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P. O. Box 96	**пошт. фах 96**
MK-2000 Štip, Republic of Macedonia	**МК-2000 Штип, Република Македонија**
Tel. ++ 389 032 550 575	**Тел. 032 550 575**

E-mail: todor.serafimovski@ugd.edu.mk

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ROCKFALL HAZARD ASSESSMENT FOR ACCESS ROAD TO DAM "SVETA PETKA" USING ROCKFALL HAZARD RATING SYSTEM (RHRS)

Igor Peševski[1], Milorad Jovanovski[1], Megan Guy[2], Niamh O'Hare[2]

[1]*Faculty of Civil Engineering, "Ss. Cyril and Methodius" University, Partizanski odredi 24, MK-1000, Skopje, Republic of Macedonia*
[2]*Queen's University Belfast, Belfast, Northern Ireland, UK*
pesevski@gf.ukim.edu.mk // jovanovski@gf.ukim.edu.mk
mguy02@qub.ac.uk // nohare04@gub.ac.uk

A b s t r a c t: Large number of roads in our country are constructed in mountainous and hilly terrains. Execution of cuts in the hard rock masses is inevitable. In light of the geological nature of the rocks, processes like rockfalls and landslides in different forms and magnitude are very usual. They occur during construction activities and afterwards in exploitation of the roads. Correct protective measures must be undertaken in order to secure the safety of traffic and people using this roads. One such case is the access road to Dam "Sv.Petka", where constant rockfalls, result of great rupture tectonics and steep cut angles built in marbly limestones, endanger the safety of traffic and construction workers using this road. In order to stress out the hazard invoked by rockfalls and the need of protective measures, we used the well established Rockfall Hazard Rating System (RHRS). Posted speed limit has great influence. Along other possibilities that this method offers is the planning of annual programs for protection measures, with separation of most dangerous zones according the classification, before any undertaking of geotechnical analyses of slope stability. Further software modeling is needed in order to get a better understanding of the nature of rockfalls.

Key words: rockfall; safety; hazard; RHRS classification

INTRODUCTION

As one of the most frequent geological hazards with real risks to the environment and the goods, in recent years, numerous classifications treat rockfall hazard among wich Brawner and Wyllie (1975) and Wyllie (1987), Pierson *et al*. (1990), Scesi et al., (2001), P. Budetta (2004), Jovanovski, Gapkovski (2006).

Hydro Power Plant "Sveta Petka" began construction in 2005. The first phase of construction included completion of the sites access road in 2007.

The nature of the method of creating cuts for the access road has resulted in the marbly limestone rockmass being at a steep sloping angle to the road, this together with intense tectonics and vibrations from through traffic and construction work at the dam which all together cause rock movement on the cliff face and therefore constant rockfalls to the roadway surface.

Investigation into the most hazardous areas and the extent of rockfall in these areas is necessary to decide on remedial action with the aim of diminishing the danger completely. This is vital to ensure the safety of vehicles and passengers travelling this road. We used the Rockfall Hazard Rating System (RHRS) which will provide a method for the road agency to react to hazards rather than accidents. The RHRS will also provide economical planning of remedial works in the future. In order to be most efficient and effective the Hazard Rating System should be an ongoing constant process where conditions or notoriously hazardous areas are monitored in the way of keeping accurate records and photographs of current conditions and any change of conditions occurring.

ASSESSMENT AREAS

In general, the roadway under investigation is deemed very hazardous in terms of rockfalls. Therefore in order to minimize the extent of investigation the areas deemed most hazardous were singled out and investigated individually. It was decided the most hazardous areas were those on sharp bends in the road or areas where it would seem drivers would have difficulty because of a lack of sight distance. Sections where screed deposits are present were also of great focus because of the unpredictable and unreliable nature of this material. Table 1 shows the selected hazard zones for analysis. Each hazard zone varies in length, from 30 m to 224 m.

Initial exploration into data collection for the site and particular situation lead us to discover that the majority of rockfalls occur during the morning and early evening, leading to the belief that the displacement of these rocks is caused by temperature changes throughout the day – from low temperatures in the early morning to high temperatures in mid afternoon, returning to lower temperatures again in the early evening and night.

Table 1

Analyzed hazard zones

Zone	Cross section	Height, m	Average height, m
1	17	10,3	10,7
	22	9,9	
	23	10,3	
	24	12,2	
2	39	20,3	15,5
	40	20,6	
	42	17,5	
	54	9,7	
	57	9,6	
	61	15,2	
3	103	4,5	4,9
	105	5,2	
4	143	10,5	12,9
	145	15,2	
5	156	14,2	15,7
	157	17,2	
6	166	19,1	18,8
	167	21,75	
	170	22,2	
	174	12,2	
7	195	16,8	11,4
	196	7,1	
	197	12,4	
	201	12,6	
	203	8,2	
8	214	16,7	14,7
	215	12,7	
9	226	16,2	16,2
10	242	11,2	11,7
	243	10,25	
	245	13,7	
11	251	14,5	15,4
	253	11,25	
	256	14,25	
	257	13	
	258	13,6	
	260	14,1	
	261	18	
	262	16	
	264	14	
	265	25,6	
12	270	24,4	25,7
	272	25	
	273	27,6	
13	280A	17,25	17,5
	281	12,8	
	282	16,9	
	283	19,8	
	284	20,7	
14	295	10,1	12,7
	296	15,5	
	297	13,3	
	300	16,2	
	301	14,3	
	302	11,2	
	303	11,4	
	304	9,8	
15	308	6,7	9,6
	308A	7,75	
	309	7	
	309A	6,85	
	310	7,8	
	311	11,15	
	312	13,25	
	313	16,15	
16	320	12,5	13,9
	321	12,75	
	321A	12,5	
	322	13,5	
	325	13,5	
	326	18,5	
17	333	19,1	20,0
	334	21,1	
	335	19,7	
18	340	17,8	25,3
	340A	22,2	
	341	25,1	
	343	25,2	
	344	26,9	
	349	22,2	
	350	37,75	
19	355	30,5	28,6
	356	38,2	
	357	32,75	
	358	13,1	

Seventy vehicles, on average, use the road per day, the majority of which are construction vehicles utilizing the road in the morning which coincides with the natural daily temperature increase. Vibrations created by passing construction vehicles together with the temperature increase enhance the possibility of rockfalls occurring during this particular time of the day.

Many traffic accidents, particularly on sharp corners where the driver's decision sight distance is greatly impaired, have been recorded along the access road as well as one fatality during the first phase of construction of the dam in 2006. Subsequently, this is a very serious problem that will continue to deteriorate unless addressed in an effective and efficient way. For the rockfall hazard assesment Rockfall Hazard Rating System (RHRS) according Pierson *et al*. (1990) was modified in a suitable manner for the particular investigation.

ASSESSMENT METHOD

The Oregon Department of Transportation developed the Rockfall Hazard Rating System in 1984. This is a standardized methodology to provide a rational way for agencies to make informed decisions on where and how to most beneficially spend construction funds along areas of roadway which pass through man made steep terrain very susceptible to dangerous rockfall. As well as highlighting the most hazardous regions, the program also lends opportunity for road agencies to put in place systems to monitor, manage and maintain the road in question as well as help to predict which areas should be of particular concern in the future. This will obviously economically benefit agencies in the future in terms of saving cost on roadway repair and the labor required for this.

As a first step in the evaluation we made an inventory of the slopes on the base of formerly executed geological field works and obtained geological maps as well as field observation on the site itself.

Then according RHRS the preliminary rating system was decided in order to define most interesting areas of the access road. In this stage we made a modification of the system where among other criteria listed in Table 2, we decided on the priority for investigation based also on the extent and sharpness of bends in the road as well as the presence of screed deposits on the slopes adjacent to the road. Typical Engineering geological map is presented on Figure 1.

Table 2

Preliminary rating system

Criteria \ Class	A	B	C
Estimated potential for rockfall on roadway	High	Moderate	Low
Historical rockfall activity	High	Moderate	Low
Bends on the road	Sharp	Straight	No bends
Scree deposit adjacent to the road	Large	Small	Absent

Then based on this inventory we grouped rockfall sites into three broad categories A, B and C.

It was determined that there were nineteen zones sown on Table 1 witch are presenting a danger to drivers and vehicles altogether.

The rating system involves ten categories that allow a number of rock slopes to be evaluated and scored in order, from the least hazardous to the most hazardous. Slopes with a higher score present a greater risk.

The point system has been divided into four columns wich correspond to logical breaks in the increasing hazard associated with each category. The scores increase exponentially from 3 to 81 points and are representative scores of a continuum of points from 1 to 100. Using this exponential system, distinguishing the difference between the most hazardous and least hazardous zones becomes more apparent.

The ten categories are as follows:

1. Slope height
2. Ditch effectiveness
3. Average vehicle risk (AVR)
4. Percent of decision sight distance (DSD)
5. Roadway width

6./7. Geological character

8. Block size or Quantity of rockfall per event
9. Climate and presence of water on slope
10. Rockfall history.

Some of the categories can be measured directly on the field while for others corresponding formulae exist wich can be found in Pierson *et al.* (1990), Scesi et al. (2001), P. Budetta (2004).

The various heights of the cross sections within each hazard zone were similar and therefore taking their average deemed an adequate representation of the overall hazard zone height.

Photo 1. Typical screed deposit

The specific length of each hazard zone was found and calculations were performed to find the average vehicle risk (AVR) using the value known for the average traffic per day and the posted speed limit, 30 km/h and 10 km/h.

The percent of decision sight distance (DSD) was found for each of the nineteen hazard zones using the actual sight distances for each cross section (judged and measured from the road plan) and taking the decision sight distance as 90 m for a posted speed limit of 30 km/h and 26 m for a posted speed limit of 10 km/h. The percent of decision sight distance was calculated for each cross section within the specific hazard zone being investigated. As these values were similar, they could be evaluated within the same scoring points bracket. The remaining categories were also scored accordingly.

Table 3 presents the total scoring for hazard zone 4. In same manner calculations for all other 18 analyzed hazard zones were conducted for speed limits 30 km/h and 10 km/h respectively.

Table 3

RHRS for hazard zone 4 on the access road to dam "Sveta Petka"

CATEGORY		RATING CRITERIA AND SCORE 3 POINTS	9 POINTS	27 POINTS	81 POINTS	**Total**	
SLOPE HEIGHT		7.5 Metres	15 Metres ✓	22.5 Metres	30 Metres	**9**	
DITCH EFFECTIVENESS		Good catchment	Moderate catchment	Limited catchment ✓	No catchment	**27**	
AVERAGE VEHICLE RISK		25% of the time	50% of the time ✓	75% of the time	100% of the time ✓	**9** **81**	30 kmh 10 kmh
PERCENT OF DECISION SIGHT DISTANCE		Adequate sight distance, 100% of low design value	Moderate sight distance, 80% of low design value	Limited sight distance, 60% of low design value	Very limited sight distance, 40% of low design value ✓	**81**	
ROADWAY WIDTH INCLUDING PAVED SHOULDERS		13.5 Metres	11 Metres	8.5 Metres	6 Metres ✓	**81**	
GEOLOGIC CHARACTER – CASE 1	STRUCTURAL CONDITION	Discontinuous joints, favorable orientation	Discontinuous joints, random orientation ✓	Discontinuous joints, adverse orientation	Continuous joints, adverse orientation	**9**	
	ROCK FRICTION	Rough, irregular	Undulating ✓	Planar	Clay infilling, or slickensided	**9**	
GEOLOGIC CHARACTER – CASE 2	STUCTURAL CONDITION	Few differential erosion features	Occasional erosion features	Many erosion features	Major erosion features		
	DIFFERENCE IN EROSION RATES	Small difference	Moderate difference	Large difference	Extreme difference		
BLOCK SIZE VOLUME OF ROCKFALL/EVENT		0.3 Metres 2.3 cubic metres	0.6 Metres 4.6 cubic metres	0.9 Metres 6.9 cubic metres	1.2 Metres 9.2 cubic metres ✓	**81**	
CLIMATE AND PRESENCE OF WATER ON SLOPE		Low to moderate precipitation; no freezing periods; no water on slope	Moderate precipitation or short freezing periods or intermittent water on slope ✓	High precipitation or long freezing periods or continual water on slope	High precipitation and long freezing periods or continual water on slope and long freezing periods	**9**	
ROCKFALL HISTORY		Few falls	Occasional falls	Many falls	Constant falls ✓	**81**	
					TOTAL SCORE (30 kmh)	**396**	
					TOTAL SCORE (10 kmh)	**468**	

The posted speed in the time of design of the road was 30 km/h, but from security reasons because of the many bends on the road, it was decided in the zone which is closer to the construction site of the dam this speed to be reduced to 10 km/h. So in order to compare the influence of the reduced speed limit we did the scoring for both speeds. Another modification to the RHRS was done by reducing the points for urgent remedial action required from 500 to 400 having in mind the still active construction site on the dam under the road.

Table 4

Priority for remedial action required

<300	Keep areas under observation
300 – 400	Remedial action priority in these areas
>400	Urgent remedial action required

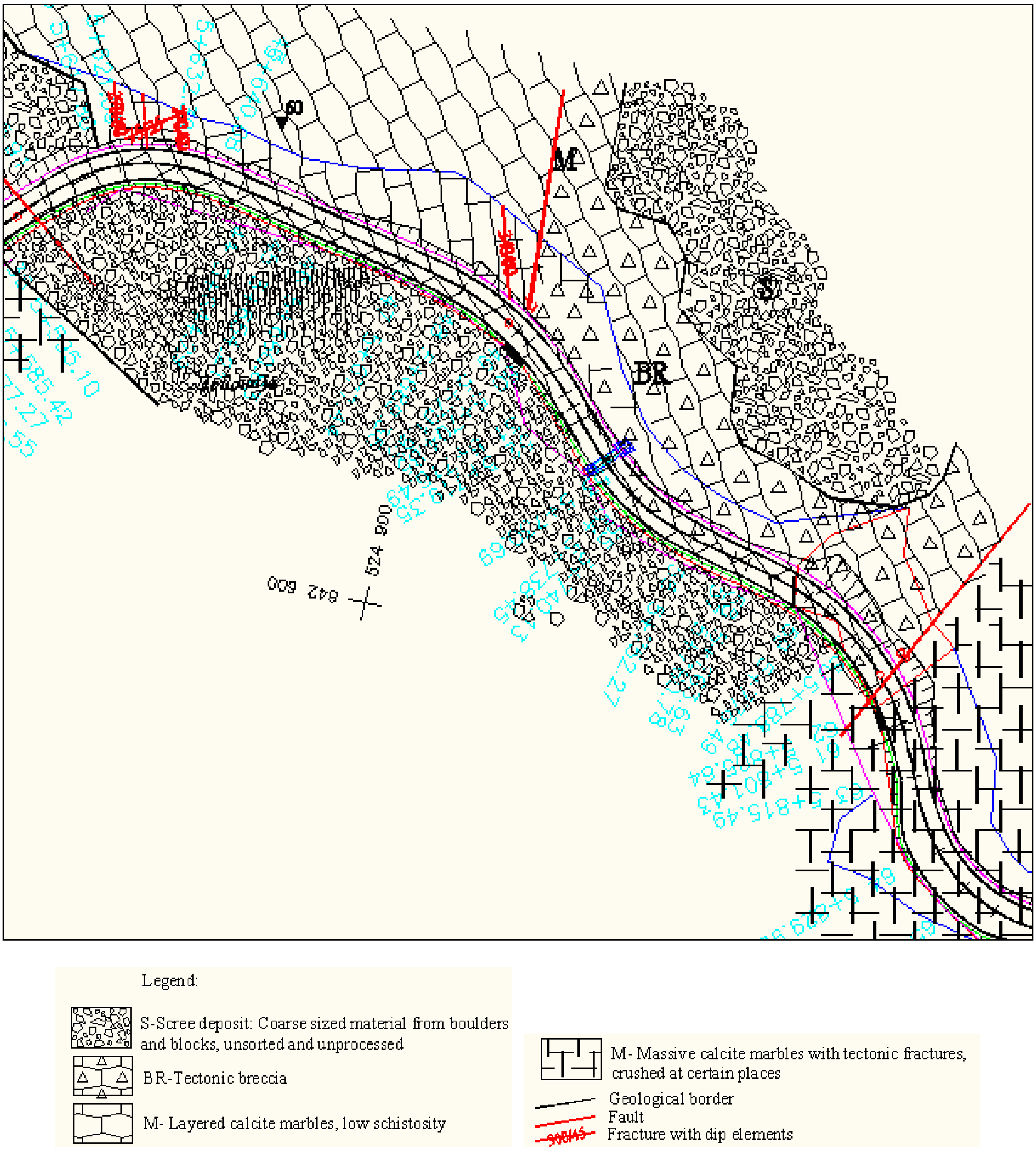


Fig. 1. Engineering geological map for access road to dam Sv. Petka (Chainage km.5+595 – km.6+854)

RESULTS

The obtained scores for each hazard zone are presented in tables 5, 6 and graph 1. Most of the zones should be taken as priority when considered for remedial action. However it's very noticeable how the posted speed limit has a great influence on the results. As expected, more zones become more dangerous as the vehicle travels through at a slower pace.

The number of zones for urgent treatment increases from two to nine with the decrese of speed. Thus spending more time in a hazard zone heightens the likelihood of being struck by one or more falling rocks. However, as the lower speed would cause less vibrations into the ground these results would suggest that vibrations caused by traffic travelling through the hazard zone does not pose as much of a threat as was expected. The time spent in the hazard zone is more of a risk

Table 5

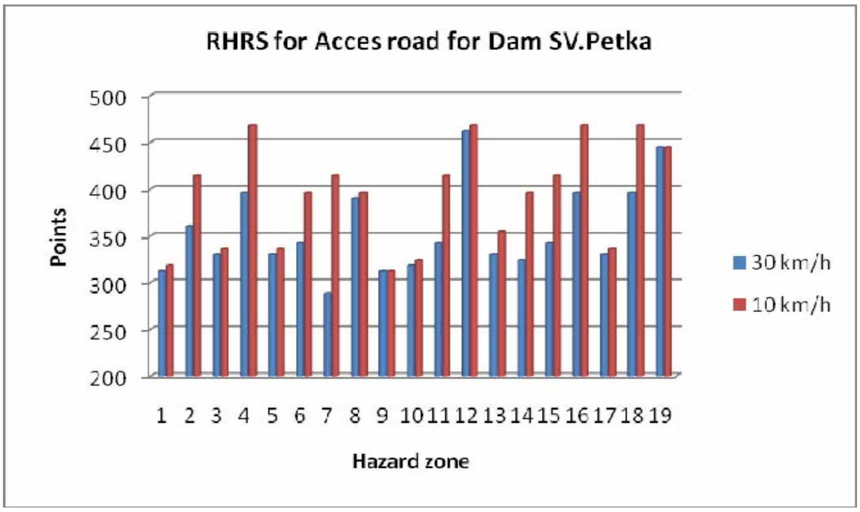
Results for posted speed of 30 km/h

Score	Hazard zone	Inspection rating
288	7	Observe
312	1, 9	Priority
318	10	
324	14	
330	3, 5, 13, 17	
342	6, 11, 15	
360	2	
390	8	
396	4, 16, 18	
444	19	Urgent (2)
462	12	

Table 6

Results of analysis with posted speed of 10 km/h.

Score	Hazard zone	Inspection rating
312	9	Priority
318	1	
324	10	
336	3, 5, 17	
354	13	
396	6, 8, 14	
414	2, 7, 11, 15	Urgent (9)
444	19	
468	4, 12, 16, 18	



Graph 1. Total scores for RHRS rating for 30 and 10 km/h

REMEDIAL ACTION

According all analysis, the possible remedial action that can be performed on a problematic slope are various. The choice of action should be case specific and of course should depend of the extent of hazard presented by the slope. A few of these engineering solutions include:

– ripping of instable blocks, attachment of double road net, along with nonsystematic anchoring,

– anchoring in potentially unstable zones in combination with shotcrete and steel net,

– cleaning of scree deposits and possible cementing with shotcrete,

– construction of reinforced concrete type of gallery protection,

– support with reinforced concrete columns, wich are reinforced with anchors in the cuts,

– concrete supports,

– blasting should be excluded from any action because it further develops conditions for disturbance of the rock masses, i.e. the possibility of additional rockfall manifestations.

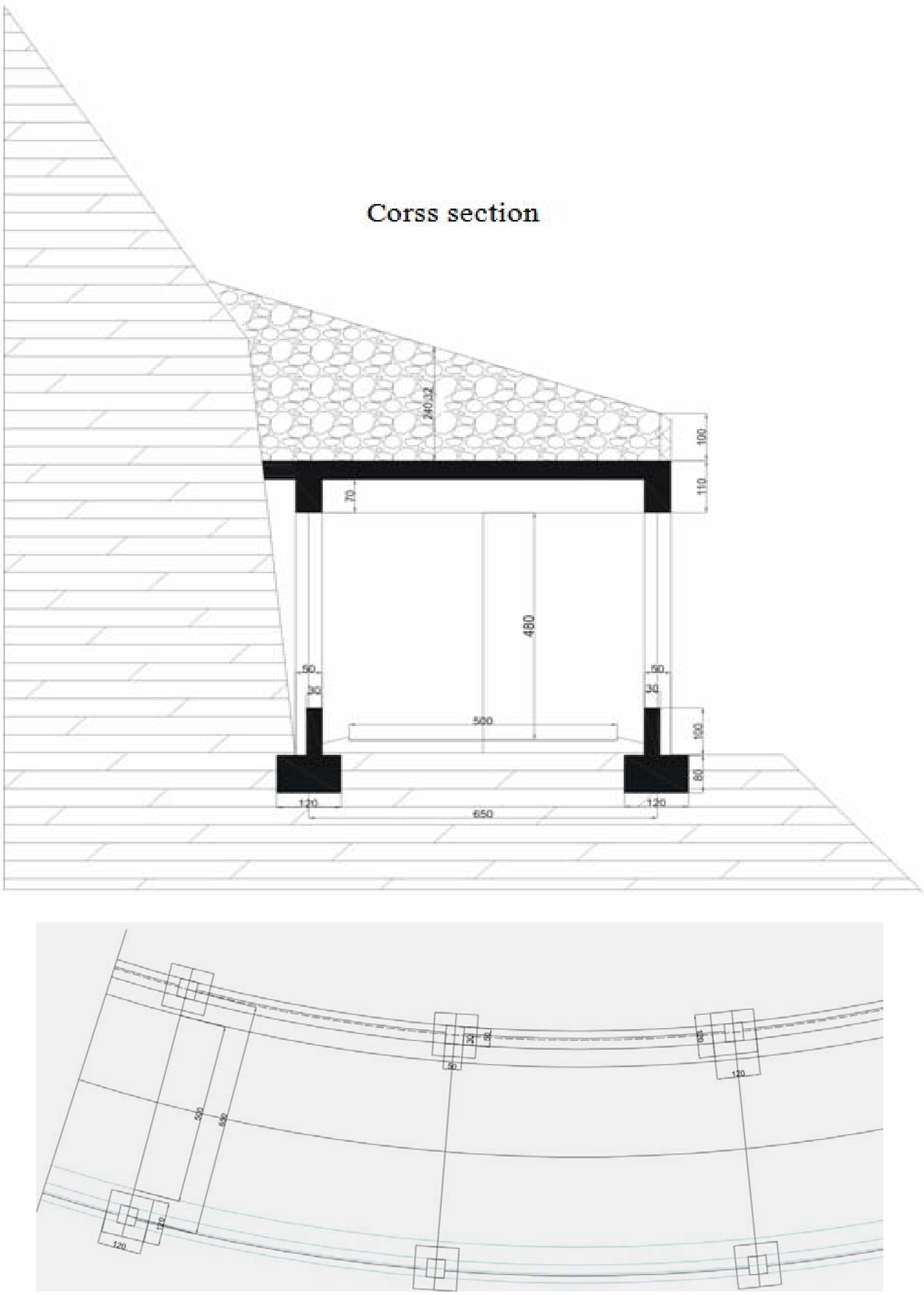


Fig. 2. Possible solution with gallery for most hazardous areas

It is important to determine the most appropriate stabilization methods with not only the aim to repair the problem in the present but to continue to remedy the problem into the foreseeable future, of course in economically feasible manner. This should involve the setting up of an Annual Stabilization Program to ensure continual monitoring of the condition of all problematic areas and consistent action throughout the year. It should also involve the monitoring of areas which have the potential to become dangerous so as action can be applied before the problem becomes more difficult and costly to remedy.

FUTURE WORK

The goal in every project is to be as cost effective as possible. In order to select the appropriate remedial measures from this perspective we propose further analysis by taking the next steps:

1. Use of the evaluation software like Rockscience RocFall to simulate the most hazardous cross sections in order to provide a more informed future prediction of the behavior of hazardous areas.

2. A more in depth investigation into a more specific and accurate size and volume of rocks falling in each hazard zone.

3. Annual Stabilization Program is to be initiated for the entire access road.

5. Research into the possible use of electronic slope monitoring systems and using these to keep maintenance labor and costs to a minimum.

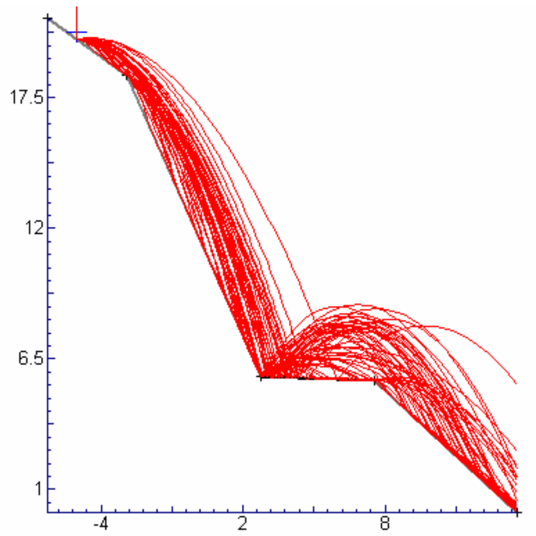


Fig. 3. Output of Rocscience program RocFall from detailed analysis

CONCLUSIONS

Hydro Power Plant "Sveta Petka" began construction in 2005. The sites access road was finished in 2007. The roadway is deemed very hazardous in terms of rockfalls.

Rockfall Hazard Rating System (RHRS) according Pierson *et al.* (1990) was modified in a suitable manner for the particular investigation.

Classification was made for 19 analyzed hazard zones with posted speed limits of 30 km/h and 10 km/h respectively in order to see the effect of reduction of speed.

The number of zones for urgent treatment increases from two to nine with the decrease of speed.

Engineering solutions for remedial works are presented.

Setting up of an Annual Stabilization Program is essential in order to ensure continual monitoring of the condition of all problematic areas throughout the year.

Additional work should be done in order to get a more detailed insight of the rockfall's nature, and usage of software is recommended to model the behavior of falling rocks on the roadway. The posted speed limit sign on one section from the access road of 10 km/h should be replaced with 30 km/h.

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Р е з и м е

ПРОЦЕНА НА ОПАСНОСТА ОД ОДРОНИ НА ПРИСТАПНИОТ ПАТ ДО БРАНАТА „СВЕТА ПЕТКА“ КОРИСТЕЈЌИ ГО СИСТЕМОТ ЗА ПРОЦЕНУВАЊЕ НА ОПАСНОСТА ОД ОДРОНИ (RHRS)

Игор Пешевски[1], Милорад Јовановски[1], Меган Гej[2], Ниам О'Харе[2]

[1]*Градежен факултет, Скопје, Универзитет „Св. Кирил и Методиј“, Партизански одреди 24, МК-1000, Скопје, Република Македонија*
[2] *Queen’s University Belfast, Belfast, Northern Ireland, UK*
jovanovski@gf.ukim.edu.mk // pesevski@gf.ukim.edu.mk // mguy02@qub.ac.uk // nohare04@gub.ac.uk

Клучни зборови: одрон; безбедност; опасност, класификација РХРС

Голем број на патишта во нашата земја се изградени во планиско-ридски подрачја. Ископот на засеци во цврстите карпести маси е неизбежен. Геолошката природа на карпите, а секако и инженерската, активност се причина појавата на геолошки процеси како што се одрони и свлечишта со различна форма и големина да е многу честа. Тие се појавуваат за време на самата изградба на патиштата и за време на нивната експлоатација. За да се обезбеди сигурноста на сообраќајот и луѓето кои ги користат овие патишта треба да бидат преземени соодветни заштитни мерки. Еден таков случај претставува пристапниот пат до браната „Света Петка“, каде постојаните одрони, резултат на голема руптурна тектоника и стрмните засеци изведени во мермеризираните варовници, ја загрозуваат безбедноста на сообраќајот и на градежните работници кои во време на изведба на браната го користат овој пат. Со цел да се нагласи ризикот кој го предизвикуваат одроните, како и потребата од заштитни мерки, искористен е добро познатиот систем РХРС. Заклучено е дека поставеното ограничување на брзината има големо влијание врз опасноста. Помеѓу другите можности кои ги нуди овој метод се и годишни програми за преземање заштитни мерки со издвојување на најопасните зони според класификацијата, а пред преземање на какви било геотехнички анализи за стабилноста на косините. Потребни се понатамошни софтверски моделирања за подетално утврдување на природата на одроните.