APPLICATION OF GPR DURING INVESTIGATION CONCERNING CAUSES OF PAVEMENT FAILURE AND ROAD SUBGRADE QUALITY IN GRANITOID MASSIF NEAR SIMTANY

VYUŽITÍ GPR PRO PRŮZKUM PŘÍČIN PORUŠENÍ VOZOVKY A PODLOŽÍ SILNICE V PROSTŘEDÍ GRANITOIDNÍHO MASIVU U SIMTAN

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Abstract

The survey of damaged engineering buildings is in many cases very demanding in terms of the selection of a right exploration method in relation to the results obtained for subsequent engineering works, time for survey implementation, and violations arising from survey activities. Heterogeneity of materials of a natural and anthropogenic origin is a fundamental axiom which can subsequently lead to either a distortion or a failure threatening statically the existence of a building structure. On the test object of a pavement, after some time of its use, severe deformations became evident whose causes and future evolution were not known. Within the design of survey techniques being able to quickly and efficiently uncover the causes of failures, the GPR (Ground Penetrating Radar) investigation was included which as an indirect, non-destructive survey method very quickly helped to clarify he causes of failures of the building structure.

Abstrakt

Průzkum porušených inženýrských staveb je v mnoha případech velmi náročný z hlediska volby správné průzkumné metody ve vztahu k získaným výsledkům pro navazující inženýrské práce, času na realizaci průzkumu a další porušení vznikající při průzkumné činnosti. Heterogenita materiálů přirozeného i antropogenního původu je základním axiomem, který může vést následně buď k deformacím, nebo až k porušení staticky ohrožujícímu existenci stavební konstrukce. Na zkoumaném objektu vozovky se po čase jeho užívání projevily závažné deformace, o kterých nebylo známo, co je způsobilo a jaký bude jejich vývoj v čase. V rámci návrhu průzkumných technik, schopných rychle a efektivně odhalit příčiny porušení byl zařazen průzkum georadarem-GPR (Ground Penetrating Radar), který jako nepřímá, nedestruktivní metoda průzkumu velmi rychle přispěl k objasnění příčin porušování stavební konstrukce.

Key words: GPR, engineering-geological investigation, failures, road structures, road subgrade

1 INTRODUCTION

The investigation works were required on site in order to find out the origin of pavement failures on the side of the road sloping south-west towards the pond located west of the village of Simtany. The pavement failures, especially in the area of road shoulders, have a character of a discrete local subsidence, rough potholes and cracks. One of hypotheses was the relationship between the pavement failures and potential slope deformations, or the sliding of subgrade.

With regard to the very limited possibility to perform more time-consuming survey works on a relatively narrow and busy road, which would lead to the reduction of traffic, the GPR (Ground Penetrating Radar) method was deployed as the main method to investigate the geological situation and determine possible inhomogeneity in the rock mass.

The GPR method is the worldwide most dynamically developing and applying method of research in the field of road and railway constructions. A number of works addresses GPR applications for road constructions. In particular, it is the applied research on the quality of pavements [1], [2], [4], [5], or materials used for the construction of roads [9]. Other publications are focused on the development and improvement of methodologies for GPR measurements on roads such as [8]. Only part of the works deals with a comprehensive evaluation of both the materials of road body and subgrade, on which the works [7], [10], [11], [12], [13], [14] are grounded. The Ministry of Transport of the Czech Republic also issued a special methodical technical prescription, describing the use of GPR for the survey of road constructions [22].

The area of interest is located in the Highlands Region, mainly in the cadastral area of Simtany (cadastral area No. 724653), at the boundary of the map sheets 23-214 and 23-223 of the base map at 1:25 000 scale. The studied area (Fig. 1, 2, 3) is located west of the village of Simtany and is part of the I/19 road connecting the village of Simtany with the town of Pohled north of the local pond.

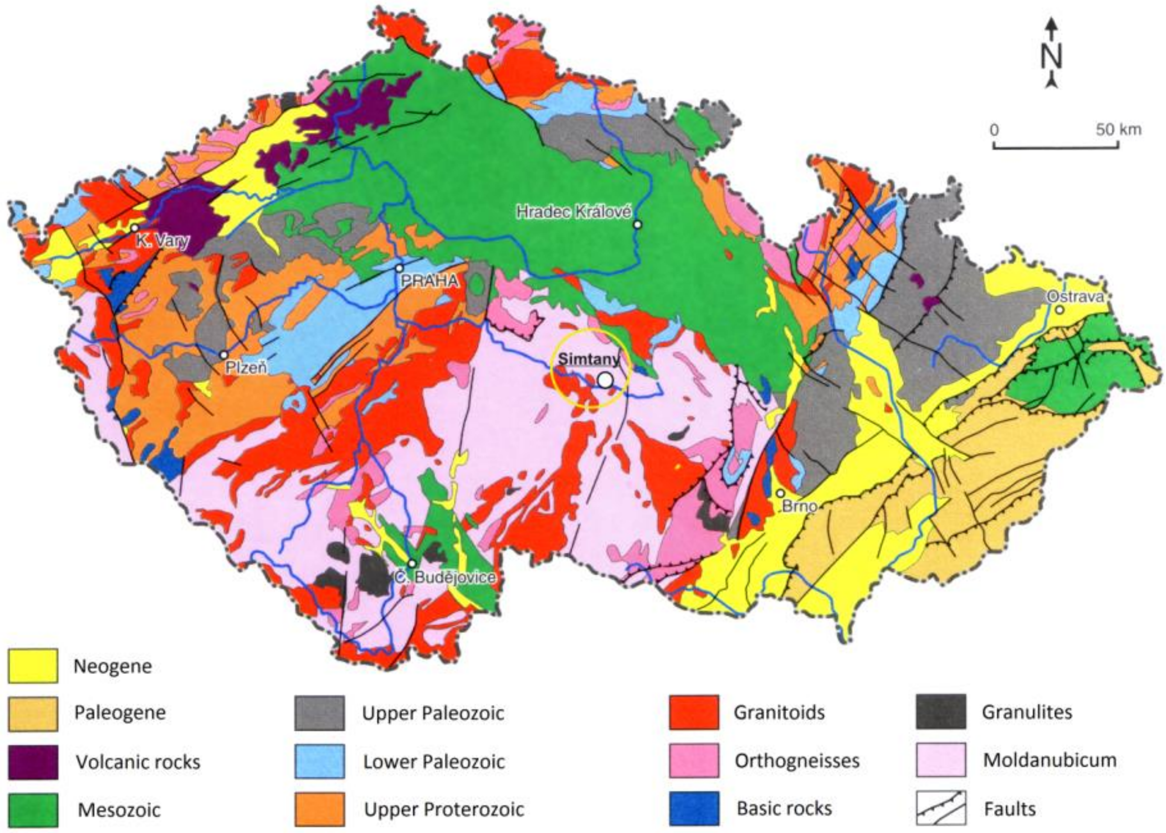

Fig. 1 The location of the area in question on the basis of a geological transparent map of the ČR compiled by ČGS (Czech Geological Survey) [18].

Fig. 2 The detailed map of the locality; the road section of interest, or measured profiles on which the measurements were made, in red [19].

Fig. 3 The aerial photograph of the locality; the road section of interest, or measured profiles on which the measurements were made, in red [16].

Right in the area of interest, no archival survey works are recorded by the map server of the Czech Geological Survey.

The earliest recorded works are registered at a distance of about 300 m and more of the area of interest.

For comparison of the results, probe profiles were used which are located in a considerable distance, but under similar conditions of the rock environment as the studied location. The probes of the following IDs (CGS-Geofond) were used: 398414, 684570 and 394824. Their location can be seen from Fig. 4.

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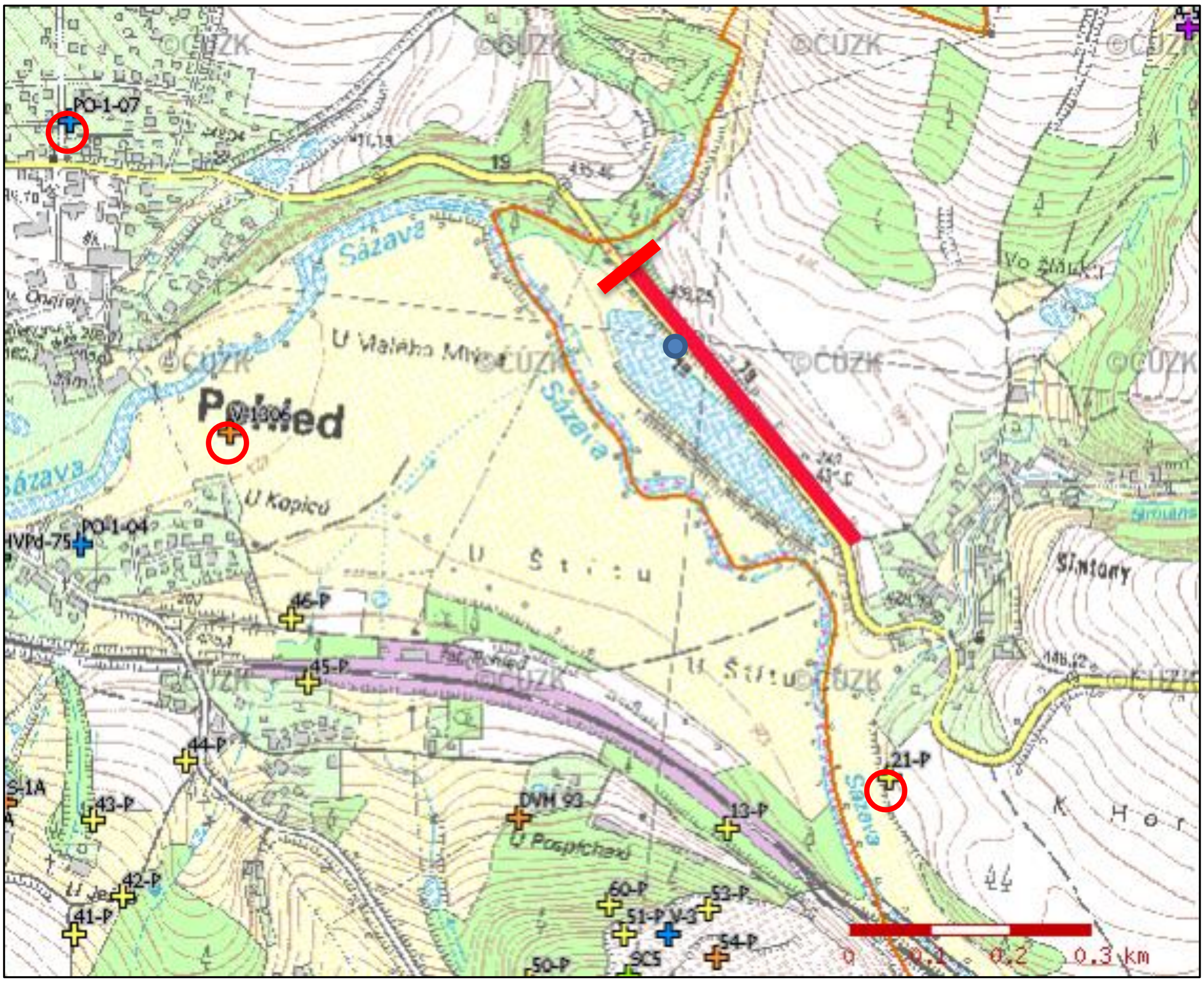

Fig. 4 The actual situation of the locality according to the mapping application of the CGS Geofond. The probes used for comparison are in red circles. The shown lines (in red) correspond to the measured georadar profiles, the location of the manual verification probe Rv-2 is indicated in blue [15].

Using a hand set (Eijkelkamp) with Edelmann drills, two shallow probes for the direct verification of results from georadar measurements were carried out. Drilling was made off the pavement with regard to the safety of the crew and the surrounding area as well.

2 NATURAL CONDITIONS

In the context of natural conditions, the attention was paid to the geomorphology of the area, the basic geological structure of the rock mass and the hydrological and hydrogeological conditions that are characteristic for the studied geological environment.

2.1 Geomorphological conditions

According to the geomorphological division of the Czech Republic [16], the area in question belongs to:

- Czech Highlands Province,
- Czech-Moravian System Subprovince,
- Bohemian-Moravian Highlands,
- Hornosázavská Upland,
- Jihlava-Sázava Furrow
- Pohledy Upland District.

The Pohledy Upland is characterized by rugged hills formed by plateaus and broadly rounded inter-valley ridges bordering the river valley cut of the Sázava River [3].

2.2 Geological conditions

From a regional geological point of view, the location of Moldanubicum belongs to the Bohemian Massif (Fig. 5) which is mainly composed of strongly metamorphosed rocks (parageneses) sporadically permeated by acidic intrusive rocks [6]. From a petrographic point of view, biotite granites of the Moldanubian Pluton Paleozoic age are represented across the entire documented area of the slope offcut. These are the rocks on the surface and in shallow near-surface parts disintegrated (residual soil - R6) to completely weathered (completely weathered - R5) to coarse-grained sands, in surface outcrops highly weathered rocks (highly weathered - R4), to a depth then acquiring a character of slightly weathered rocks (slightly weathered - R2-R3) – to describe the classes of rock, the classification was used that was stated in the ČSN 73 6133 standard [21] and in no longer valid ČSN 73 1001 [20], which, however, is in practice still used as an additional one.

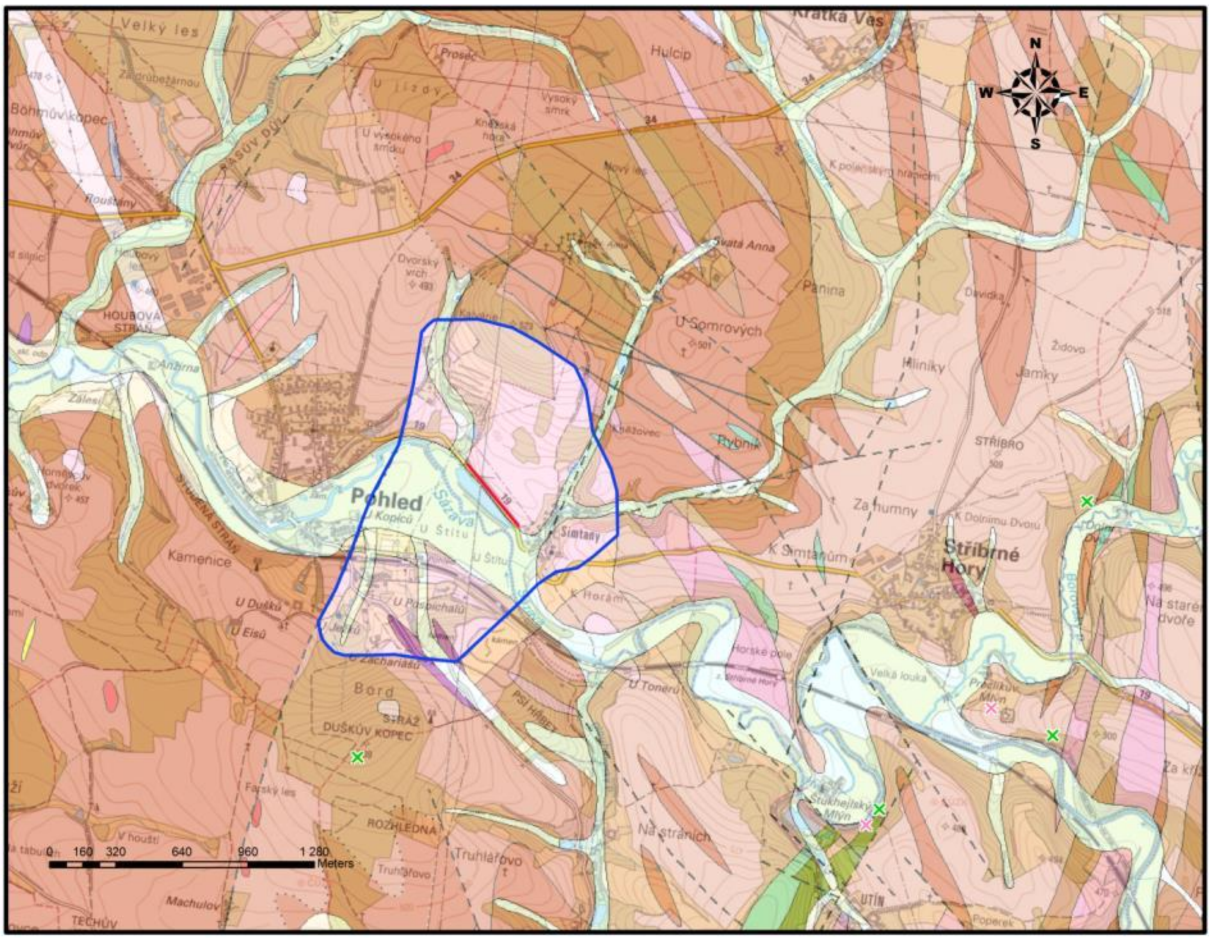

Fig. 5 Cut out from the geological map at a scale of 1:50 000 [18]. The plutonic body of biotite granite is bordered by the blue line, the road section of interest then by the red line.

The Quaternary cover is represented by a thin (about 1 m) complex of deluvio-eluvial sandy-nature soils over the road, then by fluvial or limnic sediments under the road. The road body itself and parts of the slopes with an incline to the pond are built by landfills of a variable composition and low thickness.

2.3 Hydrological and hydrogeological conditions

The Sázava River represents the main gathering channel in the area of interest. The area is therefore directly drained by the Sázava River, or by its small right-hand tributaries. The watershed of the first order is then formed by the Elbe River. Southwest of the area of interest there is a water reservoir - a pond.

According to the zoning of the Czech Republic to base layers, the locality is in the zone 6520 Crystalline turf in the Sázava River Basin [17].

Groundwaters in the area of interest are bound to the fissures and fault zones of the pre-Quaternary bedrock.

The backfill layer (structural layers of the road) is locally used as a collector of infiltrated vadose water. However, this type of saturation may be considered seasonal. It is a typical fluctuation of the underground water level in an unconfined aquifer with a considerable oscillation – from full saturation of the collecting environment to complete drying in precipitation-deficit periods.

The groundwater level was not reached by means of the carried out control, hand-drilled probes to a depth of 1.3 m below the ground.

3 ENGINEERING GEOLOGICAL CONDITIONS

The following geological profile was encountered in the area of interest:

- anthropogenic fills – structural layers and sporadically additional fills in slopes,
- deluvia,
- fluvial sediments (only in the alluvial part, i.e. not under the road itself)
- pre-Quaternary bedrock.

3.1 Anthropogenic fills

Due to the fact that the probes were not made directly in the pavement, we can only assume the composition of the anthropogenic layers. According to radargrams the structural layers achieve the thickness of 0.4 to 0.8 m. For the structural layers, local materials were probably used, which could distort the real thickness in the records. The radar-captured inhomogeneities in structural layers have no direct response in failures in the bituminous surface. We assume, therefore, that these are rather structures in which a migration of water through structural layers occurs. Locally, then piping or erosive processes can apply here, as is evident in particular in the eastern end of the section in question.

The slope from the pavement towards the pond also bears, in some places, signs of anthropogenic sediment, for which e.g. building rubble was used as well.

The ground surface is then outside the structural layer mostly covered by up to a 0.2 m thick layer of forest land.

3.2 Deluvia

Deluvia (often even runoffs of the same material) primarily cover the slope space above the road. In the vast majority, this is the transfer of residues from weathering of granites in the form of coarse sands and sandy loams.

Based on the ČSN 73 6133 standard [21], they mostly rank to the class S2 with possible transitions to the classes F2-F4.

3.3 Fluvial sediments

Fluvial sediments occur in the base of the slope where they are overlapped by pond sedimentation. The thickness of sediment deposits was detected by the radar on the profile P2 in the value of about 2.0 m, by the archival probe V-1306 situated almost in the middle of the floodplain of the Sázava River then in a value of 3.5 m.

3.4 Rocks of pre-Quaternary bedrock - granites

Granitic rocks, as already described above, are in a varying degree of weathering. On the surface and in shallow near-surface parts, they are almost completely disintegrated or completely weathered, locally then they are in some surface outcrops just highly weathered, to a depth then acquiring a character of slightly weathered rocks, however, broken by discontinuities.

Residues and sandy geests of these rocks are suitable, or at least conditionally suitable, for embankments and for the use in the core of the road subgrade. These are mainly non-frost-susceptible soils.

4 METHODOLOGY OF WORK

With regard to the very limited possibilities of implementation of time-consuming survey works on a relatively narrow and busy road, the GPR (Ground Penetrating Radar) method was deployed to investigate the geological conditions and to determine possible inhomogeneities. For proper orientation of radar waves transmitted to the subgrade, it was necessary to ensure full contact of the antenna with the ground, which was fulfilled in that locality.

The GPR method based on transmitting and receiving electromagnetic waves is very sensitive to environmental disturbances by the electromagnetic field induced by electric wires under high voltage or metal wires in general that affect the propagation of electromagnetic waves from the transmitting antenna to the

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receiver. This can be avoided by selecting shielded antennas during the measurement. In case of a need to show indirectly the environment through the depth in the order of meters, high-frequency antennas should be used with frequencies of hundreds of MHz and a short wavelength of propagated electromagnetic waves.

During the measurement at this location, the GPR set by the Swedish producer Malå was used. The set was formed by an antenna system of 250 and 500 MHz. The antenna system is designed as shielded against spurious electromagnetic interference from the environment. As a control unit, RAMAC Pro EX and as a display unit then View XV11 were used.

Measurements were performed across the entire section in question longitudinally in the roadside (profile P1) in 4 opposite direction travels (reverse profiles were used for control), always twice with both antennas on frequencies of 250 and 500 MHz. In the NW end of the section of interest, the profile perpendicular to the road I/19 ranging from the floodplain to the area of fields over the road, was subsequently measured. Much better results were achieved with the antenna system of 500 MHz. To evaluate the data in the form of radargrams, the software RadExplorer 1.41. was used.

Using the hand set (Eijkelkamp) with Edelmann drills, two shallow probes for verification of the results from georadar measurements were carried out. Drilling was made off the road with regard to the safety of the crew and the surrounding area.

5 MEASUREMENT RESULTS, MASSIF STABILITY ANALYSIS

5.1 GPR measurement results

On the basis of the measurements performed within the shoulders of the road, the likely level of a depth boundary of the surface of highly weathered granites (category 4 and less weathered) depicted by the red dashed line (Fig. 6 and 7) was established during interpretation.

In all the studied profiles, the probable interface of overburdens (both natural and anthropogenic) and highly weathered granites below the road in depths (from the surface of the pavement), ranging from about 1.3 to 1.6 m, was interpreted. In radargrams, this line is represented with a pink dotted line.

The depth of the interpreted interfaces is encumbered with an error quantified at about 10 % due to the variability of dielectric properties of the rock mass in the measured profiles.

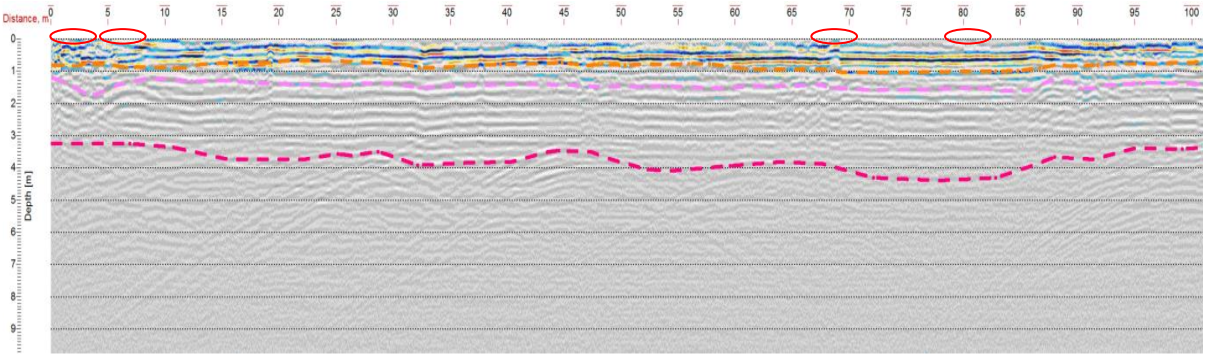

Fig. 6 The radargram of the selected portion of the longitudinal profile measured with GPR in the shoulder of the road with the interpretation of each interface (surface of granites - red, highly weathered granites - pink, eluvium - orange). The red ellipses highlight the examples of inhomogeneities in structural layers of the road.

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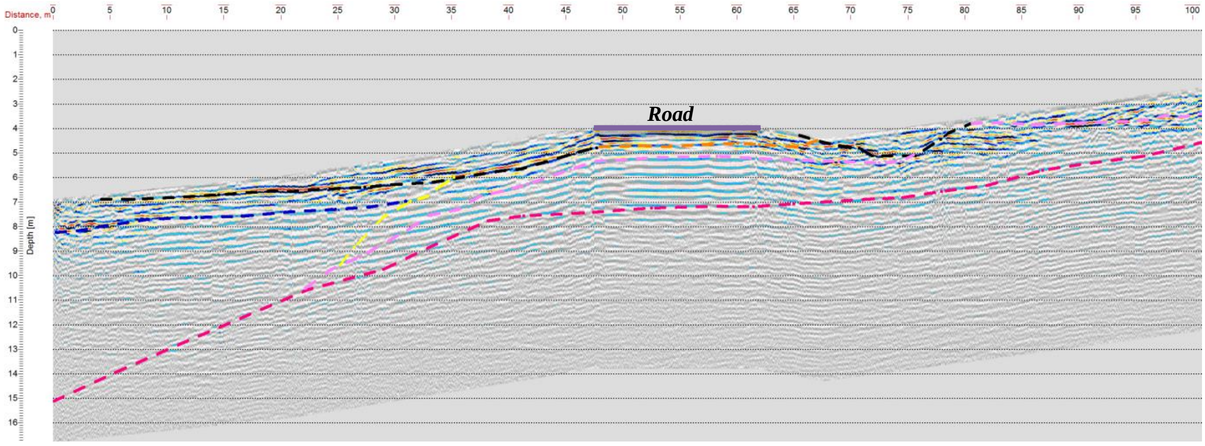

Fig. 7 The radargram of the selected part of the cross section area measured with GPR from the alluvial floodplain area near the pond against the slope NE with the interpretation of each interface (surface granites - red, highly weathered granites - pink, eluvium - orange, deluvium - yellow, alluvium - blue, anthropogenic layers - black).

5.2 Stability conditions and the principle of deformation occurrence in the local road

As follows from the results from the field reconnaissance and radar measurements, there is no reason to believe that roadside disorders have their origin in landslides in the true sense of the word (sliding). The hypothesis of landslides is not supported by either the geological structure of the area (granite massif) or signs of disturbances in the bitumnous surface of the pavement.

According to findings in situ, the road damage was caused in connection with the effects of flowing and leaking surface (rain) waters. In many places of the pavement and the adjacent slope, it is evident that during increased precipitations, an overflow of rainwater over the surface of the terrain from highly lying fields occurs. This is clearly obvious from the presence of minor erosion furrows and rain gullies in the slope and also from the presence of flushed (alluvial) sandy soils in the area of the road shoulder. Especially in the eastern part of the area of interest, also the places can be documented where infiltration of rain water in the shoulder of the road occurs, its migration through structural layers and re-discharge to the surface in the slope at the side of the shoulder towards the pond. These phenomena are then probably accompanied by piping as well. In radargrams, quite many inhomogeneities in structural layers of the pavement were interpreted, which can then be related to these phenomena.

6 CONCLUSIONS

The GPR method proved to be suitable for the given type of exploratory assignments and provided a reliable insight into the composition and condition of the rock environment under a pavement and base courses. This is a relatively cheap, quick and non-destructive method of survey which was as the only feasible without limitation of traffic on the road. The survey with the GPR method clearly defined the ground surface under the structural layers of the pavement. The compliance of GPR measurements with the reality was then established also using manually drilled test probes.

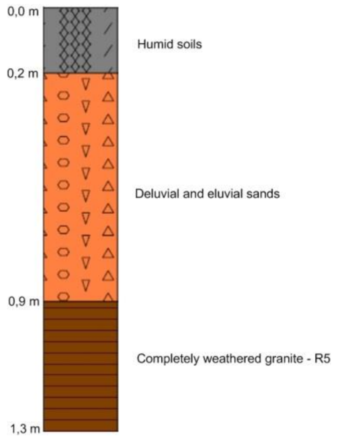

Fig. 8 A simplified profile of the manually drilled probe Rv-2

Fig. 9 The example of the yield of disintegrated (residual soil - R6) to completely weathered biotite granites (completely weathered - R5) to coarse-grained sands by hand drilling.

The survey and the evaluation of the survey results clearly confirmed the stability of the roadway subgrade and refuted the existence of potential slope failures (sliding) in the investigated section of the road. Objectively existing disorders are not caused by slope movements in the true sense of the word, i.e. landslides, but by the effects of surface water flowing on the road from above-lying parts of the slope. Part of the water flows over the surface of the pavement, and part of it then seeps in the "north" shoulder, migrates through structural layers and on the "southern" side of the road then rises from the structural layers. Thus, also piping phenomena occur here that weaken the structural layers by follow-up internal erosion. The pavement is also violated by the overflowing surface water that due to its erosive effects gradually takes away the material of the unpaved shoulder area and thus significantly reduces and weakens it locally. The shoulders and lanes of the road (in both directions), the closest to the shoulder, are then damaged (broken) first of all by freight transportation. Without the application of the GPR method, those results could not be obtained in such a short time and without destruction of the road.

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[18] www.geology.cz, informační portál ČGS.

[19] www.mapy.cz, mapový portal fy Seznam.

[20] ČSN 73 1001 Základová půda pod plošnými základy.

[21] ČSN 73 6133 Navrhování a provádění zemního tělesa pozemních komunikací.

[22] TP 233 Georadarová metoda konstrukcí pozemních komunikací, Technické podmínky, Ministerstvo dopravy ČR.

RESUMÉ

Průzkum porušených inženýrských staveb je v mnoha případech velmi náročný z hlediska volby správné průzkumné metody ve vztahu k získaným výsledkům pro navazující inženýrské práce, času na realizaci průzkumu a další porušení vznikající při průzkumné činnosti. Heterogenita materiálů přirozeného i antropogenního původu je základním axiomem, který může vést následně buď k deformacím, nebo až k porušení staticky ohrožujícímu existenci stavební konstrukce. Na zkoumaném objektu (silnici) se po čase jeho užívání projevily závažné deformace, o kterých nebylo známo, co je způsobilo a jaký bude jejich vývoj v čase. V rámci návrhu průzkumných technik, schopných rychle a efektivně odhalit příčiny porušení byl zařazen průzkum georadarem-GPR (Ground Penetrating Radar), který jako nepřímá, nedestruktivní metoda průzkumu velmi rychle přispěl k objasnění příčin porušování stavební konstrukce. Při měření na této lokalitě byla využita sestava GPR švédského výrobce Malå. Sestava byla tvořena stíněným anténním systémem 250 a 500 MHz.

Z geologického hlediska tvoří podloží konstrukčních vrstev komunikace biotitické granity moldanubického plutonu paleozoického stáří v různém stupni zvětrání. Ve všech studovaných profilech bylo interpretováno pravděpodobné rozhraní pokryvných útvarů (jak přirozených, tak i antropogenních) a silně zvětralých granitů pod komunikací v hloubkách (od povrchu vozovky) v rozmezí cca 1,3 – 1,6 m. Dle radargramů dosahují vlastní konstrukční vrstvy komunikace proměnlivé mocnosti 0,4 - 0,8m. Hloubka interpretovaných rozhraní je zatížena chybou kvantifikovanou na cca 10%.

Jak vyplývá z výsledků terénní rekognoskace i radarových měření, není důvod se domnívat, že poruchy krajnice komunikace mají původ ve svahových pohybech v pravém slova smyslu (sesouvání). Radarem

zachycené nehomogenity v konstrukčních vrstvách nemají přímou odezvu v poruchách v živičném krytu. Lze předpokládat, že jde spíše o struktury, ve kterých dochází k migraci vod konstrukčními vrstvami. Místně se zde pak mohou uplatňovat i sufozivní procesy.

Dle zjištění v terénu a po analýze radarových měření vzniklo tedy poškození vozovky v souvislosti s účinky proudících a prosakujících povrchových (srážkových) vod.

Nasazení georadaru jako hlavní průzkumné metody se ukázalo v daných podmínkách jako vysoce účelné a efektivní řešení (rychlost provedení bez nutnosti omezení či vyloučení dopravy, nízká nákladovost) s poměrně vysokou vypovídací schopností. Podstatně lepších výsledků z hlediska možností interpretace bylo dosaženo s anténním systém 500 MHz.

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