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Hazard mitigation of rock walls and slope at portals adjacent to tunnels

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ABSTRACT Rockfall protection and rockfall mitigation are key elements in the security and safety of infrastructure, mine works, buildings or people. Even small rockfalls, or debris flows can block infrastructure and can have far-reaching economic effects beyond the immediate disruption. Emergency state of rocky walls and slopes in portal adjacent areas of tunnels remarkably increases risk of driving on roads. This can be applied both for railway tunnels and road tunnels. Therefore it is necessary to prepare a draft of recovery measures, which decrease this risk to minimum. However, the measures must be implemented in the highest possible quality with elements of structures having minimal requirements on maintenance.

1 INTRODUCTION

The problem of falling rocks on roads and railways belongs to long-term problems, which occur mainly as a consequence of rock weathering on released and also existing slopes of rocks. The above stated problems are referred in big extent to high and sharp rocky cuts. Frequently the slope is identical with adjacent portal areas of railway and road tunnels situated in dissected geomorfological space. As it was already mentioned, in given cases there is not only a threat of small and bigger rocky fragments falling from the released rock, but there is also the threat of the fall of big rocky blocks situated on the existing massif, eventually on slopes above own rocky stage, or the fall of trees, which can be caused by bad weather conditions.

2 KINDS OF PROTECTION

For given problems there are two basic kinds of protection - active and passive one. By the term active protection against rocks falling we understand such structure, resp. other protection of rocky massif, which directly prevents breaking-away a rocky fragment of rocky block from the slope. Among such systems we can include various anchoring and injection systems, for example reinforced concrete anchoring blocks, anchored to the rocky terrain by system of rope anchors, respectively nailed slopes. By the term passive protection we understand protection of the infrastructure (in our case railways and roads), which does not directly prevent breaking-away a rocky fragment or a rocky block but it decelerates, resp. gives direction to its fall, eventually in another way prevents its fall on the infrastructure. Among such protections we can include, for example, protection nets, free or anchored, protecting fences, but also dynamic barriers, which belong among the most sophisticated and progressive systems in this field of protection.

3 REASONS FOR APPLICATION OF TUNNELS PROTECTION AGAINST THE FALL OF ROCKS

Passive protection against rocks falling is designed on places with the threat of the fall of rocky blocks and fragments, or where such a threat occurred in the past. In adjacent areas of tunnel portals the risk of falling blocks on the railway or the road in increased.

The increased risk in caused mainly by sharp slopes situated above the front face of the tunnel tube. Even when for the start need of tunneling and for stability provision for adjacent portal slopes some geotechnical structures are designed (framing anchoring walls, gravity structures or anchoring systems), still there is increased risk of rocky fragments and rocky block falling even over such structures. Considering financially effective design and construction of such protection it is necessary to asses risk firstly. The first proposal deals with elimination of non-stabile parts of rocky slopes, resp. at some bigger deterioration and application of protective devices. However, frequently we can see combination of removal of critical rocky blocks and installation of trapping and protective devices.

4 PASSIVE PROTECTION AND RISK ASSESSMENT

In the case that the rocky massif is mostly disturbed and an application of protective measure is considered (protective nets, dynamic barriers,...) it is necessary repeatedly to assess risk and presumed trajectories for the fall of rocky blocks. This will be done always on the spot of the site, while after observation of the site by means of various calculation methods the risk assessment is found. In the case of active measures it is necessary to find geological parameters and dimensions of the interest area, in order to dimension with safety stabilization elements with sufficient bearing capacity, strength, resp. anchoring strength achieved by anchored systems in critical points. In the case when active protective measures are designed, it is also necessary to do examination of the site, and by means of calculation methods to assess risk of the fall of rocky fragments or rocky blocks. From such assessment it is possible to find, in addition to the risk assessment of the block fall, also its fall trajectory, and the last but not the least, also amount of kinetic energy, which will be developed by the fall of the rocky block. The last mentioned data is decisive for the design of the measure.

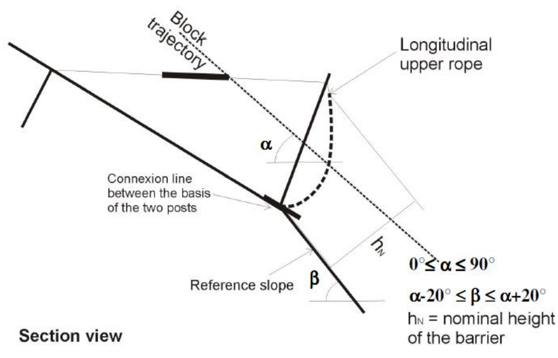

Figure 1. Cross-section for calculation of the rocky block trajectory pursuing ETAG 27.

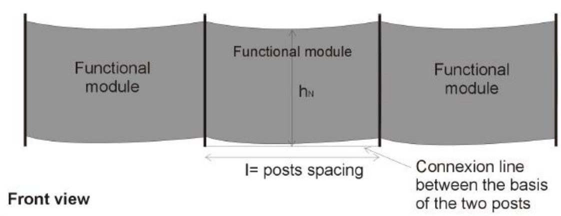

Figure 2. Face view on the barrier and nominal height h_N.

Considering the fact that these problems are theoretically not very developed in our country, we take the opportunity to use the European regulation Technical guardline - ETAG 27. The referred European regulation replaced old standards, and deals mainly with forms of dynamic barriers testing. We remind that all dynamic barriers are tested in practice in scale 1:1. Tests are done on barriers with three fields and with required distance between posts of 10 m. The burden, in the referred case the concrete block with given mass for individual energy classes of barriers falls always into the central field.

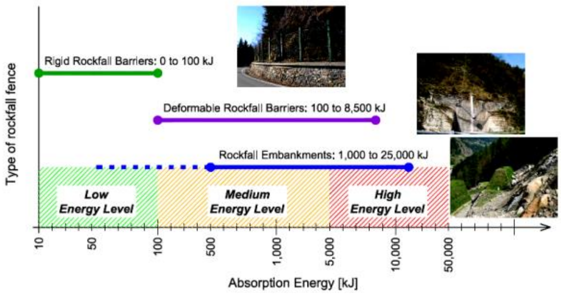

Figure 3. Application of safety devices.

As at each civil engineering structure, also at these safety structures of active and passive protection we must take into consideration the view of their functionality, feasibility, and also economic costs. Because of that it is really necessary to pay attention in big extent to the risks assessment. It means it is necessary to assess advantages of extensive big scale implementation of active safety structures and implementation of local passive structures. In practice, when the massif is extensively disturbed, the passive elements of protection proved to be the best. These are built directly on the slope of the massif, mostly with support of deep foundations (micro-pile foundation). They are built in accordance with the need to provide maximal protection of the infrastructure, however, mostly in one continuous row.

5 APPLICATION OF PROTECTIVE MEASURES IN PORTAL ADJACENT AREAS OF TUNNELS

5.1 DYNAMIC BARRIERS

Considering extensive set of problems, in the following we shall pay more attention to the progressive passive protective elements, which still are not so much developed in practice, it means we shall deal with application of protective fences and dynamic barriers.

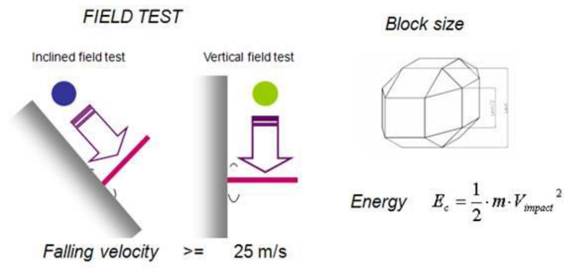

Figure 4. Scheme for calculation of energy developed at the fall of the burden to the area of the barrier.

Amount of energy developed at the fall of the block into the trapping net of the dynamic barrier is obvious from the following formula for calculation of energy Ec:

Ec = ½ . m . Vimpact2

where m = mass of the fallen block; and Vimpact= speed of the fallen block measured one meter before the fall of the block to the net.

The height of the barrier is designed on basis of the assessment of the fall of the “burden”, and as it was already mentioned, also on the basis of the absorption rate of kinetic energy presented in kJ. The barriers are applied in range 500 – 5000 kJ, in accordance with the absorption rate of kinetic energy. To make it more clear, for example, the dynamic barrier absorbing energy 2000 kJ is able to trap rocky block falling with free fall up to the mass 5000 kg from height 40 cm. Dynamic barriers consist of columns with required length anchored in the massif by means of fixed or more advantageous swing stand with support of deep foundations.

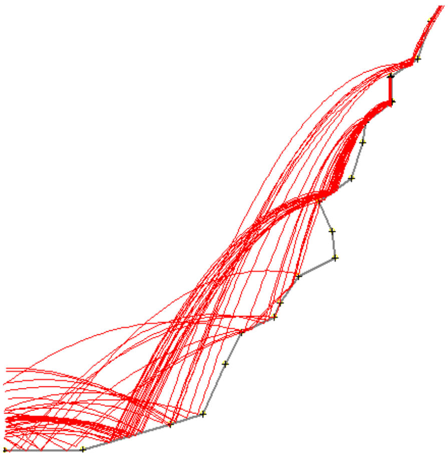

Figure 5. Results scheme of calculation.

The distance between axes of the posts is always 10 m (in accordance with regulation in force – ETAG 27). Considering the height, they are always imbedded in safety height from the object on basis of calculation of maximal folding of the protective net, which is fixed to columns with system of steel ropes. Anchoring ropes create very important element of dynamic barriers, secure position of columns, and together with anchoring prevent their shift. The decisive elements of barriers are mainly energy dissipation device (the device absorbing kinetic energy from the fall of the burden). We speak about the burden, because the referred structures are able to trap also falling trees, or parts of trees.

In practice we can meet also dynamic barriers with axes distances of columns less or more than 10 m, or with their length smaller than 30 m. In given case it deals with atypical structures.

5.2 PROTECTIVE FENCES

For cases when fragments appear as the consequence of seismic activity from road or railway transportation or motion of deer, then protective fences are suitable for the application. Those fences are able without any risk to trap small up to medium fragments of rock massif with size 30 – 50 cm falling with speed 15 – 25 m/s.

The height of protective fences is also designed on basis of needs. As in the case of dynamic barriers also in this case it is necessary to take into consideration whether the passive device is realized perpendicularly to the massif or under certain angle. The protective fence is also made of the system of anchoring and trapping ropes and the protective net. Lugs of the protective net must be designed in the way which will prevent a through of small elements.

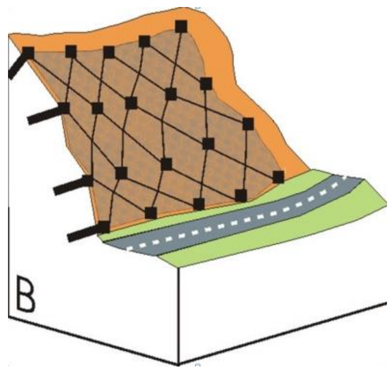

Figure 6. Scheme of secured drapery system.

5.3 AVALANCHE BARRIERS

Special group of protective devices is created by so called avalanche barriers. These are applied only on places where is the treat of avalanches, either snow-slide or land-slide. These barriers are applied in big extent in breakaway area of avalanches, in unique cases they are applied in accumulation zones. Mostly they are specially adjusted barriers for trapping of blocks. These protective devices should contain, in addition to trapping nets, also the net with smaller lugs, which will prevent the fall of smaller fragments. In such cases only passive trapping devices are applied, because the active elements preventing the avalanche launching is very difficult and financially very demanding.

5.4 ROCKFALL NETTING

Some slopes with unstable weathered surface layer is necessary to stabilize by active protection with rockfall netting. At these situations it is important that the selected system provides high resistance with minimum displacement of unstable rock block (usually 1 to 1.5 cubic meters of volume). In real conditions the surface of slope is uneven and mobilization forces are acting perpendicular to the plane of netting. The netting has to deform in order to start performing, in general the stiffer netting is used the lower deformations a movement of the rock block is allowed. To stabilize the surface and to protect infrastructure against falling rocks netting with a different rigidity, tensile strength (up to 300 kN/m) and the corrosion protection can be used. Netting is commonly combined with nails to secure overall instability, this applications are also called "secured drapery systems".

Mainly used systems are panels made of steel ropes with high stiffness / strength (e.g. HEA panels, ...) or high tensile strength netting formed by double twisted steel mesh with integrated steel ropes (e.g. Steelgrid HR, ...), which can be protected with polymeric coating in order to secure requested design life.

5.5 PROTECTIVE GALLERIES

Certain special group of road protection at the portal adjacent structures is realization of protective galleries, with filling made of dynamic barriers. Their application was realized up to now as a temporal solution for protection of the road during realization of civil engineering works, however, by parameters it is able to serve as a permanent protective structure.

The referred atypical structure of such passive protection is made of steel I profiles, a double-twist protective net preventing the fall of small rocky fragments to the road area, and special HEA panels, which provide resistance of nets at the fall of a rocky block.

5.6 DATA AND TRANSMISSION TECHNOLOGIES

Passive elements of protection against the fall of rocks have been applied in the world already for a long time. The arrival of new technologies made easier the investigation of events which occurred in structures. By an event we understand all phenomena, which has some impact on given structure – trapping of the fall of a rocky block, eventually a tree, etc. This information, on basis of various optic measuring devices, arrives to the central trapping unit (computer or other electronic device), which immediately sends signals in the form of SMS, MMS, by e-mail, or facsimile to the administrator of the device. In some cases the duty of regular inspections can be omitted. This function can be profitable mainly in areas with difficult access. By this the administrator has only the duty of regular inspections, which can be performed on basis of maintenance manuals from individual producers of devices. Those inspections fluctuate mostly in range from 3 up to 5 years. The devices themselves, mainly dynamic barriers and anti-avalanche barriers, are designed and produced in the way, that in the case of some event occurrence only damaged part will be replaced on the structure (for example a column, a part of the net, anchoring rope, …) and there is no need to replace completely the whole unit. Some dynamic barriers are designed in the way that if the rock falls directly on the column, the column will be detached from the anchor and it will prevent creation of big deformation of the element.

6 EXAMPLES OF APPLICATION OF PASSIVE PROTECTIVE DEVICES

As it has been already mentioned in the previous sections, the subject of rockfall mitigation of passive and active systems in the form of barriers and netting is becoming a common application for rockfall hazards. In our territory (Czech and Slovak Republic) are appearing many applications of all kinds. All applications have been realized approximately in the last ten years. We shall mention some of them. Interesting recent application was an installation of the rockfall systems at reconstructed section of the railway track Liberec – Tanvald in Czech Republic. It is rocky artificial built cut on both sides of the railway line in the section before an entrance and exit of portal of Dolnolučanský tunnel. Cut has a max. height 19,0 m. The technical solution consists in cleaning the rock walls of loose stones and vegetation and cover by high strength protective net Steelgrid HR attached to the slope by steel nails. For additional strength of the netting to a rocky surface, horizontal ropes were used. The Steelgrid HR mesh is a composite of double twisted steel wire hexagonal mesh, type 8x10, diameter 2,7mm with high tensile strength steel cables, diameter 8 mm, woven into the mesh during the manufacturing process every 1,0m.

Another interesting application is a protection of rock slope Kalvárie, near to the railway line Všetaty – Děčín in Czech Republic. The rock slopes are very close to the major national railway where they interfere locally with the railway track. Slopes are 10-20 m high above the track and geological structure and degree of the weathering directly threatens the safety of the track. The main element of the remediation are rockfall barriers, which are capable of withstanding the impact of a rock block with energy levels in excess of 1000 - 5000 kJ. The height of the barrier are 4 – 6,5 m. The limited section of the rock slope under the line of dynamic barriers is secured with steel netting, which is anchored to the rock slope with nails.

Figure 7. Recostruction of railway section Liberec – Tanvald, tunnel Dolnolučanský.

Figure 8. Rockfall protection and rockfall mitigation on railway section Všetaty – Děčín, Czech Republic.

Figure 9. Rockfall protection and rockfall mitigation on railway section Všetaty – Děčín, Czech Republic.

7 CONSLUSION

Passive and active protection of roads and railways in portal adjacent areas of tunnels, as well as in case of the other civil engineering structures, plays not trivial tasks in safety enhancement and fluency in transportation, as well as in decrease of the number of collision situations. The last but not the least it is the decrease of injuries, in some cases also life losses. Obviously, the referred structures should also involve their design and risk assessment, which to the right application of these devices.

Present time and progress in research and development of new technologies did not remain behind in this circuit of problems. By gradual increase of referred events the necessity of implementation of protective and capture measures decreasing their impact came to the forefront. This trend of research development is continuously developing.

REFERENCES

BUNDESAMT FŪR STRASSEN & BAUDIREKTION GD SBB (1998) Planung, Bau und Unterhalt von Schutzgalerien gegen Steinschlag und Lawineneinwirkungen

EUROPEAN ORGANISATION FOR TECHNICAL APPROVALS (2012) ETAG 27 Guideline for European Technical Approval of Failling Rock Protection Kit

MACCAFERRI CENTRAL EUROPE s.r.o. - SG GEOPROJEKT spol. s r.o. - STRIX Chomutov a.s., Firemná literatúra (2010–2015)

TÓTH, V. – PRELOVSKÝ, B. – NOVÁK, M.: Elimination of the emergency state of rocky walls and slopes in portal adjacent areas of tunnels. In: Transport and city tunnels 2010 : 11. Medzinárodná konferencia podzemných konštrukcií. Praha, 2010, s. 706-711