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HIGH-ENERGY ROCKFALL BARRIERS FOR 3,000 KJ IMPACT ENERGIES TO PROTECT B4 HIGHWAY AT ILFELD, GERMANY

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Abstract. At the beginning of this century, a reassessment of the natural hazard potential along the German highway B4 in the Harz mountain range called for the protection measures. Particularly, at Ilfeld with its geological scenery, two advanced 40 m tall rock cliffs bore a constant hazard to the adjacent B4. Landscape conservation, however, made a remediation by means of blasting off the endangered block masses impossible. Within the natural hazard protection concept, a 90 linear meters of high-energy rockfall barriers for impact energies up to 3,000 kJ were installed. The concept of flexible ring net barriers for high energies as well as design for the rockfall protection in the case of the B4 at Ilfeld is presented here in detail.

Key words: engineering geology, high-energy rockfall barriers, rockfall hazard, rockfall potential, catch fence, flexible ring net, RX-300, Geobrugg, Ilfeld.

Abstrakt. Analiza zagrożeń naturalnych, wykonana na początku obecnego wieku wzdłuż niemieckiej autostrady B4 w górach Harcu, wskazała na potrzebę budowy odpowiednich zabezpieczeń. Szczególnie poważne okazało się zagrożenie w okolicach Infeld, gdzie znajdują się dwie 40-metrowe skarpy skalne. Wysadzenie ich w powietrze zostało uniemożliwione przez służby ochrony krajobrazu. Na długości 90 m zainstalowano więc bariery ochronne przeciwko obrywom skalnym, wytrzymałe na uderzenia o sile do 3,000 kJ. W artykule omówiono szczegóły techniczne tej bariery — elastycznej, wysoko wytrzymałej sieci pierścieniowej oraz całego systemu zabezpieczającego autostradę B4 pod Ilfeld przed obrywami skalnymi.

Słowa kluczowe: geologia inżynierska, wysokowytrzymałe zapory zboczy, obrywy skalne, prawdopodobieństwo powstawania obrywów, parkan zabezpieczający, elastyczna siatka zabezpieczająca, RX-300, Geobrugg, Ilfeld.

INTRODUCTION

Originally, the German national highway B4 (Bundesstrasse 4) was connecting the cities of Kiel in the north, with Nürnberg in the centre of Bavaria (Fig. 1). The extension of the national highway system replaced, however, the original function. Nowadays, the road still serves on many sections as a main connection between local centres and towns.

In the centre of Germany, between Erfurt and Braunschweig, the B4 crosses the Harz mountain range near its highest point, the “Brocken”, in the Harz National Park. At this section, the road traffic features a high percentage of trucks and buses. Just north of Nordhausen, at Ilfeld, the B4 winds through a narrow valley, cut by the river Behre into the south Harz Mts. Here, the erosion has created a steep cut into the hills and exposed nearly vertical cliffs at a short distance to the road. Whereas the rock cut generally forms a continuous line, some single pillars advance the rim and create a spectacular rock formation, which attracts many tourists. It is for that reason that just above the B4, at the foot of the cliffs, a trail allows access to pedestrian and bikers.

In the past, rock fall events have been taking place, which have represented an on-going hazard for road traffic as well as for pedestrian. A major rock fall event in the beginning of this century has lead, however, to the conclusion that the road authorities cannot tolerate this situation any longer. A renowned German consultant for applied geology was assigned to work out a mitigation solution. Besides examining the entire road

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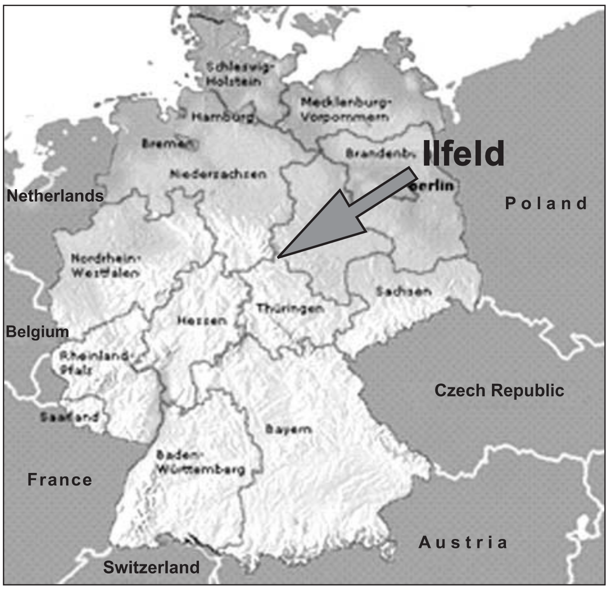

Fig. 1. Location of the project near Ilfeld at the national highways B4

section for about 1 km, a special solution had to be elaborated for a short section of approximately 80 m with two advanced cliffs. The objective here was to not only secure the endangered road section of the B4 but also consider the environmental aspects, particularly to conserve the unique landscape.

GEOLOGY

At the section of interest, the cliffs are composed of an approximately 40 m tall porphyrite rock formation (Fig. 2). These porphyrite formations are partly bedded on siltstone or possibly also on claystone and chert layers. Dip angle of the layers declines towards the B4. Joints and fractures in the formation form block masses with sizes up to about 20 m^3.

RISK ANALYSIS

Road sections with close distance to rock faces evidently bear a higher risk in case of a rock fall event. Therefore, at the sections of the two advanced cliffs with a distance of less than 15 m to the road, falling boulders could reach the B4 easily. Moreover, they may also develop very high energies. Trees in between cliff and road may reduce rockfall hazard slightly, yet cannot stop it. Rockfall events have been taking place, although the history has not been recorded thoroughly.

Therefore, any predictions, particularly regarding boulder sizes and frequency of rockfall events based on such records, could not be drawn. Boulder sizes had to be merely estimated based on geological examination of the formation by means of analysing fractures and joints. For the section under consideration, boulders-block masses sizes were estimated to reach up to 20 m^3. However, in the past no such big events have been noted. It may be assumed, therefore, that the rocks will split upon impact.

Weathering processes reduce the strength of the rock mass especially in the exposed layers and, therefore, mainly fracturing and jointing are left. Since this is a long-term ongoing process, the prediction of rockfall is not possible in an accurate way. Rainfall or precipitation affects the strength of the joints, mainly. An increase of pore and joint water pressure leads to a reduction of cohesion and friction between sound and weathered rock, and is often a triggering mechanism for rockfall events or small debris flows. The influence of this mechanism depends on two aspects mainly: firstly, on the permeability of joints and rock mass, and secondly, on the annual distribution of precipitation, whereas the highest rockfall potential is directly correlated to the amount of precipitation.

Freezing processes taking into account the increase of pore and joint pressures caused by volume extraction due to freezing water located in joints and fissures may have also considerable influence for this specific geology.

Fig. 2. Rock cliff of porphyrite rock

PLANNING AND DESIGN

According to the road authorities, the endangered road section had to be secured even in case of a high-energy rock fall. However, blasting off problematic rocks within this scenic cliff landscape was out of question.

In the original planning, the designer was looking at different solutions including dislocation of the road across the river or construction of a concrete rock shed. However, cost consideration soon lead him to a flexible rockfall protection system (Gerber, Haller, 1997; Gerber, 1999). The distance of the protection system had to be selected in such a way that the clearance of the road and the trail would be maintained, even at maximum deflection upon design impact. Only the tested and certified rockfall protection systems were admitted (Fig. 3).

Rockfall hazards can be mitigated either actively by preventing rocks from falling out of the rock face or passively by stopping falling of the rocks. There exists a number of active measures such as e.g. concrete facing or applying a mesh or net in combination with nailing. However, the impact to the landscape was still considered not acceptable. In addition, the solution was expected not to be very economical.

Fig. 3. Tested and certified RX-300 Rockfall Barrier after an impact, Telemark/Gvaleviken, Norway

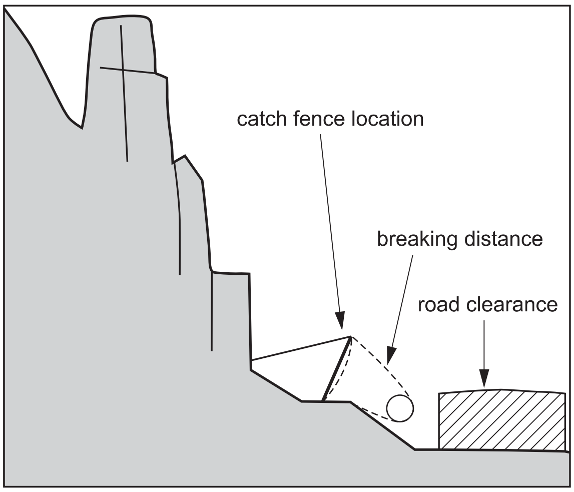

Fig. 4. Typical cross-section with catch fence location between rock cliff and road

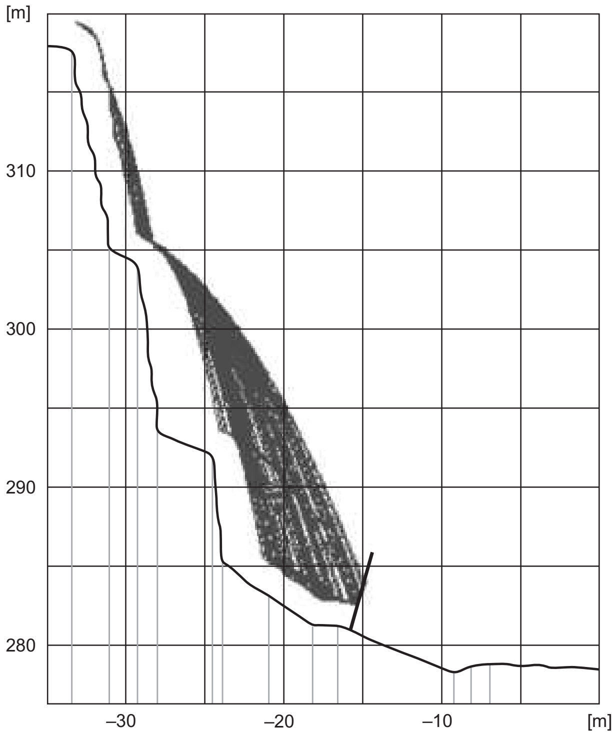

Fig. 5. Trajectories of rockfall simulation

Therefore, a passive solution by means of a retaining structure had to be considered. Concrete walls, due to their inherent stiffness, cannot economically absorb high dynamic impact energies. Earth dams will not only be very costly, but will also impact the area landscape. Additionally, the limited space would not have allowed constructing such a structure. Thus, the road authorities were looking for a catch fence solution, which can

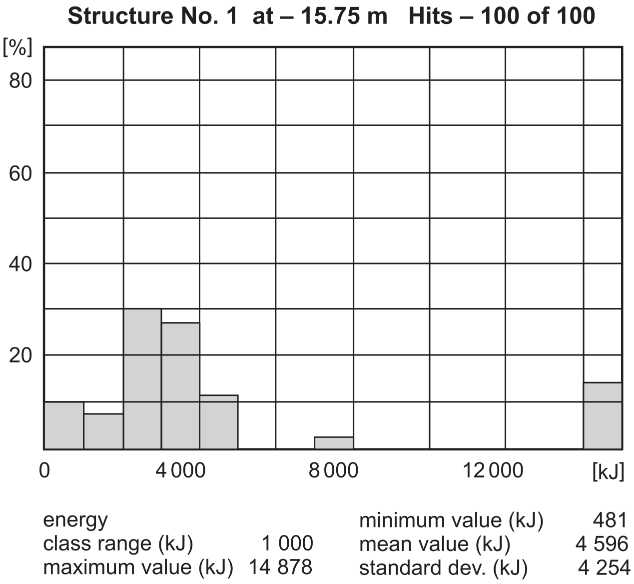

Fig. 6. Expected energies along the catch fence

be placed on the slopes between rock face and road, just underneath the rock cliff (Fig. 4).

A number of different simulation programs are available nowadays. For this rockfall problem, Dr. Spang Ltd. (Spang, 2001) has performed a simulation utilizing the program Rockfall 6.1. This software allows calculating rock trajectories, bounce heights and impact energies based on cross-sectional data and a design boulder, which represents the biggest boulder determined by the geologist and the road authorities. For the preliminary design, the maximum block mass was estimated to be of approximately 20 m^3, according to the risk analysis. The rock shape was assumed to be of cubical form. However, due to software limitation, the block had to be simplified to cylindrical shape with diameter similar to the length.

The rockfall simulation has been performed on a critical cross-section, representing the most endangered section at the two advanced cliffs, which were closest to the road. In order to reduce impact energies, a location of the rockfall barrier as far as possible from the rock cliff was favoured. However, a safety distance to the road, corresponding to the system's braking distance, had to be preserved. This braking distance depended upon the system type and height of the fence. Therefore, a preliminary design indicated an 8 m minimum safety distance.

Further input parameters, required by the simulation program, were selected based on engineering experience of comparable sites. Among the relevant parameters, there are those describing the terrain surface behaviour, such as friction behaviour, damping factors, roll resistance and roughness. The results of the rockfall simulation are depicted on Figures 5 and 6. The max. impact energy was calculated to approx. 15,000 kJ (acc. Figure 5), the max. bouncing height to approx. 3.0 m.

EXECUTED SOLUTION

The simulated energy of about 15,000 kJ cannot be absorbed, however, by means of conventional catch fence technology. GEOBRUGG's certified RX-300 barrier with a design capacity of 3,000 kJ represents the barrier with the highest energy absorption capacity presently on the market (Fig. 7).

In accordance with the road authorities, additional consideration regarding the design boulder was taken into account. Upon the first impact, a block mass of 20 m^3 would very likely split into smaller pieces. Furthermore, preventing large block fall and thus maintaining the landscape, was in very strong public interest. The road authorities decided, therefore, to additionally nail the large blocks on the cliff from the top as invisibly as possible. Thereby, the objective was to raise the factor of safety against sliding and to reduce the potential block sizes by providing an according nailing.

Based on the nail pattern and the expected slide mechanism, the largest block mass reaching directly the road was estimated to decrease considerably. Finally, the road authority accepted a reduction of the design boulder to the size of a 4 m^3 block. Reducing the block mass size almost linearly affects the impact energy ($E = m \cdot v^2$), particularly since the rotational energy for this problem can be neglected. An additional simulation with the new design boulder size of 4 m^3 indicated lower impact energies than the 3,000 kJ, which can be caught by the state-of-art rockfall barriers, such as GEOBRUGG's tested and certified RX-300 barrier.

Based on the rockfall simulation, a max. bounce height of nearly 3.0 m was expected at the top of the block. The selected fence height of 5 m considers both, the aspects of maximal bouncing height and minimum remaining working height after the first impact, which has to be above 60% of its original height, according to the Swiss Guidelines.

Fig. 7. Installed RX-300 Rockfall Barrier with a designed absorption capacity of 3,000 kJ

SYSTEM DESCRIPTION

The proposed rockfall protection barrier ideally and safely absorbs the energy from a rockfall, within the elastic limits and with a minimum of maintenance after the impact, independently of the point of impact. The proposed RX-300 system has been 1:1 field-tested and is certified by the Swiss Agency for the Environment, Forest and Landscape (SAEFL), which takes a worldwide leading role with its guidelines for approval of rockfall protection kits (Gerber, 2001). The design, layout and anchoring of a rockfall barrier considers easy installation, taking into account that such installations have to be constructed mostly in difficult, steep and remote terrain. Lightweight parts, a minimum of anchors, and quick erection are the important aspects.

The ring nets are the major component of the system (Fig. 8). They are often the first part to be impacted and must transfer the forces to the structure, that is to the support ropes, suspensions, posts, and finally to the anchors. Ring net, arranged like Olympic Rings, made out of high grade steel wires, have proved

Fig. 8. Ring net

to be very effective in their energy absorption capacity. This type of a net has a very high internal elastic/plastic energy absorbing capacity and, therefore, is maintenance-free in a large range. In addition, trees can be stopped safely with ring nets.

The impact load has to be transferred from the net into the support ropes. It is essential that the support ropes be designed to react uniformly regardless of the impact point in the net. A special double support rope designed with incorporated energy absorption devices at specified locations proved to provide the optimum balance between energy dissipation, net sagging and maintenance. The used brake ring allows for a multiple impacting of the system without destroying the ropes or reducing their break strength, which is an important safety factor (Fig. 9). The new support rope design increased considerably the flexibility of the system at the connections with the posts, without increasing maintenance needs.

Fig. 9. Brake rings

The principal function of the posts is to support the net. In case of an impact to the net, the post must not collapse but keep the net upright. A minimum size of the used wide flange (HEB)-profiles has been evaluated for each net height. In case of direct impacts at the posts near the base plate, a rated break device at the connection of a post to a base plate allows the post to become separated from the base plate and, therefore, to protect the anchors of the base plate from being destroyed. The anchoring of the lateral and up-slope anchor ropes is provided with wire rope anchors. Wire rope anchors with double sleeve are the best to absorb high impact forces, especially if the axis of the anchor is not exactly in line with the anchor ropes.

CONCLUSION AND OUTLOOK

High-energy catch fences offer new and cost effective protection possibilities, and replace conventional solutions such as rock sheds, galleries, realignment of roads, earth dams, etc. They also match the increasing demand for protection of public infrastructure and human life.

As the project clearly has shown, a potential for high-energy rockfall is reserved not only to the high mountain areas but also dominates often the flanks of river valleys crossing flat plains or emerge in low mountain ranges like the Harz.

Although rockfall protection system have been developed over the last decades to the energy absorption capacity level of 3,000 kJ, further improvement of the systems will eventually lead to even higher absorption capacity barriers. Applications of such systems are at hand, as the B4/Ilfeld project has clearly shown.

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