Monitoring of Tempi Valley Critical Rock Masses: Establishment of Special Monitoring Network and Procedures in Aegean Motorway S.A. Concession Project

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ABSTRACT

The paper aims to describe the installed monitoring network of critical rock masses stability and deformations and the procedures that are followed by the Concessionaire in order to ensure the safety of users along the National road in Tempi Valley. The road runs between the mountains of Olympus and Ossa in a canyon characterized by steep rock slopes on both sides, parallel to Pinios River that streams through it. The intense discontinuity systems of the rock slopes could activate planar slide of large rock masses, rock wedges as well as individual rockfall events concluding on the pavement during the roadway operation and therefore could cause accidents and damages on the infrastructure.

The concessionaire Aegean Motorway S.A. (AMSA) is responsible for the Operation and Maintenance of this road. For this reason, an extensive rockfall protection and stabilization design for the mitigation of rockfall risks along the National road through Tempi Valley was realized in the years 2009 and 2010.

A procedure was established as outlined in detail in the Rockfall Protection Inspection and Maintenance Manual (RIMM) setting out the necessary actions for the continuous inspection of the areas of increased rockfall risks within the Concession Project and for the operation and maintenance of the rockfall protection systems. All rockfall measures as well as rock slopes of the valley are being inspected systematically with any new rockfall event and/ or damage to the protection measures documented in designated forms. Moreover, a special geodetic monitoring network has been established in critical rock masses with specific warning and alarm thresholds. The monitoring system of critical rockmasses in Tempi Valley is enhanced with grout bridges applied to rock discontinuities where movement is supposed to occur prior to failure. All the collected data are the subject of interpretation by rockfall experts in line with the established procedure.

INTRODUCTION

Transportation corridors in many regions worldwide are often susceptible to slope failures. Particularly, rockfalls constitute a major hazard in numerous rock cuts along roads in mountainous regions giving rise to casualties, as well as a large amount of damage and injuries (Budetta, 2004). Rockfall and other natural hazards caused major disasters in the past decades that were a wake-up call for authorities, insurance companies and the public. The assessment of the prevailing hazards, vulnerabilities and risks was recognized as an important task. Within this context, many countries developed various risk-based guidelines and procedures related to the management of road networks against natural hazards. The benefit of these procedures – recommendations is that risks are managed uniformly with specific goals and transparency in the use of resources.

One of the pioneer countries in the field of natural hazards management in Europe is Switzerland. Switzerland is a country exposed to many natural hazards and efforts have been made to apply the same strategy and similar approaches across the country. (Raetzo et al., 2002). The Swiss federal regulations are established for the whole territory and for all types of landslides. The Swiss federal recommendation outlines a three-step procedure consisting of: Hazard identification - description, Hazard assessment and Risk management - treatment. Other European countries with similar guidelines are Andorra that is inspired by the Swiss recommendations, Italy where the guidelines exist at regional level, Germany with some recommendations that were developed at regional level (Bavarian alps) and Austria and Croatia where national guidelines as well as procedures are under discussion (Lambert & Nicot, 2013).

On the other hand, Greece is a country with mountainous terrain, steep slopes and high seismicity that increases the rockfall hazard. There have been several rock fall events or slope failures recorded in the recent history of Greece at various locations along highways and other roads, near inhabited areas and archaeological sites. Indicatively, the following failures could be mentioned: The major landslide at Mikro

Horio of Evritania region in 1963 that led to loss of 13 human lives and buried a whole village, the Panagopoula landslide in 1971, Tempi Valley rockfall in 2009 as presented in figure 1 & 2 that led to loss of a human life and the closure of the national road Athens – Thessaloniki for approximately 4 months, the Santorini rockfall in 2011 with one human loss, and many others.

Figure 1. Tempi Valley rockfall 2009 by helicopter

Figure 2. Tempi Valley rockfall 2009

As mentioned by Koukis et al. (2005), the landslide activity in Greece is increasingly high as a result of increased urbanization and development in hazardous areas, continued forest reduction and extreme meteorological events with serious socio-economic consequences.

Although many efforts have been made by authorities and research centers to mitigate the consequences of natural hazards in Greece, there has been no common or standardized policy at country level. In the absence of a common strategy, each case is managed separately with the adoption of guidelines and procedures by countries more organized in the field of natural hazards.

In the present paper, information is provided regarding the tools and the procedures followed by the Concessionaire Aegean Motorway SA, to ensure the safety of users along the old National road in Tempi Valley that connects Athens to Thessaloniki. Moreover, a special monitoring network has been established in order to observe potential block movements.

Tempi Valley is a gorge of a total length of about 7.5km with its narrowest section in its eastern part. The steeper northern escarpment has a maximum height of slightly over 300 m. The tectonic situation is very complex – with several generations of cross-cutting faults, joints and erosion pattern. The whole slope section of Tempi Valley gorge is vegetated by evergreen shrubs that grow from earth filled rock joints. Under these geological conditions, also taking into account the erosion factors (rain, ice, wind, vegetation) that affect the slopes, rockfall events are expected.

PROCEDURES APPLIED BY THE CONCESSIONAIRE IN TEMPI VALLEY ROAD

Measures applied in Tempi Valley

A rockslope stabilisation design by Omikron Kappa (2009) was realized in the Tempi gorge in the years 2009 and 2010 in order to improve the rockfall hazard situation for the highway. The implementation of the design comprised scaling of rockwalls & critical rock masses, implementation of rock-nets with rock-bolts and the construction of rockfall barriers with different energy absorption levels (100 to 2’000 kJ). Additional mitigation measures, as designed by GEOTEST, were carried out in order to stabilise or to survey instable rock formations in the higher slopes of the Valley that are called Special focused areas (SFA). Some of them were eliminated by scaling works. Others have been stabilised with rock-bolts and rock-nets. In one case, the construction of a rockfall barrier (2’000 kJ) was necessary. Several SFAs are additionally monitored with a geodetic survey system in order to notice movements and deformations of rockmasses at an early stage. In total, the applied measures (passive and active) in the Tempi Valley gorge are summarized as 2,5km of rockfall barriers, 200 rock bolts, 13.200m^2 of meshes (tecco & spider type) and more than 2.500tns of scaled blocks.

Risk Analysis Study (RAS) in Tempi Valley

A significant tool in the Concessionaire’s hands in ensuring that the highest safety standards are applied in the Tempi gorge is the risk analysis for rock fall hazards along the valley as firstly issued in 2010 and updated in 2017 by GEOTEST (2017). As per Andrianopoulos et al. (2013), the purpose of risk classification systems is to identify the slopes with the highest level of risk and thus determine priorities for immediate mitigation measures or further detailed investigation. The Concessionaire (AMSA) has chosen the Swiss approach for the risk calculations considering that Switzerland is the country with the longest tradition in natural disaster reduction. It was decided that the risks shall be calculated using the most recent method of EconoMe 4.0 developed by the Swiss

Federal Office of Environment (FOEN) which is used for the hazard analysis projects of the Swiss government.

The main goal for the risk assessment in Tempi Valley is to calculate the current risk levels and to identify potential persistence of inacceptable risk levels in order to be able to take the necessary steps for mitigation. The hazard analysis assesses the natural rockfall hazards with respect to their probability and extent. First, relevant scenarios are selected based on known (historic) events, on geological and on morphological parameters. Second, protection measures have been taken into account (rock fall fences, drapery systems, scaling and stabilization of rock masses, that were carried out between 2009 and today). In general, the risk concept proposed by FOEN (Federal Office for the Environment, Switzerland) is adopted. The risk analysis in Tempi Valley shows that the risks (both individual and collective) have been reduced substantially over the past years with the realisation of rockfall mitigation measures and with the control inspections and maintenance work. The results show in addition, that no high-risk zones are present today. Such zones were recognised in former assessments and were efficiently mitigated with technical protection measures.

Rockfall Protection Inspection and Maintenance Manual (RIMM)

The RIMM (GEOTEST, 2016) is a document developed by the Concessionaire and GEOTEST in 2010 and updated in 2016, in order to describe the procedures and necessary actions for the continuous inspection of the areas of increased rockfall risk within the concession project boundaries and for the operation and maintenance of the rockfall protection systems installed therein. The safety concept of RIMM is based on the following elements, (i) Inspection of the roadcuts & natural slopes above the roadcuts: the roadcuts and the critical slopes above need to be controlled visually with respect to fresh detachment zones, active rock discontinuities (cracks) and potentially unstable rock masses, (ii) Inspection of rockfall barriers and tecco and spider meshes according to manufacturer’s manual, (iii) State of the anchors, (iv) Geodetic measurements of critical outcrops: reflector prisms are bolted to the surface of critical rock masses. Surveying records and displacements are being evaluated by the geologists, (v) Grout bridges: the grout bridges are applied to rock discontinuities where movement is supposed to occur prior to failure. Cracks in the grout bridges would indicate movement. Based on the inspection findings, maintenance interventions and activities are decided and scheduled.

The inspection and maintenance types are categorized as follows: (i) periodical inspections which are carried out twice a year. The first inspection is made in Spring (usually after the normal raining period), the second in Autumn (before deterioration of weather in Winter). Bi-annual reports are issued after the bi-annual inspections. Additionally to the periodical inspections, (ii) extraordinary inspections are organized in order to ensure fast response to a possible hazardous situation (e.g. rockfall incident, earthquakes, heavy rain falls, exceeding Tachymetric measurements on prisms, cracked grout bridges). According to the findings of the inspections, maintenance measures are realised. Maintenance will be either a scheduled campaign or an immediate intervention in order to carry out mitigation measures in an extraordinary case.

All observations made during the visual controls and the control inspections are being recorded and integrated into the RIMM in a separate folder (in the form of a project Journal). For every control inspection a new control sheet needs to be filled out and added to the journal. In case of observed damages, the damages are documented in the damage report sheets with documentary photographs added to these sheets. For the works qualified “OK” during the inspection (showing no harm or damage), filling out the summary control sheet is sufficient. Movements of rock masses and rockfall events since the last control inspection or debris with a certain volume stopped in the barriers are documented in the Rockfall event report sheet. Significant issues, such as rock fall events, are also mentioned in the biannual inspection reports.

It is worth mentioning the following possible (not conclusive) mitigation or precautionary measures in case of an extraordinary situation, such us: (i) Safe observation of the situation along the road by trained personnel (ii) documentation of rock fall events observed, (iii) transmission of data to geologists for evaluation and guidance (iv) more detailed survey program of an instable or possibly instable rockmass (geodetic or other survey methods), (v) scaling of an instable rockmass, (vi) stabilisation of an instable rockmass, (vii) installation of new rockfall protection measures, (viii) closure of the highway as a precautionary measure.

In any case the observed situation and remediation measures (required or executed) are properly documented. The final situation is analyzed in order to confirm that the parameters of the Risk Analysis Study are met. The operation of the road can be resumed once the level of residual risk is below the acceptable level as per the findings of the RAS.

The whole length of Tempi Valley has been separated by certain sections with typical features of slopes and roadcuts based on the geological set up and the installed measures. This kind of separation is of high importance for the best scheduling of inspection and maintenance activities. Access paths have been documented for each section and marked on site in order to make the approach at all slopes easier, as presented in figure 3. On site, fixed steel wire ropes are installed to make access quicker and safer.

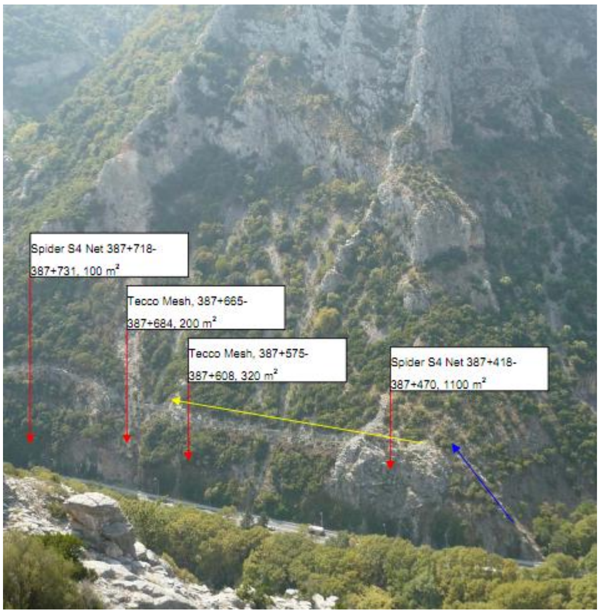

Figure 3. Overview of section 11

The inspections are carried out by trained personnel (i.e. alpinists/geologists/ specialized civil engineers) appointed by the Concessionaire. These inspections are mainly performed either on foot or on rope. Supportive equipment (drones) is also used if necessary. During the inspection of the roadcuts and the natural rock walls/slopes, special attention is given to unstable rock formations and possible old and new detachment zones. If there is reasonable suspicion for a larger instability, further close inspections are carried out. Further measures have to be taken if movement is detected. The inspection at the foot of a roadcut or a rock wall/slope includes control of the presence of debris that has been fallen from above. It also includes the inspection of material that has been stopped behind the rockfall barriers/ fences, or into the trench (if any). Repeated rockfall from the same source area with smaller volumes could already announce a larger event and should be assessed urgently. Observations that are made during the inspection are entered in the data sheet and can be indicated directly on the photograph. All relevant records are kept in the Journal folders of the RIMM.

All parts of the barrier systems have to be controlled according to the maintenance manuals of the manufacturer. If parts of the system are damaged the diminution of the protection properties has to be evaluated and if necessary, immediate measures have to be taken. In case of damage to any of the rockfall protection measures, the damage report sheet has to be completed. In this sheet, damages to the rockfall protection are described, documented and classified with respect to the severity of the incident. The induced and finally completed measures are documented. Inspection and maintenance activities are presented in pictures 4& 5,

Figure 4. Inspection and scaling works

Figure 5. Emptying of barrier from trapped blocks

Monitoring Network

Horizontal and Elevation Reference Points have been established for the needs of the rock stabilization monitoring inside Tempi Valley. The reference stations are connected by precise observations, adjusted and coordinated independently of any other control survey in the vicinity. The geodetic measurements of critical rock masses are carried out by qualified personnel (i.e. surveying engineer). The data of the measurements are processed and visualized by the measuring team. In case of measured movements above the threshold values an interpretation of the data must be carried out by the responsible geologist. In case of an asserted difference between the consecutive measurement and the zero measurement of a single prism, action has to be taken. Three level of movement are defined: (i) the “awareness” level where a control measurement has to be carried out the following day and if the results are confirmed further measures have to be discussed with the responsible geologist (e.g. more frequent measurements), (ii) the “pre – alarm” level where a control measurement has to be carried out the following day, a field inspection has to be carried out by the Alpinists or the responsible geologist. If movement of the rockmass can be confirmed by field observations (e.g. by grout bridges in most surveyed SFAs), further measures have to be taken after discussion with the responsible geologist (e.g. more frequent measurements, closure of the highway, etc.) A control measurement has to be carried out in any case the following day to confirm the results of the previous day, (iii) the "alarm" level where closure of the National road is enforced. A field inspection has to be carried out by the Alpinists or the responsible geologist. The next steps are similar to the pre – alarm level actions. Finally, the decision to reopen or to keep the road close according to the findings is taken.

Figures 6-8 of the installed geodetic network are presented below.

Figure 6. Prisms installed in special focused area SFA1.

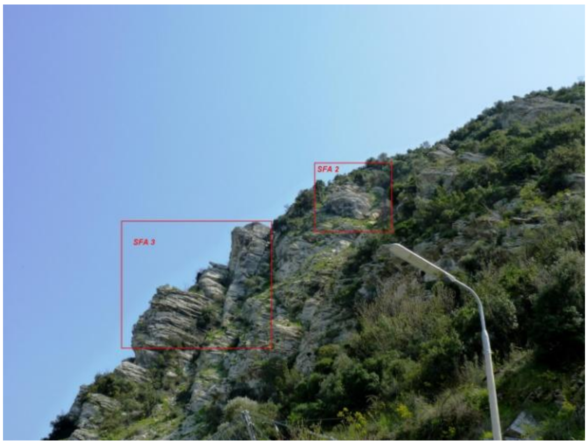

Figure 7. Special focused areas SFA2 & SFA3.

Figure 8. Prisms installed in special focused area SFA2.

Prisms are mainly installed in special focused areas (SFAs). Monitoring is performed at least once per month and always after an extraordinary situation like an excess rainfall or suspicious rockfall incidents close to the SFA areas. In any case all the monitored areas are stabilized either with active or passive protection measures. Hence the monitoring network is an additional precautionary measure to confirm the existence or not of slope activity. At figure 9 the plan view of SFAs 1-3 is presented.

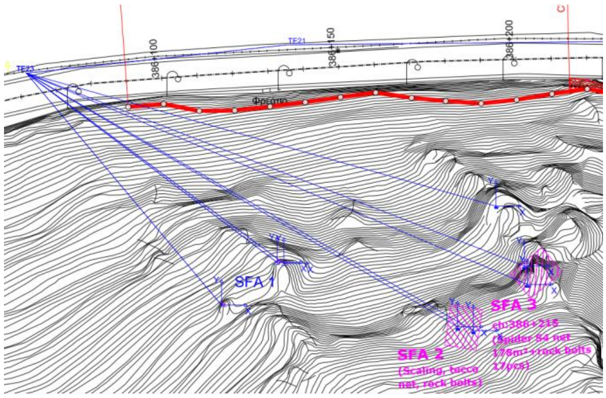

Figure 9. Plan view of installed geodetic network at SFAs 1 - 3.

Moreover to the geodetic monitoring network, another network consisting of grout bridges is applied to rock discontinuities where movement is supposed to occur prior to failure (figures 10 & 11). Cracks in the grout bridges would indicate movement. In total almost 100 grout bridges have already been installed in Tempi Valley in various locations.

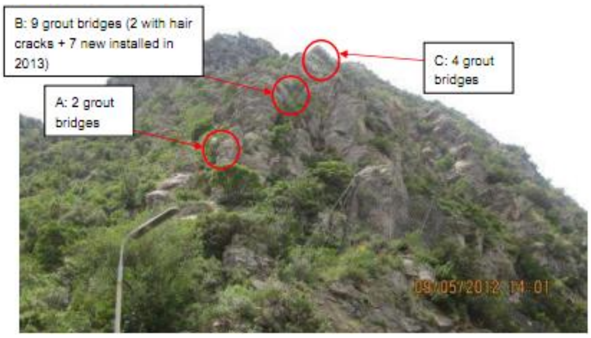

Figure 10. General View of the installed grout bridges at section 6 (old chainage 386+650).

Figure 11. Detail of grout bridges

Details of the condition of all grout bridges are recorded in designated forms and evaluated. Condition of each grout bridge is compared with the initial condition right after its installation. A general rule is the installation of more than one grout bridges per block in order to assess the real or a false alarm movement.

CONCLUSIONS

Monitoring of Tempi Valley is not the case of a system (simple or advanced) that just records movements. It is a procedure of continuous inspection and maintenance of a gorge under traffic, with several faults, dense vegetation and steep slopes, affected by the changing weather conditions. Expert judgment and fast response to the findings is part of the procedure. The extensive rockfall stabilization and protection systems have to be inspected in detail and maintained according to the construction manuals. Significant tools to this effort are: the developed Inspection & Maintenance procedure (RIMM), the installed monitoring networks (geodetic prisms, grout bridges), the technical equipment (drones, GIS etc) and the risk analysis study of Tempi Valley (RAS) that measures the risk level and which should be reviewed periodically in case of geological alteration of the slopes, change in the protection measures or the traffic situation. All these tools in combination with the proper engineering judgement assure the best achievable safety level for the users and the infrastructure.

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