Exploration Geophysics, Remote Sensing and Environment XXXI.2 (2024)

DOI: 10.26345/EGRSE-057-24-204

GPR DETECTION OF VOIDS UNDER CONCRETE COMMUNICATIONS (CASE STUDY)

DETEKCE VOLNÝCH PROSTOR POD BETONOVÝMI KOMUNIKACEMI POMOCÍ GPR (PŘÍPADOVÁ STUDIE)

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Abstract

The aim of this study is to present direct and indirect detection of voids under concrete communications on two specific examples of GPR measurements. The first study is an example of direct detection based on the increased reflectivity of the interface on the radargram in the place of the cavity created between the concrete slabs of the parking lot cover and its underlying layers. The formation of cavities was caused by the loess collapsibility observed in the basements of the underlying layers. The likely cause of loess collapsibility was probably their overwetting as a result of subsidizing water from a broken pipe between individual parts of the area's drainage system (drainage channel, retention tanks, absorption well) and due to excessive rainfall in the assessed area. Damage of the pipelines was verified by camera tests, which were carried out as part of a comprehensive diagnosis of the causes of the parking damage. GPR measurements confirmed the assumption of cavities presence above the areas where the drainage elements are located. The second study is an example of the detection of underground spaces under the floor of a storage hall. The construction of the floor above the underground spaces caused an increased attenuation of the signal, so that the ground-penetrating radar was not able to detect any other interface under the floor. The presence of underground spaces was therefore detected indirectly on the radargrams, based on the specific appearance of the floor construction above these spaces. In addition to the different manifestations of hollow spaces on radargrams, both studies demonstrate the need for a comprehensive approach to the issue of locating hollow spaces under concrete using GPR measurements.

Keywords

Geophysical measurements, GPR, void detection, concrete communications and floors

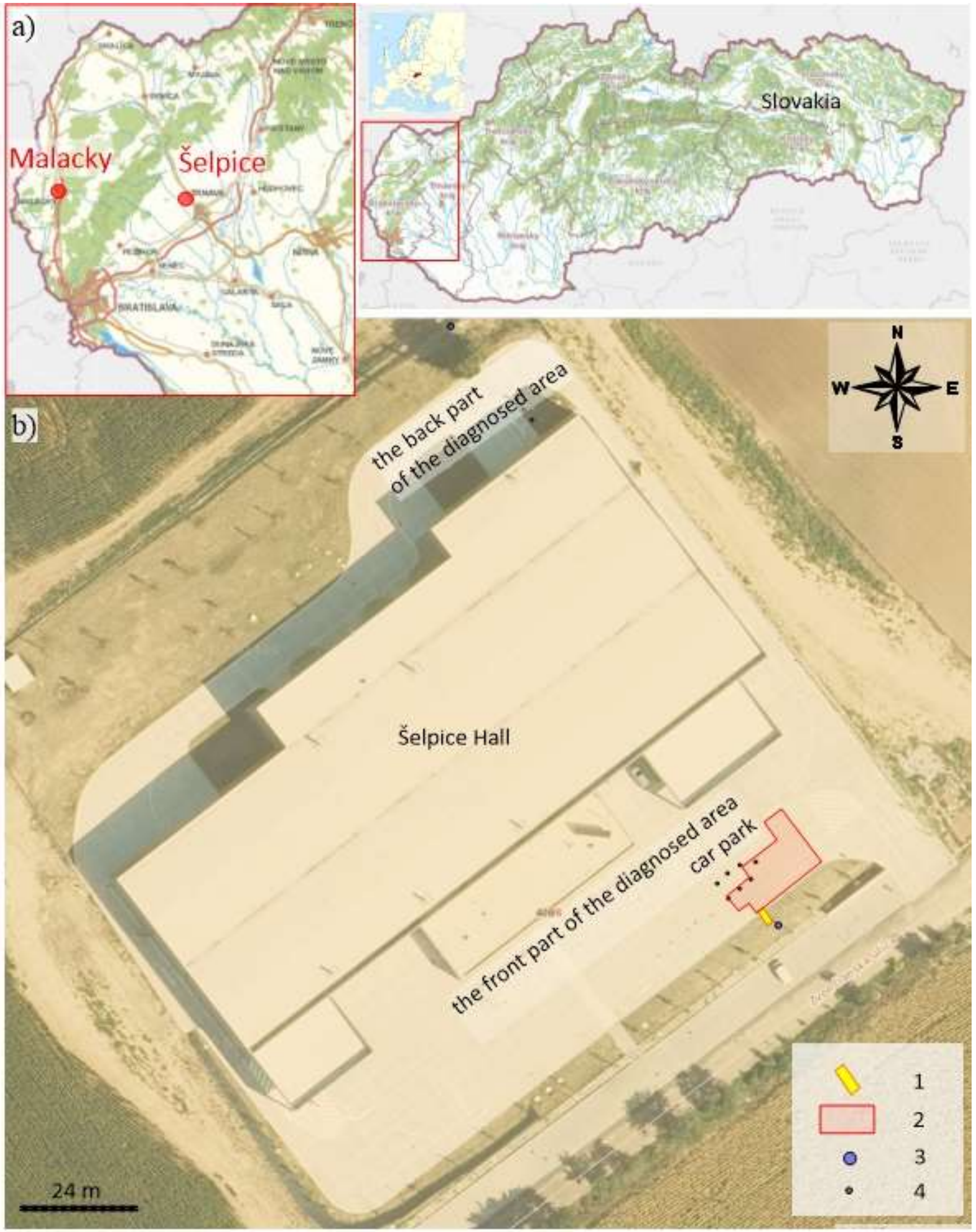
Introduction

Cavities under concrete communications and floors represent a hidden danger. They can lead to their cracking or even damage, falling of installed devices and serious failures of building structures. As a non-invasive geophysical method, GPR enables the detection and localization of hollow spaces below the surface (Sprinkel el al., 1986; Billinger 2009, Thitimakorn et al. 2016, Yuan et al., 2024). We can detect cavities created naturally, e.g. by subsoil settlement or suffusion, or man-made cavities such as cellars, pipes, underground reservoirs, shafts, etc. Whether the GPR measurement will be able to capture the cavity under the surface is influenced both, by the material and construction of the communication layers (floor) and by the transmitting frequency of the antenna. Antennas with a lower frequency have a greater depth range, antennas with higher frequencies have a finer resolution and are used for more detailed mapping. However, the construction of the floor can cause a strong attenuation or scattering of the passing wave (e.g. reinforced concrete, steel plate, ...) and thus make it impossible to detect objects and interfaces under the floor.

In this contribution, the use of GPR in the detection of hollow spaces under concrete surfaces and their various manifestations on radargrams is presented on two specific examples. The main goal of the study was to determine the extent of cavities from surface. Accurate interpretation of specific manifestations of cavity presence on radargrams was possible thanks to the correlation of radargrams with a specific environment when measuring close to the revealed cavity.

The first study is from the area of the Trnava Hills and is an example of the direct manifestation of the presence of cavities on the radargram. These cavities were formed under the concrete communications around the production hall built on the fringe of the village of Šelpice (Fig. 1). After heavy rainfall, repeated inbreaks of the curb and the drainage channel (Fig. 2a right) occurred in the diagnosed area above the drainage pipe leading from the retention tanks, located under the surface of parking lot, to the infiltration well. The removal of the parking lot concrete slabs at the damaged site showed the presence of extensive voids between the concrete cover and the underlying layer in the vicinity of the retention tanks (Fig. 2b) as well as their continuation under the uncovered parts of the parking area (Fig. 2c).

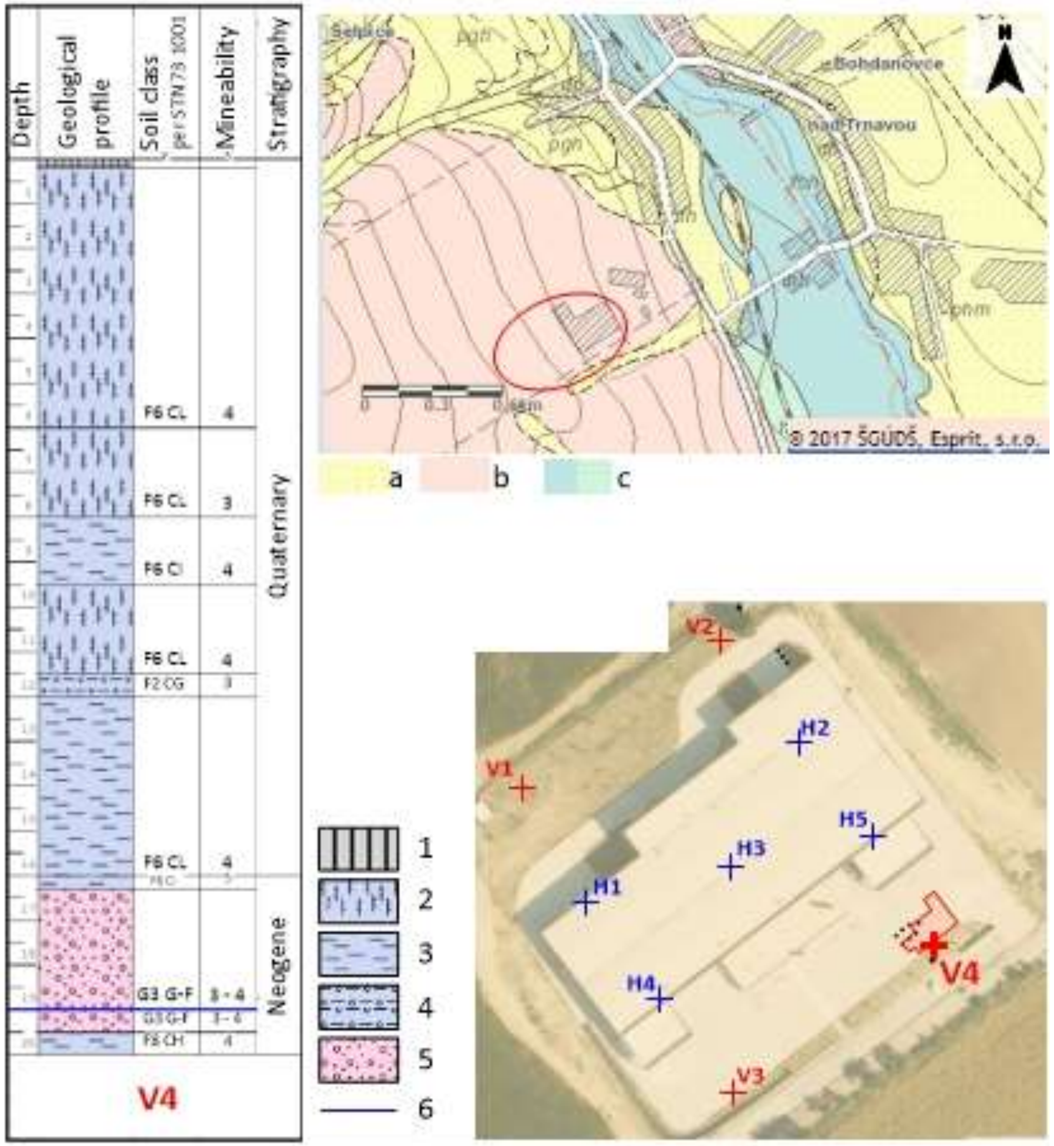
The task of the GPR measurements was to determine the extent and expansion of cavities in the area. However, for this it was necessary to know the cause of their formation. A more detailed study of the available materials (mainly exploratory boreholes carried out in this area) showed that the voids between the concrete panels and the underlying layers were created as a result of loess collapsibility under the underlying layers of the diagnosed building. The diagnosed areas of the hall complex in Šelpice are located in the Podunajská nížina (Danubian lowland), in the Trnavská pahorkatina (Trnava Upland) part. From a geological point of view, the pre-Neogene basement consists of crystalline rocks, on which Neogene marine sediments (reaching a thickness of up to 1000 m) and lacustrine-fluvial sediments are lying. However, from the point of view of the solved problem, Quaternary sediments are mainly interesting. In addition to fluvial-alluvial sediments linked to valley alluvial streams, large accumulations of loess are characteristic for the Trnava Upland area. These were also confirmed in boreholes (Fig. 3) realized during the engineering geological survey (Pavlech, 2018) before the start of construction. Based on the coefficient of collapsibility (Imp) determined on the samples from the wells, these loess horizons were classified as collapsible (Imp > 1%), in one case even on the border of very collapsible (Imp > 3%).



The second study is devoted to a demonstration of the use of GPR measurements in the detection of underground spaces under a concrete floor in a storage hall in Malacky (Fig. 1a). Unlike the first study, in this case the radargrams did not allow the presence of hollow spaces under the floor to be verified directly. However, the structural opening in the floor of the hall, like the exposed panels in the parking lot in Šelpice, brought important information about the specific construction of the floor above the underground spaces, which made it possible to use GPR measurements in this case as well.

Fig. 1 a) Localization of the areas of the presented case studies in the Slovak Republic. b) Area of the hall in Šelpice (source zbgis, ÚGKK SR, Bratislava); 1 - place of the parking lot curb and drainage channel damage, 2 - part of the parking lot where the concrete cover is removed, 3 - infiltration wells, 4 - retention tanks

Fig. 2 Faults and voids in the front part of the area inŠelpice with their marked location (localization basis: zbgis, ÚGKK SR, Bratislava): a) curb and drainage channel collapse, b) voids between the concrete cover and the bed layer under the removed concrete slabs in the vicinity of retention tanks, c) continuation of the failure under the uncovered parts of the parking area with a detail of the cavity under the concrete slab



Well / dept of soil sample	H1 7.5 - 7.7 m	H2 4.5 - 4.7 m	H4 1.5 - 1.7 m	H5 6.0 - 6.2 m
Imp (%)	0.07	1.14	2.91	1.24

***Fig. 3** Geological conditions in the area of the diagnosed site in Šelpice; geological map (source: Digital geological map of the Slovak Republic), geological profile of the V4 well and the values of the coefficient of relative collapsibility (Imp) determined as part of the engineering geological survey (source Pavlech, 2018); a - proluvial sediments (rainy loams, sandy loams, clayey to sandy-loamy gravels, washed loess), b - eolian sediments (loess, loess clays, c) fluvial sediment, 1 - topsoil, 2 - loess, 3 - clay with an admixture of sand, CaCO3 concretions, 4 - gravelly clay, 5 - gravel with an admixture of fine-grained soil, 6 - groundwater level*

Methodology

Georadar or GPR (Ground Penetrating Radar) is a geophysical method using radar pulses to map structures and objects below the surface. Transmitted electromagnetic waves pass through the environment, while the enveloping curve of electromagnetic waves has the shape of a cone expanding towards the depth. When a wave hits the interface of layers that have different dielectric parameters, part of the energy is reflected back, and the rest continues to propagate through the medium. The reflected energy is recorded and displayed in the form of a time course, where the amplitudes and the time of passage through the individual layers can be seen. Based on the parameters of recorded reflected waves (size and frequency, time shift between their sending and receiving), information is obtained about the state of the diagnosed environment. Thus, GPR can reconstruct a high-resolution image of subsurface structures. For underground cavities, the dielectric contrast between the cavities and the surrounding environment, which enables strong electromagnetic reflections, is important.

In both mentioned cases, the measured GPR data were processed as profile 2D measurements in the Reflex W program, where a correction was made for the removal of time zero, low-frequency changes in the velocity of the carrier wave were removed, all radargrams were amplified, filtered, and route averaging was performed on them to highlight continuous reflexes. The velocity for the conversion of time record to depth was determined based on available information and analysis of refraction hyperbolas.

Šelpice - direct cavity detection

The GPR measurement in order to determine the presence and expansion of cavities under the concrete slabs of the parking lot in the area of the production hall in Šelpice took place in two stages. The first stage was focused on the screening of the entire area of the parking lot in the front part of the area in order to verify the condition of the subsoil and to find out the causes of the occurrence of exposed cavities and their location in the area. Based on the results of the first stage, in conjunction with the study of the available materials and a comprehensive inspection of the area and its surroundings, the origin of the mentioned cavities was determined. Subsequently, the second stage of GPR measurements was carried out. This was already focused specifically on the surroundings of the retention tanks and on the spatial definition of the revealed cavity created between the concrete panels and the base layer of the parking lot in their vicinity.

As part of the first stage, the MALA GroundExplorer (GX) georadar and HDR (High Dynamic Range) antenna with a GX frequency of 160 MHz and 450 MHz were used for the measurement, for better coverage of different depth levels. The location of the profiles was chosen directly at the measurement site based on the interpretation of the data measured in real time. The situation of GPR measurements from the first stage is shown in fig. 4. In the second stage, the CX 12 georadar inspection system from the company MALA with a high-frequency antenna of 1.6 GHz was used. 16 parallel profiles (010 - 025) and two perpendicular profiles (025 and 026) were measured in the front part of the area around the parking lot with the cover panels removed. The spacing of the profiles was 1 m. In addition, three parallel profiles (029 – 031) were realized in backside of the area, where the connections of the retention tanks with the seepage well are located, in places where similar signs of subsoil settlement as in the front part are beginning to appear on the surface. The situation of GPR measurements from the second stage is shown in fig. 5.

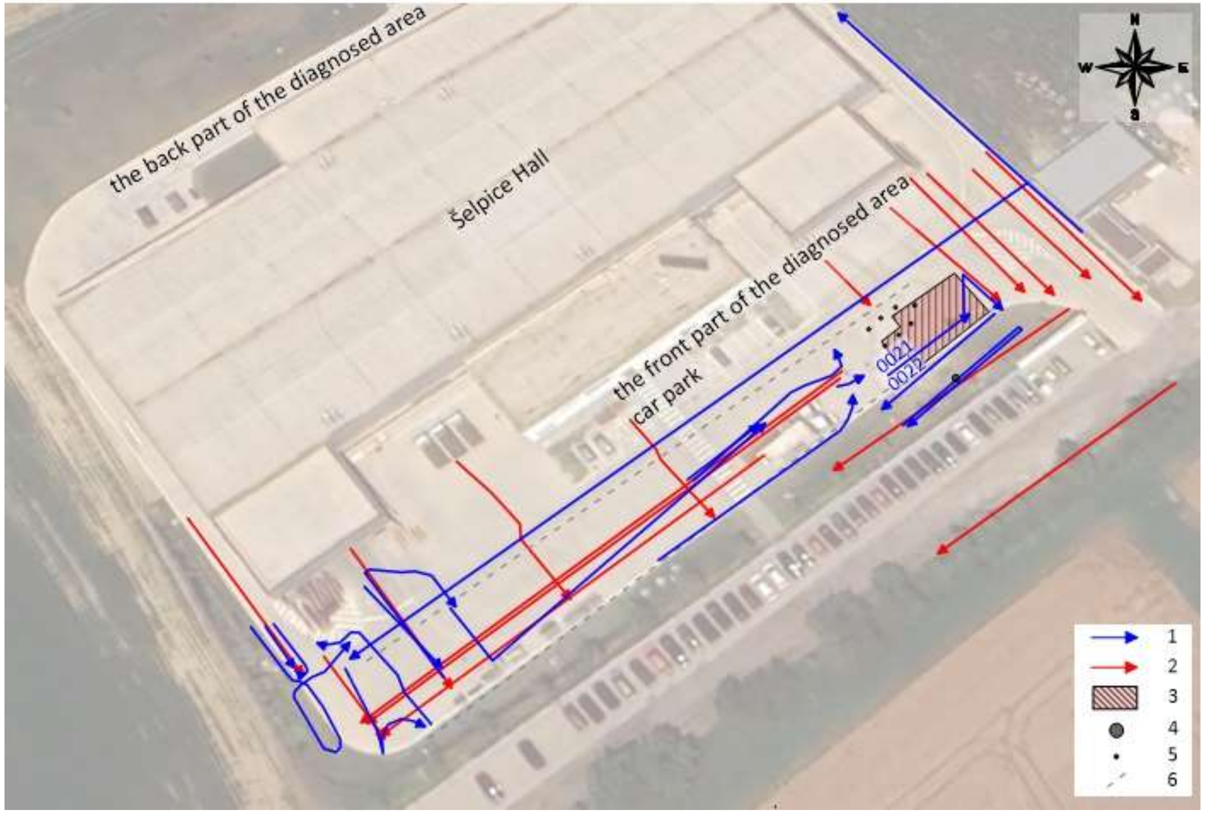


Fig. 4 The situation of the first stage of GPR measurements in the area in Šelpice: 1 - GPR profiles measured with a 450 MHz antenna, 2 - GPR profiles measured with a 160 MHz antenna, 3 - the area of the removed concrete cover of the parking lot, 4 - a seepage well, 5 - retention tanks, 6 - drainage channels

As part of a comprehensive solution to the problem of the creation and expansion of cavities, a video inspection of rain and sewage pipes was also carried out in the area to verify their technical condition and functionality. A V10 3288PTN borehole, well and pipeline inspection system with a 50 mm rotating camera on a push cable was used. The pipes connecting the drains, retention tanks and infiltration wells were checked both in the front and in the back part of the area.

Malacky - indirect detection of underground spaces

During the survey in the areas of the hall in Malacky, similar to the case of the area in Šelpice, two georadar systems were used to cover different depth levels. The measurement was carried out on 10 profiles. Each profile was measured with both systems - the MALA GroundExplorer (GX) georadar with 450 MHz and the Malå inspection georadar system with a high-frequency antenna of 1.6 GHz. The location of the profiles was chosen directly at the measurement site, based on the interpretation of the data measured in real time. The situation of GPR measurements is shown in fig. 6a. Profile 4 was led directly through the inspection hole in the floor covered with a steel plate. Figure 6b illustrates a particular construction of the floor above the subterranean spaces, which incorporates a trapezoidal sheet.

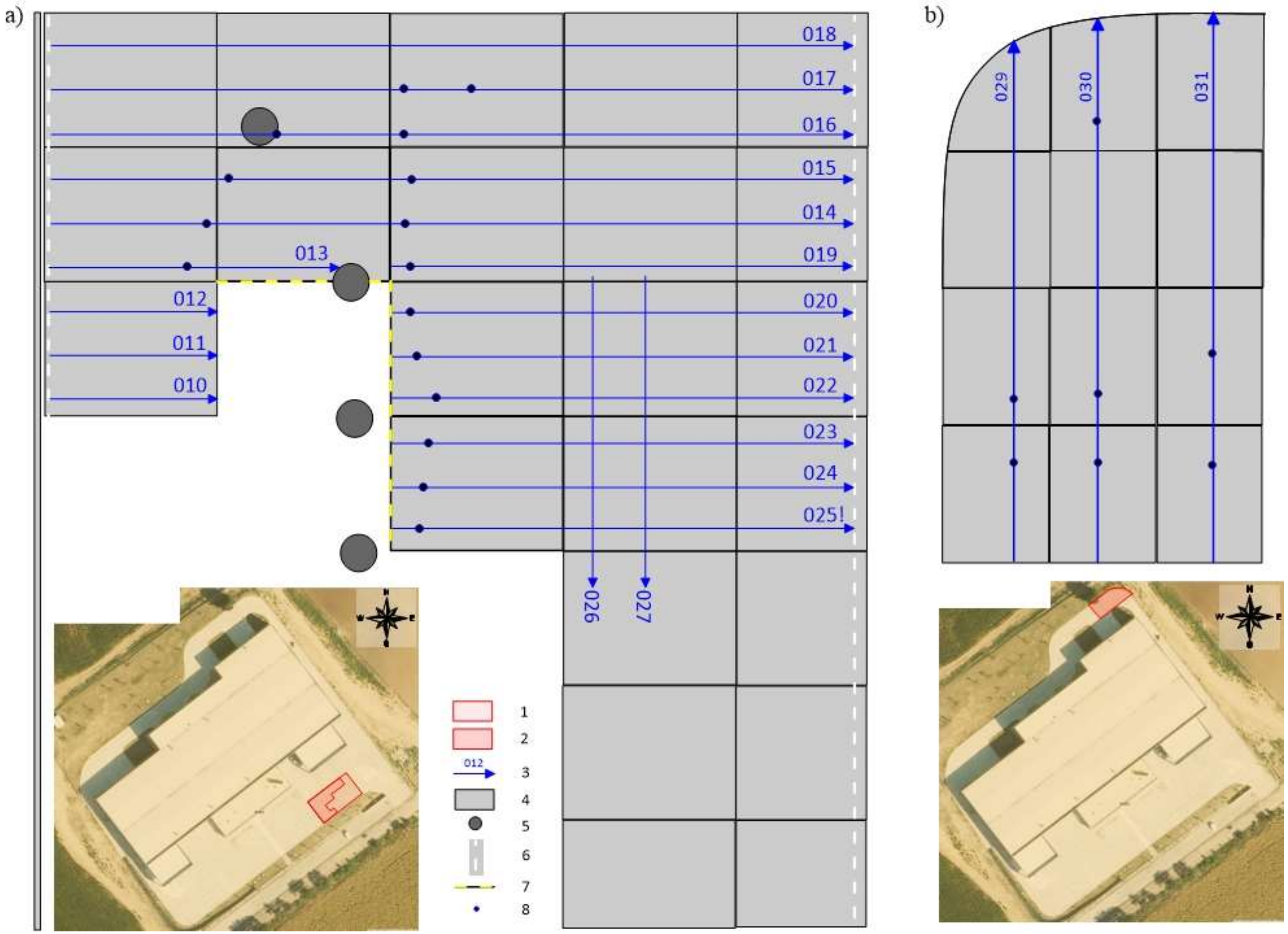


Fig. 5 Situation of the second stage of GPR measurements of the area in Šelpice: a) front part of the parking lot, b) backside of the area; 1 - area with removed concrete cover, 2 - area of GPR measurements with a 1.6 GHz antenna, 3 - GPR profile, 5 - concrete plates of the parking lot/roadway cover, 5 - covers of retention tanks, 6 - drainage gutters, 7 - places with visible continuation of the cavities under the parking lot cover, 8 - marking of the expansion of the cavity

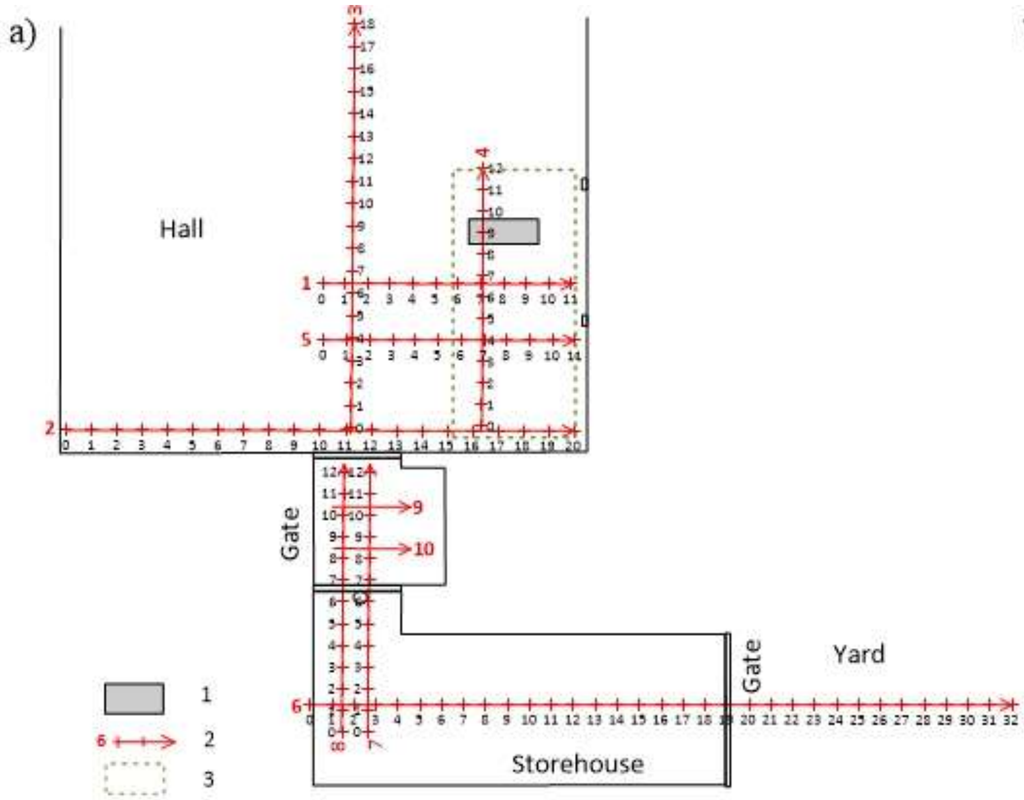


Fig. 6 a) Situation of GPR measurements in the hall in Malacky; 1 - inspection hole in the floor of the hall above the hollow spaces, 2 - GPR profiles with meterage, 3 - area of trapezoidal sheet manifestations on the interpreted radargrams. b) side view of the floor construction with a trapezoidal sheet in the inspection hole

Measurement results

Šelpice - direct cavity detection

Measurements from the first stage of the survey did not show the presence of voids or other significant deformations of the basement at greater depths (up to 1.6 m with a 450 MHz antenna, up to 12 m with a 160 MHz antenna), except in the area where the retention tanks are installed. On the radargrams measured in their vicinity with a 450 MHz antenna (Fig. 7), when compared with the recording from other parts of the measured area, the environment here is inhomogeneous and that the return embankment in these places is not consolidated. The result of the first stage was the finding that the occurrence of the cavity exposed in the front part of the parking lot is probably linked to the area around the retention tanks, while their formation occurred as a result of loess collapsibility in their basement.

The resolution of the used antennas in the first stage did not allow to detect the cavities directly under the concrete panels. As part of the second stage, when measuring with a 1.6 GHz antenna, the presence of a cavity under the concrete panels of the road cover of the parking lot was reflected directly on the radargrams displayed in real time. In places where there was a cavity, i.e. space filled with air, there was a significant increase in the reflectivity of the interface at the contact of the concrete panels with the underlying layers (Fig. 8). Based on these anomalous manifestations on the radargrams, the spatial occurrence of the cavity was marked directly in the field during the measurement (Fig. 5a).

The same manifestations as on the radargrams in the front part of the area around the exposed cavities were also recorded on the profiles measured in the backside of the area (Fig. 9). There is a high probability that due to loess collapsibility a cavity between the concrete panels of the road and its underlying layers was created.

The GPR survey demonstrated that the formation of voids beneath the concrete panels of the parking lot and the surrounding road is exclusively associated with the vicinity of the drainage systems. Therefore, the collapsibility probably occurred due to the leakage of water from the pipes connecting the drainage channel, the retention tanks and the infiltration well. This assumption was also confirmed by the results of the video inspection of the pipes. The camera recording revealed deformations of the cross-section, leaky joints and deposits. Some sections of the pipes were impassable (Fig. 10 a). Stagnant water in the bends of the pipes confirmed the settlement of some sections, which in the case of one pipe led to a crack in the longitudinal direction (Fig. 10b).

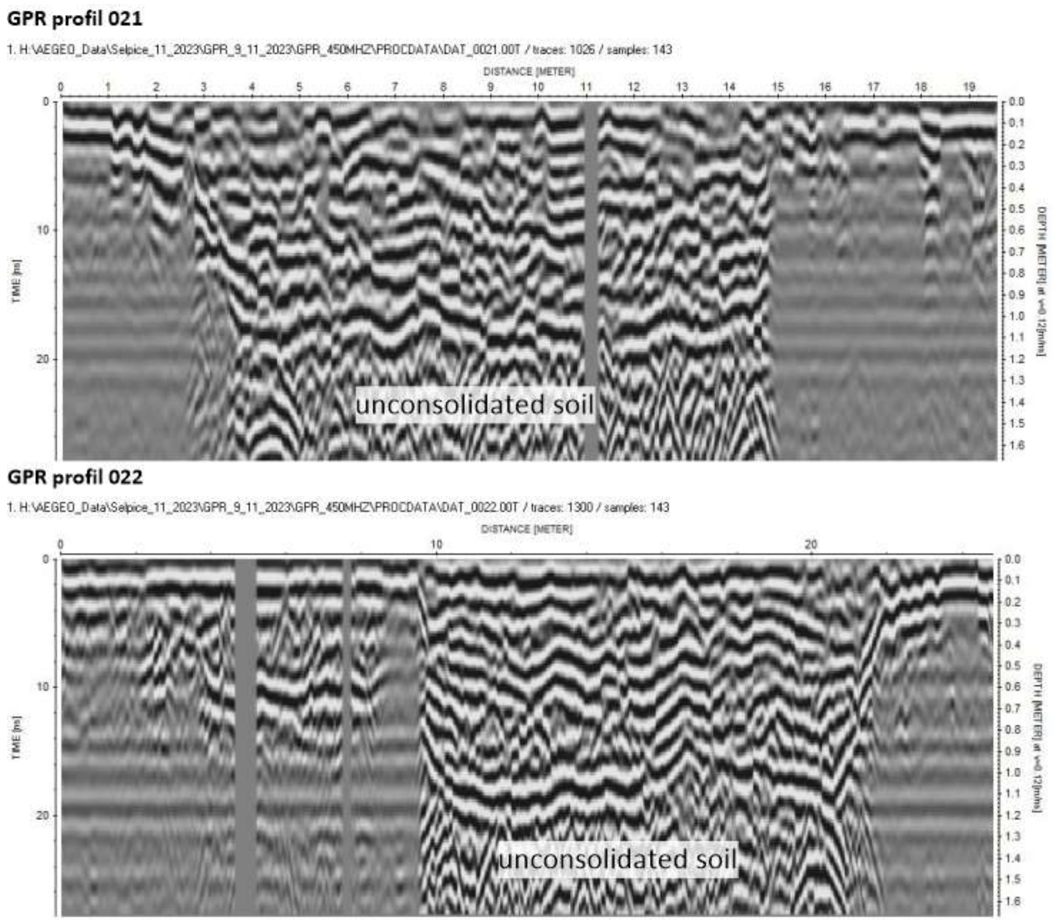


Fig. 7: Examples of processed radargrams measured by the 450 MHz antenna in Šelpice during the first stage

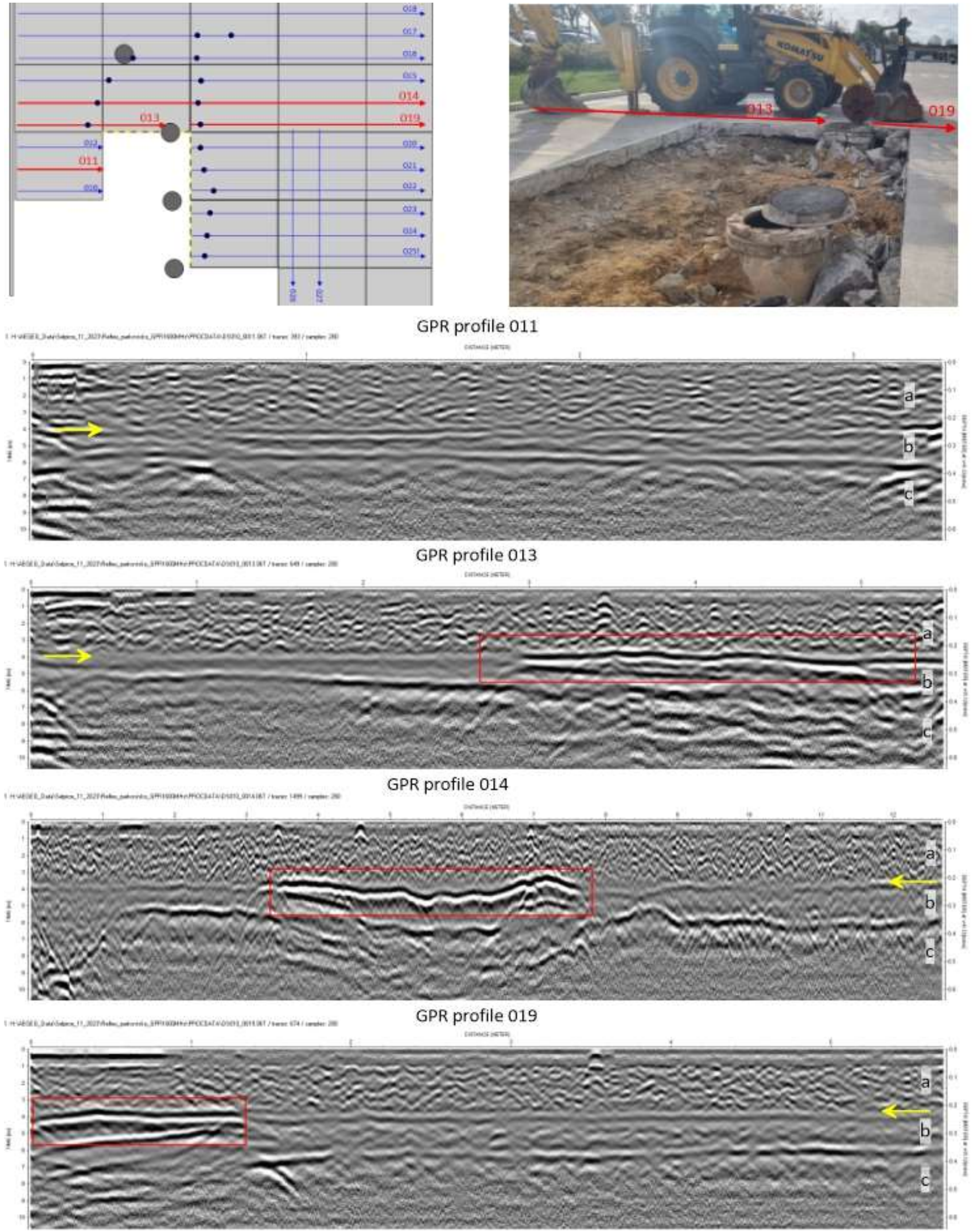


Fig. 8: Example of processed radargrams measured by the 1.6 GHz antenna in the second stage on the parking area in the front part of the area in Šelpice. Yellow arrow – contact of concrete slabs with the underlying layers, red rectangle – increase in reflectivity of the interface (indication of the presence of a cavity)

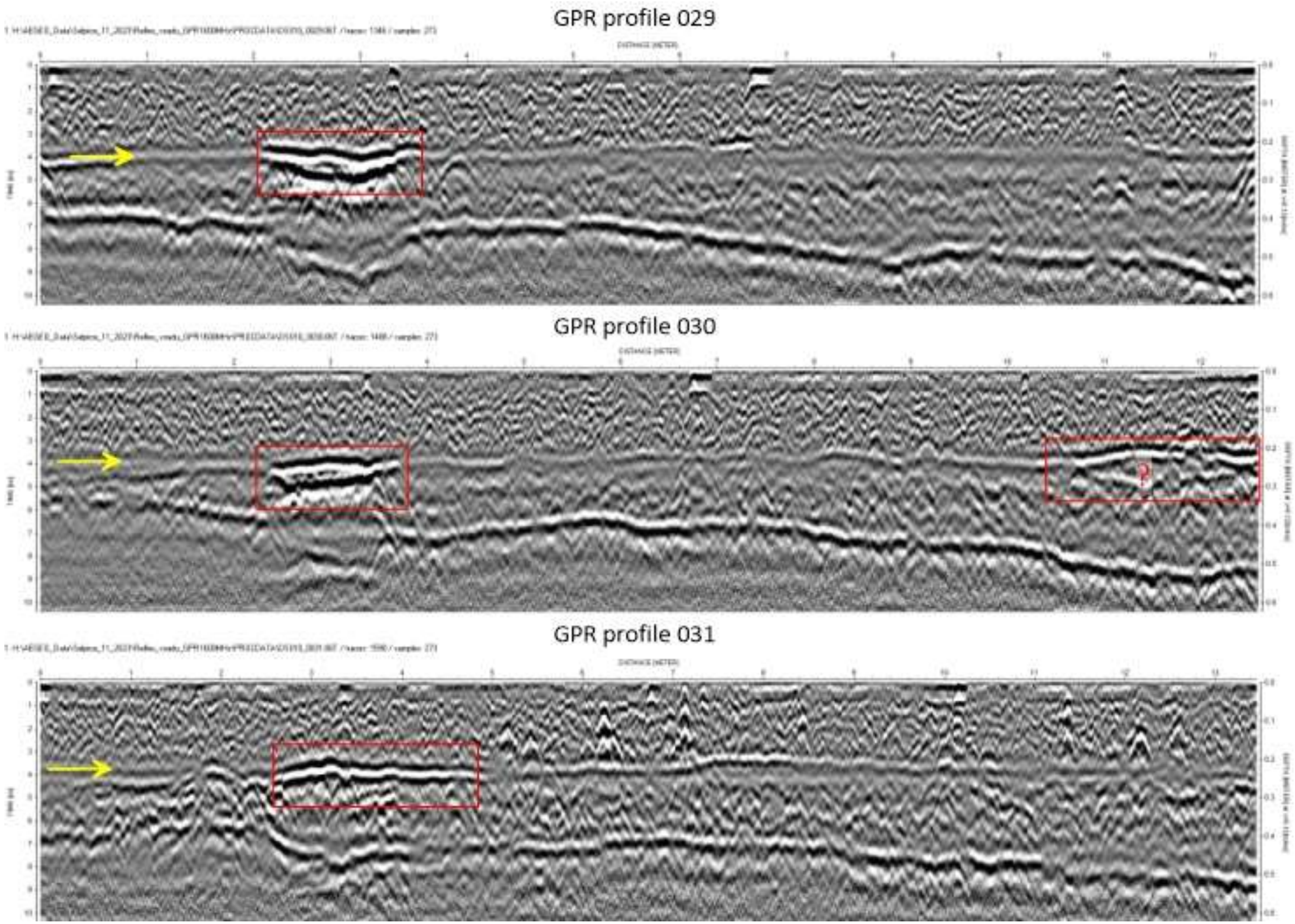


Fig. 9: Example of processed radargrams measured by the 1.6 GHz antenna in the second stage on the area in the backside of the area in Šelpice. Yellow arrow – contact of concrete slabs with the underlying layers, red rectangle – increase in reflectivity of the interface (indication of the presence of a cavity)

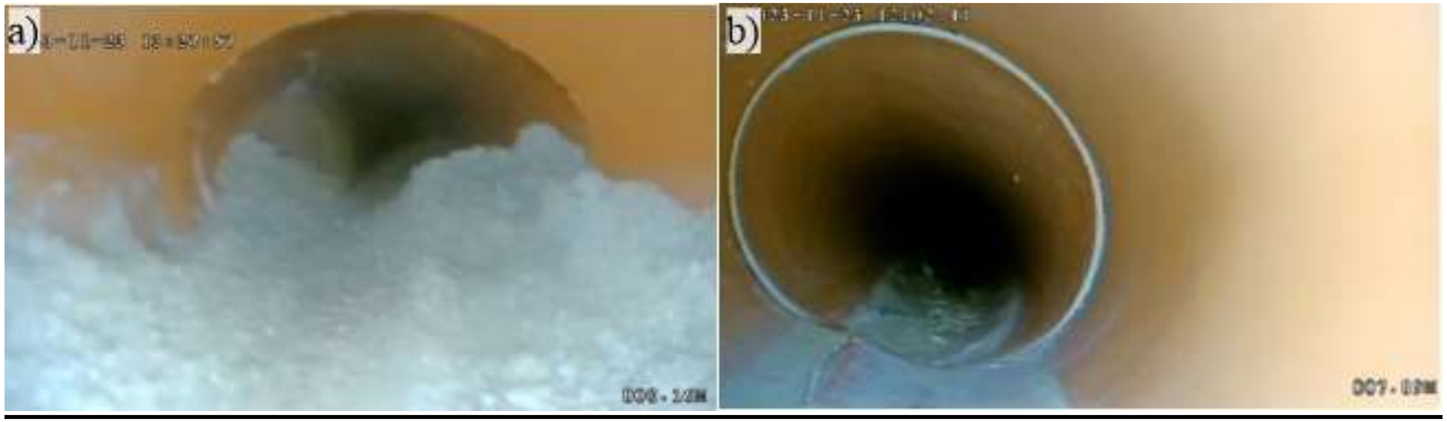


Fig. 10 Video inspection records of pipes connecting drainage elements in the area in Šelpice; a) deformations of the cross-section and deposits, b) rupture of the pipe in the longitudinal direction

Malacky - indirect detection of underground spaces

Underground spaces did not appear directly on the radargrams. The presence of a trapezoidal sheet in the floor above the underground spaces caused an increased attenuation of the signal, and the GPR did not recorded any other interface below this surface. However, the radargrams clearly showed the presence of two structural types of floors in the hall, as can be seen on profile 1 in fig. 11. Profile 1 passes through both types of floors. In the first part of the profile (up to approx. 5.8 m), the rebar reinforcement of the first type of floor (depth approx. 0.18 m) is displayed on the radargram. Below it, at a depth of approx. 0.3 m, there is an interface between the concrete and the embankment. No heterogeneities were detected in the layer below the concrete that could indicate the presence of voids. The situation is different in the second part of the profile (from 5.8 m to 11 m), which passes close to the inspection hole. At a depth of 0.15 m to 0.21 m, the trapezoidal sheet of the second type of floor and the subsequent attenuation below it are captured on the radargrams. The extent of the underground spaces under the floor of the hall was thus determined based on the manifestation of the second type of floor construction with trapezoidal sheet metal (Fig. 6). Both types of floors were also captured on the radargrams of profiles 2 and 5. Profile 4 leads directly through the inspection hole and passes through the floor with a trapezoidal sheet in its entire length. On profile 3, only the rebar reinforcement of the first-floor type was present.

On the radargrams conducted outside the hall, the presence of engineering networks and older excavations was detected, and the original terrain is probably located from a depth of 2 m (Fig. 12).

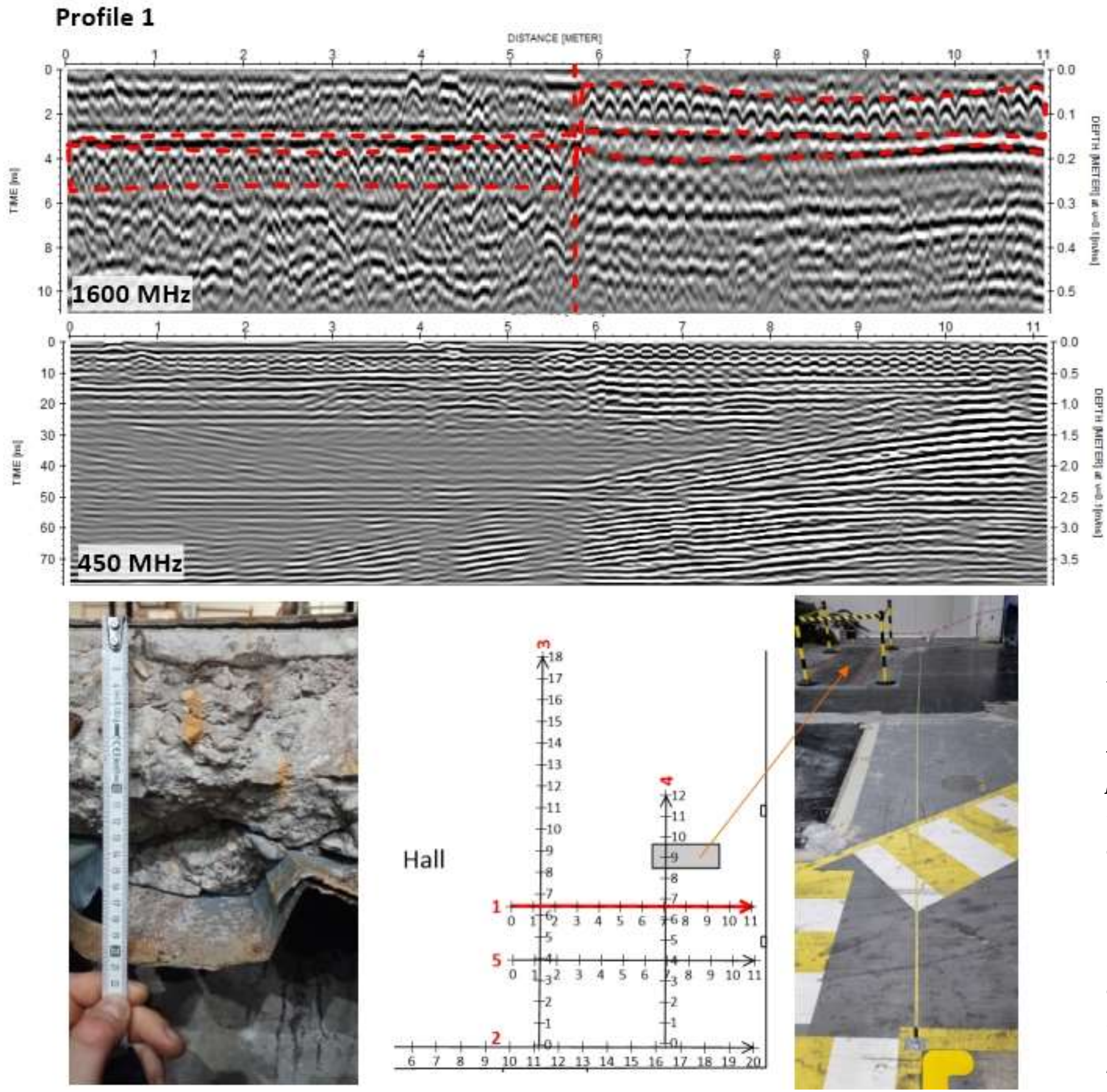


Fig. 11: Radargrams from the measurement of 1600 MHz and 450 MHz antenna in the hall in Malacky - profile 1, documentation from oriented profile in the area of the hall and a photo of the floor structure with trapezoidal sheet metal in the inspection hole in the floor. On the radargram from the 1600 MHz antenna, sections with manifestations of two different structural types of floors are marked

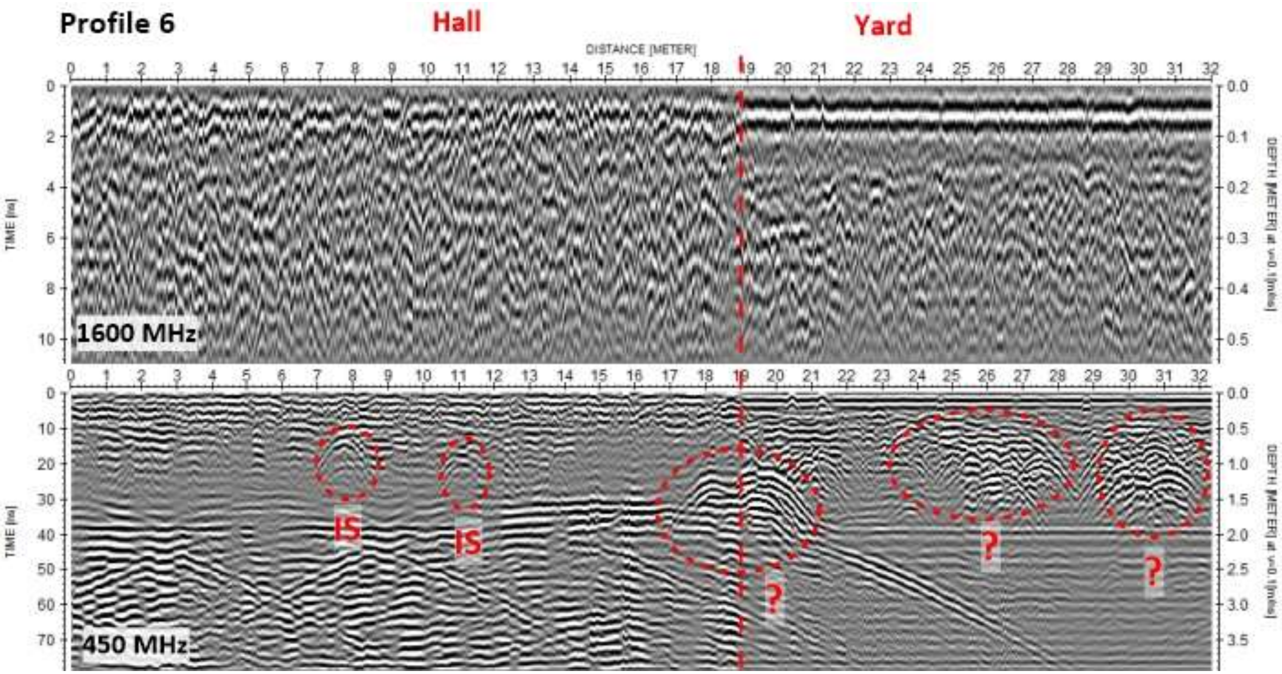


Fig. 12: Radargrams from measurement with 1600 MHz and 450 MHz antenna in Malacky - profile 6. The radargram from the 1600 MHz antenna shows sections with the presence of utility networks (IS) and older excavations (?)

Conclusion

These case studies demonstrate direct and indirect void detection under concrete cover in two different environments. In the first case, the cavity created under the concrete panels of the parking lot in the foundation of the building was directly displayed on the radargrams by the increased reflectivity of the interface. This made it possible to detect its expansion directly in the field during measurement. However, this finding was preceded by the determination of the cause of the formation of this cavity, so that the places of its possible occurrence in the entire area could be determined. It turned out that the cause was the loess collapsibility under the concrete communication. The likely cause of loess collapsibility was probably their overwetting as a result of subsidizing water from a broken pipe between individual parts of the drainage system (drainage channel, retention tanks, absorption well) during excessive rainfall in the area. The GPR measurements showed that the occurrence of the cavity is tied only to the area around these drainage elements of the area. The second case was about mapping the extent of underground spaces under the floor of the hall. Unlike the first case, these areas did not appear directly on the radargrams. The construction of the floor above the underground spaces caused an increased attenuation of the signal, so the georadar was not able to pick up any other interface under the floor. Nevertheless, the GPR measurement made it possible to delimit their extent, thanks to the specific expression of the floor structure above these spaces. Whether we see cavities directly on radargrams or only because their occurrence is tied to a specific environment and structures, the presented examples show that the detection of cavities using GPR measurements must be approached as a complex task in order to bring the required information.

Acknowledgment

This work was partially supported by the Slovak Research and Development Agency under contract VEGA 1/0180/24.

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