REMEDIATION OF LANDSLIDES ON THE R1 EXPRESSWAY IN SLOVAKIA

SANÁCIA ZOSUVOV RÝCHLOSTNEJ CESTY R1 NA SLOVENSKU

František Baliak [1], Martin Brček [2], Viktor Janták [3], Peter Mušec [4]

Abstract

The occurrence or reactivation of slope failures on landslide, cut and embankment slopes often cannot practically be avoided during the development of linear structures. Within the R1 Nitra – Tekovské Nemce construction, landslide No.1 was activated in km 0.8- 1.0 on section 1, landslide No.2 in km 0.3, landslide No.3 in km 0.7 – 1.0 and landslide No.4 in km 9.6 – 9.8 on section 2, landslide No.5 in km 2.4 – 2.6 on section 3. The article presents the characteristics of these landslides, implemented stabilization methods for disrupted slopes and monitoring results of assessed locations from the moment of landslides formation until current state from the Independent Engineer's perspective. As a background for geologic and tectonic characteristics of the environment, in which the geodynamical phenomena occurred, we used the results of multi-stage engineering and geological survey implemented during the preparation phase on all stages (references Matejček et al., 2008a; 2008b, 2008c; Mazúr & Lukniš, 1980) and geotechnical monitoring during the works construction.

Abstrakt

Pri výstavbe líniových stavieb sa v praxi často nevyhneme vzniku, resp. reaktivizácii zosuvov na zosuvných, zárezových a násypových svahoch. V rámci výstavby R1 Nitra – Tekovské Nemce sa aktivizoval zosuv č. 1 v km 0,8 – 1,0 na 1. stavbe, zosuv č. 2 v km 0,3, zosuv č. 3 v km 0,7 – 1,0 a zosuv č. 4 v km 9,6 – 9,8 na 2. stavbe, zosuv č. 5 v km 2,4 – 2,6 na 3. stavbe. V príspevku je uvedená charakteristika týchto zosuvov, realizované metódy stabilizácie porušených svahov a výsledky monitoringu hodnotených lokalít od vzniku zosuvov po súčasný stav z pohľadu nezávislého dozoru. Ako podklad pre geologicko-tektonickú charakteristiku prostredia, v ktorom sa dané geodynamické javy odohrali nám poslúžili výsledky viacetapového inžiniersko-geologického prieskumu realizovaného v etape prípravy vo všetkých stupňoch (referencie Matejček et al., 2008a; 2008b, 2008c; Mazúr & Lukniš, 1980) a geotechnický monitoring počas výstavby diela.

Keywords
R1 expressway, landslides, factors and causes, stabilization, monitoring

Kľúčové slová
rýchlostná cesta R1, zosuvy, faktory a príčiny, stabilizácia, monitoring

1 Introduction

The expressway **R1 Nitra – Tekovské Nemce** includes three individual constructions (sections):

- Expressway R1 Nitra, west – Selenec
- Expressway R1 Selenec – Beladice
- Expressway R1 Beladice – Tekovské Nemce

Section S1 **R1 Nitra, west – Selenec,** was implemented as a four-lane divided road of R 22.5/120 category, in western part of Nitra region, in Nitra district. The territory, through which the Expressway R1 route passes, is mostly formed by agricultural land with arable soil. At the beginning of the section the route is connected to R1 section already in operation, Trnava – Nitra, at the Lehota Intersection. The end of the section is connected to the R1 Selenec – Beladice section at the Selenec intersection. The total length of the Expressway in this section is 12.589 km; there were two elevated intersections, 18 bridges, out of which there were 12 bridge objects implemented on the Expressway, as well as abutment and retaining walls and utilities objects. As a part of the construction, there is also the Operation and Maintenance Centre „Selenec“ which forms a technical base for the Concession Section of R1 Expressway, in length of 52 km (Badíková et al., 2011). During implementation, **the landslide No.1** was activated on this section in km 0.8 – 1.0 in chain age km 0.200 – 0.300, branch marked LEMN1 in summer months 2010. It was relatively shallow distortion during slope cut implementation of about 80m.

Section S2 **R1 Selenec – Beladice** is implemented in Nitra region, in Nitra and Zlaté Moravce districts. The territory, through which the construction passes, is formed by agricultural soil, except for the built-up areas. The overall length of the section is 18.966 km. At the beginning of the section the Expressway route is connected to the section R1 Expressway Nitra, west - Selenec, the end is connected to section R1 Beladice – Tekovské Nemce at the Tesárske Mlyňany Intersection. In this section there are two elevated intersections, 21 bridges, out of which there are 12 bridge objects on the Expressway, abutment and retaining walls and utilities objects (Badíková et al., 2011). During the implementation there was **landslide No. 2** activated in km 0.3 (Selenec intersection), **landslide No.3** in km 0.7 – 1.0 and **landslide No.4** in km 9.6 – 9.8.

Section S3 **R1 Beladice – Tekovské Nemce** is located in Nitra region, in Zlaté Moravce district. The territory, through which the route passes, is formed by agricultural soil, except the built-up areas. The overall length of the section is 14.311 km. At the beginning of the section the route is connected to R1 Selenec –Beladice section, at the end to the already built section - R1 Tekovské Nemce - Žarnovica. In this section there are two elevated intersections, 23 bridges out of which there are 18 bridge objects on the Expressway, abutment and retaining walls and utilities objects implemented. A part of the construction is also the Tekovské Nemce service area (Badíková et al., 2011). **Landslide No.5** was activated during the construction in km 2.4 – 2.6.

The report presents the characteristics of these landslides, implemented stabilizing methods for disrupted slopes and monitoring results of assessed locations from the moment of slides formation until current state from the Independent Engineer’s perspective. The slides occurred in sections with geologic and tectonic structures of favourable conditions for their formation, e.g. floury soils levels lying on neogénne clays, interchanging of pervious and impervious layers and soils, etc.

From the shape point of view, they are frontal landslides and from the activity at time of occurrence perspective they are active landslides, mostly along the rotation and planar surfaces of sliding.

For the sliding slopes stability monitoring it was necessary to monitor the development of subsurface horizontal shifts in slopes using the method of accurate vertical inclinometry, mostly combined also with mode monitoring of subsurface waters level (HPV = SWL). Also the effectiveness of proposed redevelopment measures of stabilizing and fortifying, dewatering and drainage nature was verified during the measuring.

2 Geological conditions

The PPP Project, R1 Nitra, west – Tekovské Nemce leads through geo-morphological unit called Podunajská pahorkatina, sub-units Zálužianska pahorkatina, Nitrianská niva, Žitavská pahorkatina, Hronská pahorkatina and at the end it meets sub-unit Pohronský Inovec. The whole territory has undulating relief with exchanging elevations of mild slopes and depressions down to river valley bottom lands of bigger streams - Nitra a Žitava.

From the geological structure perspective, the environment in question is formed by neogénne and post-tertiary sediments. Neogénne emerges in the subsoil of post-tertiary regolith represented by Beladice strata (Pontian) and Volkovce beds (Dacian). From the lithological point of view these are varied clays with medium and high plasticity, or sandy clays. Beds in Volkovce area contain significant amount of sands and gravels. In the upper bed of prior post-tertiary sedimentary complex there are regolith post-tertiary structures represented by polygenetic sediments such as clays, floury soils silts and sands. In river valley bottom lands there is strong presence of bottom lands sediments – gravel and sands. The last four kilometres of R1 Expressway route are led through the area of neogénne volcanic complex of pyroclastic andezit from Pohronský Inovec with post-tertiary regolith of fine-grained soils.

The geological structure in the area of the slope defects occurrence in all three sections of the R1 Expressway, which are subject of this article, is formed exclusively by fine-grained soils of regolith post-tertiary units and neogénne subsoil (Pontian, Dacian).

3 Problem of identification

Slope defects on the Expressway route occurred in areas which did not show any signs of potential instability risk in previous period. However, due to anthropogenic activity, slope deformations occurred during the construction process. Slope defects were recorded on all three Expressway structures. The common factor of all slope defects, which are subject of this report, is the long-term influence of climate impacts on exposed cuts walls formed by fine-grained sediments and the changes of soils geo-technical parameters and slopes stability loss.

4 Landslides characteristics, their stabilization and monitoring

4.1 Landslide No.1 – cut slope landslide in km 0.200 – 0.300 of Lehota intersection (Nitra, west – Selenec)

Slope defect occurred on the right-side of the cut slope of LEMN1 branch built as a part of SO 102 object, Lehota intersection. It is an access branch under the SO 202 bridge object, in direction to Nitra. In affected area, the route is led in cut with slopes decline of 1:2.5 and the excavation is partially absorbed by the retaining walls (fig. 1).

In the affected area, the road is led in cut, in depth of 5 – 8 m. According to the survey works (JN-6 and JN-7 holes) of detailed engineering and geological survey, cover post-tertiary floury soils sediments with characteristics of clay with medium plasticity (F6 Cl), infiltrated by inter-layers of clay with high plasticity (F8 CH) and of solid to firm consistency were found in the area. Neogénne was verified in depth from 7.20 m b.t. to 9.80 m b.t., again in clay stage (F6 CI) with concretions of $CaCO_3$. Forming of this slide was invoked by the favourable geologic and tectonic structure for slope motions formation, specifically by the presence of transferring polygenetic floury soils, significantly damped and frozen lying on neogénne pre-consolidated, volume-unstable clays after the long-term influence of precipitations in summer months of 07 – 08/2010.

In terms of slope motions classification (Nemčok et al., 1974) it is a frontal slide along the rotational and planar surface of sliding, at time of occurrence an active one currently stabilized one (fig. 2). The estimated surface of sliding was in depth of about 8 m b.t.

REDEVELOPMENT MEASURES

The Contractor started the redevelopment of the branch cut slope landslide on the right side in November 2010. The proposal for stabilization and redevelopment measures were elaborated as a combination of improved over limed soil, geotextile and quarry stone application. After soil unloading, the stone with fraction of 32 – 125 mm was laid in the vacant area, at the slope foot with fraction over 125 mm. Then backfills and shape modifications were implemented. A full-area drain was built for consistent dewatering and drainage ditches with inter-axial

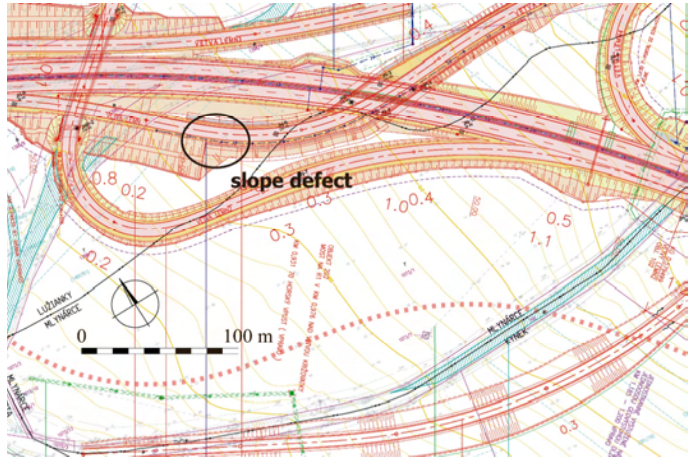

Fig.1 Situation at SO 102 Lehota Intersection

Fig.2 Disjointed wall of slope defect (09/2010)

Fig.3 Supercharging of the slope and drainage edges (03/2011)

Fig.4 Monitoring system (09/2011)

distance of 6m under the upper edge of the excavation. The drains are built with gravel aggregate with fraction of 32 – 63 mm and 32 – 125 mm (fig. 3).

After finishing the terrain modifications and dewatering measures, a monitoring system of monitoring holes (INK-1, INK-1´, INK-2 and INK-2´ into the depth of 21 m), which are part of the monitoring object system of long-term geo-technical monitoring, was built in the affected area (fig. 4).

4.2 Landslide No.2 – Slope defects at Selenec Intersection, branch in km 0.600-0.800 (Selenec - Beladice)

The landslide occurred during the implementation of the left-sided cut slope of branch 5 SO 102 „Selenec Intersection“in km 0.600 – 0.800, in chainage 0.300 of the route SO 101 (fig. 5). At the time of occurrence it was several fragmental slides with total width up to 250 m and length in the direction of motion up to 50 m.

The depth of the slide area was up to 2.50 m. In terms of slope motions classification (Nemčok et al., 1974) it is a frontal landslide along the rotational – planar to planar surface of sliding, at time of occurrence active, currently stabilized (fig. 6). The area affected by the loss of stability is from the engineering and geological perspective formed by post-tertiary regolith at the interface with polygenetic complex of cohesive soils with neogénne Pontian sediments. As the intersection project was changed during the construction in this area, there is no monitoring hole in the affected area. The closest monitoring hole is JS-13, which proved the presence of post-tertiary soils (silts and clays) down to the depth of 1.50 m, under which neogénne sediments occur in clay development transiting into sands in the depth of 8.50 m. The neogénne sediments emerge even up at the surface at the point of slope defect.

REDEVELOPMENT MEASURES

The stabilization process of the landslide was extensive. Firstly, a deep left-sided drain was built along the defected section, the slid soil was excavated and transferred step by step behind the sliding area, then the cross dewatering and stabilizing counter-forts were implemented under the line of sliding level within the axial distance of max.10 m and the excavated soil was replaced with quarry stone with 32 – 64 fraction. The slope gradient above the dive was decreased to 1:4 (fig. 7). Then the whole area was covered with mould. The slope is currently stabilized. Slope monitoring is performed by visual inspections and evaluation of the only inclinometer borehole - I6, which was implemented to the depth of 15 m b.t. From the obtained shifts values (up to max. 9 mm) it can be stated these were formed in connection with the inclinometer hole assembly (fig. 8).

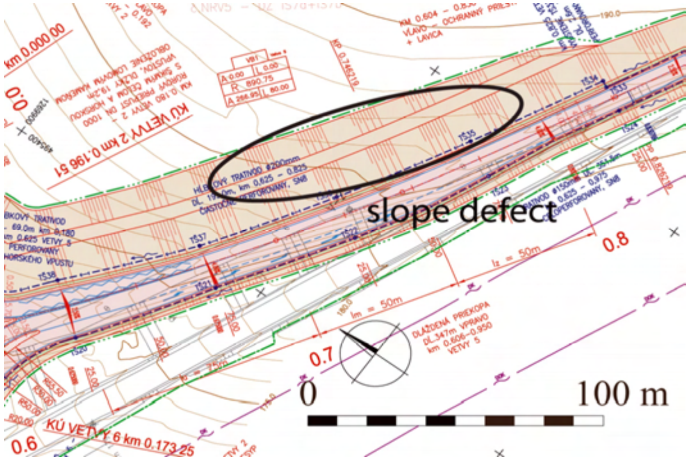

Fig.5 Situation of SO 102 Selenec Intersection, branch 5

Fig.6 Separated wall– overlapping the construction site border

Fig.7 Drainage and slope loading

Fig.8 Inclinometer I6

4.3 Landslide No.3 – Slope defects on route of SO 101 in km 0.700 – 1.000 (Selenec –Beladice)

The landslide was activated on right-side of the cut slope of SO 101 in km 0.7 – 1.0 (fig. 9). The slide was up to 160 m wide and length was up to 60 m in the direction of motion. The depth of sliding surface was up to 9 – 10 m. In terms of slope motions

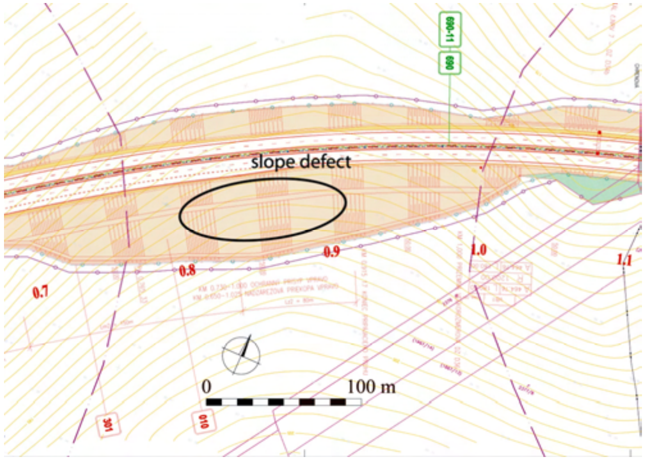

Fig.9 SO 101 R1 route

Fig.10 Head of the slide

Fig.11 System of dewatering holes

Fig.12 Slope loading and final modifications

classification (Nemčok et al., 1974) it is frontal slide along the rotational and planar surface of sliding, active at time of occurrence, at the moment stabilized (fig. 10).

Geological conditions in km 0.700 – 1.000 were verified by monitoring holes JS-22 and JS-23. Regolith post-tertiary sediments here reach discharge of 3 – 3.4 m on neogénne complex of fine-grained soils.

REDEVELOPMENT MEASURES

In the first phase, the unloading of the slid soil was executed as a redevelopment measure, than the cross drainage webs were built ending into the longitudinal drainage. The slope was loaded by quarry stone and the upper slope part above the berm was modified according to 1:2.75 incline (fig. 12). After finishing the redevelopment works the Contractor built 3 vertical inclinometer holes. The I2a and I2b inclinometers of 15 m depth did not show any significant motion (<3mm). The measuring of l1 inclinometer in 20 m depth (the crest of the slope) showed the maximum motion 13 – 20 mm. Besides measuring the shifts in inclinometer holes, there is a necessary visual monitoring of possible morphological changes on the cut slope performed. In the summer months of 2011, a fan-shaped system of horizontal-deep dewatering holes was built in order to eliminate water accumulation in the cut body and other potential symptoms of instability (fig. 11).

4.4 Landslide No.4 – Slope defects on route of SO 101 in km 9.600 – 9.800 (Selenec – Beladice)

The slide was activated on right-side of cut slope of SO 101 in km 9.6 – 9.8. Its width reached 200 m. Depth of the surface of sliding was down to 10 m (fig. 13). According to the slope motions classification (Nemčok et al., 1974) it is a frontal slide along the rotational and planar surface of sliding. From the activity point of view, it was an active slide at the time of occurrence, currently stabilized (fig. 14). Its formation or the re-activation of the slide was influenced by the formation of slide deluvial deposit already mentioned during the project preparation phase in JS-148 and JS-149 holes and which were formed during the slopes sliding in the past. Neogénne is mostly in clay stage sporadically with sand layers.

REDEVELOPMENT MEASURES

The stabilization of the slide consisted of unloading of the slid material and implementation of drainage measures including drainage webs building into about 2 m depth, then building of surface drain. The slopes were definitely sloped in 1: 2.25 incline down to the border of permanent occupation of the construction (fig. 15).

Within the geo-technical monitoring there were originally two inclinometer holes embedded into the slope, out of which I4 inclinometer was removed and INS-3 inclinometer is dysfunctional. There were two new holes built in their neighbourhood, in

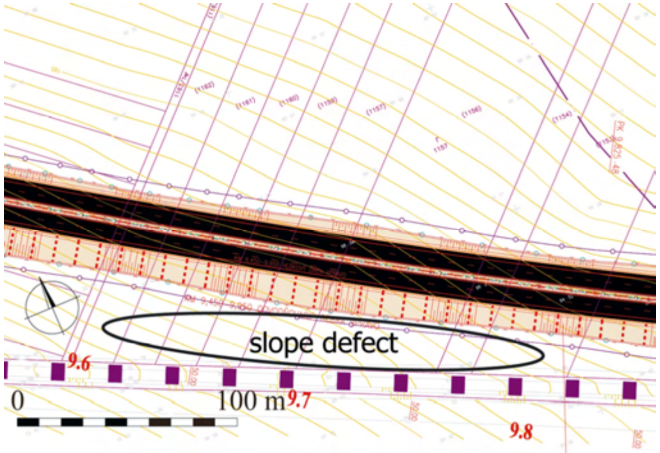

Fig.13 SO 101 R1 route

Fig.14 Slide at the right side cut

which there were minor motions up to 1 mm recorded. In km 9.800 there is an inclinometer hole -I5 where maximum shifts of 100 mm along the sliding surface were recorded in depth of 3 m as of August 23, 2011. Besides shifts monitoring in the inclinometer holes, regular visual monitoring of morphological changes on slope is executed (fig. 16).

4.5 Landslide No.5 – Slope defects on the SO 101 route in km 2.300 – 3.800 (Beladice – Tekovské Nemce)

On SO 101 construction in km 2.300 – 3.100 there were multiple slides activated on left side of the cut slope, while the most affected area was in km 2.450 – 2.650 (fig. 17). The width of sliding area was in total up to 800 m and the length in the direction of the motion up to 60 m. In accordance with the slope motions classification (Nemčok et al., 1974) this is a frontal sliding area along the rotational and planar surfaces of sliding of the depth up to 8 m. From the activity point of view these were active slides, currently they are considered as potential up to

Fig.15 Redevelopment – drainage webs

Fig.16 Monitoring system–inclinometer holes

stabilized. From the engineering and geological conditions perspective the slides were activated in area with the occurrence of post-tertiary regolith of fine-grained soils down to depth of 4.60 m on the neogénne sediments mostly in clay or less sandy stage. The geological conditions in the area of the slope defect were in the phase of monitoring verified by the JB-72 hole (fig. 18).

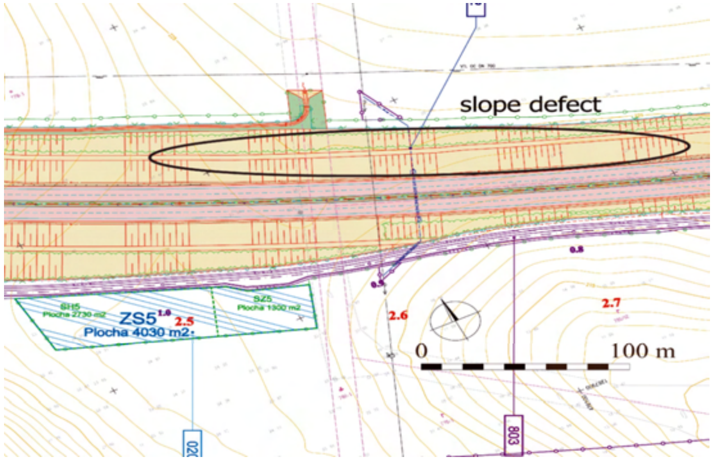

Fig.17 SO 101 R1 route

Fig.18 Slope defect in left side cut

Fig.19 Drainage webs and surface drainage

Fig.20 Inclinometric and piezometric holes

REDEVELOPMENT MEASURES

An extensive stabilization was performed on the slope, which consisted of unload of the sliding soils along the surface of sliding, slope dewatering by the system of cross dewatering webs and drainage filtration backfill of 63/125 mm fraction with shear castellation and slope additional fill-up with berm creation at the level of about 3.0 m from the cut top. The slope was modified within the incline of 1:1.25. The webs were implemented down to the depth of 2.5 – 3 m, width down to 1 m and above the cut a circuit drain was built (fig. 19). Based on the fact that performed stabilizing measures were not sufficient, the improvement of the slope stability was performed by the additional slope dewatering using the siphon drains. Slope redevelopment implementation by mentioned technology is a subject to other report. Within the monitoring there were three vertical inclinometer points embedded (IV3, IV4, IV5) on the level of slope berm (fig. 20), the system of geodetic control points and monitoring hole for the subsurface water level monitoring. The monitoring at the mentioned points is currently still in progress. Currently there were only minimal excess deformations (up to 2 mm) recorded.

5 Conclusions

The slides formed in sections with geological and tectonic structures of favourable conditions for their formation, e.g. floury soils levels lying on neogénne clays, interchanging of pervious and impervious layers, occurrence of deluvial deposit etc.

From the shape point of view, these are frontal slides and from the activity at the time of occurrence perspective they are active slides, mostly along the rotational and planar surfaces of sliding. From the cut slopes stability point of view the transferring of polygenetic floury soils, surface erosion, vertical (scour) erosion and volume changes in neogénne pre-consolidated clays represent the highest risk. The transferring is invoked by the change of the floury soils humidity (over-damping) or soils freezing and in that case by the change of their consistency parameters. The most predisposed to transferring are the Würm pure Aeolian floury soils. The creation of slope deformations and overall stability are a subject to geotechnical monitoring of earth and building constructions within the whole R1 PPP Project. Monitoring includes the measurement of surface and subsurface deformations, pressures, subsurface waters and volume overflows. In view of the expressway location into nature environment it is necessary to monitor presented parameters also now after putting the R1 Expressway into operation. For sliding slopes stability monitoring it was necessary to monitor the development of subsurface horizontal shifts in the slopes by the method of accurate vertical inclinometry, mostly in combination with scheduled monitoring of subsurface waters level (SWL) monitoring. During these measurements we also verified the efficiency of proposed redevelopment measures of stabilizing and fortifying, dewatering and drainage nature.

Acknowledgements

Partial results of VEGA no.1/0944/11 task solution were also used in the article.

References

BADÍKOVÁ N., JANTÁK V., MICHALICA L. Vybrané okruhy geotechnických problémov pri realizácii projektu PPP pre výstavbu R1 z pohľadu nezávislého dozoru. In *: Zborník 10. Slovenskej geotechnickej konferencie s medzinárodnou účasťou „ Geotechnické problémy líniových stavieb“*. STU Bratislava , Nakladateľstvo STU, 2011, s.661-672, ISBN 978-80-227-3504-9

MATEJČEK A., ET AL. *R1 Nitra, západ – Selenec, podrobný IG prieskum*, GEOFOS s.r.o. Žilina, 2008a

MATEJČEK, A. ET AL. *R1 Selenec – Beladic, podrobný IG prieskum*, GEOFOS s.r.o. Žilina, 2008b

MATEJČEK, A. ET AL. *R1 Beladice – Tekovské Nemce, podrobný IG prieskum*, GEOFOS s.r.o. Žilina, 2008c

MAZÚR E., LUKNIŠ M. *Regionálne geomorfologické členenie*. In: Regionálna geografická syntéza SSR, Mapa, Bratislava, 1980, Geogr. úst. Slov. akad. vied.

NEMČOK A., PAŠEK J., RYBÁŘ J. Ďelení svahových pohybu. *Sbor. geol. Věd.*, Ř.HIG (Praha), 1974, 77–97

Authors

[1]Prof. RNDr. František Baliak, PhD., Slovak University of Technology in Bratislava, Faculty of Civil Engineering, Radlinského 11, 813 68 Bratislava, Slovakia, frantisek.baliak@stuba.sk

[2]Mgr. Martin Brček, PhD., Slovak University of Technology in Bratislava, Faculty of Civil Engineering, Radlinského 11, 813 68 Bratislava, Slovakia, martin.brcek@stuba.sk

[3]RNDr. Viktor Janták, ARCADIS Geotechnika, a.s., Slovak Organizational Branch, Miletičova 23, 82109 Bratislava, Slovakia, jantak@arcadisozsr.com

[4] Ing. Peter Mušec, ARCADIS Geotechnika, a.s., Slovak Organizational Branch, Miletičova 23, 82109 Bratislava, Slovakia, musec@arcadisozsr.com