Approach to reduce the risk of rock slope above road in section Strnady – Štěchovice

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1 INTRODUCTION

The slopes above the road II/102 in section Strnady - Štěchovice represent a substantial risk for the operation from road construction in 1st mid-20th century. (Zaruba 1987). An increasing number of cases of falling stones on the road have been observed in recent period. Fortunately it was without any casualties. Road management and maintenance office in Kladno decided to solve this alarming situation. They contacted the Department of Geotechnics of the Faculty of Civil Engineering, CTU in Prague with request for assessment of the risk and recommendations for its elimination.

The main aim of the assessment was determination of the risk which was based on our own site survey. The second aim was to design risk reduction measures, together with the proposed long-term monitoring of the selected rock objects (the places with the highest potential risk), using wireless data transmission system with connection to the warning system.

2 DESCRIPTION OF THE SITE

Assessed section is 12.45 km long, and there were 4 basic defined surveyed subsections with the highest risk, Figure 1a. These are the sections: Strnady, Vrané, Štěchovice 1 (Žižkův vrch) and Štěchovice 2 (Šlemín - Hradišťko).

Evaluated section of most risky rock slopes along the road II/102 Strnady - Štěchovice is in indifferent equilibrium. It is caused by both the steep valley rock slopes and also the unfavourable inclination of rock layers – rock slabs. See Figure 2. Progressive weathering occurs along parallel discontinuities which can result in possibility of their loosening and subsequent movement or even fall into the valley.

Figure 2. View on the section with highest risk - Vrané nad Vltavou section

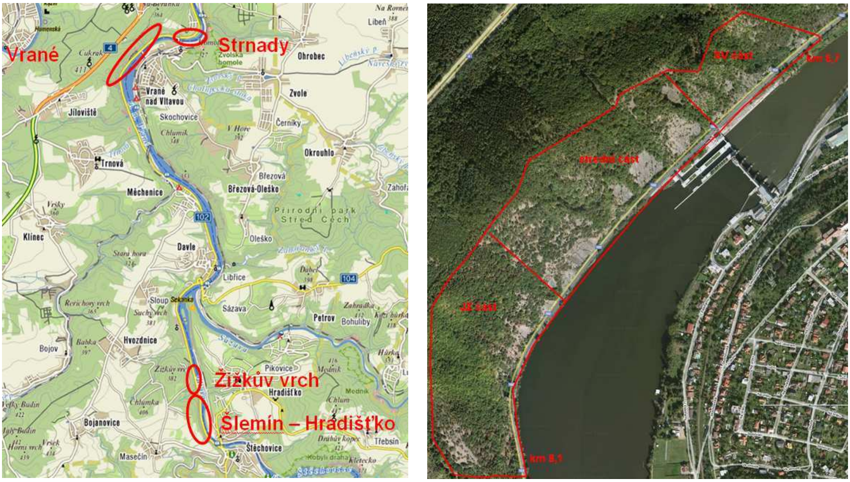

Figure 1. a) Assessed sections , b) Vrané nad Vltavou – section with highest risk

3 RISK REDUCTION

It is almost impossible to guarantee required slope stability (usually expressed as a factor of safety F = 1.3 to 1.5) by cutting and reduction of steepness of the slopes, because it would mean a huge excavation of rock mass, which would also affect land in the upper edge of the slope.

The solution to this potential risk can have several approaches, depending on the acceptable risk. This risk is given by to direct threat of falling released rocks from small fragments to large blocks, which directly threaten the traffic on a road at the foot slope. or nearly situated buildings and water structures. Recent cases where the fall of loose blocks and their collision with vehicles occurred mean that a danger is very high. However, there is not a direct hit by the falling block, but also a potential collision of fallen blocks on the road with a passing vehicle.

One extreme solution is an approach whose main premise is to implement such remedial measures, which would effectively not allow direct impact of falling blocks with the road. It is obvious that this solution on one hand can reduce the risk to ensure a high level of safety for several decades, but also implies the extremely high costs of these remedial measures. But 100% safety can be never reached.

The second extreme solution is based on reduction of remedial measures to the minimum with maximum attention devoted to the limiting the direct collisions of persons and vehicles with falling rocks. This solution has its limits in terms of monitored blocks, where the drivers would be informed in advance about released block by some warning system (traffic lights, gate).

The approach chosen by investigators is based on the finding of some optimum between these two extreme solutions. For sections where the potential danger is less, (for example with respect to the small size of possible loosed fragments, or in case where toe of the slope has some retention area) was chosen first passive approach. This approach involves both limiting the movement of loose particles down the slope, and its capture just before the impact on the road. For large blocks (of the order of 10 m^3) with the highest potential risk in the event of its release, it is recommended the second approach, i.e. monitoring of behavior of these blocks (especially inclination and displacement in time). For cases with higher potential of release and with relatively demanding measures to dissipate its energy the disintegration (blasting) is recommended (usually for size of blocks 5-10 m^3).

4 PROPOSED MEASURES FOR RISK REDUCTION

Because of variable character of the observed area four types of remedial and protection measures were proposed:

4.1 *Retaining reinforced walls*

Retaining reinforced earth walls are recommended in places where the heel of the slope is significantly displaced from the road so it is possible to create a very helpful storage space. Larger stones may be a partially disintegrated during falling and the smaller particles can be captured by retaining walls. The recommended height of the wall was designed from 1.5 to 3.5 m. We recommended reinforced soil with using old tires, especially on the side toward the slope, which should significantly dampen the impact of fallen rock blocks. Schematic cross section is shown in Figure 3. It seems to be a very effective and low cost measure with great potential for energy absorbing. Therefore, this measure should be implemented wherever the morphological conditions permit it. Moreover, it is possible to increase total protected height by vertical steel sections and fixed wire mesh. This fence is especially very useful for capture of smaller rebounding fragments which have greater rebound height than larger blocks.

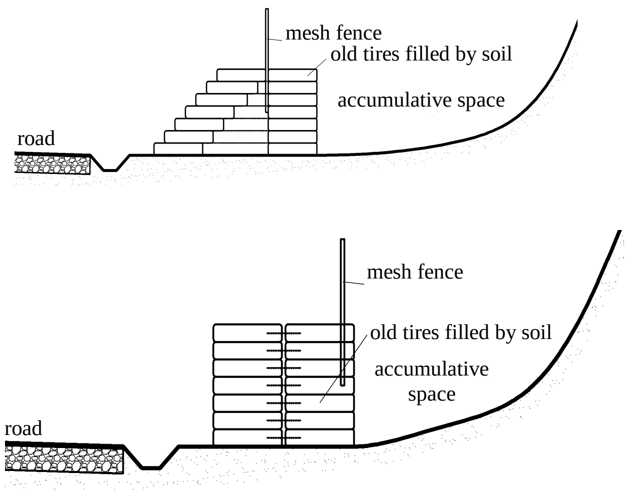

Figure 3. Schematic cross sections of retaining reinforced earth wall with old tires facing

4.2 *Palisade wooden walls*

In principle this remedial measure is recommended in areas where there is a narrow space between the heel of the slope and the road and where debris size is smaller and less frequent. Steel beams H 200 sections with the horizontal wooden lagging of approx. 18 cm in diameter were designed - see Fig.4. This category of remedial measures may include a safety steel wire mesh fence where some poles are anchored and fencing has enhanced strength.

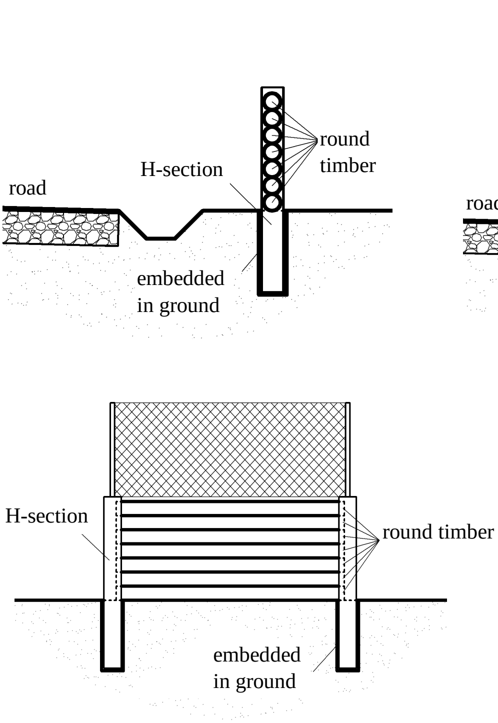

Figure 4: Schematic cross sections of palisade wall

4.3 *Covering by mesh*

In principle selected parts of the rock slope is covered by steel wire mesh or high strength geogrid anchored by bolts or anchors into the rock. The main purpose of this measure is reducing the movement of weathered fragments and even larger boulders of the order of up to 1 m^3 to hold them in place during the first stage of the weathering and fix their position until further weathering into smaller pieces. After that weathered particles are targeted removed. This measure is easily realizable on a flat surface slope of the slab character. The measure requires regular inspections and releasing the captured material.

4.4 *Dynamic Barriers*

Dynamic barriers represent special approach. They are most suitable on the places where spontaneously falling boulders and large debris may fall down. In principle dynamic barrier consists of high strength steel mesh which is connected to the steel vertical anchored beams. The connection is made by using brake elements that capture the deformations, absorb energy and stop the block. These barriers represent an effective but demanding system which requires gradual release of captured blocks in order to restore full functionality of the barrier. Therefore, it is recommended only for places where there is a real danger of rock fall, which can impact the road. In our case we assumed that the proposed dynamic barriers have been able to keep the size of boulders up to 2 m^3.

4.5 *Disintegration of rock (blasting, mechanical loosening)*

Disintegration is very suitable for very danger rock blocks which are unstable and their fall could be expected soon. Blast is usually controlled with micro-second delay and with steel mesh protection, preventing wide spread of loose parts. This measure solves the most problematic cases, and thus significantly reduces the potential risk of falling blocks to the road. The procedure requires safety measures; work on the slope is not easy with respect of difficult access. Hydraulic wedges are most commonly used for mechanical disintegration.

4.6 *Monitoring – warning system*

The purpose of monitoring which is associated with the warning system can be divided into several follow-up phases. In principle, monitoring is observation of deformations. Deformation can be understood as a result of weathering processes - such as the influence of water freezing in rock cracks, crevices, the influence of temperature changes which cause increase or reduction of rock volume, as well as the process of development of shear strength on potential slip surfaces, such as discontinuities of stacking surfaces etc. Shear strength is a function of shear displacement. In the first phase shear strength increase with the displacement, but after crossing the so-called peak strength, shear strength can be reduced on shear surface. This second phase may occur as a gradual acceleration of deformation in time, with resulting shear strength excess and sudden shear and slide (or fall). The basic character of the expected deformation is illustrated in Figures 5a and 5b, when the first case is classical shear and second case is overturning.

Figure 5: Block with expected a) translation movement, b) rotation movement

5 PHASES OF THE MONITORING

The following phases of the monitoring are proposed:

- Regular visual inspections of the documentation points or other points that were photographically documented and at least briefly described. This stage is a rough assessment of the visually observable changes;
- Regular visual inspection of remediation measures - assessment of the status of remedial measures, the volume of captured loose debris, boulders and recommendations for their release, to restore the storage space;
- Geodetic observations in the recommended time intervals to monitor relatively large areas on a slope for selected observation points. The aims are to identify places with excessive movements, to assess their development over time, to recommend the installation of additional documentation points or implementation of other remedial measures;
- Instrumentation and monitoring of selected blocks with deformation measuring of displacements of particular blocks, widening of cracks with using crackmeters and inclinometers with high resolution. Time intervals can be selected depending on the potential danger. It is possible to define critical conditions for increasing deformation rate and provide wireless transmission of measured data to a desk of responsible person.

5.1 *Describe the methods of continuous monitoring using MEMS sensors with wireless data transmission*

For monitoring of rock slopes where there is very limited access and where there is a necessity to perform long term monitoring, is worthwhile to use wireless data transfer. This approach allows connecting different sensors used for monitoring on the wireless network. Once the data are sensed they are sent to the central point of the wireless sensor network and afterwards all measured data from a short period of time are together transferred again wirelessly via internet on the server for further processing.

The authors of this paper have a lot of experience with similar type of monitoring which is designed, installed and operated in the Prague metro. Processing and analysis of data can be operated automatically and measured data can be displayed on a web interface.

At the same time it is possible to create a warning alarm system, which defines the critical value of measured deformation. In the event that the measured value of deformation is higher than critical, system will send a warning e-mail and SMS messages to the addresses of all persons responsible for safety management of the road. This system can be extended to include an automatic traffic lights and gates on the road. Scheme of the continuous measurement system using MEMS sensors with wireless data transmission is shown in Figure 6.

Wireless technology works in non-licensed band of 2.4 GHz no the ZigBee platform that operates on Intel chips. The whole solution of wireless data collection from individual measuring points that can connect both analogue and digital sensors is supplied by Crossbow Company. Everything is just a question of interconnection of relevant chips (interfaces) for sensing (data collection) with the chip for wireless communication. The heart of the whole system is an embedded computer running the Linux operating system which communicates with the gateway point of wireless ZigBee sensor network via

Ethernet or USB interface. This embedded PC acts as well as temporary storage of monitored data before they are sent to the server in the office. Each network point is necessary to program before its installation for specific task, position and connected sensor in the wireless sensor network.

The results can be continuously evaluated and it is possible to define the limit values of deformation, respectively time development of deformation. In case of exceeding of limit deformations, warning system will automatically signal on the road (speed reduction signal, an increased risk of falling rocks, locking the gate etc.), while a group of experts will visit the section on which signal was registered and, if necessary, to recommend controlled blasting of the rock. To check the automatic sensors classic isolated strain gauges (although with a lower degree of accuracy) will be installed as a comparative measurement. It is a classical form of dual control.

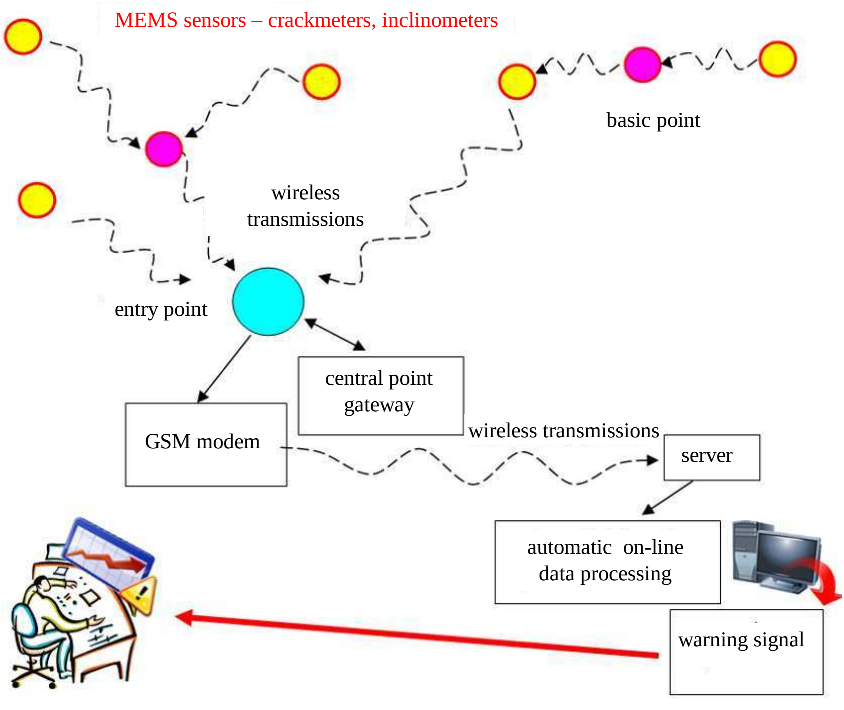

Figure 6. Scheme of monitoring system using MEMS sensors and wireless network

6 CONCLUSION

The risk associated with a rock fall on the road is currently very topical and much discussed not only in the Czech Republic but also worldwide. Defining and quantifying the risks is very difficult, since the risk depends on many factors and specific condition of particular site.

One of the most important measures for reducing the risk of the site are regular visual inspections by experienced geotechnical engineer and using of modern methods of monitoring system connected to the warning signal.

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