Road cut monitoring by photogrammetric methods

LUBICA IGLAROVA[1], PETER WAGNER[2] & PAVEL BARTOS[3]

[1] *Geological Survey of Slovak Republic. (e-mail: iglarova@gssr.sk)*
[2] *Geological Survey of Slovak Republic. (e-mail: wagner@gssr.sk)*
[3] *Slovak Technical University, Faculty of Civil Engi. (e-mail: bartos@svf.stuba.sk)*

Abstract Three rock cut localities, situated in various geological structures, were selected for observation as part of a project of monitoring slope movements in Slovakia. Monitoring of road rock cut stability is usually based on regular, repeated documentation of the rock walls, dilatometric measurements and use of various methods of photogrammetry. The initial state of monitoring consists of reconnaissance assessment of the geological, tectonic and structural conditions. Based on this information the overall stability conditions of the rock mass may be estimated, together with its blockiness and loosening.

Dilatometric measurements are usually used for the registration of the movement of individual blocks. The general changes of the whole road rock cut may be observed using photogrammetric methods. Repeated photogrammetric measurements comprise changes in the representative slope profiles and make it possible to determine the movement of partial units in selected profiles. Moreover, the photogrammetric methods make it possible to identify and quantitatively express the volume of failed parts of the cut, which, by loosening and falling, endanger the vicinity.

In the latest surveys a new method of digital photogrammetry has been used which presents a modification of analytical photogrammetry, using digital photographs. Advantages of this method include its accuracy, the wide spectrum of processing possibilities available and straightforward integration into GIS.

The paper describes comparison of the results achieved by various photogrammetric methods including use of digital photogrammetry. The measurements were obtained on selected localilities of road rock cuts during several years of photogrammetric monitoring.

Résumé: Dans le cadre du projet slovaque de suivi des déformations des talus, des déblais rocheux sur des trois sites différents ont été choisi disposant des conditions géologiques différentes d´un cas à l´autre. Le suivi courant des déblais rocheux consiste en une documentation régulière et répétitive des talus, en des mesures dilatométriques ainsi qu´en une application de divers méthodes photogrammétriques.Le début du suivi comporte une évaluation préliminaire des conditions géologiques, tectoniques et de la structure du massif. Grâce à ces informations, il est possible d´examiner les conditions de stabilité globales du massif rocheux, le niveau de sa désagrégation et décompositions en blocs y compris.

Le plus souvent, les mesures dilatométriques servent à détecter des mouvements des blocs rocheux individuels. Les changements globaux des déblais routiers peuvent être observés à l´aide des méthodes photogrammétriques. Les mesures photogrammétriques réalisées du façon périodique permettent à enregistrer des changements des profiles de référence des talus et elles permettes à identifier des mouvements des blocs individuels. A part ça, grâce à la photogrammétrie, il est possible d´identifier et d´évaluer de façon quantitative les volumes des sections défectueuses des déblais qui soient susceptible à menacer leur entourage.

Dans les reconnaissances dernières, la photogrammétrie numérique a été utilisée. Cette méthode présente une photogrammétrie analytique se servant de la photographie numérique. Les atouts comportent un niveau élevé de la précision, les domaines vastes d´application et une connexion directe avec le GIS.

Dans cet article, la comparaison des résultats donnés par des différentes méthodes photogrammétriques est présentée. Les mesures ont été sur les sites sélectionnés des déblais routiers pendant plusieurs années.

Keywords: discontinuities, extensometers, monitoring, photogrammetry, stability, weathering

INTRODUCTION

In the scope of the project, Partial Monitoring System Environmental Geofactors of the Slovak Republic, part Landslides and other Slope Deformations, several slope deformations have been monitored for a long period occurring in various geological environs. The Project's Orderer is the Ministry of the Environment of the Slovak Republic and the solver is the Geological Survey of the Slovak Republic (Klukanova & Liscak 2004). While relatively slow movements of a creep or sliding character can be monitored and recorded by various methods (geodetical, inclinometric, etc.), the movements of a falling type (rocks), cannot be monitored directly due to its large velocity. In this case we can monitor deformation evolution and replacement of rock blocks, which may indicate initial stage of the falling process. In some cases, such observations enable to identify the most jeopardized rock wall sections and, subsequently, to propose optimum remedial measures and thus to prevent large economical damage and a direct imperilment to human lives.

There are many methods available for monitoring of slope movements of a falling character and there have been significant advances in this field. A substantial base for effective application of individual monitoring methods is grounded in a detailed documentation of a rock outcrop, together with a delineation of engineering geological quasi-homogeneous units of the same blockiness and loosening, which are in a similar stability state. The purpose of zoning a rock massif makes it possible to select an optimum monitoring method and monitoring facility emplacement within the rock wall. The monitoring methods can be divided into two major groups according the method of data acquisition – direct and indirect measurements of displacements and deformations of rock blocks. The direct methods comprise various indicators, dilatometers, extensometers and other facilities. Among the indirect methods there belong a wide range of photogrammetry methods; recently, their capacities and quality is fully replaced by the method of digital photogrammetry.

The essence of the quasi-homogeneous units delineation in the rock massifs have been described in several publications (Matula & Holzer 1978, Matula 1981 and others) and their applications in concrete rock environment are characterized by specific features. The direct measurements of deformations and replacement of rock blocks have witnessed turbulent developments, from simple mechanical dilatometers and extensometers to sophisticated signalling warning systems (Zvelebil 1996, Vlcko & Petro 2002, Greif, Sassa & Fukuoka 2004 and others), which are based upon dilatometric and extensometric measurements principle, prevailingly. According to the knowledge from scientific literature and acquired experience from our own measurements (which at the model sites we took using a bar portable dilatometer and displacement gauge) we may state, that the direct observations are suitable for displacement recording of discrete blocks within an outcrop. A global assessment of the stability state of a rock wall and delineation of stability critical sections is enabled thanks to methods of close range photogrammetry. Moreover, these methods make it possible to acquire information on three-dimensional orientation of selected discontinuities, which are inaccessible for a direct measuring by compass. This is why our main concern is focused on the photogrammetry methods application for monitoring of road cuts occurring in different rock environs.

METHODS OF CLOSE RANGE PHOTOGRAMMETRY

Methods of close range photogrammetry enable a wider section of a monitored road cut to be evaluated, and to a rather higher degree of precision, to estimate replacement values of selected parts (blocks) of an outcrop. Although we can divide the methods according to various criteria, for our purposes we assess as the best fitting the division in the methods of analytical close range photogrammetry, which utilize standard analogue images and methods of digital photogrammetry with digital images.

Analytical methods of the close range photogrammetry

Within this group of methods we characterize briefly those, which were applied in the monitoring of sites in the past period (years 1995 to 2003). In fact, these were stereoscopic measurements of profiles on stereocomparator and rock blocks movement measurements at outcrop using the method of time baseline (Bartos & Gregor 2001).

Stereoscopic measurements

These measurements utilize a pair of terrestrial analogous images (stereopair) acquired by a surveying terrestrial camera at the end points of suitable photogrammetric baseline. The photos correspond to requirements of stereoscopy, which means, when watching a stereopair in stereocomparator there is created a virtual stereoscopic model (three-dimensional) of a depicted site. There are delineated characteristic profiles (vertical or horizontal) within the area of a monitored rock wall; along these sections a change in their configuration is evaluated for various time periods. In the course of repeated measurements it is important to secure unified outer orientation of stereopair for individual periods and unified reference nivelation system for all profiles delineated. From the comparison of profile configurations it is possible to identify sections of material loss, or sections with fragment accumulation increment. In the case of a dense profile network there is possible to derive a volume of released (or being released) rock blocks. If in the course of the repeated measurements unequivocal trends of material decrement within certain wall parts are identified, which can lead even to a formation of overhangs, there it is reasonable to assess these parts as susceptible for a rock fall. The accuracy of the point coordinates determination is given by position mean error (reference plane parallel to the image plane) 10 cm and vertical mean error 15 cm (reference plane perpendicular to the image plane).

The time baseline method

The time baseline method principle is based upon repeated imagery while simultaneously keeping unchanged the internal and external orientation of the image. The same camera and standpoint is used as well as the shoot axis orientation. The accuracy of the displacement measurements is in indirect proportion to an observed point distance from the standpoint and thus also to image scale. For instance, if at the determination of displacements Δx we are applying measurements of horizontal parallaxes of a certain accuracy, which is given by a mean error m_p = 0,003 mm, their accuracy at monitored sites from the closest to the most distant points ranges from 1,0 to 2,5 mm (the Banska Stiavnica site) and from 0,5 to 1,5 mm (the Demjata site). Analogically, for the preciseness of the vertical displacement determination Δz at accuracy of vertical parallaxes measurements m_q = 0,005 mm, the accuracy of displacements determination ranges from 2,0 to 4,0 mm (Banska Stiavnica), or from 1,0 to 2,5 mm (Demjata).

DIGITAL PHOTOGRAMMETRY

Method characterization

The digital photogrammetry is a modification of analytical photogrammetry, which utilises digital images and mathematical models of analytical photogrammetry in computational environ of a photogrammetric digital station.

The digital image provides an object depiction using CCD (Charge Couplet Device) scanners (linear, areal), which consist of CCD elements. Thus the object depiction is composed of picture elements (pixels), which are defined by the dimension of the CCD element. Each depicted element is characterized by its co-ordinates in digital co-ordinates system and it is a bearer of numerical information on the density (0-255, at 8-bit record). Digital images of high resolution are suitable for digital processing, for distinguishing of essential rock massif characteristics and for solutions related to stability state assessment.

During the processing there a measurable digital model of the rock object is created in the photogrammetric digital station; this is enabled through orientations (inner, mutual and absolute) of digital stereopairs. The station represents an opened universal system, which enables input, manipulation and output of spatial digital data in raster as well as vector format. Its main constituents are hardware and software, which can be applied for all issues of a modern photogrammetry (aerotriangulation, photogrammetric evaluation, editing of graphic data, creation of orthophoto images, orthophoto maps, implementation of three-dimensional vector data into digital stereomodel, perspective views, etc.).

Integration of digital photogrammetry methods within information systems (GIS) makes possible to reach an extraordinary optimisation and automatization of 3D data acquisition. Moreover, a wide spectrum of output presentation opportunities enables to select those, which are the most convenient for the site under evaluation.

The advantages of the digital photogrammetry when comparing with other analytical methods

Based upon the theoretical assumptions and acquired experience, as well, we may generalize the assets of the digital photogrammetry against analytical methods as follows:

- An enhanced accuracy of the 3D data acquisition on a digital model created by orientation of digital stereopair in digital working station. This accuracy is dependent on scale number, mainly (however, this is valid also for analogous images) and on geometrical and radiometrical resolution capacity of digital images. The decisive influence upon the accuracy 3D data acquisition shows the geometrical resolution capacity;
- An option of orthophoto images, or orthophoto map creation (of a constant scale) by digital differential re-drawing based upon compiled morphology digital model of the rock-cut;
- Enhanced technology of automated creation and visualisation of morphology digital model using stereo-correlation, which consists of semi-automated measurements of selected horizontal, vertical, or any arbitrary oriented profiles, as well as measurements of block edges rock within the outcrop and discontinuity orientations;
- An option of results output and visualisation of measurements in raster or vector form, which is compatible with geographic information systems.

From the above review of the advantages of the digital photogrammetry against classical methods it is obvious that besides well-adopted outputs, the digital photogrammetry offers other options for measurement presentation with distinctly higher accuracy level.

CASE STUDIES OF PHOTOGRAMMETRY METHODS APPLICATION IN THE MONITORING OF ROAD CUTS

Monitoring of slope movements indices of a falling type is carried out at three representative sites, which applies for road-cuts along roads with a dense traffic. From the geological point of view each site is situated in a different geological environment (Figure 1).

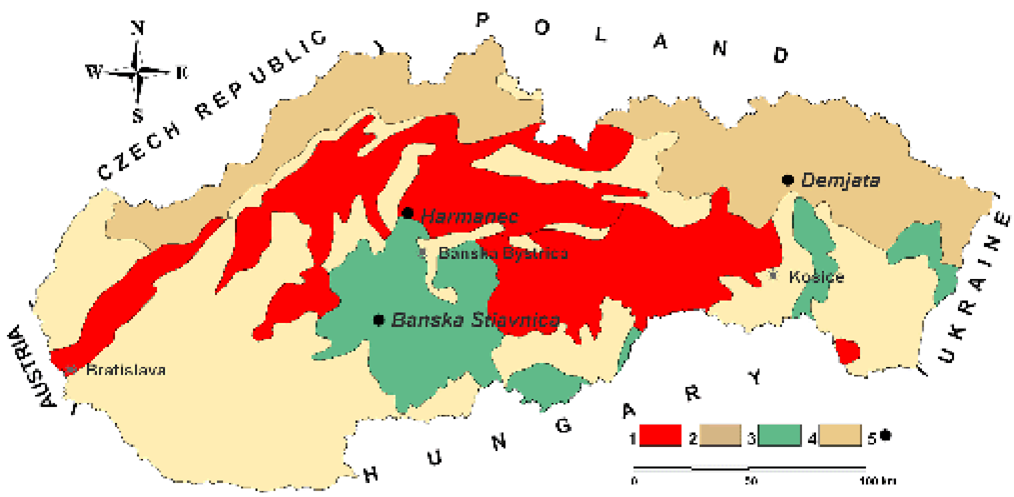

Figure 1. Situation of monitored localities. 1 – region of core mountains, 2 – region of Carpathian Flysch, 3 – region of Neogene volcanics, 4 – region of Neogene tectonic depressions, 5 – monitored road cuts

The road cut near Demjata village

Site description and ways of monitoring

The incised road cut of the road interconnection northerly of the Demjata village (ca 12 km north of Presov, Eastern Slovakia) is situated on the tectonically deteriorated flysch formation of the Palaeogene age, composed of massive sandstones, which prevail over layers of calcareous claystones and siltstones. The road cut length is about 100 m and the height reaches up to 15 m. Due to unsuitable spatial orientation of the eastern wall against the bedding strike and against dominant discontinuity systems, as well, and thanks an intense influence of exogenous phenomena the sandstone blocks show a tendency of loosening and falling off from the massif. The claystone beds undergo an intense selective weathering and locally they degrade into a material of clayey soil character. Due to acute jeopardizing of the traffic a catch wall of about 2 m height was built on both sides of the road. However, the loosening of the higher parts of the road cut indicates, that the release of larger rock blocks could lead to repeated direct jeopardizing of the traffic. For the space between the wall and slope is almost totally filled with rock fragments and blocks of larger dimensions which were loosed from the upper slope parts, the further fallen blocks may directly hit the state road.

The monitoring of the eastern wall of the road-cut was launched in 1995 with compiling of basic engineering geological data on the locality (processing information on lithological setting, structure and massif weathering – Figure 2). Simultaneously, the first surveying of the site was carried out by analytical methods of close range photogrammetry, which provided a comparative model for further observations. The time baseline photogrammetric method was used in this initial stage, which enabled annual monitoring of morphological change of the road cut. This method was amended by stereoscopic measurements in 5 selected vertical profiles. In the year 2000 there were installed measuring points on the rock wall for direct dilatometric measurements. The method of digital photogrammetry has been applied at the site since 2004.

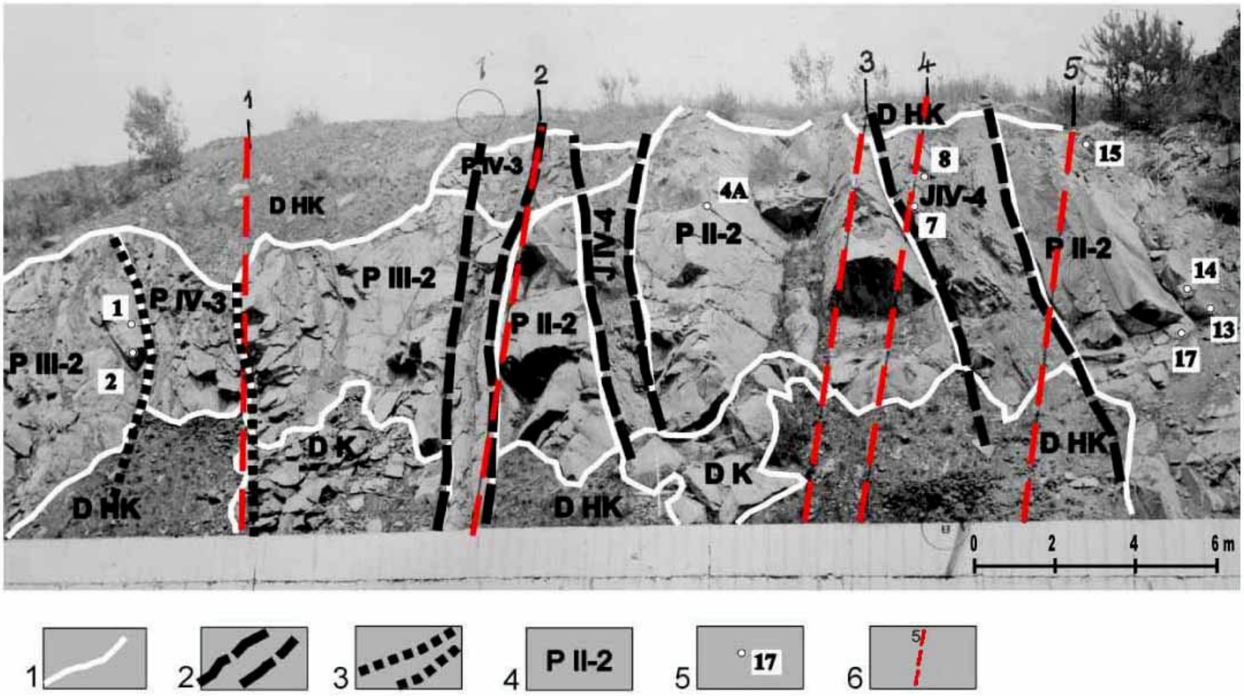

Figure 2. The road cut near Demjata village. 1 – borders of engineering geological quasi-homogeneous units, 2 – zones of intensive weathering, 3 – zones of tectonic failures, 4 – method of indication of engineering geological units (P – sandstones, J – claystones, D HK – loamy-stony scree, D K – stony scree, II – representative size of the rock blocks from 600 to 2000 mm, III – from 200 to 600 mm, IV – from 60 to 200 mm, 2 – compressive strength of rock material from 50 to 150 MPa, 3 – from 15 to 50 MPa, 4 – from 5 to 15 MPa), 5 – designation of several observed points, 6 – representative profiles

Monitoring results acquired by analytical methods of the close range photogrammetry

From the measurement results it is obvious there are variable dynamics of the block fall-off process in various rock zones of the road cut, which have been defined based upon engineering geological and photogrammetric massif assessment. The most distinct displacements have been recorded near a tectonic failure zone (points 1, 2, profile 1) and in the zone of intense selective weathering (points 7, 8 – Figure 2). Within the period of 7 years the largest displacements were measured in points 1 (49,2 mm) and 2 (43,3 mm); this represents an average orientation movement velocity 7 mm/year. Within the zone of selective weathering, displacements of rigid blocks attained ca 20 mm per 7 years. However, there has been clearly identified a replacement of fine-grained rock material, which underwent the weathering. The wall morphology changes were recorded by stereoscopic measuring along profiles; notable differences within individual profiles have been detected in the profile 1. These changes occurred due to fall-out of several blocks from the wall reaching a volume up to 1 m^3. The fall-out of the sandstone block took place also in the middle part of the profile 4 and in profile 5 there was a slip recorded of the upper edge of the road cut.

The results of the monitoring performed by analytical methods of photogrammetry have revealed distinct dynamics in the change of the observed geological environment, which occurred due to its lithological and structural inhomogeneity leading to gravitational movements of rock blocks from slow replacement type even to falling and intensive progressive evolution of weathering process. However, due to the prevailingly plastic character of rock deformation and potential weak zones it was possible to identify a trend of gradual deformation increment in several points, leading finally to release of certain rock blocks. Such development enable us to predict, which parts of the outcrop are likely for a movement origination of the falling type. Sudden changes of the falling character (without previous "warning") are typical for solid sandstone blocks, which lost their support due to deformation and weathering of the claystone sublayers.

We have pointed out and communicated the most critical sections of the road-cut to the road administration and based upon this signalling several remedy measures have been applied (for instance, emptying of the space between the catch wall and the artificial outcrop).

Some results of digital photogrammetry application

Thanks to high quality of the background utilised by analytical photogrammetry methods in previous years the transition to the digital photogrammetry methods was rather smooth at this site. The digital imagery from the year 2004 was compatible with depictions from previous years, which enabled a common assessment of the individual stages of the rock slope evolution.

The enhanced technology of digital photogrammetry makes it possible to select and depict any profile within the rock outcrop. The Figure 3 brings a mutual comparison of the rock wall configuration within the chosen profile 1 from the years 2001, 2002 and 2004. This comparison gives evidence of a voluminous rock-fall, which took place in the period between the 2002 and 2004 measurements and a compilation of relatively stabile rock wall configuration.

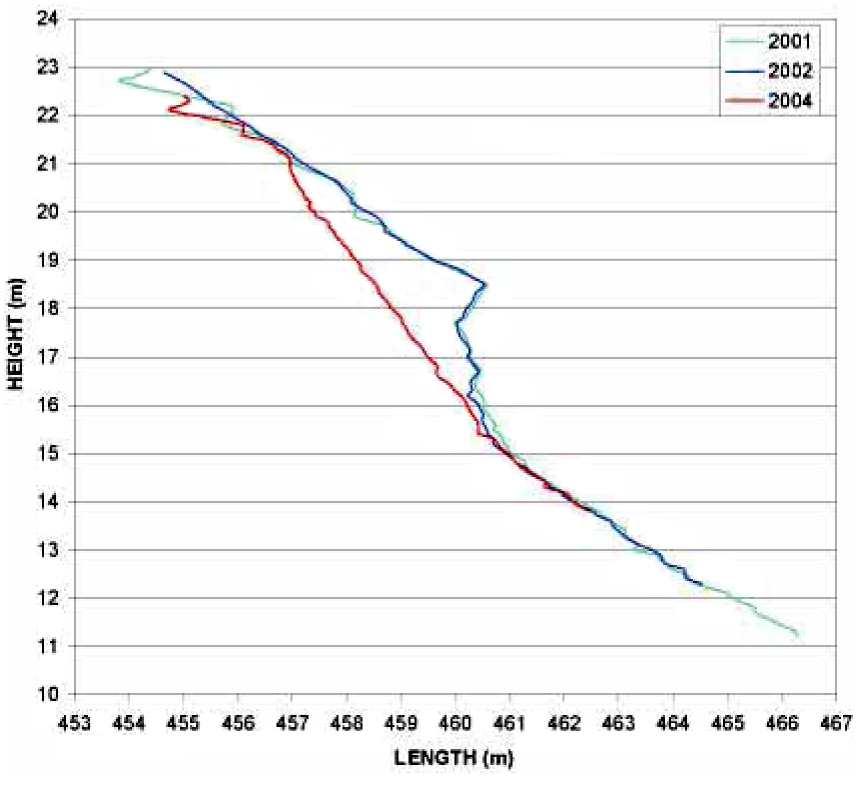

Figure 3. Profile 1 – a comparison of the rock wall configurations for the years 2001, 2002 and 2004

The illustrative possibilities of the digital photogrammetry has been confirmed for a complex assessment of the configuration changes of the entire rock outcrop or certain sections. The semi-automated measuring of selected horizontal cross-sections (contours) in any reference height makes it possible to draw their projections for individual measuring periods. Figure 4 depicts the course of contours recorded in the years 2001 and 2004 (at relative height levels ranging from 14 till 19 m) within selected rock outcrop section. In the picture there can be clearly identified places of the greatest decrement in the rock material (right upper side of the picture, contours 18 and 19 m) as well as the sites of the scree cones formation (the bottom part of the picture, contour 14 m).

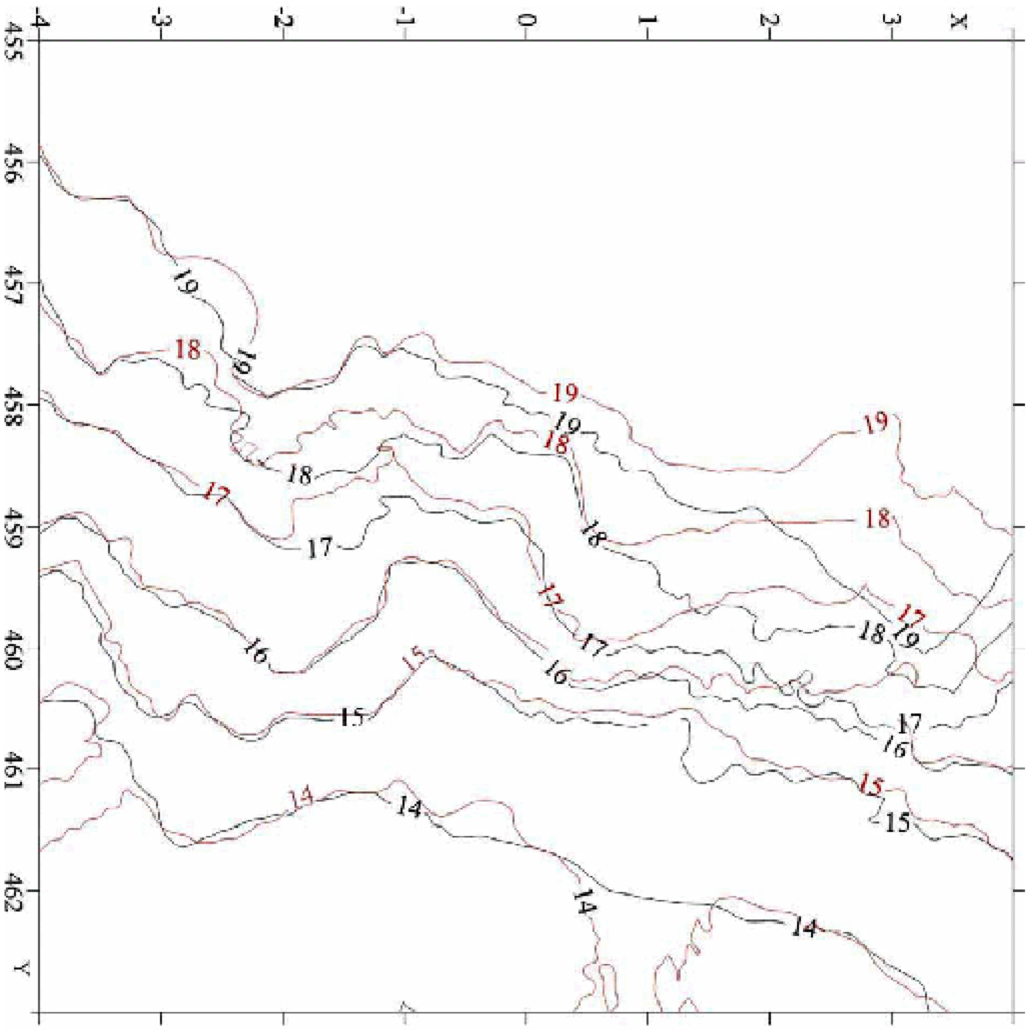

Figure 4. The contour projection within the selected section of the rock wall (between profiles 1 and 2, see Figure 2) in the years 2001 and 2004

The above examples as well as other possibilities of digital photogrammetry (e.g. a creation of digital model of rock wall in various time intervals and at any orientation of the model according to requirements), including much better information accuracy are a strong argument for application of this method in future.

The road cut in the town of Banska Stiavnica

Site description and ways of monitoring

The incised road cut of a length of about 80 m and a height up to 12 m circular of the town of Banska Stiavnica (Central Slovakia) towards the village of Štiavnické Bane has been established within the environment of Neogene volcanites (pyroxenic andesite porphyry on the eastern wall and a strongly hydrothermally and tectonically disrupted and argillitized andesite to argillite on the western wall of the road cut, equipped with a catch wall). Originally massive rock masses have been progressively deteriorated after the excavation works. The intensity of the rock environment disintegration is conditioned mainly by the degree of rock massif jointing and it is manifested by a total rock decomposition into soil occurring in the zones of intense tectonic and hydrothermal alteration; frequently by loosening of originally rigid massif with displacements and even falling off blocks and fragments of various dimensions. The released material accumulates at the base of the road cut, locally it spreads over communication and threats the traffic on the eastern stripe. This was the reason why the locality was selected for regular monitoring by photogrammetry methods, which since 2000 have been amended by dilatometric measurements within selected sections of the eastern wall of the road cut. Among the observed deformations there prevail gravitational loosening of blocks and fragments of various dimensions.

The monitoring of the eastern wall of the road cut began in 1995. In this year a detailed engineering geological documentation was carried out of the road cut rock wall. Among the methods of analytical photogrammetry annually applied was the time baseline method and stereoscopic measuring of selected 8 representative profiles. At this site the method of the digital photogrammetry started to be applied in the year 2004.

Monitoring results acquired by analytical methods of the close range photogrammetry

The monitoring measurements have revealed a distinct degradation of the southern parts of the road cut within the zone of loosened banks (Figure 5), where,in the years 2000 and 2003, fall off blocks of a total volume attaining 16 m^3 occurred. At this very place, the change in the road cut wall morphology is observable on the vertical profiles PF6 and PF8. Within the middle sections of the profiles there can be identified certain smoothening of the profile line, which is a consequence of smaller fragments fall-out and their accumulation at the bottom parts of the road cut wall.

The rock blocks position changes measurements by the time baseline method detected the most extensive process of massif loosening in the closest vicinity of the fall-off bank (points k3, k4), where there had been observed a block displacement reaching 70 mm before the fall itself (from the beginning of measurements, this means the period of 7 years). The time baseline method measurements illustrate rock blocks loosening process and their displacement along pre-determined slip planes. The distinct manifestation of the blocks bulging towards the road occurred in the subhorizontal direction (points s3, s5).

In order to observe the dynamics of rock blocks release from the massif, from the initial till the final degradation stage represented by rock fall, the measuring points for direct dilatometric measurements were installed. Due to the fact (observed also at the other monitored sites), that the points are generally emplaced in relatively solid blocks (which is pre-conditioned by possibility for their technical realization), the movements measured by dilatometric methods are usually significantly smaller as the total dynamics of the rock massif, recorded by photogrammetric measurements.

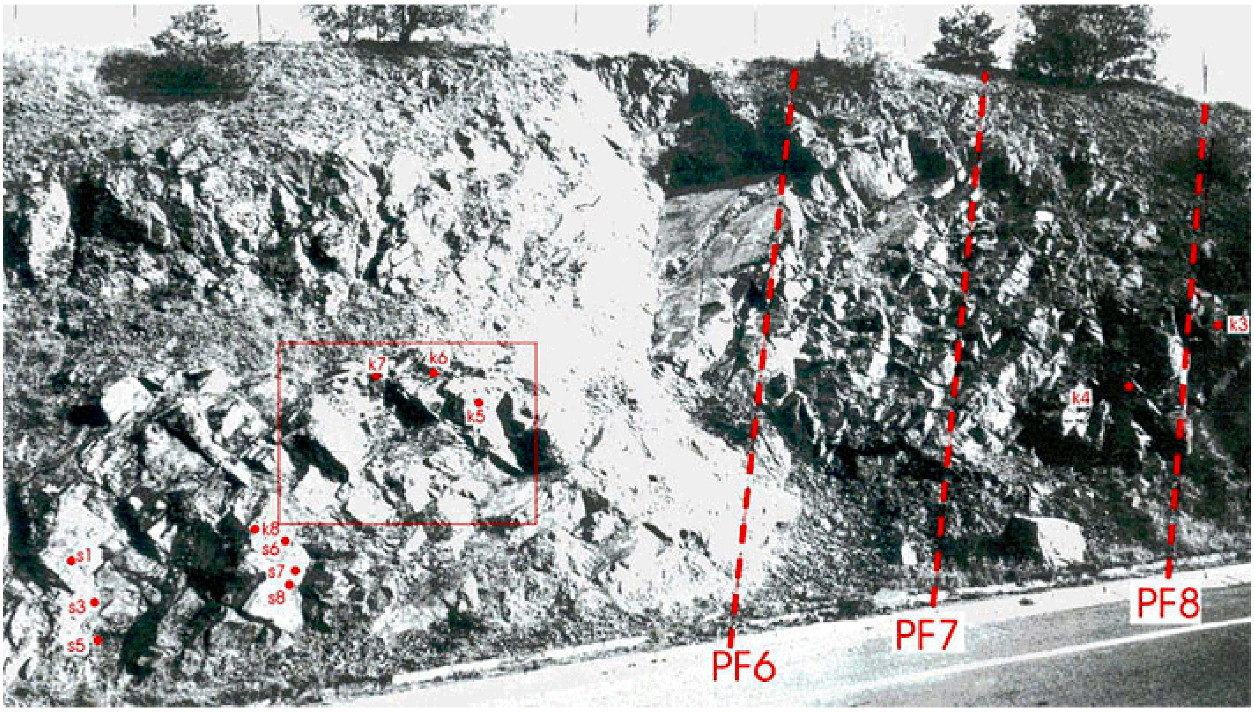

Figure 5. The rock cut at the site Banska Stiavnica. PF6-PF8 – representative profiles; k3-k8 and s1-s8 – designation of several observed points; an area of detail in Figure 6 is bordered by red line

The analytical photogrammetric monitoring methods results have shown that the rock road-cut slope is locally unstable. There have been observed the permanent loosening and fall-off rock blocks, which have undergone an intense disintegration. However, we have to point out, that the block loosening happens irregularly, individual displacements cannot be extrapolated to the closest vicinity and practically each block behaves individually. Moreover, these rocks are characterized by great strength and by elastic behaviour mode, prevailingly, which causes origination of sudden brittle failures, leading to occurrences of falling-type movements (without any previous "signalling" in form increment of measured displacement trend).

Some results of digital photogrammetry application

When adopting the digital photogrammetry method for monitoring at the locality Banská Stiavnica there was not possible to create links to previous measurements results, obtained by methods of analytical photogrammetry in the years before. The reason has been an insufficient compatibility of ground data. This is why we adopt the background information processed from the basic measurements from digital photogrammetry, which were carried out in the 2004.

Due to outcrop character, typical of sharply edged solid rock blocks there have been selected among digital photogrammetry methods the most suitable measuring of edges displacement on defined blocks within the rock outcrop. This approach enables to make a selection of representative rock blocks from relatively wide section of the outcrop and to derive their displacement vectors for each monitored period. An example of such assessment by the digital photogrammetry method is presented in the Figure 6. This picture brings a comparison of the selected blocks position at initial measurements, which were carried out by autumn 2004 with their position at measurements in autumn 2005. Due to massif and rock material character the replacement of the selected block reached minimum values. Nevertheless, the capacity of the digital photogrammetry as well as the accuracy of this method have substantiated its application in further monitoring of this rock road cut stability.

Figure 6. Measurement of the rock blocks edges by the method of digital photogrammetry (red line – position in 2004, green line – position in 2005)

The road cut westerly of the village Harmanec

Site description and ways of monitoring

The monitored locality is situated in the selected section of an extensive road cut westerly of the village Dolny Harmanec (Central Slovakia, ca 18 km north-west of the town of Banská Bystrica). The road cut height within monitored section reaches ca 25 m. The road cut has been excavated in the rock environment made of Middle Triassic dolomites; these rocks were apparently of massive structure, however, they are strongly tectonically disrupted and they used to undergo a quick decomposition when exposed. The rock fragments used to fall-of within the entire defile and to form extensive accumulations at the foothill. The scree creation is very intense mainly in the spring season and there is necessary to maintain the state road permanently. The presence of dominant dislocation zones and remarkable erosion rills contributes to loosening of larger rock blocks, or washing out of voluminous disintegrated material, which could cause serious problems for the traffic.

The monitoring of this locality is of specific character. Due to relatively compact rock massif, disintegrated on the surface and the character of falling-off fragments attaining dimensions of several centimetres, cannot be applied the methods, which are focused on observation of individual blocks (or parts) of the rock outcrop. The loosening of larger rock blocks occurs sporadically and potential jointing planes are not distinct enough. Moreover, due to the brittle nature of the dolomite decay there occur immediate destructions, without any preceding signalling. This is why since 1999 the monitoring has been focused in the morphologically distinct chute, which dissects the rock massif; we assess the evolution of weathering and erosion processes in this very place. Here we have applied a simultaneous study of processes of stability, weathering and erosion within single site (Janova & Liscak 2002).

The monitoring results

When carrying out the site's monitoring by analytical methods we applied the stereoscopic method, through which we established horizontal profiles. The object was scanned from a distance of about 15 m. This way we measured 15 horizontal profiles at various vertical levels; at each of them we compared the rock wall configuration around the erosion rill initially measured in 1999 with the configuration recorded in the years 2001, 2002 and 2003. The most distinctive incising as well as side-spreading of the erosion rill was recorded in its upper part, this means 16 m above reference level. It has been detected that the erosion process advance very intensively, irregularly and there is a permanent need for road maintenance (first of all, regular removing of scree, accumulated below the rill mouth). A permanent effective remedy measure in this case can be only installing of protective dense nets – however, there arises a problem of effective bolting and a long-term functionality of the reinforcement due to significant annual decrements of the rock material from the rock slope.

Due to rather specific character of the monitoring at this site we have sustained the classical monitoring and analogous character of the output data, although since 2004 we have implemented the digital photogrammetry method. However, the capacity and accuracy of these outputs are of much higher quality. To illustrate the situation, in Figure 7 we present the results of digital photogrammetry measurements carried out in September 2004 and October 2005 in selected horizontal profiles. Although relatively short (annual) interval proves for distinct weathering process dynamics, with the most profound manifestations within the profile with relatively height level of 17,4 m, where the decrement of the massif surface reached ca 30 cm. The profiles` processing at various height levels makes possible to define the released material volume within certain time span.

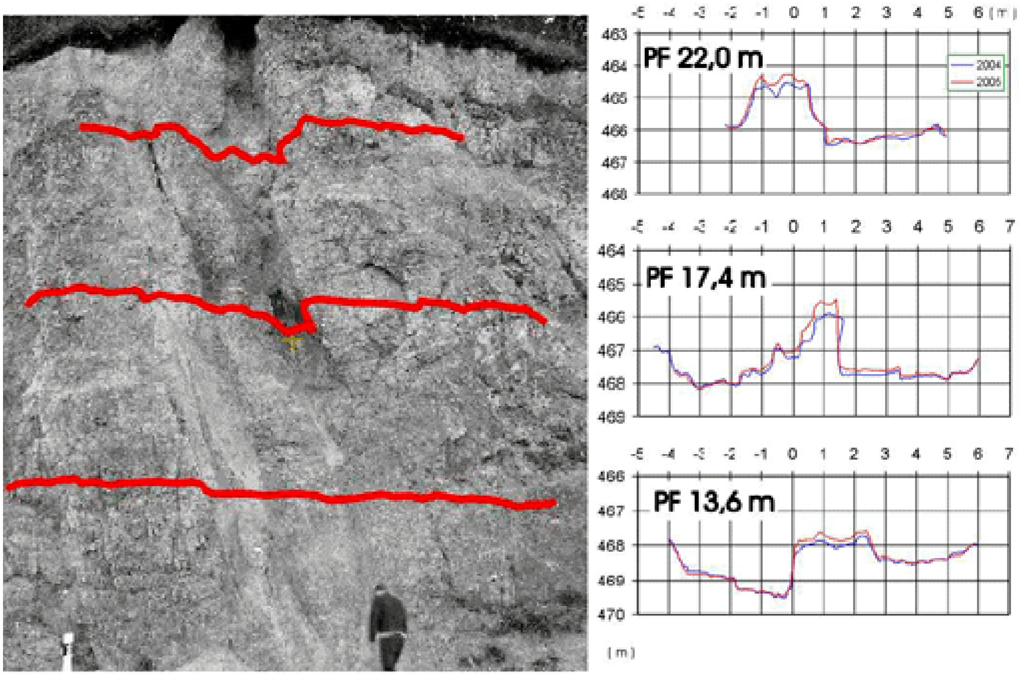

Figure 7. The road cut near Harmanec village. A configuration of the rock wall in selected horizontal levels in 2004 and 2005

CONCLUSIONS

The monitoring of rocky road cuts stability and the prognosis of slope movements of falling character belongs among very complex issues of the engineering geology. Recent experience has shown that in major cases the movement of each basal unit of the rock massif (block) is individual and monitoring points network cannot record the changes within the entire entity of blocks, from which the rock wall consists. Moreover, the rock deformation character, leading to the falling process differs depending upon each rock environ. There occur only minimum deformation changes in the brittle rocks environ with a limited plastic reserve and the rock failure generally takes place after sudden exceeding of a strength limit (there have been observed such behaviour at the Harmanec site). The rocks with a great plastic reserve and massifs with potential weak zones are deformed and replaced gradually; in such case there is possible to identify certain trends leading to origination of falling-type movements (road cut at the Demjata village).

Based upon the above facts and long-term practical experience we assess the methods of close range photogrammetry to be the most convenient for estimation of the rock wall stability as a whole. These methods provide a basis for delineation of the most jeopardized sections, which can be monitored more precisely using various dilatometric and extensometric methods. However, their application usually meet technical problems with measurement points fixing in the deteriorated parts of the massif.

The method of digital photogrammetry has brought about an advance in application of photogrammetry methods. This method offers more simple data acquisition, considerably wider possibilities for processing and presenting of results and larger assessment accuracy. In fact, it has brought about technical enhancement of up-to-now measurements and output modes based upon rich experience from the previous measurements by analytical methods of the close range photogrammetry.

A fundamental question of the further monitoring of rock walls stability dynamics doesn't excist in the data acquisition and presentation technique improvement, solely. From the viewpoint of new measurements technologies application we unequivocally prefer the digital photogrammetry method or other modern methods of data acquisition. The principal task subsists in the monitoring objects actualisation, in preparedness at information acquisition and providing and creation of reliable prognosing and warning systems. The up-to-date monitoring objective makes an inventory of the actual rock wall state and it could indicate some trends of the deformation evolution, or blocks replacement. A qualitatively higher monitoring level could be based upon deriving of certain critical limit displacement values, which could signalise a high probability of rock blocks falling. The derivation of such values is individual for various rock environs and in some cases it is very disputable. Supported by the derived critical displacement values there should transit into higher quality level also the data acquisition system, which would be based upon continuous measurements and upon information transfer directly into the monitoring centre. The monitoring designed in this manner could meet fundamental requirements laid upon reliable prognosing and timely warning of falling movements.

Although the majority of presented ideas on the improvement of the rock walls monitoring objectives and preparedness are technically realizable, most of them are very costly facilities. Their future realization depends mostly upon the level of the threat to road sections and upon the involvement of the road administration in safeguarding the traffic on roads.

Acknowledgements: The authors are thankful to The Ministry of the Environment of Slovak Republic for its support and kind permission to publish this paper. They also are thankful to the grant agency VEGA (grant project No 1/1153/04) for its kind support.

Corresponding author: Dr. Peter Wagner, Geological Survey of Slovak Republic, Mlynská dolina 1, Bratislava, 817 04, Slovakia. Tel: +421 2 59375415. Email: wagner@gssr.sk.

REFERENCES

BARTOS, P. & GREGOR, V. 2001. Interdisciplinary activities of photogrammetry in engineering geology. *In: Proceedings of the Conference „Geology and the Environment 2".* Dionyz Stur Publishers, Bratislava, 123-127 (in Slovak)

GREIF, V., SASSA, K. & FUKUOKA, H. 2004. Monitoring of rock displacements at Bitchu-Matsuyama rock slope in Japan using Linear variable differential transducers sensors. *In: Proceedings of the 9th International Symposium on Landslides, Rio de Janeiro.* Balkema Publishers, Swets &Zeitlinger, Lisse, 773-779

JANOVA, V. & LISCAK, P. 2002. Applications of the terrestrial photogrammetry in monitoring of weathering processes. *In: Proceedings of the Conference „Interdisciplinare applications of photogrammetry and engineering g eodesy"* . Slovak University of Technology, Bratislava, 69-74 (in Slovak)

KLUKANOVA, A., & LISCAK, P. 2004: National Environmental Monitoring of Slovak Republic – Part Geological Hazards. *In: Engineering Geology for Infrastructure Planning in Europe.* Springer Verlag Publishers, 650- 656

MATULA, M. & HOLZER, R. 1978. Engineering geological typology of rock masses. *Grundlagen und Anwendung der Felsmechanik. Felsmechanik Kolloquim Karlsruhe.* Trans. Tech. Publications, Clausthal, 107-121

MATULA, M. 1981. Rock and soil description and classification for engineering geological mapping. *Bulletin of the IAEG,* **24**, 235-274

VLCKO, J. & PETRO, L. 2002. Monitoring of subgrade movements beneath historic structures. *In: Proceedings of the 9th Int. Congress of IAEG, Durban.* SAIEG, Pretoria, 1432-1437

ZVELEBIL, J. 1996. A conceptional phenomenological model to stability interpretation of dilatometric data from rock slope monitoring. *In: Proceedings of the VII th Int. Symposium on Landslides*. Balkema, Rotterdam, 1473- 1480.