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THE CONTRIBUTION OF GEOPHYSICS TO THE PREPARATION OF ROAD AND RAILWAY TUNNEL CONSTRUCTION IN THE AREA OF VÁCLAV HAVEL AIRPORT (RUZYNĚ)

PODÍL GEOFYZIKY NA PŘÍPRAVĚ STAVEB SILNIČNÍHO A ŽELEZNIČNÍHO TUNELU V OBLASTI LETIŠTĚ VÁCLAVA HAVLA (RUZYNĚ)

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Abstract

Ruzyně Airport expects further expansion of operations. The construction of a new flight path is in the design phase. The construction of a high-speed railway from the centre of Prague to the airport is also in a high stage of design preparation. In connection with these tasks, an engineering-geological survey was carried out for the terminal railway tunnel of the high-speed railway and the road tunnel. The tunnels will deal with traffic in places where air traffic would intersect with other transport. Geophysics was also used within the complex of survey methods, both for the problems of geological exploration, but also for the assessment of corrosion and technical seismicity. The measurements were carried out under increased safety supervision and demands on the reliability results. The conclusion of the article draws attention to the issues associated with the application of geophysical measurements in interdisciplinary projects.

Abstrakt

Letiště Ruzyně očekává další rozšiřování provozu. V projekční fázi se nachází výstavba nové letové dráhy. Ve vysokém stadiu projekční přípravy je také stavba rychlodráhy z centra Prahy na letiště. V souvislosti s těmito úkoly byl proveden inženýrskogeologický průzkum pro koncový železniční tunel rychlodráhy a silniční tunel. Tunely budou řešit provoz v místech, kde by se letový provoz křížil s ostatní dopravou. V rámci komplexu průzkumných metod byla použita i geofyzika, a to jak pro problematiku geologického průzkumu, ale také pro posouzení korozity a technické seismicity. Měření probíhala za zvýšeného bezpečnostního dozoru a nároků na spolehlivost výsledků. Závěr článku upozorňuje na problematiku spojenou s aplikacemi geofyzikálních měření v mezioborových projektech.

Keywords
Geophysics, corrosion, technical seismics, vibration, geology

Klíčová slova
Geofyzika, koroze, technická seismicita, vibrace, geologie

1. Introduction

The area of geological investigation is adjacent to the southeast part of the Terminal 3 (Vaclav Havel Airport). The area of interest is crossed by the taxiway TWY L. See Fig. 1. The Fig. 2 shows the detailed scheme with the projected tunnels, bore holes and the stations for observation of stray (parasitic) currents (ST 1, 2, 3 and 4).

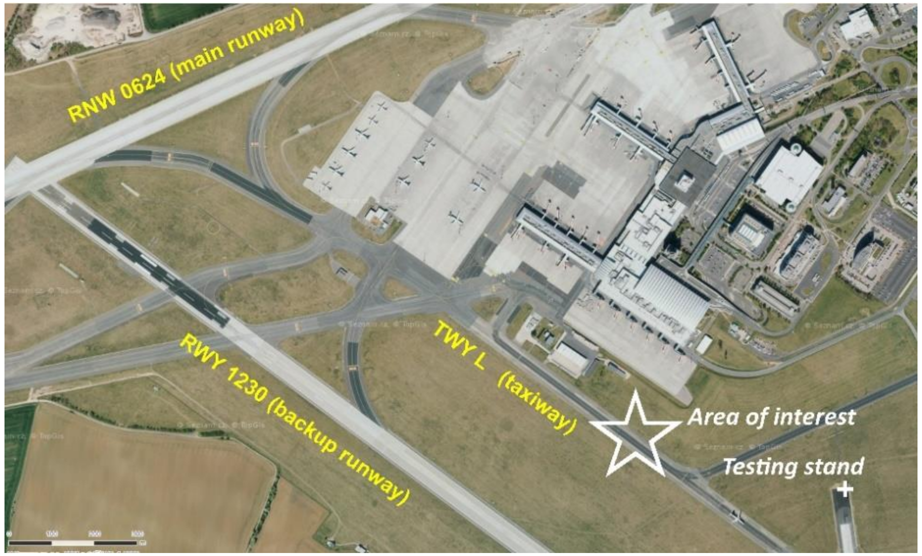


Fig. 1 The map with the area of interest

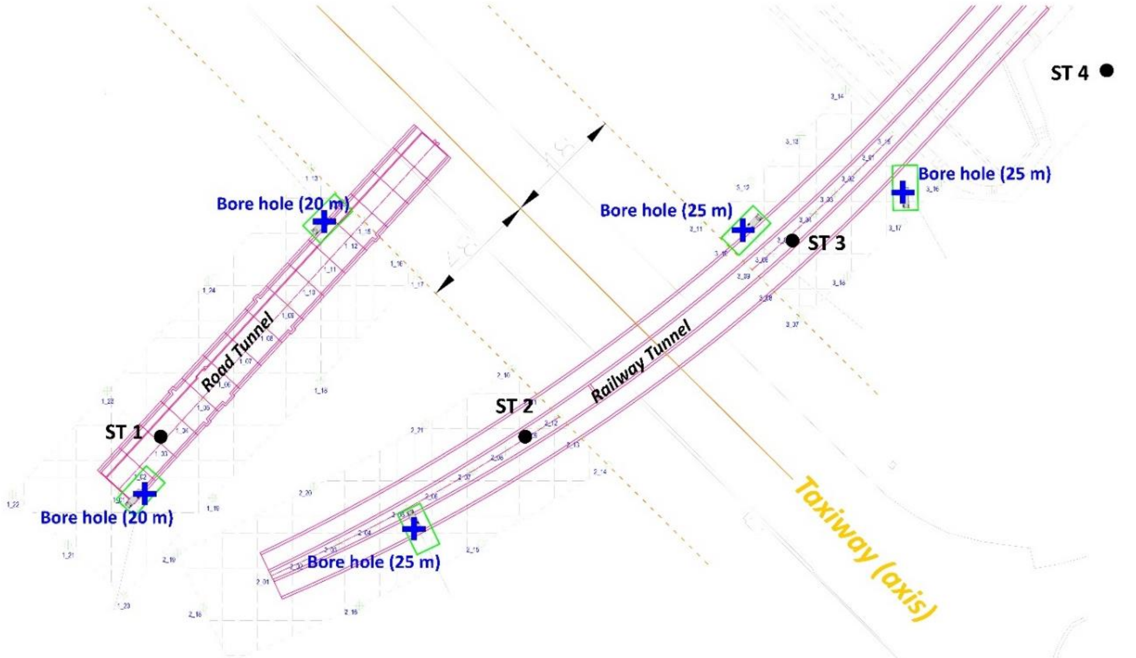


Fig. 2 The detailed map of tunnels, boreholes and pickets ST 1, 2, 3, 4

The complex of geophysical measurement, which was executed for railway and road tunnel, was devided to three parts:

a) The geoelectrical measurement for a determination of a danger of corrosion,
b) The geophysical measurement for a better specification of the geological conditions,
c) The passive seismic measurement for a specification of a technical seismicity.

Local geological conditions, more precisely geotechnical conditions, are complicated for tunnel construction. The investigations carried out so far have found out in particular the fact that under the gradually become firmer Turonian Formation, weathered rocks of Cenomanian age are occurred and their consolidation occurs deeper. With regard to the situation that this phenomenon may occur significantly in places where tunnels will be excavated, it was decided that the reliable, but point data from drilling work will be further extended and refined by geophysical research.

The measurements at Vaclav Havel Airport had certain technical complications for geophysics. Mainly strict safety measures of flight supervision (such as the impossibility of entering flight paths and the space under aircraft engines) had to be observed. Furthermore, measurements in 2021 took place in a strict regime of measures against COVID-19. For this reason, air traffic was minimal, i.e. the average technical seismicity decreased.

2. Corrosion hazard

The geoelectrical measurements were executed with relation to Czech standards (see ČSN 03 8375, ČSN 03 8372, ČSN 03 8365, TP 124, METODICKÝ POKYN MD).

The assessment of corrosion risk is based on the current density of the stray current field J_p [mA/m^2] and the magnitude of the detected resistivity (Ωm). The calculated values are compared with the relevant standards (ČSN 03 8372). See Tab. 1 bellow.

Tab. 1 Corrosion hazard by ČSN 03 8372

Resistivity [Ωm]	**Current density J_p [mA/m^2]**	**Characterization**	**Level**
> 100	< 0,0001	very low	I
50 - 100	0,0001 – 0,003	medium	II
23 - 50	0,003 – 0,1	increased	III
< 23	> 0,1	greatly hight	IV

The stray currents were measured on the observation stations ST 1, 2, 3 and 4 (see map on Fig. 2). The representative resistivity was find out by resistivity tomography (ERT) from the same area. The final results is presented in Tab. 2 (see below).

Tab. 2 Computation of current densities J_P

Station	R *) [ohmm]	Total vector **) [mA/m^2]
ST 1	15	0,0008
ST 2	15	0,0093
ST 3	15	0,0167
ST 4	15	0,1383

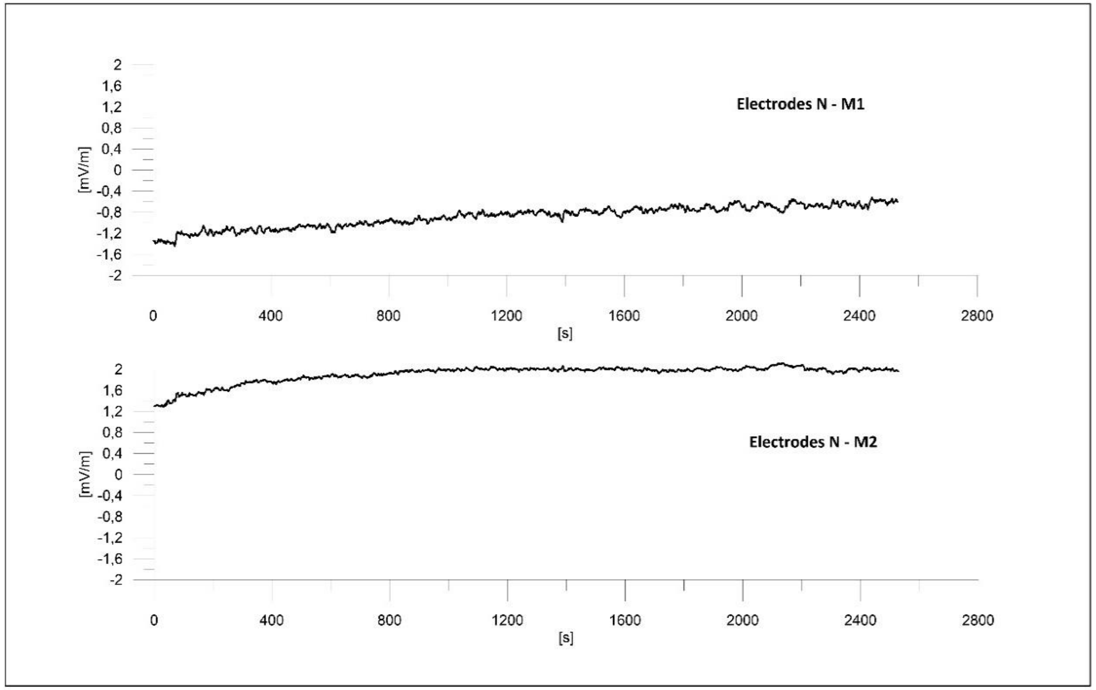
*) representative value derived from resistance measurements
**) total vector of gradient potential [mV/m] divided by resistivity [Ωm]

The area of interest was in general classified in the corrosion level IV in the sense of ČSN 03 8372, see Tab.1. The reason for this conclusion is in principle the result of measurements at the ST4 station, which detected the presence of intense stray currents that can spread further into the projected tunnel structures. According to Technical Instruction TP 124 of the Ministry of Transport of the Czech Republic, it is also level 4. For the situation in the investigated area, it should be noted that the territory is strongly influenced by an unspecified electromagnetic field and that the electromagnetic component 50 Hz is also part of stray currents.

On Fig. 3 are presented as example the graphs of differences between potentials of electrodes N – M1 and N – M2.

3. The geophysical measurement for the geological conditions

The implemented drilling network proved to be insufficient due to the complexity of the geological conditions, and therefore connecting geophysical profiles were set out between the boreholes. The map with executed geophysical profiles P1, P2 and P3 and boreholes S1, S2, S3 and S4 is presented on Fig. 4. Construction work and complicated terrain situation (landscaping for the aircraft stand area) caused that the P3 profile was led about 10 m laterally from the S4 and S5 probes (which does not have a major impact on the interpretation of geological conditions). The measurement was composed of ERT (Electrical Resistance Tomography) and seismics, that's mean refraction and reflection seismics and MASW (Multichannel analyse surface waves). The geophysical complex was choose take into geological conditions and by lit. (see Butler, 2005; Barton, 2007; Rozsypal, 2008 and Park, 2018).



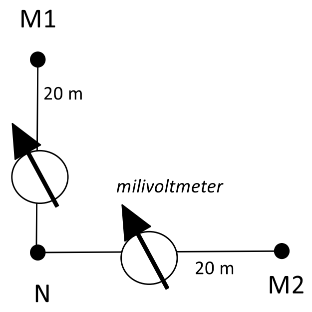


Fig. 3 The graphs of differences between electrodes N-M1 and N-M2

The method of resistance tomography was performed in the arrangement of Wenner–Schlumberger electrodes and in the dipole variant. Fig. 5 shows the results of geophysical measurements from the P1 profile (the profile P2 and P3 have are analogous results). The appendix is organized in such a way that the geological sections found by the probes S2 and S1 are drawn in more detail at the top right. Furthermore, a refractive seismic model, a reflective seismic model and a model compiled from surface wave analysis (MASW method) are plotted in the appendix. At the bottom of the appendix is a resistive incision (resistance tomography method, ERT). In the annex there is also a schematic geological-geophysical section. When interpreting the data, it is necessary to realize that we are in an environment built by clays, claystones and sandstones. The surface part of the Turonian is made of clay gravel. From a physical point of view, the resistivity of the environment decreases with grain size and humidity. Wet clays have low resistances of around 20 ohmm, typical soils are characterized by resistances of 50 to 100 ohmm. Dry gravel has resistances in the order of thousands of ohmm. Solid sandstones have resistances in the higher hundreds of ohmm. For seismics, the more solid the environment, the higher the seismic velocities. However, seismic velocities are also partially increased by the clays present in the rock. The situation at Ruzyně Airport is therefore a complicated interpretation situation. Therefore, the geological-geophysical section must be viewed as schematic. From the interpretation of the data, it is clear that both the Cenomanian and Turonian formations are not geotechnically uniform in both horizontal and vertical directions. Relatively often, unimpaired positions alternate with less fixed positions.

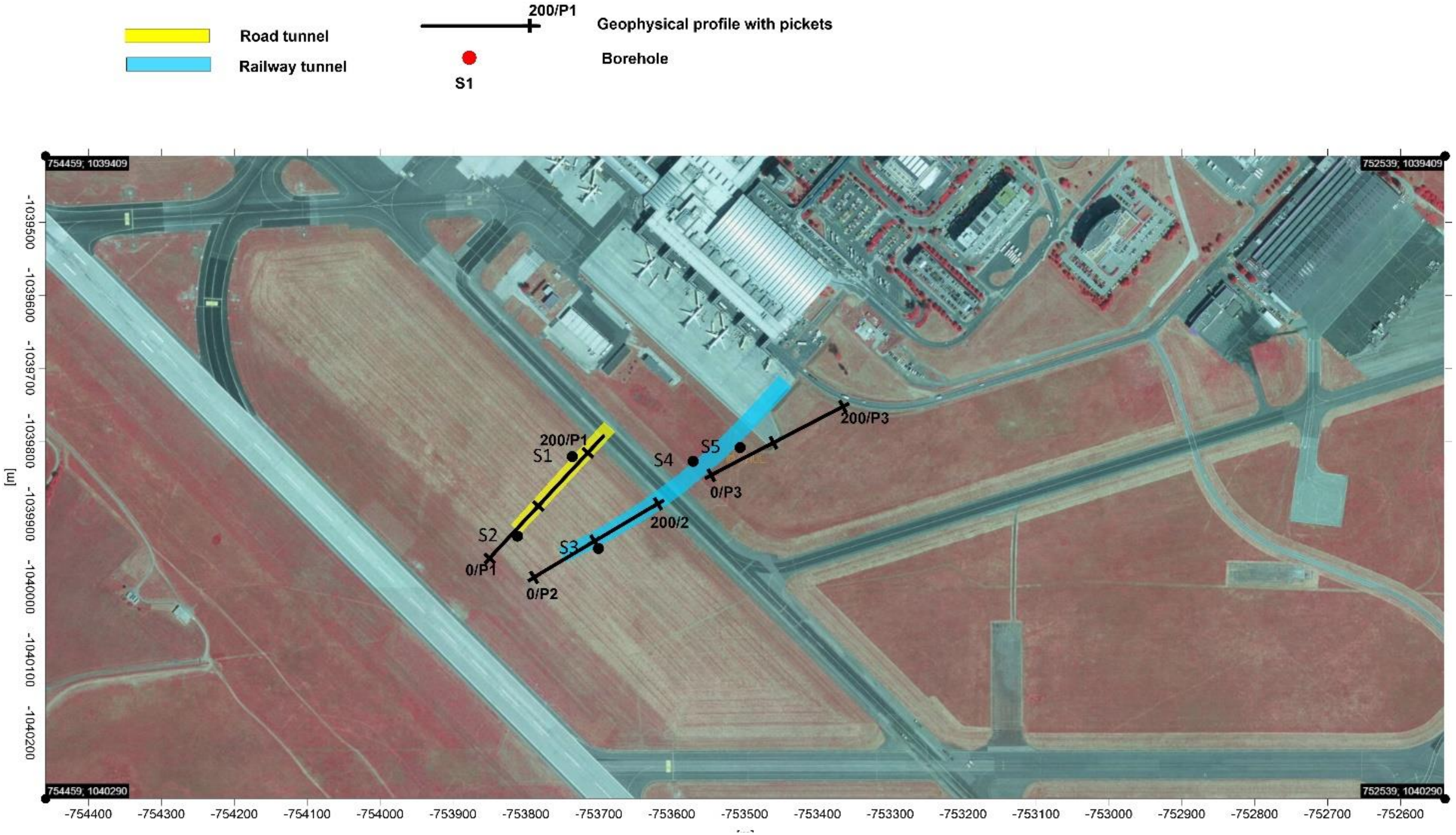


Fig. 4 Map with geophysical investigation profiles P1, P2 and P3

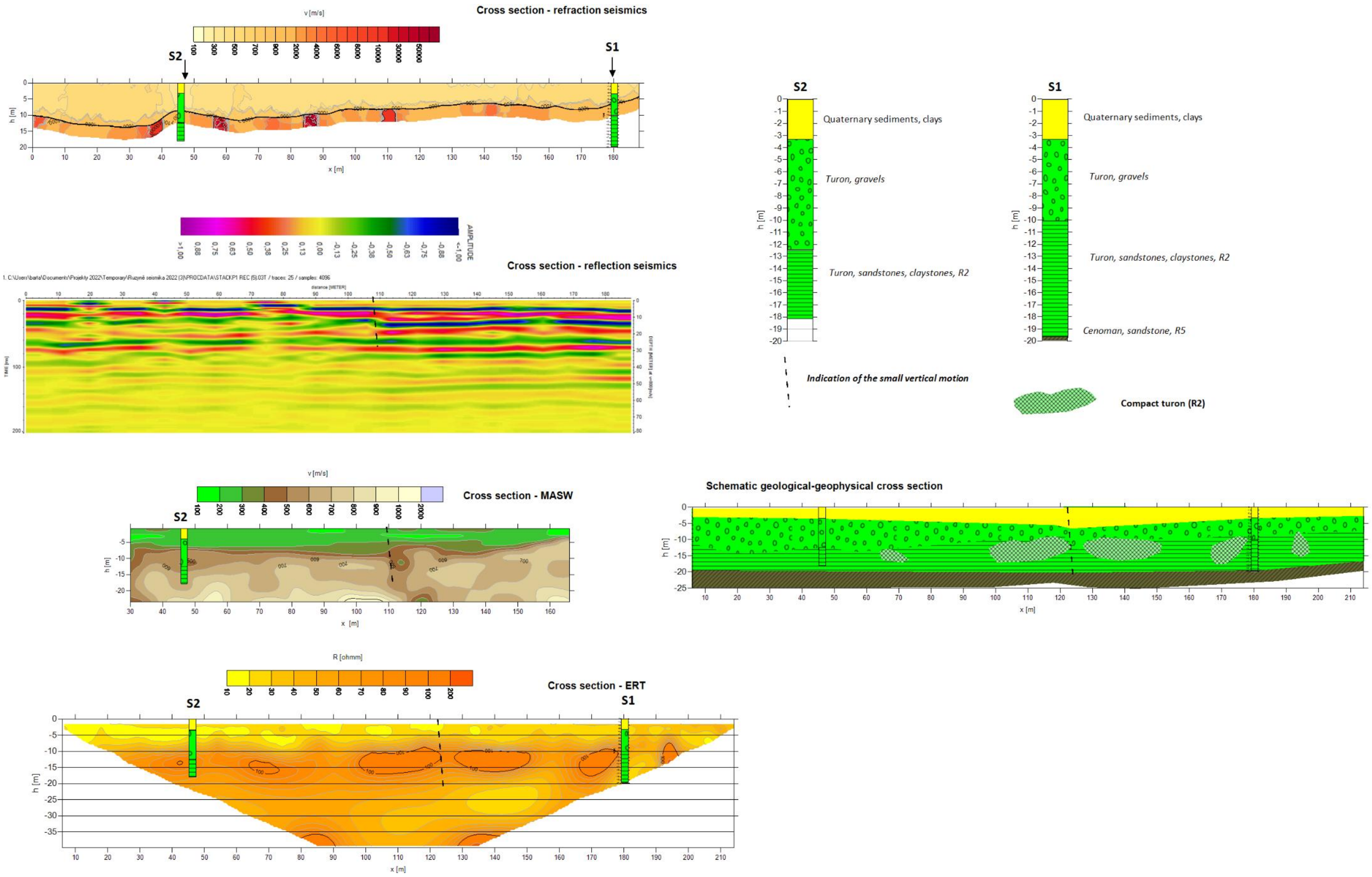


Fig. 5 Geophysical results. Profile P1

The results lead to the conclusion: If we consider that the foundation joint of the tunnels will be located at depths of about 10 to 16 m below the terrain, it is necessary to consider that the excavation will take place in soils of Quaternary age, which pass deeper into the rocks of Turonian to Cenomanian age. The rocks of both the Turonian and Cenomanian have a varied petrographic composition and alternating geotechnical properties. Minor tectonic disturbances were also found on the measured profiles.

4. Technical seismicity

Technical seismicity was measured during 2021, i.e. under covid restrictions. The airport was little used and the measurements had to be processed taking this into account. The evaluated data showed that aircraft that moved in action mode (engine touring, aircraft take-off) were able to develop vibrations, which were manifested on the vertical component by a value of up to 8.61 mm/s (active engines, aircraft standing on TWYL, large airliner). Small aircraft for the transport of several people reached values up to about 4 mm/s. Aircraft towed or taxiing at low speeds caused a peak of velocity of oscillation of about 0.5 mm/s. This data is value for places approx. 30 m of aeroplane.

The conclusion from the technical seismicity measurements monitored in 2021 is that seismicity is acceptable in the measured places, even in the vicinity of the Taxi Way. A critical situation could occur if the aircraft engines were started for a longer time (touring) directly above the tunnel (relocation thickness about 1.5 m). These conclusions are based on ČSN 730040 with regard to Government Regulation No. 272/211 and ČSN EN 1998-1 (see lit. at the end of the article). In the final report for 2021, there was a recommendation to prohibit the possibility of aircraft stalling and the transfer of engines to full thrust in places directly above the tunnel structures. We had not any relevant information for this case.

The recommendation of a ban on parking over tunnels did not meet with the understanding of the airport administration and therefore a solution was sought in 2022 as part of the additional survey. The aim of the new work was to specify the value of vibrations in close proximity to aircraft engines at full thrust of the nozzles. It is interesting that in the available literature such information is not found. To some extent, this is because there is a protective zone around aircraft engines (tens of meters). In the foreground of the engine, it is mainly to prevent objects (on the case of geophones) from being sucked into the engine. Behind the engine, it is mainly about the safety of persons and the possibility of destruction of the sensing system by gas pressure and sound pressure.

Obtaining reliable information about vibration in the vicinity of the engines was laborious and required a series of indirect measurements and their subsequent interpretation. These measurements were executed on 2022 year as supplementary exploration. The supplementary measurements were done in two steps:

1st step…… standard active seismic measurement on the place for review of seismic conditions
2nd step ...... vibration test and evaluation.

The supplementary measurements was accomplished on the testing stand (see the map on the Fig. 1). The detailed arrangement of the geophysical profiles and testing field works are showed on the Fig 6.

Fig. 6 Testing stand. Map of geophysical profiles (left on the top), testing airplane (right up), geophysical measurement (in the centre), layout with geophones (right on the below)

The active seismic measurement (1st step of measurement on the Testing Stand) consists from one layout (profile O) which was situated on the lengthways axis of the runway and from the profile K, which was situated as perpendicular (see map on the Fig. 7). The seismic measurement verified a relative homogeneity of geotechnical conditions of the Testing Stand (see Fig, 7b) and enable an assessment of a damping of seismic waves (see Fig. 8).

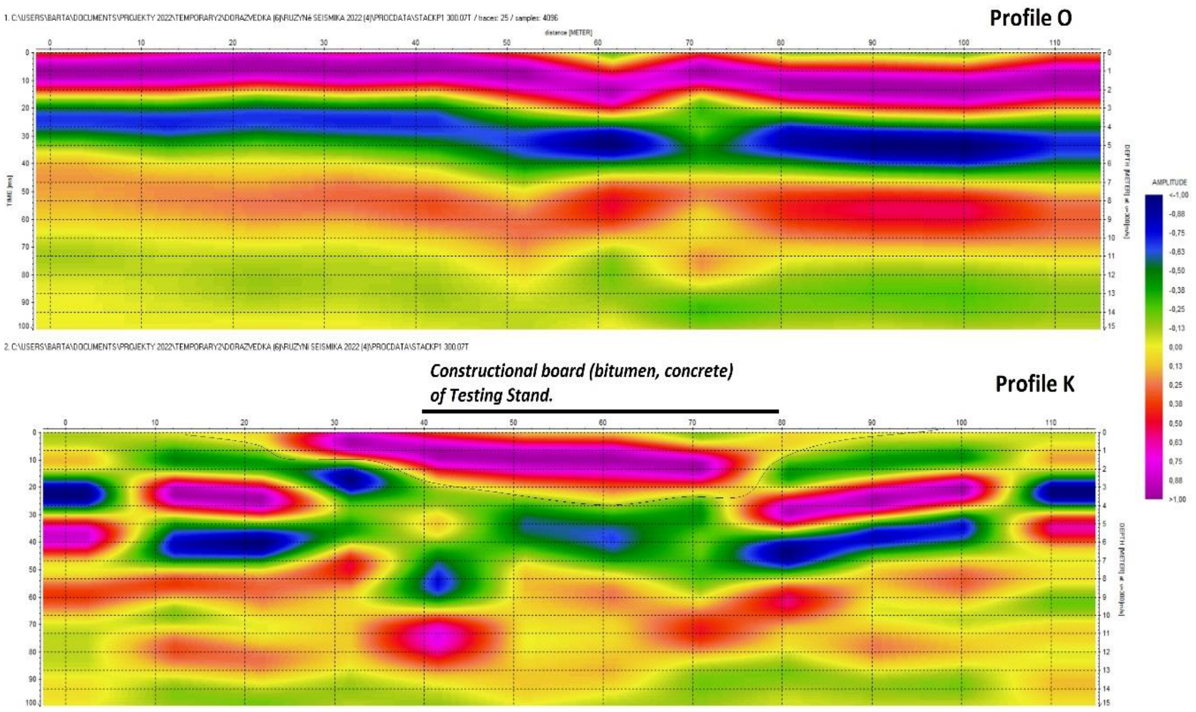


Fig. 7 Seismic reflection cross sections. Testing Stand. Profile O and K

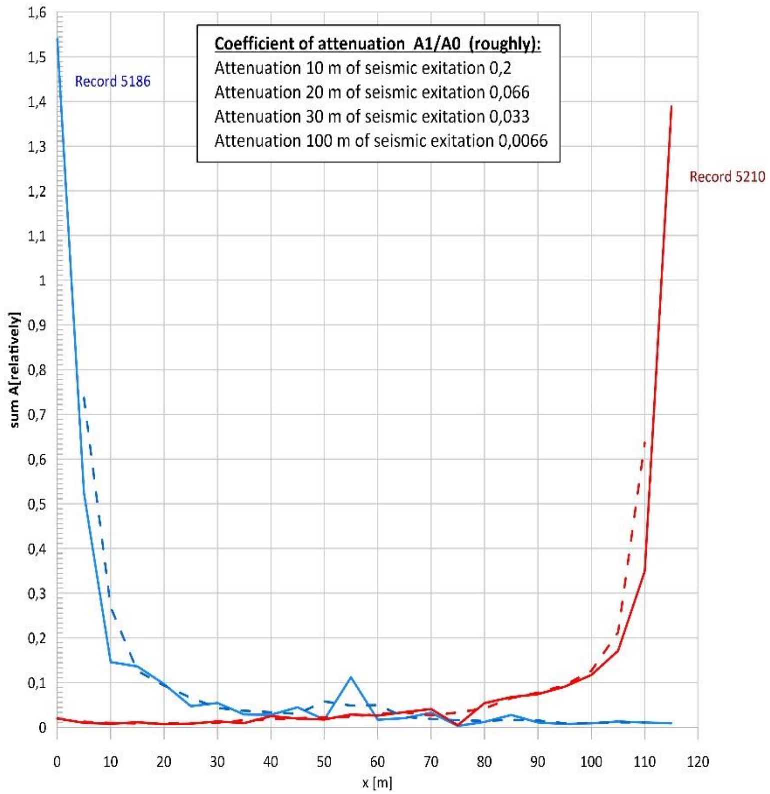


Fig. 8 Coefficients of attenuation computed from record 5186 and 5210

The passive measurement (2nd step of measurement) consisted from vibration test and evaluation all gained data. The field works were executed by four seismic equipment as follows:

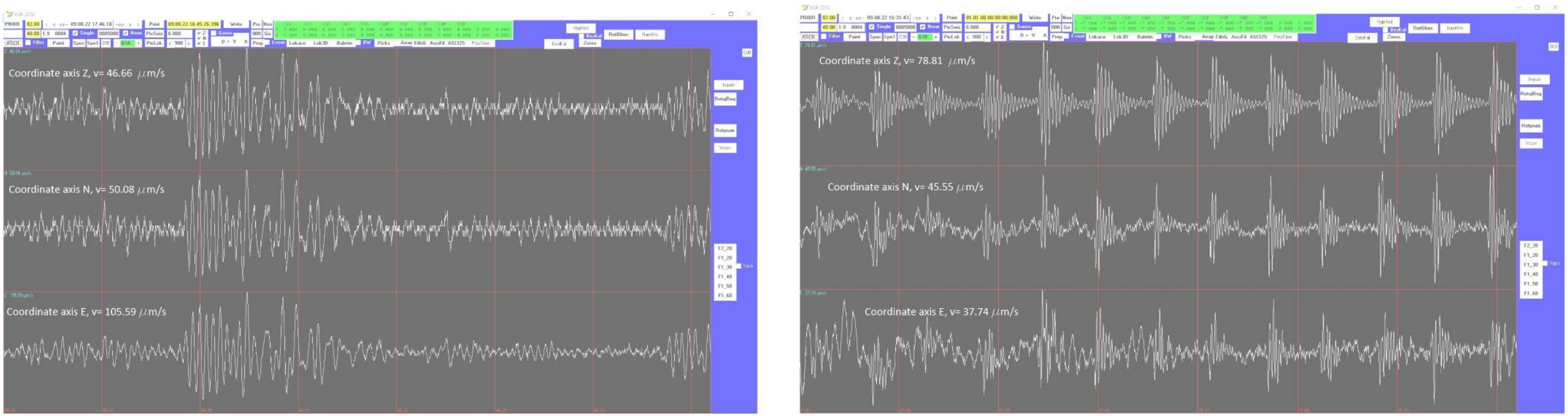
- GIA (4 channels for three dimensional geophones, product USMH AVČR),
- GIB (4 channels for three dimensional geophones, product USMH AVČR),

- Terraloc Mark 6 (48 channels, product ABEM, Sweden),
- Terraloc Pro 2 (48 channels, product ABEM, Sweden).

The seismic equipment were setting in take consideration to safety regulation (see Fig. 6, map), out of protection strips. Since it was not possible to measure directly under the aircraft, the location of geophones (seismic sensors) was chosen so that we could estimate the maximum possible limit of seismic load close to the aircraft from partial knowledge.

In the Fig. 9 one can observe examples of seismic records from the GIA and GIB apparatus. On the GIA apparatus the peak particle velocity anomalies reached values of up to about 0.106 mm/s (i.e. the vibration rate) and on the GIB apparatus around 0.137 mm/s. The GIA apparatus was located behind the end of the aircraft, the GIB apparatus was located laterally from the aircraft (see Fig. 6 or 10).

The Fig. 10 shows the position of the test aircraft in relation to the seismic profiles P1, P2, P3 and P4 and the position of the GIA and GIA apparatuses. The figure also shows typical traces (velocity of vibration) from the P3 and P4 profiles. Measurements on the P1, P2, P3 and P4 profiles were carried out by the Terrraloc instruments and for this reason only the seismic component Z (vertical) was measured.



Record of GIA, geophone 1 A, time 16:45

Record of GIB, geophone 1 B, time 16:31

Fig. 9 Examples of records of GIA and GIB equipment

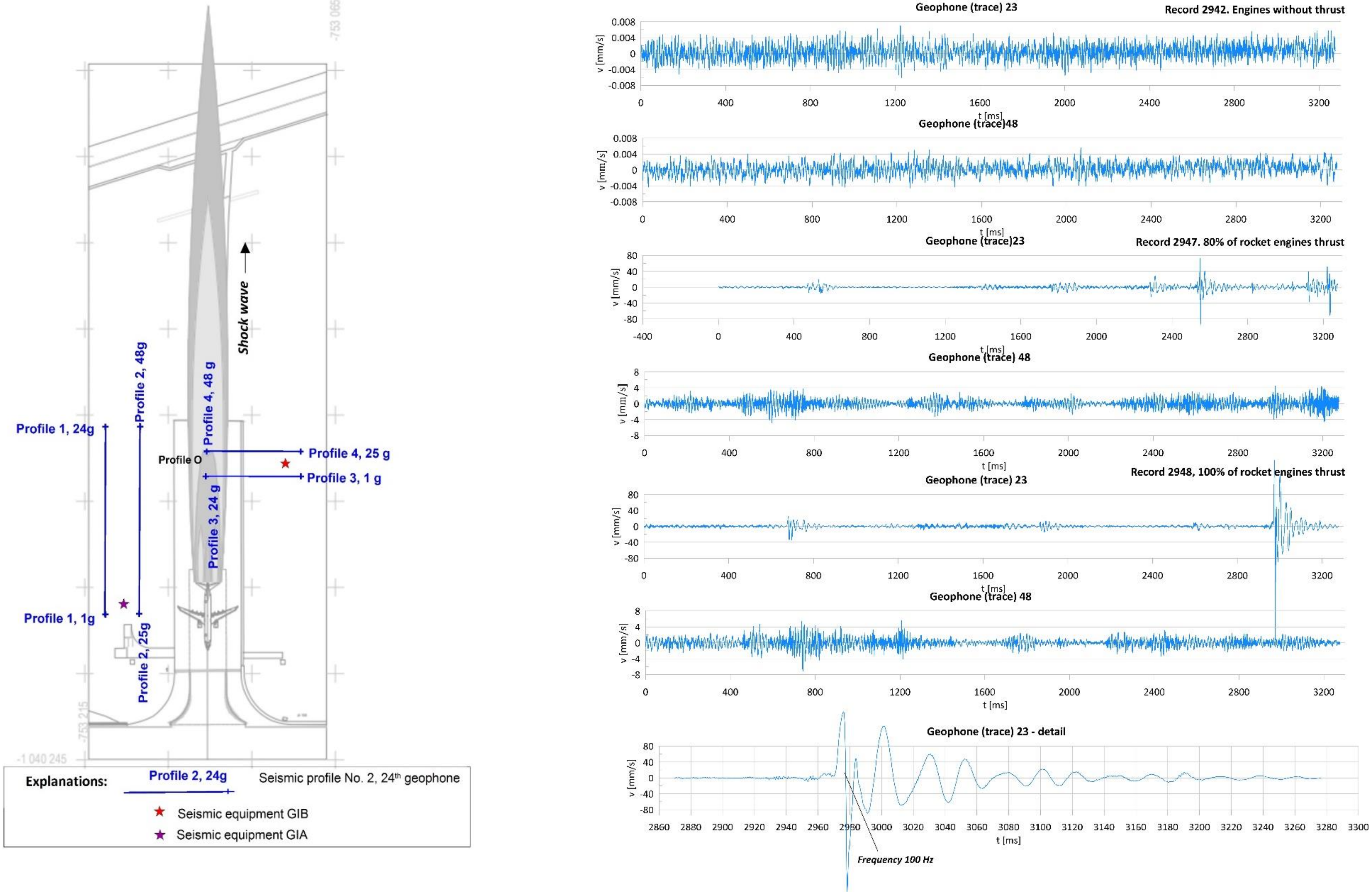


Fig. 10 Map with position of testing airplane (left) and presentation of selected traces from profiles P3 and P4 (right)

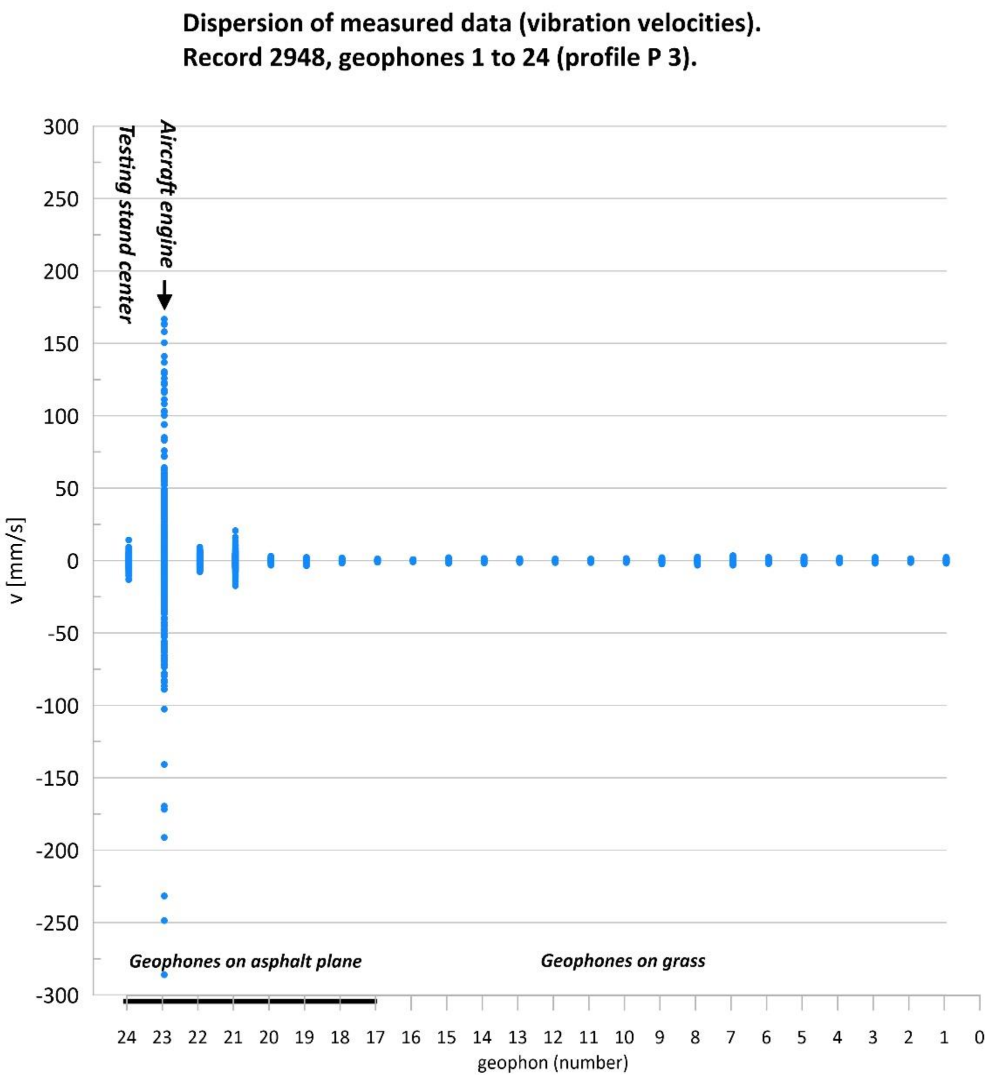


Fig. 11 Dispersion of vibration velocities, profile P3, 100% engine thrust

The Fig. 11 shows dispersion of vibration velocities from profile P3 in the situation with 100 % engine thrust. The horizontal axis presents the individual traces of geophones. The vertical axis presents values of velocities of vibrations. The graph contents all measured velocities detected with sampling time 0.250 msec. The graph is a proof of a reality that maximum vibrations are concentrates on the geophone (trace) No. 23 which is located right opposite behind the rocket engine. The vibrations is sharply moderated in the vicinity.

Conclusions from measurement on the Test stand:

Peak particle velocity values reach extreme values only when measured in the extension of the longitudinal axis of the aircraft, i.e. frontally behind the aircraft engines. In our case, at a distance of 100 m from the aircraft on the P3 profile, values around v = 170 mm/s were measured. This can represent values around 2,550 mm/s when converted to the source location (for a very approximate estimate using conclusions on the attenuation coefficient, see Fig. 8). However, taking into account the scattering graph, see Fig. 11, it can be concluded that these extreme values are caused not by waves propagating through the rock environment, but by a pressure wave propagating through the air, and this wave penetrates the rock environment only minimally (this statement is based mainly on the analysis of Fig. 11 and the results of measurements at other sites). Under these circumstances, it can be expected that even with full operation on TWY L, the planned underground structures will not be endangered, provided that they are built in accordance with ČSN 730040 (Loading of buildings by technical seismicity and their response) according to Table 9, classification into class F (reinforced concrete and steel lining of metro tunnels and collectors, civil defence shelters). When moving aircraft on TWY L, it can be expected that the seismic waves spreading through the rock will reach a maximum peak particle velocity in the order of units of mm/s, in extreme cases in the first tens of mm/s, The lowest dominant frequency is around 20 Hz. As part of the testing, the noise load was also measured. In the absence of the tested aircraft, an average value of 60 dB was measured. At full thrust of the motors of the tested airplane, a value of +130 dB was detected 30 meters from the motors.

5. Generalization piece of knowledge

The geophysical project described here illustrates the current trend that not only geological information, but also some other data is required from a geophysical survey. The geophysical reports often addresses the issue of corrosion of the investigated locality, technical seismicity (see chapters 3 and 4 of the text), thermal leaks, contamination, etc. Recently, we have also encountered more applications of geophysical methods in areas relatively new to geophysics such as archaeology, criminology and geotechnics. This trend is logical and, in principle, welcome. However, it should be noted that in some cases the interests and experience of a geophysicist overlap with the interests of other experts, i.e. noise measurement specialists, archaeologists, geotechnicians or electrical engineers. The boundaries between disciplines often merge, views on the same issues sometimes differ, and disputes about the competence and correctness of evaluation methods are no exception. The contribution presented here is, among other things, to draw attention to these topical issues. It is in the interest of the geophysical community not to lose positions and to expand its scope further. On the other hand, it is necessary to establish communication with colleagues from related professions and seek mutual agreement and understanding. In the opinion of the authors of the article presented here, it will be necessary in some cases to organize joint professional workshops, which is a topic that can be taken up especially by professional associations (associations, chambers, etc.).

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ČSN 03 8375. Ochrana kovových potrubí uložených v půdě nebo ve vodě proti korozi.

ČSN 03 8372. Zásady ochrany proti korozi neliniových zařízení uložených v zemi nebo ve vodě.

ČSN 03 8365. Stanovení přítomnosti bludných proudů v zemi.

ČSN 73 0040. Zatížení stavebních objektů technickou seismicitou.

ČSN EN 1998-1 (EUROKÓD 8): Navrhování konstrukcí odolných proti zemětřesení. Část 1: Obecná pravidla, seizmické zatížení a pravidla pro pozemní stavby.

TP 124. Základní ochranná opatření pro omezení vlivu bludných proudů na mostní objekty a ostatní betonové konstrukce pozemních komunikací, Metodický pokyn Ministerstva dopravy.
Metodický pokyn MD: *Dokumentace elektrických a geofyzikálních měření betonových mostních objektů a ostatních betonových konstrukcí pozemních komunikací*.
Nařízení vlády č. 272/2011 Sb.: Nařízení vlády o ochraně zdraví před nepříznivými účinky hluku a vibrací.

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