# VELA DRAGA – ROCKFALL PROTECTION OF THE A8 MOTORWAY– A DIFFICULT CONSTRUCTION SITE ON A MAIN TOURISTIC TRAFFIC LINE IN ISTRIA


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ABSTRACT
The A8 is an important motorway running between Kanfanar and Matulji, in western Croatia. The first construction began in the mid-1970s, with significant upgrading and extensions over the past four decades. A build-operate-transfer concession agreement has been in place since 1995. In recent years, several minor rockfall events have occurred and have resulted in the need for rockfall mitigation and slope stabilization. In 2015 and 2016, a design-build tender was carried-out with construction started in October 2017. The economic and touristic importance of this motorway, along with other physical constraints such as limited working corridors, high vertical slopes and its location in a national park, bear great similarities to highway expansion projects in the mountains of Alberta and British Columbia. In this paper, an overview on the design and construction process and the intended mitigations will be presented and discussed.



RÉSUMÉ
L'autoroute A8 est une autoroute importante entre Kanfanar et Matulji, dans l'ouest de la Croatie. La première construction a commencé au milieu des années 1970, avec des améliorations et des extensions importantes au cours des quatre dernières décennies. Un accord de concession de construction-exploitation-transfert est en place depuis 1995. Au cours des dernières années, plusieurs éboulements mineurs ont eu lieu et ont entraîné la nécessité d'atténuer les éboulements et de stabiliser les talus. En 2015 et 2016, un appel d'offres de conception-construction a été réalisé avec une construction débutée en octobre 2017. L'importance économique et touristique de cette autoroute, ainsi que d'autres contraintes physiques telles que des couloirs de travail limités, des pentes verticales élevées et sa localisation dans un parc, présentent de grandes similitudes avec les projets d'expansion routière dans les montagnes de l'Alberta et de la Colombie-Britannique. Dans le présent document, un aperçu du processus de conception et de construction et des mesures d'atténuation prévues sera présenté et discuté.


## 1 INTRODUCTION

The motorway A8 is the eastern branch of the Istrian Y Motorway (Figure 1), which has a high importance for this touristic region as the main traffic route servicing the eastern side of the Istrian Penninsula in Croatia. As it winds its way through the Učka mountain range, many steep rock slopes are encountered and pose a hazard to passing motorists. The continued growth of traffic volume over recent years supports the necessity for upgrades to improve both flow as well as safety (Figure 2). The project area is located near the eastern terminus within the middle of the Učka Nature Park. Following the occurrence of several minor rockfall events, a comprehensive rock slope inspection and corresponding rockfall investigation was carried-out in 2015 and 2016. In 2017, a tender procedure led to the award to a Slovenian joint venture, Bina Istra d.d., to undertake mitigation measures. The first phase of construction began in October 2017 with a planned completion in February 2018. The second phase will start in fall 2018.

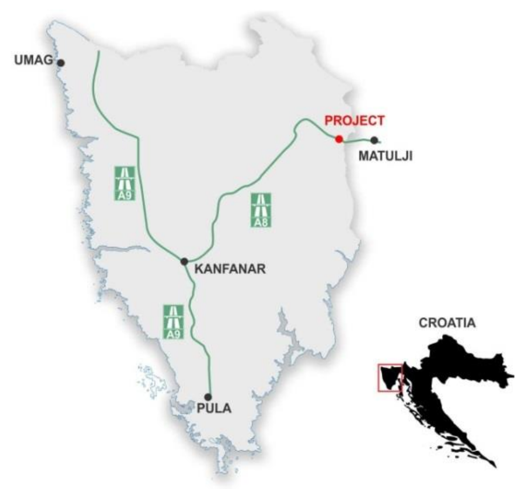

Figure 1. Location of Istrian Y Motorway and project area.

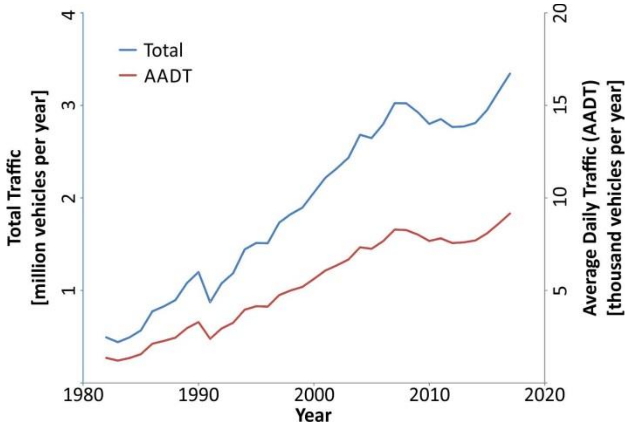


Figure 2. Traffic volume in the project area

## 2 SITE DESCRIPTION

The section of motorway of concern is approximately 225 m long (Figure 3). Of this, 105 m is constructed on backfill material with a 8-15 m high retaining wall supporting the outer shoulder. The remaining 120 m of road is a viaduct constructed within a few meters of the slope. The road corridor is a maximum of 10 m wide, including a 1.25 m paved shoulder on either side. Each lane of traffic is 3.75 m wide. At either end of the road segment, there is a U-shaped portal that stands just over 9 m high and is approximately 7 m wide. Running along the inside shoulder there is a main electrical power line and international optical cable line that connects services between the Istria and Kvarner regions.

The up to 60 m high, near vertical rock face behind the road and those that form the face of the portals are mostly natural slopes of foraminiferous limestone. During the initial construction, mechanical excavation has formed overhanging areas directly adjacent to the roadway in order to create room for the section along the backfilled slope.

The bluffs consist of stratified foraminiferous limestone from the lower to middle Eocene that, given the intense tectonics, is highly fractured. The rock is also highly porous with good water permeability. Where the slope has been excavated, the rock is highly fractured and erodible.

## 3 HAZARD ANALYSIS

During the course of the hazard analysis, a UAV equipped with a LIDAR scanner was used to generate point cloud elevation data and high resolution photos. A traditional geodetic survey was used for placing the data into the correct coordinate system in order to create the 3D model, over which the photos were draped. From this model, slope cross sections were generated for every 10 m and used for rockfall analysis.

In total 58 unstable blocks were identified, ranging from 0.5 to 75 metric tonnes. The weight and location of the block determined the mitigation approach. Those blocks that were obviously too large for mitigation via secondary structures, such as rockfall barriers, were removed from rockfall analysis and would be stabilized in-place.

A total of 11 characteristic block sizes were used as input for the rockfall modeling with a range between 5.4 – 13.6 tonnes at positions varying from 35 – 60 m above the road. Modelling was carried out using Rocfall 5.0 with the 2D profiles. The resulting energies were between 900 – 6500 kJ. This resulted in the further identification of blocks that were required to be stabilized in situ due to the high energy or extreme bounce heights.

## 4 TENDER DESIGN

The preliminary design used for the tender procedure consisted of the following mitigations, with their location shown in Figure 4a:

1.) *Green Lines:* Rockfall catchment fences with an energy capacity of 3000 kJ 2000 kJ, with 7 m and 6 m high posts respectively.
2.) *Yellow Zone:* Drape mesh system consisting of two layers of hexagonal netting 80/100/3.0 and 50/70/2.2 supported by an anchor system (25 mm mono bar anchors, 0.5 – 1.5 m embedment) along the brow and weighted at the toe by small concrete blocks.
3.) *Orange Zone:* Drape mesh system with 25 mm bolts (embedded 30 cm) covered with a thin shotcrete layer of 3 to 5 cm.
4.) *Green Zone:* Rock block stabilization using steel rope nets with 25 mm mono bar anchors 1 to 1.5 m embedment.
5.) *Red Zone:* Reinforced shotcrete system having two 7.5 cm layers over anchored mesh system with pattern anchoring (2.5 x 2.5 m grid, 25 mm mono bar anchors, 6 m embedment) and PVC tubes for drainage (2.5 m x 2.5 m grid).
6.) *Magenta Zone:* Single block stabilization with 16 mm steel ropes fitted with turnbuckles and 25 mm anchors embedded 1 to 1.5 m.
7.) *Cyan Zone:* Single hollow bar anchors (R38N) with anchor plates. Anchor grid 2.5 m x 2.5 m.

Figure 3. Oblique aerial view of project site showing partially installed mitigation measures.

## 5 DETAIL DESIGN

Once the tender was awarded, it became Bina Istra d.d.'s task to carry out a detailed review of the preliminary design and finalize all constructions. This process led to further detailed investigations and technical discussions between Bina Istra d.d., Učka Nature Park, the contractor and the engineering company responsible for the detail design and resulted in a few adaptations of the original measures.

The most significant change was the replacement of shotcrete material with an anchored mesh system that uses high tensile netting. Where the rock was highly fractured on the artificial overhang, a fine mesh layer was added to ensure no material would pass through the system. One of the major reasons for eliminating the shotcrete was that large amounts of water observed seeping from across the slope following rainfall. The limited drainage capabilities of the shorcrete system were deemed inadequate in favor of the free-draining mesh. Other reasons included the minimization of dead load on unstable blocks, the ability for partial revegetation, and aesthetic considerations.

Two changes were also made to the slope mesh systems:1) along the brow of the slope, an alternative product was considered viable, replacing the heavy steel cable nets with a lighter product of reinforced hexagonal netting and 2) the double layer of drape mesh was replaced by a pinned drape mesh system and extended further upslope.

To confirm the initial design of the rockfall catchment fences, the contractor (EHO projekt d.o.o.) carried out a verification according to ONR 24810 guidelines (ASI 2017). The energies and heights proved sufficient so no changes were necessary. However, some adaptations to the position as it needed to be adjusted to properly consider the elongation of the system during an impact as well as the overall lengths to best fit the site. Extra gully nets were recommended to help seal gaps beneath the barriers where they ran over highly undulating terrain. Lastly, rockwall connections and overlapping systems were required where barriers butted up against adjacent faces of the eastern tunnel portal, where any material passing by the system would immediately impact the traffic space.

Figure 4b shows the detail design with the above mentioned adapted mitigations

1.) *Green Lines:* Rockfall catchment fences with an energy capacity of 3000 kJ 2000 kJ, with 7 m and 6 m high posts respectively.
2.) *Yellow Zone:* Anchored mesh system using hexagonal netting 80/100/2.7. Anchors were 12 mm bolts embedded 25 cm on a 3 x 3 m grid.
3.) *Green* Zone: Rock block stabilization using hexagonal netting 80/100/2.7 reinforced with 12 mm steel wire ropes and pinned using 20 mm mono bar anchors.

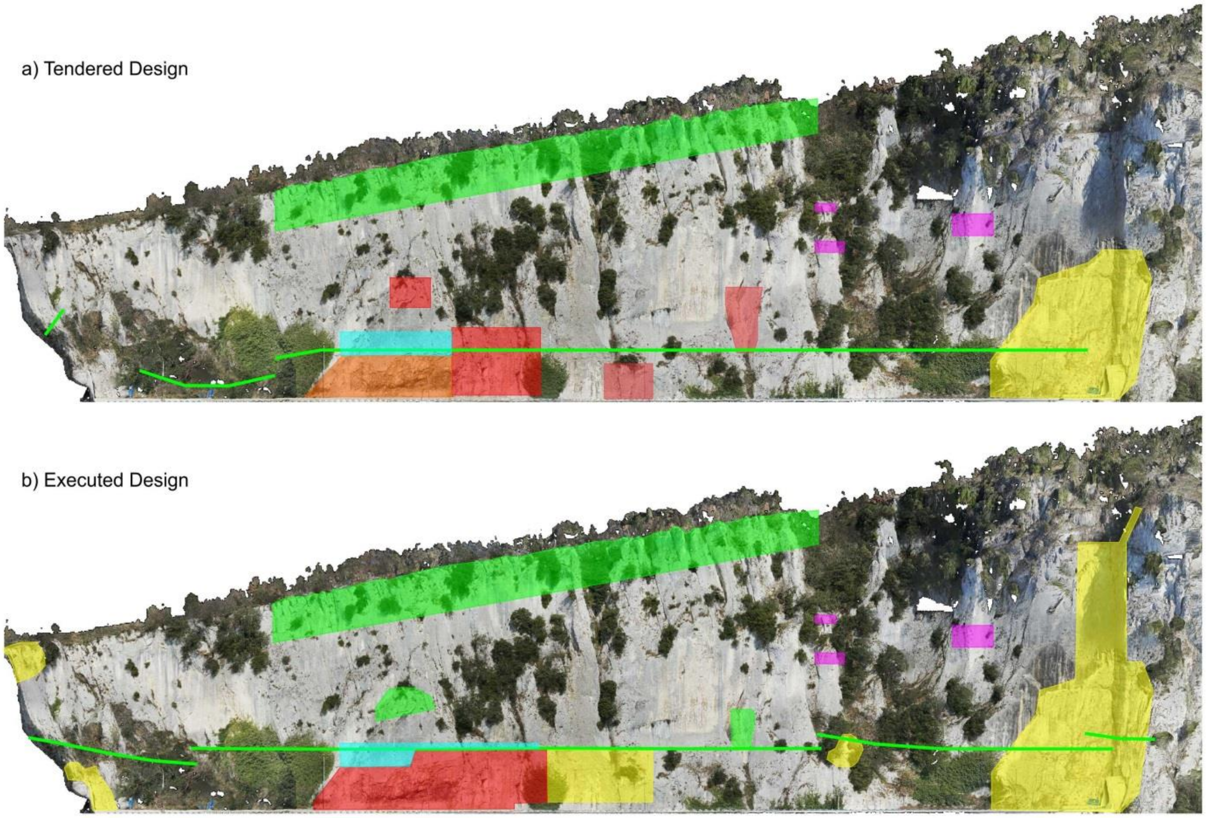

Figure 4. Mitigation layout for the tendered design and the executed design overlaying an orthophoto draped over a 3D model.

4.) *Red Zone:* Anchored mesh system using high tensile strength mesh (50/50/4.6 mm) with a fine mesh layer (30 x 30 mm). Anchors were 20 mm mono bars either 3 m or 6 m embedment or 32 mm bars with 9 m embedment.
5.) *Magenta Zone:* Single block stabilization with 16 mm steel ropes fitted with turnbuckles and 25 mm anchors embedded 1 to 1.5 m.
6.) *Cyan Zone:* Single mono bar anchors (32 mm) with anchor plates. Anchor grid 2.5 m x 2.5 m, 9 m embedment.

## 6 CONSTRUCTION

Total duration of construction was set by the contract to 104 working days. Working days were defined as any day in a week that has appropriate working conditions including weekends and holidays. A work day was set to 0:00-24:00 in several shifts. The only exception was Christmas/New Year's holidays from when due to extreme traffic intensity no work was allowed. During this time, all temporary protection measures had to be removed so that traffic could be opened in both lanes. Afterward, all measures had to be reinstalled. Though the work was successfully carried out in the contracted timeframe, approximately 20% of the scheduled time had unfavorable conditions that stopped work from continuing (e.g. weather, traffic conditions).

Construction was broken into two phases. The first consisted of work on slopes up to 32 m above the road surface. This was controlled by the reach of the truck-mounted crane fitted with a drill rig. During this phase the majority of the anchors for the mesh systems as well as all the rockfall catchment fences were installed. The crane was also used for the installation of the mesh and barriers themselves.

The second phase consisted of work above 32 m elevation and involved steep slope rope access techniques. A combination of a two-rope system with the help of certified motor winches was employed. Battery powered hand-held drills were used to install smaller rock bolts, while larger anchors were installed using a down-the-hole hammer drill (hydraulic and pneumatic) mounted on a sled. During this phase, the in situ stabilization of large unstable blocks was carried out as well as the mitigation measures along the brow of the slope.

The high economic and logistical importance of the motorway necessitated that it remain open during construction. Operations were therefore confined to a single lane, separated by a jersey barrier from single-lane alternating traffic. This left a 3.5 - 4.4 m wide construction corridor, some of which was overhung by the rock slope. Under these extremely tight conditions, operations had to be well planned out with some necessary adaptations to standard methods.

For example, a special cantilevered protection barrier was attached to a haul truck to help protect passing vehicles from falling debris during drilling operations (Figure 5). Dust was also a major concern so drill rigs were fitted with heavy rubber mats that helped control the dispersion of dust and small particles. Some limited closures were allowed for the most sensitive areas, i.e. the slope overhang and above the portals, but for only short intervals at pre-determined times (e.g. post installation on Sunday between 07:30-08:00 or anchor testing between 00:00-03:00) when traffic was at its lowest intensity.

Since the viaduct, which formed more than half of the project area, had been rehabilitated the previous year, it needed to be protected. In order to minimize damage, the surface was covered in a 6 mm geosynthetic and, in the most sensitive areas, additionally by 25 mm wood planks. Furthermore, railings were covered in by wooden form work.

Restrictions set by the Učka Nature Park led to specific requirements on the site work. These included seasonal operation restrictions due to nesting birds, documentation procedures for the discovery of karst features, the inspection of scaled material for fossils, and the minimization of impact on the landscape such as removing rock material from the slopes. As well, the washing of the grout pump was not permitted on site. This in itself was a logistic hurdle since the construction corridor was normally blocked by the various machinery and temporary structures.

The drilling and installation of anchors also had technical challenges. For example, the upslope anchors for the retaining ropes from the rockfall catchment fence must be drilled in line with the expected rope forces. This results in an anchor dipping steeply upslope, special "packers" were required, which allowed upslope injecting of boreholes. Packers consisted of expendable rubber core and steel edge plates equipped with bolts for tightening and closing the borehole. Upslope injecting was realized using 2 preinstalled high pressure PEHD ¾" pipes (vent pipe that reached the end of the borehole; injection pipe for the grout that ends approximately 0.5 m behind the packer in borehole). Injecting was performed through the lower injection pipe and was completed when grout started pouring from the vent pipe on the top of the borehole. Furthermore, because of the orientation of the stratification, drilling often led to the detachment of large rock plates that posed a risk to workers and equipment.

A total of 1554 linear meters of 90 mm boreholes were drilled with 523 pieces of solid bar GEWI/SAS anchors installed (length from 1-9 m, diameter 20 mm-40 mm). Approximately 10 m$^3$ of injection grout was used where about 20% of the boreholes needed post-injection grouting. Quality controls was performed according to EN 14490:2010 and local HR EN 1537:2013 (testing of anchors) and HR EN 445:2000 (injection grout).

Figure 5. Cantilevered screen to protect traffic from drilling operations. Wooden planks used to protect the road surface can also be seen.

Approximately 520 pieces of 12 mm rock bolts were installed for the hexagonal mesh adaptation. A further 300 more were used as temporary solutions and anchorages for things such as stabilizing the crane mounted drill at anchor locations or securing anchor bars in the boreholes for the upslope retaining rope anchors prior to injecting with grout (elsewise the bars would have slid out of the inverted holes).

285 m of rockfall catchment fences were installed in 4 separate lines. A 43 m long TSC-2000-ZD 2000kJ barrier with a height of 6 m was installed above the western portal. The remaining fences consisted of 242 m of TSC-3000-ZD 3000 kJ barriers with 7 m heights (Figure 6). A 43m, 148m and 78 m long fences were installed along the main face of the slope while a 16 m long fence was constructed above the eastern portal and which overlaps one of the other fences in order to seal off the inside corner. Furthermore, gully nets consisting of the same nets used in the barriers were installed below the fences to close off major gaps in topography.

Approximately 5200 m$^2$ of standard hexagonal mesh was installed with two sizes of mesh opening: 60 x 80 mm and 80 x 100 mm. The smaller mesh size was installed over areas exhibiting higher fracturing and spalling of smaller material. For the high tensile strength mesh that was required, 600 m$^2$ of High Performance Netting was installed underlain in sections by a finer mesh layer with a 30 x 30 mm opening.

The project was completed with zero traffic or worker accidents due to the high safety standards and protocols implemented by the stakeholders and the contractor. There were some problems with equipment failures that were the result of machinery working around the clock, since it was logistically not possible to alternate machines in such a confined work corridor. Anticipating this, the contractor was organized such that replacement parts and services were readily on hand, and the problems were normally fixed within an hour, even in the middle of the night.

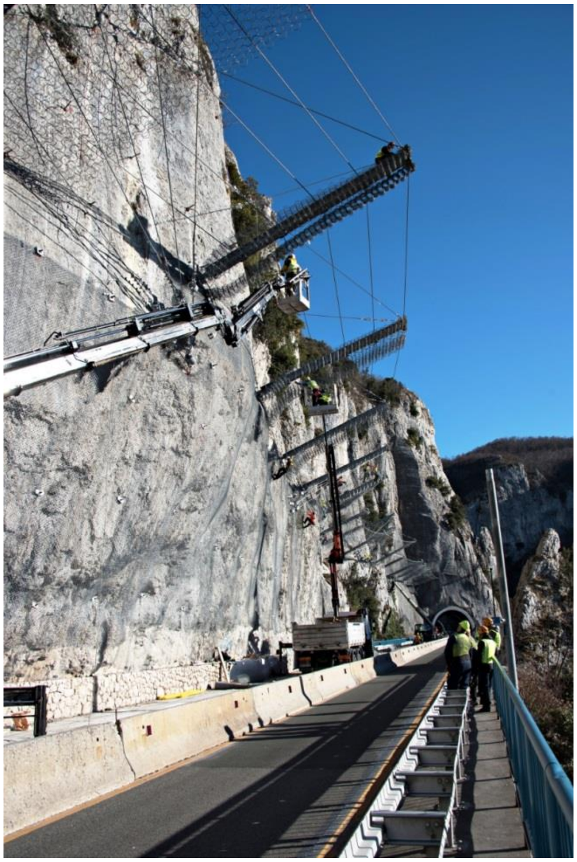

Figure 6. Installation of the 3000 kJ rockfall fence.

## 7 SUMMARY

This project represents one of the most extreme slope mitigation projects in the history of Croatia. The total cost of the project was approximately €870,000 (approx. $1.34 million CDN) including all costs by the “turnkey contract” model used. The costs include all the contract works with road regulations but exclude design, supervision and other activities made by stakeholder/investor before the tender.

The temporary protection works and safety measures put in place to protect the workers and the general public during the construction took more than 30% working time of the overall project. The remaining 70% of working hours were spent on constructing the long term mitigation measures.

One of the biggest achievement was the execution of all works in extreme conditions and limited workspace with only 4 total closures of traffic lanes during the nighttime (by 2.5-3.0 hours).

The result of the project is the complete protection of 250 m long (including slopes above the portals, Figure 7) up to 60 m high vertical limestone cliff which endangered the only traffic route between two important regions in Croatia.

## 8 OUTLOOK ON PHASE II

The phase II located between the tunnels Zrinščak 2 and tunnel Učka is recently on the level of tender design, whereby the detail design will start in spring 2018, the realization is intended for fall 2018.

Figure 7. Complete portal protection (left: western portal, right: eastern portal)

## 9 REFERENCES

ASI 2017. *ONR 24810: Technical protection against rockfall – Terms and definitions, effects of actions, design, monitoring and maintenance*. Austrian Standards Institute, Vienna, Austria.

## 10 ACKNOWLEDGMENTS

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