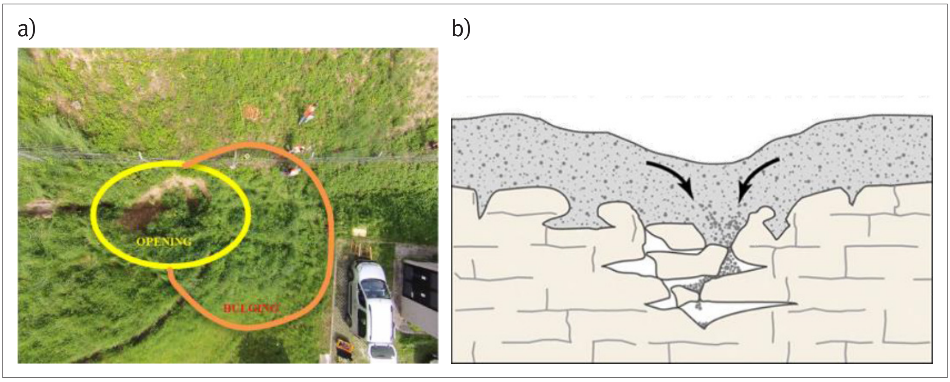

Figure 5 Suffosion sinkhole in 46th km: a) location, b) suffusion mechanism [7]

Based on investigation works which consisted of geological and geophysical investigations, it was concluded that the main reason for formation of opening is suffusion. According to Field [2], suffusion can be classified 'undermining through removal of sediment by mechanical and corrosional action of underground water'. Since the terrain on the location is made of disintegrated clastic formations of clay, silt and sand mixture, overlying fractured dolomite, the soil profile makes it very susceptible to process of suffusion. Additionally, the surface drainage system accelerated this process since surface channels end just above the location of suffusion. Therefore, genesis of this phenomenon should not be searched in underground but rather on surface, where larger inflow of water from cuttings had mechanical impact on unconsolidated sediments transporting them into upper karstified dolomite. Figure 6. shows a seismic refraction profile where the zones of lower longitudinal wave velocities can be seen in upper part with clearly visible clay pockets.

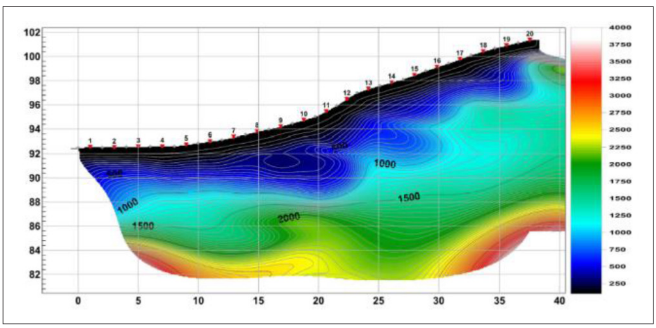

Figure 6 Refraction profile on 46th kilometer of the Rijeka-Zagreb highway

As an optimal remediation solution [8], a three phase remediation plan is established. First phase includes jet-grouting of unconsolidated sediments in order to bind soil particles by forming soilcrete with higher stiffness and strength. Raster of grouting positions is determined as 2.5 x 2.5 m triangular. After stabilization of surrounding area, next phase includes filling of the sinkhole with granulated material fraction ranging from 0 to 63 mm, while final phase includes reconstruction and extension of surface drainage system. By doing this, a further potential formation of suffusion sinkholes will be prevented.

3.3 Example 3: Pavement bulging on the Rijeka-Zagreb highway, near Veliki Glozac tunnel

Near the exit from Veliki Glozac tunnel, in km 9+500 of Rijeka-Zagreb highway (green dot on Figure 1), a pavement bulging phenomenon was noticed. The bulging occurred in length of 6 m with 20 cm pavement denivelation, covering two highway lanes, Figure 7a. After conduction of geological and geophysical investigation works, it was concluded that the reason for bulging is result of steeply sloping speological object which was partially detected during construction of highway back in 1997. and 2001. Rock mass in which this speological object was formed, has been partially mined for construction of tunnel cuttings. However, it is possible that one part of the same speleogical object, which was in fossil phase of speleogenesis, remained under the lanes of highway where bulging occurred.

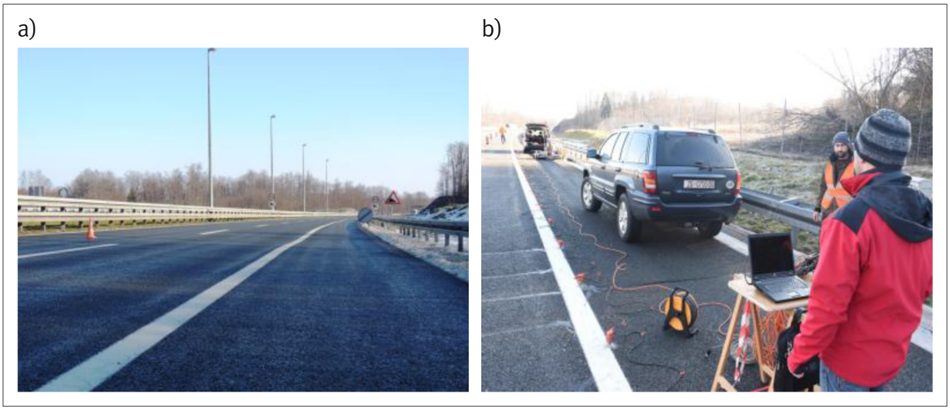

Figure 7 a) Pavement bulging in 9.5th km, b) seismic data acquistion

On this basis, a complete seismic profiling was conducted, consisting of seismic refraction method and multichannel analysis of surface waves method. The acquisition of data posed some problems since each geophone had to be drilled inside pavement in order to collect data properly, Figure 7b. One resulting refraction profile is shown in Figure 8. where three zones of reduced wave velocities can be can be distinguished. These zones are located to the depth of 12 meters, just below the location of pavement bulging. Therefore, it was decided that proper remediation measures must be taken into account.

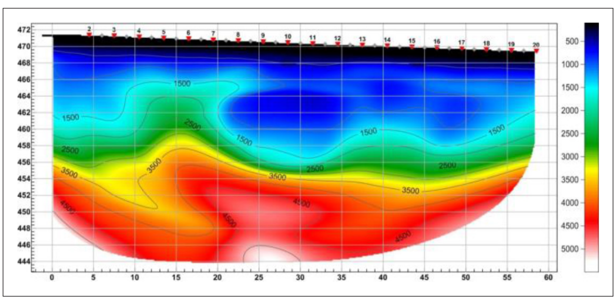

Figure 8 Refraction profile on 9.5th kilometer of the Rijeka-Zagreb highway

Planned remediation measures [9] consist of removal of existing pavement as initial phase. After that, a filling of the cavern with fine-grained concrete is planned where drilling holes will be used in same time as prospection holes to determine the actual state of rock mass in base. Next, surrounding area will be stabilised by contact grouting method, following levelling and compaction of highway subbase layers. As final phase, 18 cm thick reinforced slab will be constructed as well as layers of binding and dense tar surfacing materials.

4 Conclusion

Since the large part of Croatian highways is located in karst terrain, susceptible to process of rock mass dissolution, a number of issues regarding their exploitation have been reported in last few years. Some of these include cavern between highway lanes in 9^{th} kilometer, pavement bulging due to karstification of bedrock layers in 9.5^{th} kilometer and sinkhole suffusion on 46^{th} kilometer, all on Rijeka – Zagreb highway. To form a basis for remediation measures, a geological and non-invasive geophysical investigation works were conducted. While the geological investigation works provide answers to genesis and nature of each problem, geophysical investigation works provided an estimation of volume and extent of karst phenomena. Between few methods used for multi-geophysical approach, a method of seismic refraction yielded best results when it comes to mapping application. For each problem, a detailed design documentation was prepared including remediation measures conducted in several phases. All remediation works are accompanied by detailed quality control program.

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