LANDSLIDE RISK INCREASING CAUSED BY HIGHWAY CONSTRUCTION

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ABSTRACT

Hazard of landslides appearance is dependent on slope conditions described with geometry, soil composition, structure and soil parameters, so as hydrogeological, climate and vegetation conditions as a time variable. This paper presents experiences in the landslide hazard and risk increasing during the Adriatic Highway construction in the flysch slopes of Draga Valley near Rijeka, Croatia. The geological fabric of Draga Valley is very complex: steep slopes are consisting of limestone rocks and flysch deposits in the bottom, mainly made of siltstones and covered with clayey slope formations. The route of designed highway is lying on lower parts of the flysch slopes, where the alignment is formed partially by slope cutting and partially by embankments filling. The consequences are steeper slopes, deficiency of masses in lower parts of the slope, increasing of hydraulic gradients of ground water flows and decreasing of run-off surface waters coefficients with significant impact on pre-existing high landslide hazard in the area. Hazard increasing was resulting with numerous landslides during the highway construction. Similarities of landslides in dimension, shape, depth of slip surface, mechanism of sliding so as risk consequences were indicating on relatively explicit pattern. Based on these facts, it was possible to identify the landslide risk on similar flysch slopes.

Key Words: Landslide, Hazard, Risk, Flysch slope, Highway construction

INTRODUCTION

Natural hazards represent a threat in inhabited areas only. Risk which represents the measure and the price of the consequences is directly related to hazard. There are two risk components: the possibility of the unfavorable event and the unfavorable consequences. The combination of these two components in risk concept gives the measure of risk. Therefore, the measure of risk is the outcome of the cross section of hazard and value of elements at risk through their vulnerability. Risk evaluation is a process which assigns the individual significance of risk for the individual, organization or the community (Crozier and Glade, 2005). In some cases risk can only be evaluated by judging and experience, and express in qualitative terms. Qualitative methodology is based on the assumption of one or more persons that are conducting the assessment of landslide susceptibility and landslide hazard (Aleotti and Chowdhury, 1999). The input data is usually gained from the location survey, photographs and ortho rectified photography of the area.

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This paper pursues with the basic principles of flysch rock mass behavior and the landslide hazard and risk analysis in the area of Draga Valley during the highway construction. The segment of Adriatic Highway through the Valley was constructed during 2004 and 2006 and it was the main landslide triggering factor in this area which the instability occurrence is geomorphologically and geologically predisposed. Landslides are geomorphologic processes which can be related with the shape of the slope, material structure and material strength properties so as hydrogeological, climate and many other conditions at which they appear. The construction of a highway significantly influences on part of these conditions and the landslides hazard and risk considerably increase.

In Draga Valley the landslide area occurring during the highway construction was multiplex, and, although remedial works and stabilization of occurred sliding, it was obvious that the landslide risk in area was increased. To estimate overall landslide risk during the construction and after, in the stage of exploitation of highway, the landslide hazard and risk so as dominantly caused factories were analyzed. It is important that the assessment is done by an expert who is living with the risk, because risk perception is always influenced by some subjective values (cultural, educational, social and other).

GEOTECHNICAL PROPERTIES OF THE DRAGA VALLEY

During the designing phase for the highway the complex geotechnical works in Draga Valley are examined. Cognitions about geological fabric of Draga Valley slopes are amended after additional engineering geological and geotechnical investigation works after the instabilities occurrence during the highway construction, whereby the detailed geological fabric of the slope was established. The slopes in Draga valley are made of limestone rock mass and the Paleogene flysch deposits mainly made of siltstones with rare layers of sand, marl, and breccia in the bottom of the Valley (Fig. 1). Paleogene flysch complex in the zone Klana – Rječina Valley – Draga Valley – Bakar Bay – Vinodol Valley, has suffered deformations during the tectonic movements. They are caused by stresses of different directions and intensity. Along the significant folding and faulting, the consequence of the strains is the low degree of metamorphism visible on the expressed splitting, especially in the fine-grained members of the flysch complex.

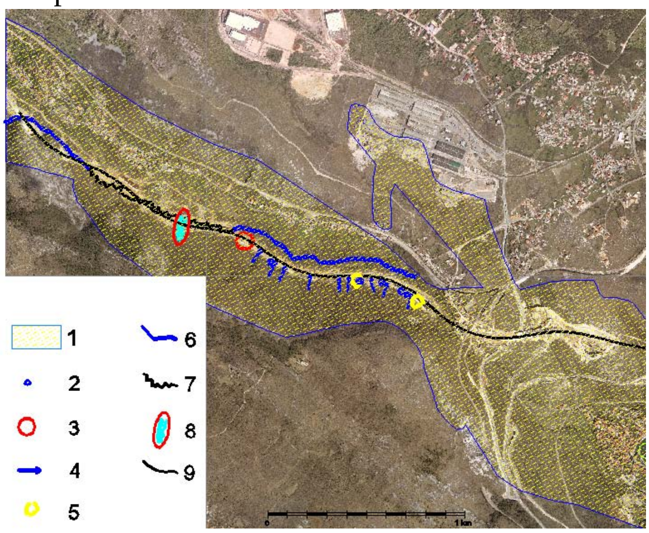


Fig. 1 Digital ortho rectified photography of Draga Valley (2004.): 1- Flysch complex area; 2- Surface wetting; 3- Fissures on the slope; 4- Flowing on the slope; 5- active landslides; 6- Main surface flows; 7- Stream Brišk; 8- Natural watercourse-; 9- Adriatic Highway in construction

By investigation works considerable deviation in the thickness of certain soil layers that are following the highway route, were noticed. In the mentioned zone there are sporadic thick zones of potentially unstable deluvial-coluvial entities which are mixture of the clayey material from disintegrated and eroded flysch deposits and gravitational transport coarse-grained fragments from hypsometrically higher carbonate parts of the slope (Magdalenić *et al.*, 1992; Arbanas *et al.*, 1994; Benac *et al.*, 2006).

Flysch rock mass is subject to chemical weathering, which is particularly expressed in the fine-grained members, especially varieties of silts and shale. Due to the mentioned processes flysch rock mass gradually increases in volume, disintegrates and dissembles into clay and silt components (Fig. 2). By gradual degradation it becomes clayey-silty completely weathering rock mass zone, whose physical-mechanical properties are more like engineering soil (Arbanas *et al.*, 1999; Benac *et al.*, 2005, Dugonjić *et al.*, 2008). Typical geotechnical profile (Fig. 3.) of the slopes in Draga Valley consists of three layers: clay cover made after disintegration of flysch rock mass (residual soil) or brought by gravitation from hypsometrically higher parts of the slope, layer of weathered flysch deposits with variable weathered characteristics, which decrease with depth and fresh flysch zone (Arbanas *et al.*, 2008).

Fig. 2 Instabilities in Draga Valley during the highway construction

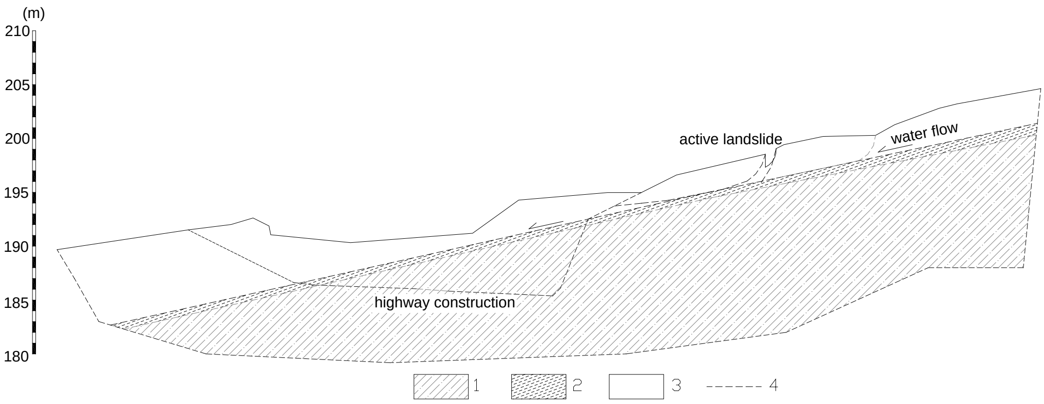


Fig. 3 Geological cross section of Draga Valley: 1- deformed siliciclastic rock mass – flysch: marls, siltstones, sandstones in alteration (position of layers is approximate); 2- weathering zone: silt and clay with rocky fragments; 3- slope deposit: sandy clay with rock fragments (10-80%); 4- sliding surface

In the entire outline of incurred instabilities engineering geological investigation works confirmed the typical geological profile. The weathering degree of the flysch rock mass can be separated in two layers: weathered flysch rock with different weathering degree and the fresh flysch bedrock. The main problem in the analyses was the determination of the strength and deformation parameters of flysch deposit layers according for the certain weathering degree. Regarding the lithological structure and degree of weathering flysch rock mass has very diverse physical and mechanical properties. In respect to the exceptional susceptibility to weathering under atmospheric conditions, some rocks from the flysch complex considerably change the physical-mechanical properties in relatively short time period of weathering. Thereat it is important to know the level of weathering (ISRM, 1978). The rock mass is mainly consists of siltstones which exhibit visual transfer from completely weathered zone with yellow color through highly weathered, moderately weathered and slightly weathered deposits all the way to completely weathered fresh rock mass colored gray and blue (Arbanas *et al.*, 2008).

Determination of the shear strength criteria and deformability modulus of flysch rock mass was based on the Geological Strength Index (GSI) concept (Marinos and Hoek, 2000; Marinos and Hoek, 2001, Marinos *et al.*, 2005). Based on recommendations from Marinos and Hoek (2001) fresh (F) siltstone flysch rock mass is placed in group E (Weak siltstone or clayey shale with sandstone layers) to H (Tectonically deformed silty or clayey shale forming a chaotic structure with pockets of clays. Thin layers of sandstone are transformed into small rock pieces.), with GSI values from 30 to 10. For determination of flysch rock mass strength the Hoek-Brown failure criterion is used (Hoek *et al.*, 2002) with uniaxial strength values of fresh (F) siltstone rock mass of σ_c=10 MPa and disturbance factor D=0.7, which corresponds to machine excavation. In completely weathered (CW) flysch rock mass on the contact with clayey cover the Mohr-Coulomb criterion is adopted with strength parameters equal the parameters in the colluvial deposits and residuals soils.

TRIGGERING FACTORS OF INSTABILITIES IN THE VALLEY

The first step in landslide hazard assessment in Draga Valley was the identification of hazard nature. It was necessary to establish landslide type on the basis of the accepted terminology (Varnes, 1984). It was established that occurred instabilities in Draga Valley were typical shallow rotational slides or shallow translational slides with slope surface on the contact of the clayey cover and flysch rock bedrock. Analysis of the landslide triggering factors implies the comparison of critical conditions significant for the beginning of landsliding with the stability conditions, assuming that the conditions which trigger sliding and the environment conditions are constant (Crozier and Glade, 2005). Analysis of the triggering factor influence and magnitude must be used in the landslide magnitude and frequency analysis. Such factors should be monitored, recorded and analyzed for longer period of time to give more reliable data. Based on previous experiences it was concluded that the main landslide triggering factors on flysch slopes were geological structure, hydrogeological conditions, intensive rainfalls which anticipated landsliding, the influence of the seasonal period, climate changes, road presence, anthropogenic interventions in environment, cover thickness, terrain slope and drainage conditions, terrain morphology, changes in groundwater level, vegetation density and seismicity of the area (Arbanas *et al.*, 1999, Dugonjić *et al.*, 2008). Anthropogenic factors are harder to assess, while the research of the natural factors is more successfully used in landslide hazard assessment. Factors that are meaningful and thereby considered in the landslide risk analyses of Draga Valley are shown bolded in Fig. 4.

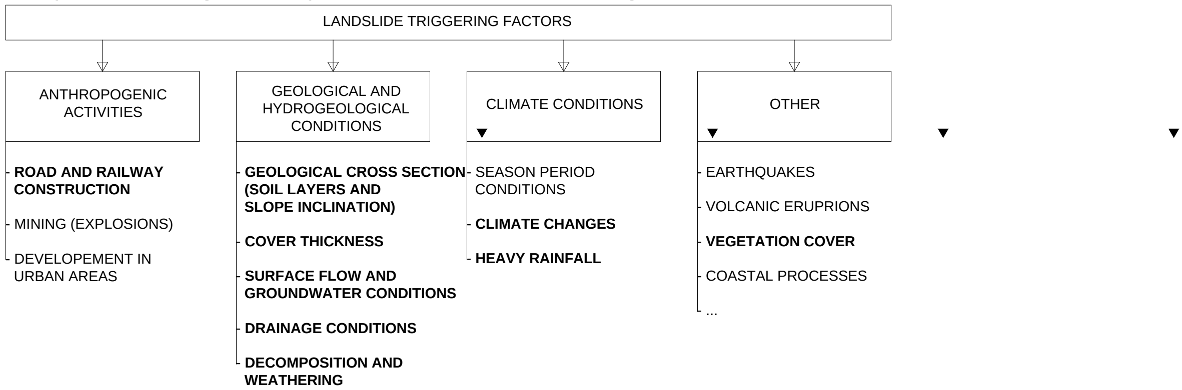


Fig. 4 Landslide triggering factors (bolded factors are used in the Draga Valley risk analyses)

During the road construction there were several positions where sliding instabilities occurred. They were episodically responses to the environment changes due to the highway construction, especially slope increasing caused by cutting and consequence ground flow gradients changes. The performed analyses are directly related with the number of included factors and the quality and quantity of data. Other problems in the analysis was the density of collected data, and the deviation of the monitoring point position and the position of landslides, which leads to the extrapolation and interpolation of data on wider area.

QUALITATIVE LANDSLIDE RISK ANALYSIS

One form of qualitative analysis is the geomorphologic analysis that allows the fast assessment of the area instability, but has certain disadvantages, such as the engineer subjectivity in the selection of the parameters (Leroi, 1996). Another form of the qualitative analysis is mapping of the area according to the triggering factors, where each factor has it own weight and contribution to the landsliding. This approach has problem of subjectivity that is present in choosing the factor influence and their weight in landsliding appearance, and problem of implementing the adopted model on different locations (Carrara, 1983).
The first step in the landslide risk analysis was the hazard identification and assessment of the landslide possibility. Table 1 gives possibility measures according to the Australian Geomechanic Society (AGS, 2000), used in the analysis of Draga Valley. The final goal of the detailed risk analysis was the assessment of the threat level in the area.

Table 1 Qualitative measure of possibility (AGS, 2000)

Level	Descriptor	Description	Indicative annual probability
A	Almost certain	The event is expected to occur	$>=10^{-1}$
B	Likely	The event will probably occur under adverse conditions	$=10^{-2}$
C	Possible	The event could occur under adverse conditions	$=10^{-3}$
D	Unlikely	The event might occur under very adverse circumstances	$=10^{-4}$
E	Rare	The event in conceivable but only under very exceptional circumstances	$=10^{-5}$
F	Not credible	The event is inconceivable or fanciful	$<=10^{-6}$

There were three main parts in the analysis of the critical parameter conditions (Fig. 5): the cognition of triggering factors, the digital terrain model analysis and the cognition of past landslides in the investigated area. The geological structure of the slope model which was adopted from the geological and geotechnical investigation works was analyzed in the first stage. These data were combined with ortho rectified and surveying photography of the area, as well as the digital modeling of the terrain. From the geological maps, geophysical measuring and investigation drilling, data about physical-mechanical parameters of deposits were established.

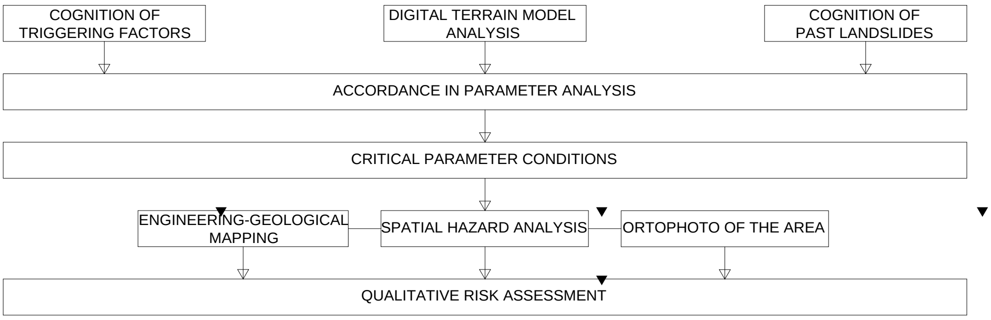


Fig. 5 Risk assessment flowchart

From the digital terrain model (DTM) (Fig. 6) the elevation map (Fig. 7) and slope map (Fig. 8) were compiled. Landslide hazard assessment was identified based on analysis of the slope of the cover, geological fabric, geotechnical properties of slope deposits and flysch bedrock, groundwater surface and hydrogeological conditions.

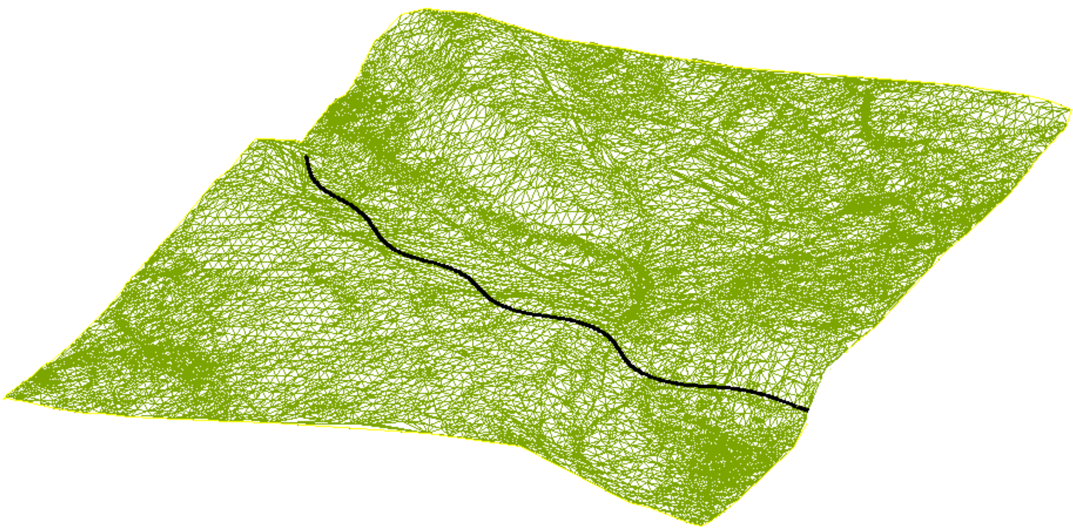
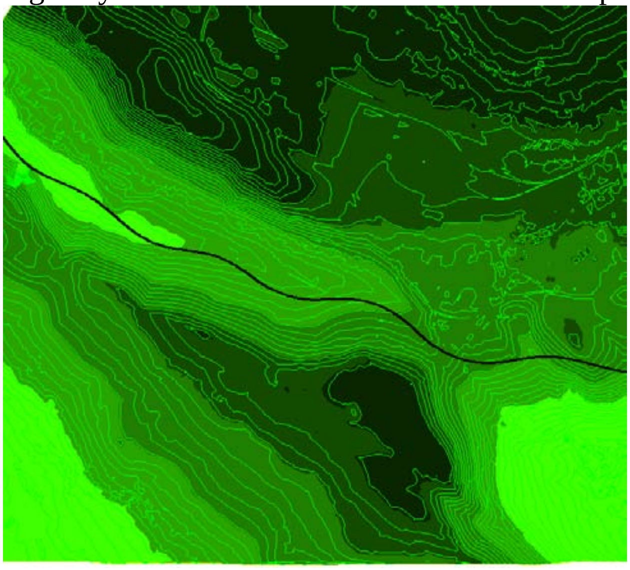


Fig. 6 Digital terrain model of Draga Valley (south-east view)

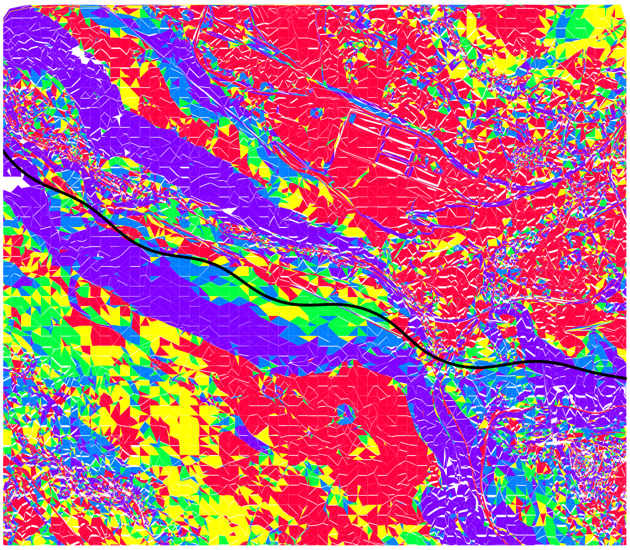
The basic thesis in hazard assessment was that similar conditions which caused terrain sliding in the past, will lead to similar instabilities of the slope mass in the future (Dugonjić *et al.*, 2008). Analyses of unfavorable conditions combinations: slope of the bedrock surface, cover thickness, groundwater level and the direction of hydrodynamic forces were assigned to that thesis. Similar to the distribution according Australian Geotechnical Society (AGS, 2000), shown in Table 3, Draga Valley area was divided into four areas of risk (Fig. 11): low, moderate, high and very high risk. The risk increasing was inducted in areas with big highways earth works and interventions on slope changes.



Number	Minimum Elevation	Maximum Elevation	Color
1	-0.001	124.549	
2	124.549	188.986	
3	188.986	248.034	
4	248.034	278.798	
5	278.798	373.633	

a) b)

Fig. 7 Elevations of Draga Valley**:** a) Surface elevation map; b) Corresponding elevation map table



Number	Minimum Slope	Maximum Slope	Color
1	0.00%	15.00%	
2	15.00%	20.00%	
3	20.00%	25.00%	
4	25.00%	35.00%	
5	35.00%	100.00%	

a) b)

Fig. 8 Slopes in Draga Valley after highway construction: a) Slopes map; b) Corresponding slopes map table

Since risk is product of probability and consequences, it is a combination of hazard analyses with vulnerability analyses for the most exposed elements at risk in the area: natural areas, infrastructure, buildings and persons. Global vulnerability for these elements (Fig 9) was estimated according to the values proposed from Leone *et al.* (Leone *et al.*, 1996). The risk analysis was provided analyzing considerable conditions before and after highway construction. The influence of highway construction was evidenced in significant risk increasing of the all most exposed elements at risk in the area: natural areas, infrastructure, buildings and persons. Low risk was established in flysch areas on the so called stable terrains with relatively low slope gradients, between 0 and 20 %, where sliding are not possible regardless of the low acclivity of bedding planes of geotechnical cross-section at the present groundwater level. The hydraulic gradient and the hydrodynamic forces are low in these areas. The instability event in conceivable but only under very exceptional circumstances so the risk is acceptable and can be managed by normal slope procedures. This level of risk is usually acceptable. These are the areas where event might occur under very adverse circumstances.

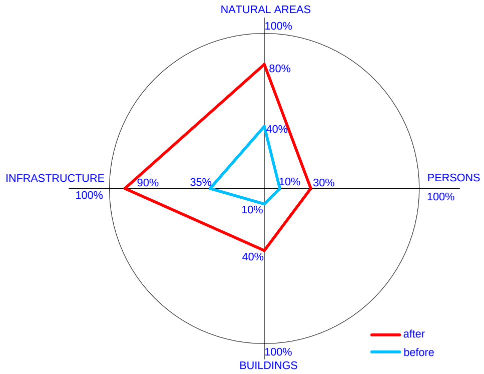


Fig. 9 Global view of vulnerability before and after the highway construction

Level of moderate risk was assigned to the areas where instabilities are possible under adverse conditions. High risk was established in the potentially unstable areas which have slopes between 15 and 37% (Fig. 10), and the cover layer is usually relatively thick (3-10m). Very high risk level dominates in the terrains with bedrock surface slopes between 20 and 35%, and locations at where landslide instabilities already occur, or in the areas where the instability event is almost certain. The most of occurred landslides in the area of highway were caused by construction. Analyzing of all influent factors, zones of extra landslide risk are determined caused by slope cutting and increment of steeps.

Table 3 Qualitative risk measure (AGS, 2000)

Risk level	General guide to implications
Very high risk	Extensive detailed investigation and research planning and implementation of treatment options essential to reduce risk to acceptable levels: may be too expensive and not practicable
High risk	Detailed investigation, planning and implementation of treatment options required to reduce risk to acceptable levels
Moderate risk	Tolerable provided implementation plan is implemented to maintain or reduce risks. May be accepted. May require investigation and planning of treatment options
Low risk	Usually accepted. Treatment requirements and responsibility to be defined to maintain or reduce risk
Very low risk	Acceptable. Manage by normal slope maintenance procedures.

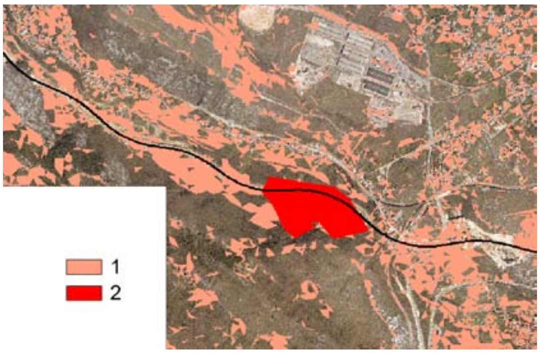


Fig. 10 Spatial hazard distribution map shown in ortho rectified photography of Draga Valley after highway construction: 1) High hazard areas; 2) Very high hazard areas

When the risk assessment is done, the best scenario is risk reducing process, but it can never be removed completely. Table 3 shows the qualitative risk measure for the five risk levels according Australian Geotechnical Society (AGS, 2000). The basic principle implies that the acceptable measure of risk must be inversely proportional to the consequences (Whitman, 1984).

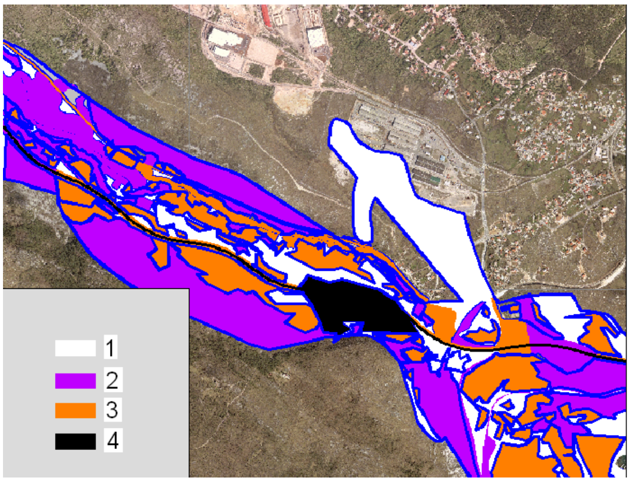


Fig. 11 Risk level map of Draga Valley after highway construction: 1) Low risk; 2) Moderate risk; 3) High risk; 4) Very high risk

CONCLUSIONS

This paper presents experiences on the landslide hazard and risk increasing during the Adriatic Highway construction on the flysch slopes in Draga Valley, part of the dominant geomorphological unit Rječina Valley – Sušak Valley – Bakar Bay – Vinodol Valley. The geological fabric of the Valley is very complex consisting of limestone rocks on the steep slopes and flysch deposits in the bottom, mainly made of siltstones and covered with clayey slope formations. The geological structure of the slope which was available from the geological and geotechnical investigation works was analyzed in the first stage of sliding hazard and risk analyses. These data were combined with ortho rectified and surveying photography, as well as the digital modeling of the terrain to obtain landslide risk map.

The basic thesis in hazard and risk assessment was that similar conditions which caused sliding in the past will lead to similar instabilities of the slope mass in the future. Based on this thesis the landslide hazard and risk analyses were provided and the Draga Valley area was divided into five risk levels: very low risk, low risk, moderate risk, high risk and very high risk. It is very easy to perceive that the highway construction had very big impact on landslide risk decreasing in the Draga Valley area. It is visible significant risk increasing of the all most exposed elements at risk in the area: natural areas, infrastructure, buildings and persons. Based on these results, it is possible to identify the landslide risk weight and define interventions to decrease landslide risk during the highways construction on similar flysch slopes.

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