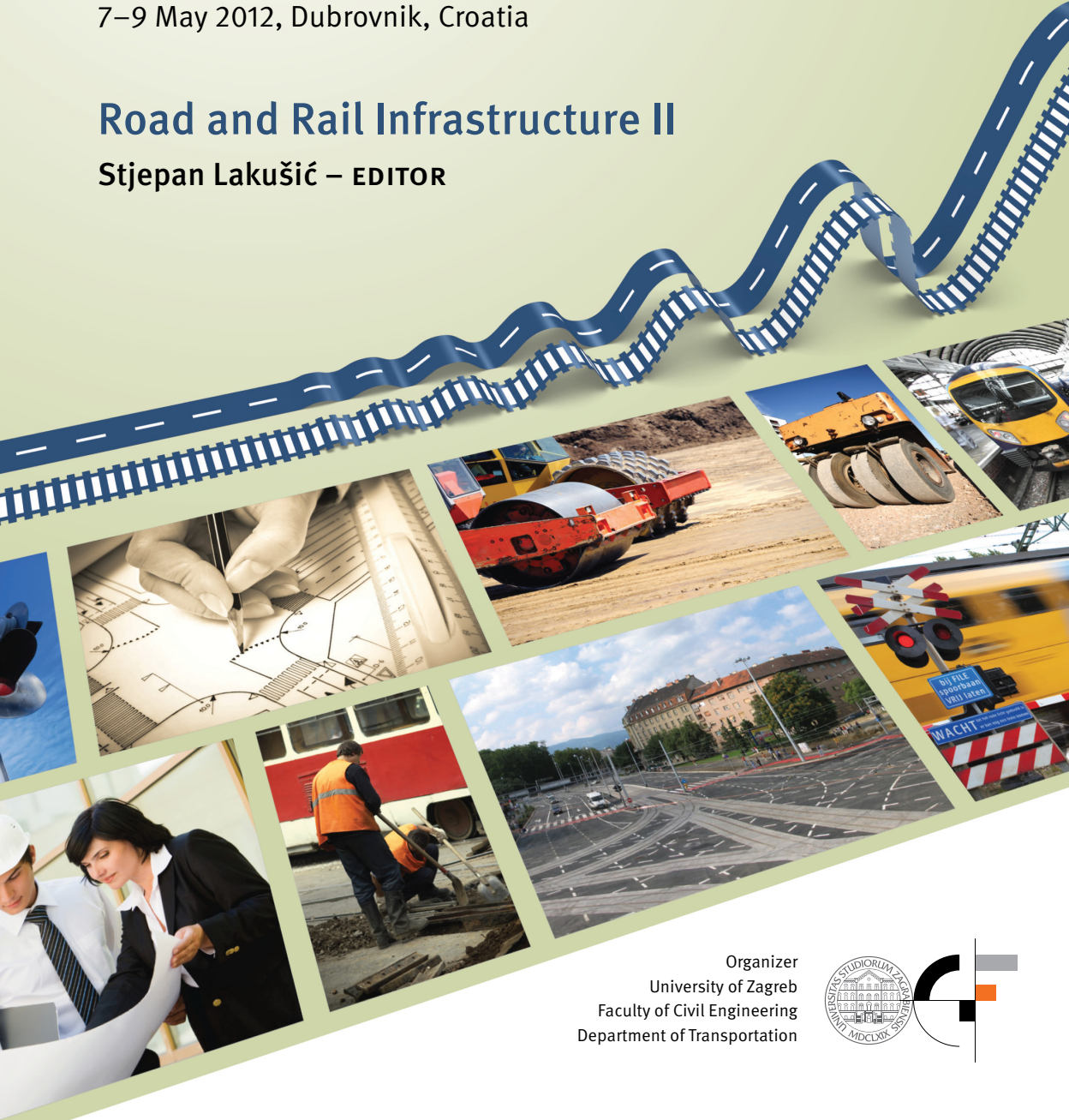


**CETRA**<sup>2012</sup>

2<sup>nd</sup> International Conference on Road and Rail Infrastructure  
7–9 May 2012, Dubrovnik, Croatia

## Road and Rail Infrastructure II

Stjepan Lakušić – EDITOR



Organizer  
University of Zagreb  
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Department of Transportation



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# Road and Rail Infrastructure II

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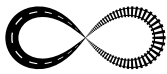
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## THE STUPICA TUNNEL – ROCKFALL PROTECTION

Meho Saša Kovačević, Antonia Mirčeta, Lovorka Librić  
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### Abstract

The D512 state road is the shortest link between Makarska and Vrgorac. In October 2010, at the site directly before the Stupica ridge, a large rockfall occurred. Under the Stupica location, where the rockfall occurred, there is a very steep slope leading towards the existing arterial road that runs along the coast. In the event of a rockfall and the rolling of large boulders down the slope, there is a high risk of endangerment to the settlement, people's assets existing transmission lines and the arterial roads. This was the largest ever rockfall that had occurred in the Republic of Croatia. The volume of the largest boulders varied from approx. 100 to 250 cubic meters. Following the rockfall, the largest boulders remained lying on the road. A rockfall of this magnitude resulted in large stress changes in the rock mass, thereby threatening the stability of the slope and consequently proving a risk to road safety. Simply removing the fallen boulder pieces and allowing traffic on the road was not possible without undertaking additional measures in securing stability against further rockfalls. In order to eliminate the direct danger to people and property caused by the landslide of rock material, plans were made for constructing a tunnel including additional measures for securing the slope at the tunnel entrance and exit using active and passive rockfall protective measures.

This paper presents the experience gained in geotechnical investigation works, design, construction, supervision, geotechnical measurements and observations during operations. Based on results from completed geological alpine mapping and trajectory simulation of the possible movement of potentially unstable boulders, barriers were designed based on specific numbers, positioning, impact capacity and set heights for protecting against rockfalls.

*Keywords: rockfall, barriers, rockfall protection, tunnel, karst*

### 1 Introduction

The D512 state road is the shortest route between Makarska and Vrgorac, i.e. Ravča (30.6 km). Besides being exceptionally important to local traffic throughout the year and vital for the tourist season during the summer period, it also provides a link to the Ravča A1 motorway node. The road is managed by the Croatian Roads company which is owned by the Republic of Croatia.

On 24 October 2010, on the D512 state road at the section immediately preceding the Stupica ridge, a large landslide occurred, releasing rock masses and subsequently closing the roadway to all vehicles [1]. The landslide happened at a section where a very steep cliff face exists, some 45 – 50 metres above the road, where the rock mass is fragmented into block-like segments with evidence showing discontinuities and fissure systems.

In front of the Stupica location, where the landslide occurred, there is a very steep slope leading towards the main arterial road which runs along the coastline. In the event of a landslide or the rolling of larger blocks down the slope, a great risk is posed to the safety of settlements, people's property, existing transmission lines, as well as the stated main arterial roads.

This is in fact the largest rockfall event that had ever occurred on the Croatian territory. The volume of the largest rockfall boulders ranged from 100 to 250 m<sup>3</sup> in size. Following the rockfall, the boulders remained on the road (Figure 1).



**Figure 1** The rockfall on the D512 state road

The rockfall of this magnitude resulted in large stress changes in the rock mass, threatening the stability of the slope and traffic safety. Simply removing the rockfall boulders and letting traffic pass wasn't an option without the implementation of additional measures for ensuring stability against further rockfalls. Based on a contract signed with Croatian Roads, IGH Corp. drew up the necessary geological and geotechnical exploratory works, the design project, and subsequently the main rockfall repair project.

## 2 The Stupica Tunnel

The main design envisages 'access to threatened' locations using a short tunnel, and carrying out a series of protection works of the most intense rockfall zone. The length of the planned works was approx. 450 m. The total length of Stupica Tunnel is 185 m. The approach cutting slopes directly prior to the tunnel entrance and exit is protected using rockfall protection galleries. The entrance gallery is 30 m long whereas the exit gallery is 15 m. The works for protecting the roadway against rockfall included designing rockfall protection barriers (Figure 2). At its 114<sup>th</sup> session held on 10<sup>th</sup> March 2011, the Croatian Government brought about a formal Decision on the Undertaking Construction in the Event of Direct Danger Posed to the D512 State Road at the Makarska–Vrgorac Section at Stupica. In order to remove direct danger to people and property caused by the rockfall material on the D512 state road at the Makarska–Vrgorac section at Stupica, Croatian Roads were given permission to construct a tunnel and additional associated slope protection at the tunnel entrance and exit.



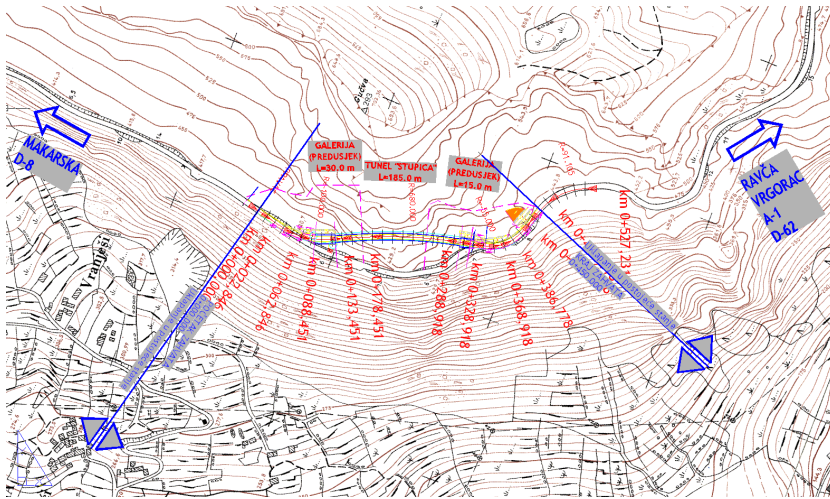


Figure 2 The main design – works necessary for rockfall protection

With the aim of accelerating works, particular corrections in the design solution were carried out. Instead of carrying out galleries, the tunnel was extended. This significantly reduced the quantity of works required in constructing the tunnel approach cutting and therefore reduced deadlines. The detailed works project was compiled by the companies IGH, Viadukt Projekt and Viadukt Kontrukcije. The design solution reviews and verifications were carried out by the Faculty of Civil Engineering University of Zagreb. Works were assigned to the company VIADUKT. The Rockfall protection barriers were constructed by OCTOPUS company from Rijeka. Rockfall protection works commenced from the northern side on 15 April 2011. Tunnel excavation works commenced in May 2011. The total tunnel length of 227 m was penetrated on 29 June 2011.

The tunnel penetration was carried out on both sides of the tunnel. Excavation was conducted by blasting and the use of hydraulic impact hammer, and a combination of both. Average daily excavation progress was 3.5 metres per day.

The overburden amounts to 95 m. The area of the excavated perpendicular cross-section is 75.23 – 101.99 m<sup>2</sup>, while the perpendicular cross-section of the clear span is 56.17 m<sup>2</sup>. The width of the traffic lanes is 2 x 3.00 m (Figure 3).





di Geologia Applicata ed Ambientale from Bogliaco in Italy, carried out geological alpine mapping of unstable boulders and subsequently drew up the respective geological and geo-mechanical report which serves as an appendix to the protection design for the road section affected by the rockfall, i.e. D512 Makarska – Ravča (Stupica section).

Geological alpine mapping recorded 52 unstable boulders (Figure 4). Due to the danger posed by works which could result in the rolling or sliding of some of the boulders situated along the discontinuity surface, it became necessary prior to commencing works to fixate such boulders using a system of anchors, elastic meshes and pre-tensed steel cables in order to protect workers and equipment.



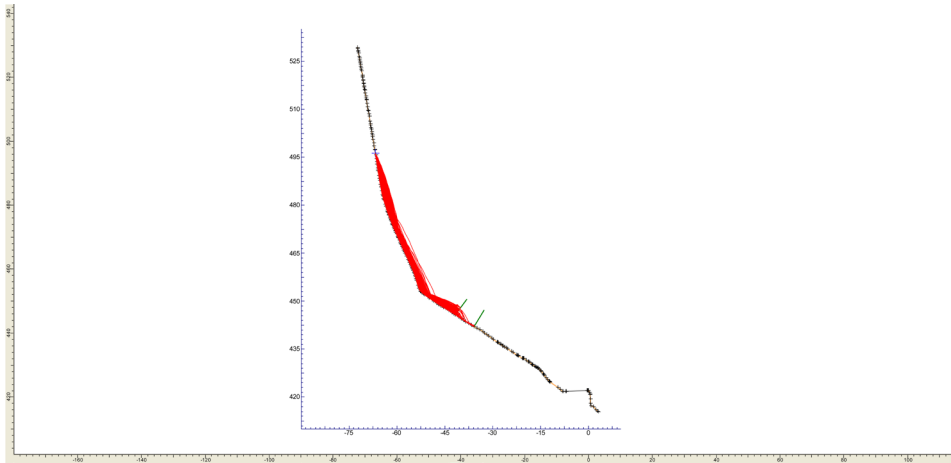
Figure 4 Unstable boulder no 41 located using geological–alpinist mapping

## 4 Rockfall protection

An analysis of the results conducted by geological alpinist mapping, trajectory simulation of the possible movement of potentially unstable boulders and taking into account that due to the essential dynamics in conducting works, instead of entrance and exit galleries, the tunnel was to be constructed longer dimension–wise than anticipated in the main project, and it was therefore necessary to change the number, allocation, energy capacity and height of rockfall protection barriers.

A rockfall simulation at the typically calculated profiles allows for the positioning, defining and dimensioning of rockfall protection barriers which according to their energy capacities, height and inclination can handle the presumed rockfall event. The trajectories of rockfall boulders was analysed using a statistical method in order to predetermine the speed and height of the incoming boulder onto the barrier position [2].

Geotechnical and kinematic analysis was carried out using the software RocFall version 4.054 (Fig. 5) [3]. Designing the rockfall protection system was conducted in accordance with ETAG guidelines [4, 5]. Prior to the undertaking the design procedure, the MEL (Maximum Energy Levels) design approach was utilised.



**Figure 5** Calculated inclination profile in km 0+109 with trajectories and positions of calculated and selected barriers BU-3 and BU-4

A solution was chosen in order to achieve satisfactory safety against a rockfall event by using a combination of a systems of so called 'double' barriers possessing an energy capacity of 3000 kJ, at a height of 6 m (Figure 6) and by 'retaining' the larger potentially unstable boulders (which cannot be halted using the barriers) using a system of anchors, elastic meshes and pre-tensioned steel cables (Figure 7). The total length of the barrier is 320 m, four barriers totalling a length of 210 m were placed along the northern approach cutting, and three barriers 110m in length were set up along the southern approach cutting.



**Figure 6** Constructed barriers Retaining unstable boulders



**Figure 7** Retaining unstable boulders

## Conclusion

Rockfall at location Stupica on roadway D512 was the largest ever rockfall event in the Republic of Croatia. The volume of the largest fallen boulders varied from approx. 100 to 250 cubic meters. A rockfall of this magnitude resulted in large stress changes in the rock mass, thereby endangering the stability of the slope and consequently road safety. Geotechnical kinematic simulation and analysis of rockfall caused by detected dangerous boulders at the calculated typical profiles was carried out on the basis of the conducted investigation works, geological alpinist mapping of potentially unstable boulders, boulder mass determination, assessment of critical trajectories for falling boulders and location prospection. As a result of analysis of the rockfall protection system, a solution was selected to meet the safety requirements for rockfalls by using a combination of a system of so called 'double' barriers possessing an energy capacity of 3000 kJ, at a height of 6 m and by 'retaining' the larger potentially unstable boulders which cannot be halted using the barriers.

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