METHODOLOGY OF GEOPHYSICAL MEASUREMENT ON RAILWAY TRACKS

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Abstract

This paper presents possibilities how to use the selected geophysical methods for railway engineering. Geophysical methods had been used in non-systematic way for railways in Europe in the remote past yet, however, programme INNOTRACK being the 6th Framework Programme of the EU made possible more systematic study of the mentioned issue. In this paper there are performed mainly records made within project INNOTRACK on localities in Czech Republic, France, Spain and Sweden. The geophysical methods proved to be credible and prompt. Thus, geophysics can offer information about the problem points along railway line rather cheap and with credible precision.

Keywords

geophysical methods, refraction seismic, seismic tomography, resistivity tomography, gravimetry, railway track

1. Introduction

For railway infrastructure administrations it is important that the geophysical methods are non-destructive, non-invasive and they do not disturb the environment. In principle, the measurements require no digging and excavations, no preparation of access roads for transport of instrumentation to the site, etc. The geophysical investigation can be organized to avoid railway traffic interruptions. It is of course an advantage, if the geophysical investigation is organized to be included in the time schedule of railway track maintenance. In such case, the geophysical investigation can be performed on a wider scale and further safety of operation is better ensured. Nevertheless, in principle, unlike other geotechnical tests and probes, the geophysics does not require traffic interruption.

G IMPULS Praha spol. s r.o. was given an opportunity to participate in extensive European programme (6th Framework Programme of the EU), which focused on the question of reducing costs of railway track maintenance. This programme also included a section dealing with the issues of the geotechnical investigations. Under this section, G IMPULS Praha was responsible for the issues of application of the geophysical methods. The mentioned project is known under acronym INNOTRACK. Within the framework of the project, the testing geophysical investigations were performed in four European countries. The aim of the work was to test the capabilities of the geophysical methods as such and also to gain knowledge to what extent the experience in application of the geophysical measurements in different geological conditions and adherence to safety and organizational regulations of different railway operators can be generalized.

The geophysical testing measurements performed under the INNOTRACK projects were executed at the following sites:

- Czech Republic: Lipník nad Bečvou, Polousí, Běchovice,
- Spain: Lleida,
- Sweden: Torp, two sites near Borlänge,
- France: Montmélian.

2. Results of measurements at the investigated sites

In almost all of the measured localities, methods of refraction seismic, seismic tomography, resistivity tomography and gravimetry were applied. The measurement was largely organized as follows: two basic longitudinal profiles along the railway track sides were laid out. At these profiles, all above mentioned geophysical methods were applied. To identify the situation at a place of rails, the method of seismic tomography was used. At one of the pair of the basic profiles, seismic geophones were placed; and at the latter profile seismic impulses were excited. In this way, the information on seismic velocities was acquired also from places, which for safety reasons were inaccessible during the traffic. In the event of traffic interruption, one geophysical profile was situated also in the trackage axis. At this profile, the measurement proceeded using the gravimetric and seismic methods (mainly seismic refraction). The measurements were conducted by modern geophysical apparatuses, see the following list:

- Multielectrode resistivity apparatus ARS-200E (GF Instruments, Czech Republic),
- Gravimeter CG-5 (Scintrex, Canada).

The processing of the acquired data was performed using mainly the following software:

- Reflex W (Sandmeier, Germany – seismic data processing),
- Res2DInv (Locke, USA – resistivity data processing),
- MAG (Geofyzika a.s.,Czech Republic – gravimetric data processing),
- Excel (database administration),
- Surfer 9 (graphic processing),
- Grapher 7 (graphic processing).

As the extent of the paper does not allow describing in detail all measured sites, typical examples illustrating the capabilities of geophysics in railway engineering are presented in the following section.

At the site near Lleida in Spain, the method of resistivity tomography was successfully applied in studying a railway embankment, which got into the state of disrepair. The embank-ment was later remedied. One of the reasons for complications in embank-ment stability is intensive irrigation of agricultural land adjacent to the railway track body. Agricultural activities are shown by groundwater level fluctuations. Underground cut-off wall, which is to separate the track-bed subgrade from its surround-ings, probably fails to perform properly its function.

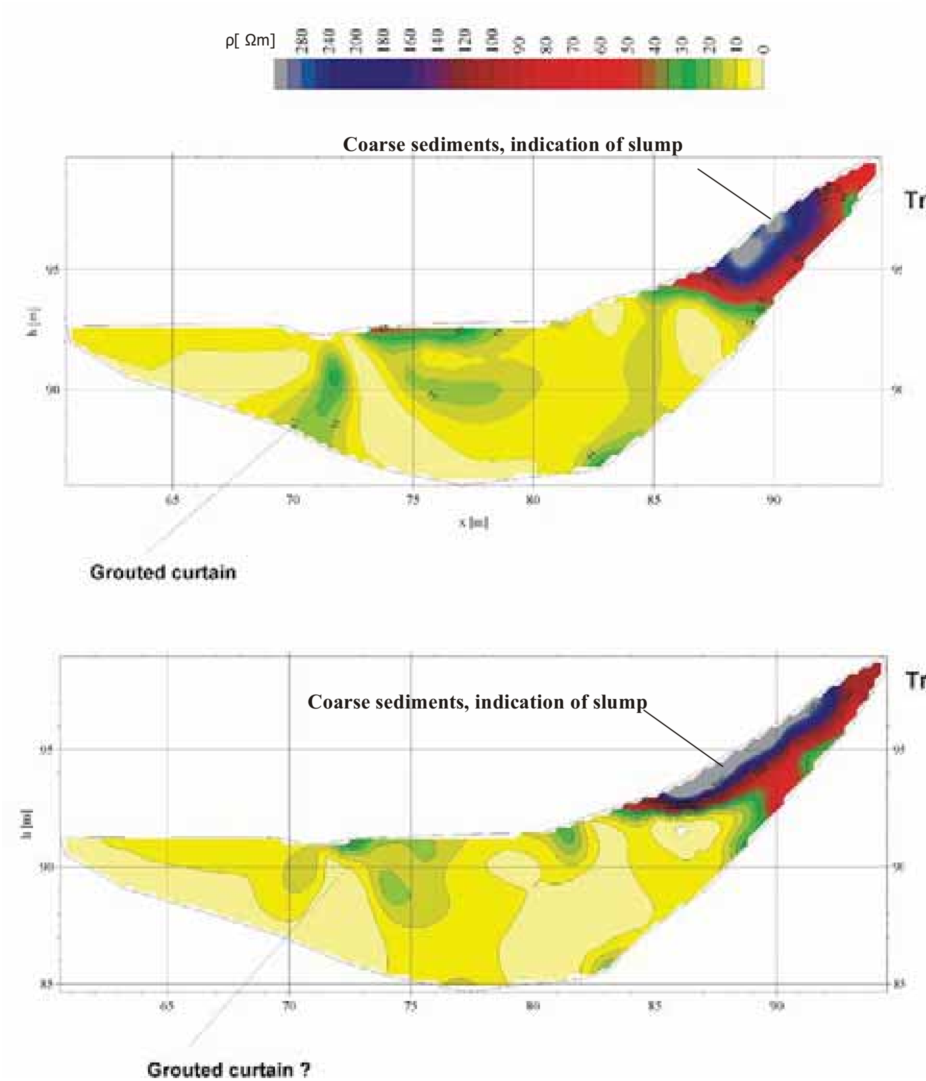

Fig. 1: Resistivity cross sections from the profiles running transversely to the railway embankment. At the profile shown in top part of the Figure, underground cut-off wall is clearly detectable. At the profile situated 50 m farther (bottom part of the Figure), cut-off wall is shown indistinctly, having probably given way to the degradation.

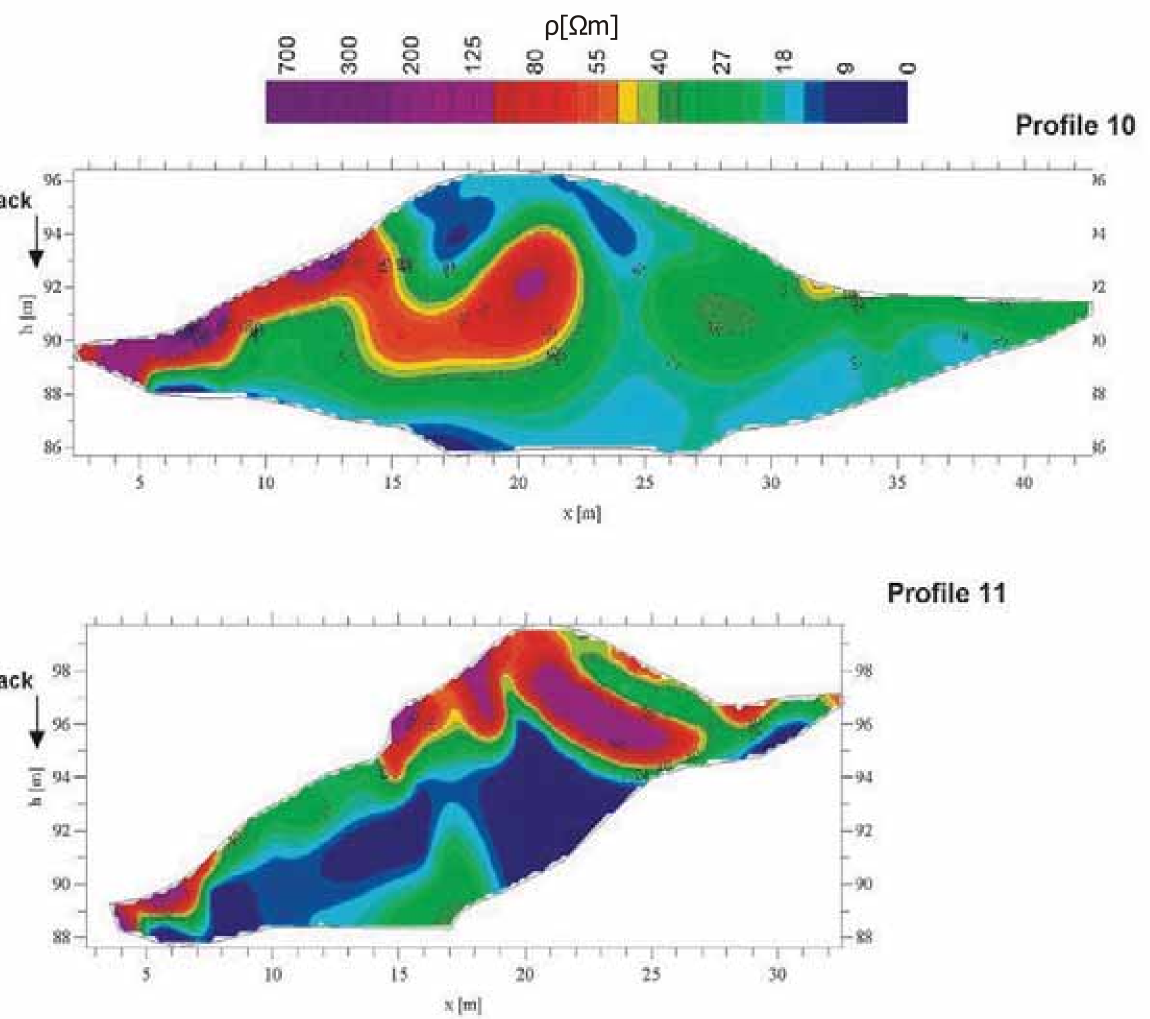

Fig. 2: Resistivity cross sections from the profiles running transversely to the railway embankment. The locality of Lipnik nad Becvou. The method of resistivity tomography clearly proved irregular composition of earths/soils in final shaping of the slopes above the railway track body. At steep parts of the slopes, close to the trackage, indications of landslide movements can be observed (cylindrical shapes of contour lines indicate the presence of slip surface).

On the following Fig.1, examples of resistivity cross sections are shown. They detect the presence of cut-off wall; however, cut-off wall condition changes with place. At the site of Lipnik nad Becvou (Czech Republic) there occur rail deformations (corrugation), particularly in the places where the track runs through a cut. The geophysical measurement using the method of resistivity tomography pointed out, in particular, the fact that the railway track runs through an area with loesses. Loesses show low resistivities (around 20 Ωm); they are frost susceptible and unstable in volume.

Cut slopes were probably in the past built up by heterogeneous earths (backfills), which is demonstrated by the presence of higher resistivities. At places, cut slopes are susceptible to slope movements. The situation is documented by two resistivity cross sections (the profiles were running transversely to the slope and perpendicular to the track) shown on Fig. 2.

On Fig.3, an example of seismic tomography application between two parallel profiles is shown. The profiles were running at left and right trackage margins. The measurement laid out in this way allows conducting the investigation also where trains run through. Such measurement layout allows performing the measurement also at the places where traffic interruption is not possible. The measurement was performed at the site of Montmélian in France.

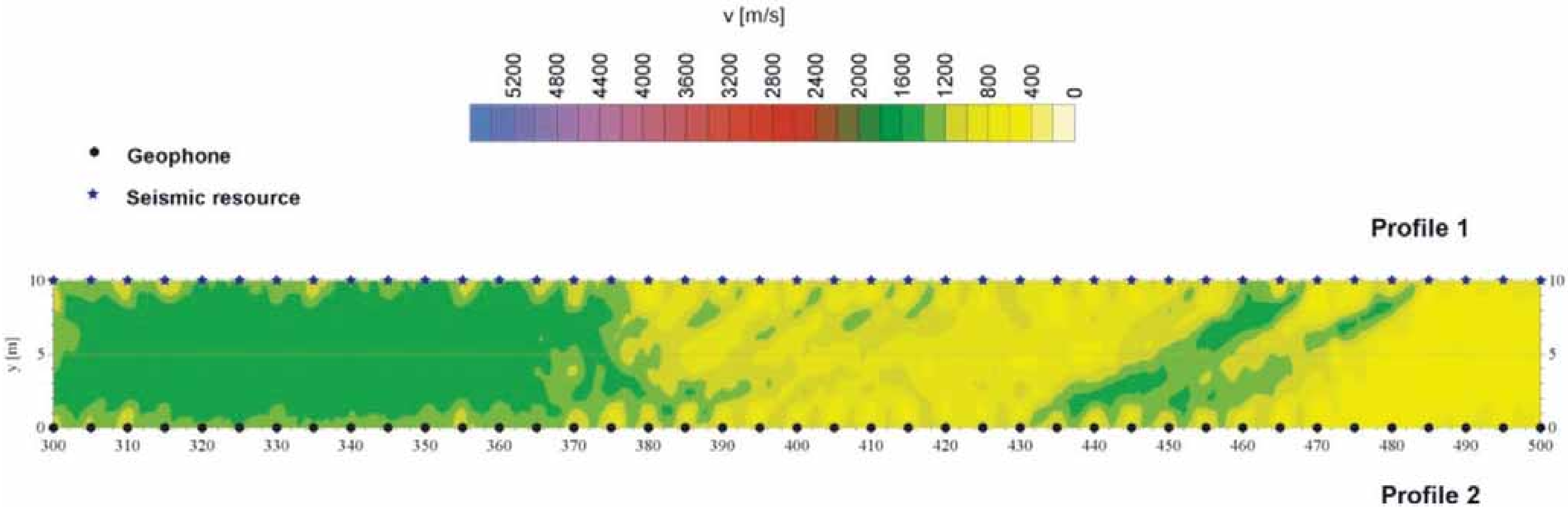

Fig. 3: An example of result of seismic tomography between two longitudinal profiles. The measured segment is located in a place without embankment, in a cut. In the segment of higher metres (from approx. m 380) the seismic velocity declines, which gives evidence of partial reduction of compactness subgrade.

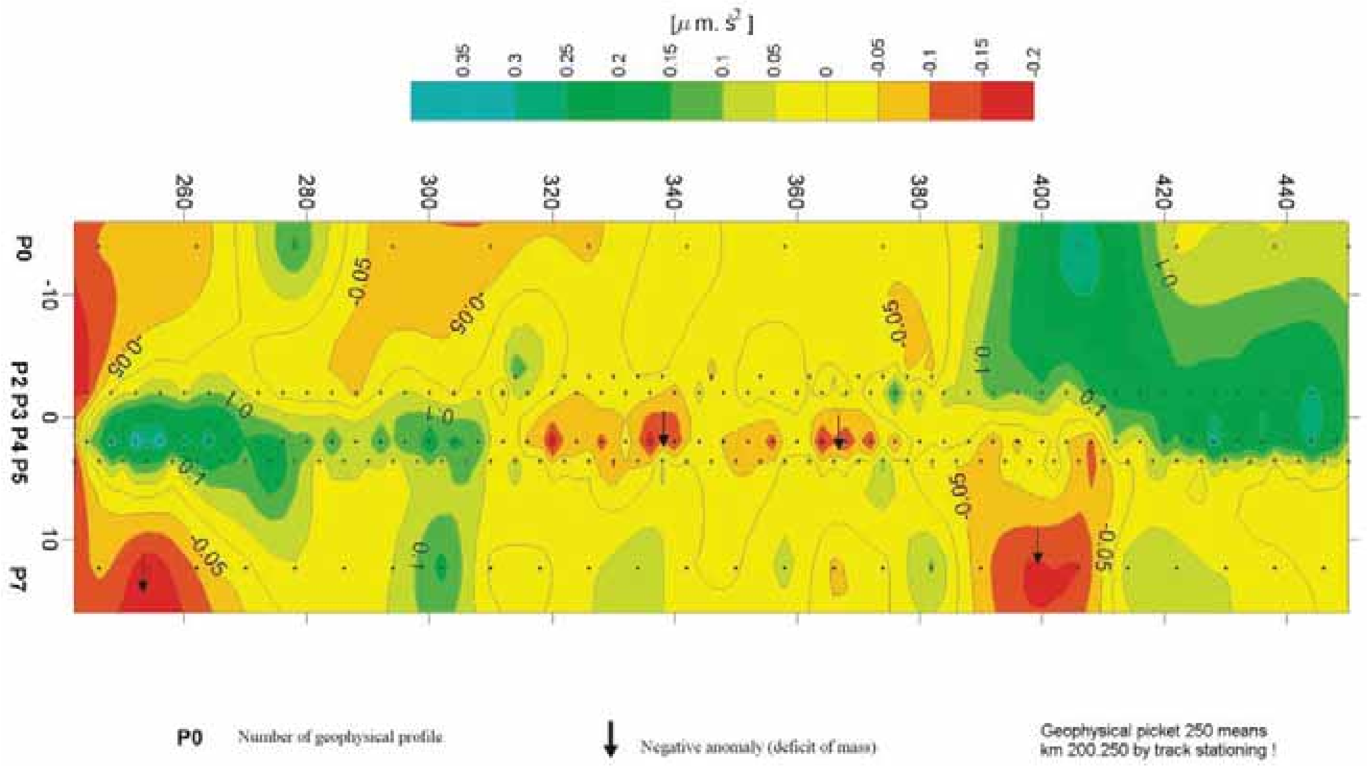

Fig. 4: An example of result of microgravimetric measurement at the locality of Lipník nad Bečvou. The measurement detected especially a significant anomaly in the surroundings of m 400 at the profile P7. This place accords with the place of frequent repairs of subgrade (rail bed underpinning) to level the track.

The investigations conducted under the INNOTRACK project demonstrated the applicability of the measurement using the gravimetric method (strictly speaking, micro-gravimetry). Gravity measurements are able to primarily delimitate places with lack of mass, i.e. for example, embankments with increased porosity or the presence of cavities. On Fig. 4, a map of contour lines of residual Bouguer's anomalies from the locality of Lipník nad Bečvou is presented. Areas with the negative anomalies mostly accord with the places where problems of rail deformations were identified. This measurement was that detected especially a significant anomaly in the surroundings of m 400 at a profile P7. This place accords with the place of frequent repairs of subgrade (rail bed underpinning). Resistivity cross section running in this place detected indications of landslide movements in the cut slope.

An important result of the investigation performed under the INNOTRACK project was the conclusion that direct relation between the magnitude of propagation of the seismic wave and modulus of elasticity can also be exploited in practice. This relation is based on the fact that the velocity of seismic wave is a function of modulus of elasticity, bulk density and Poisson number. On Fig.5, an example of graph of conversion between the velocity of a longitudinal seismic wave and modulus of elasticity is presented. In applying the above mentioned relation it has to be taken into account that the behaviour of the studied medium is somewhat different in small and big deformations. It means that with small energies causing the deformation of the rock environment (for example, seismic method) we acquire a higher value of the modulus in comparison with the appli-cation of big energies (for example, a test with big loading plate). This fact is not a handicap for the seismic methods. The mentioned problem occurs for all types of the testing methods. For practical application of results of the seismic measurements, correction formula (Masuda formula) can

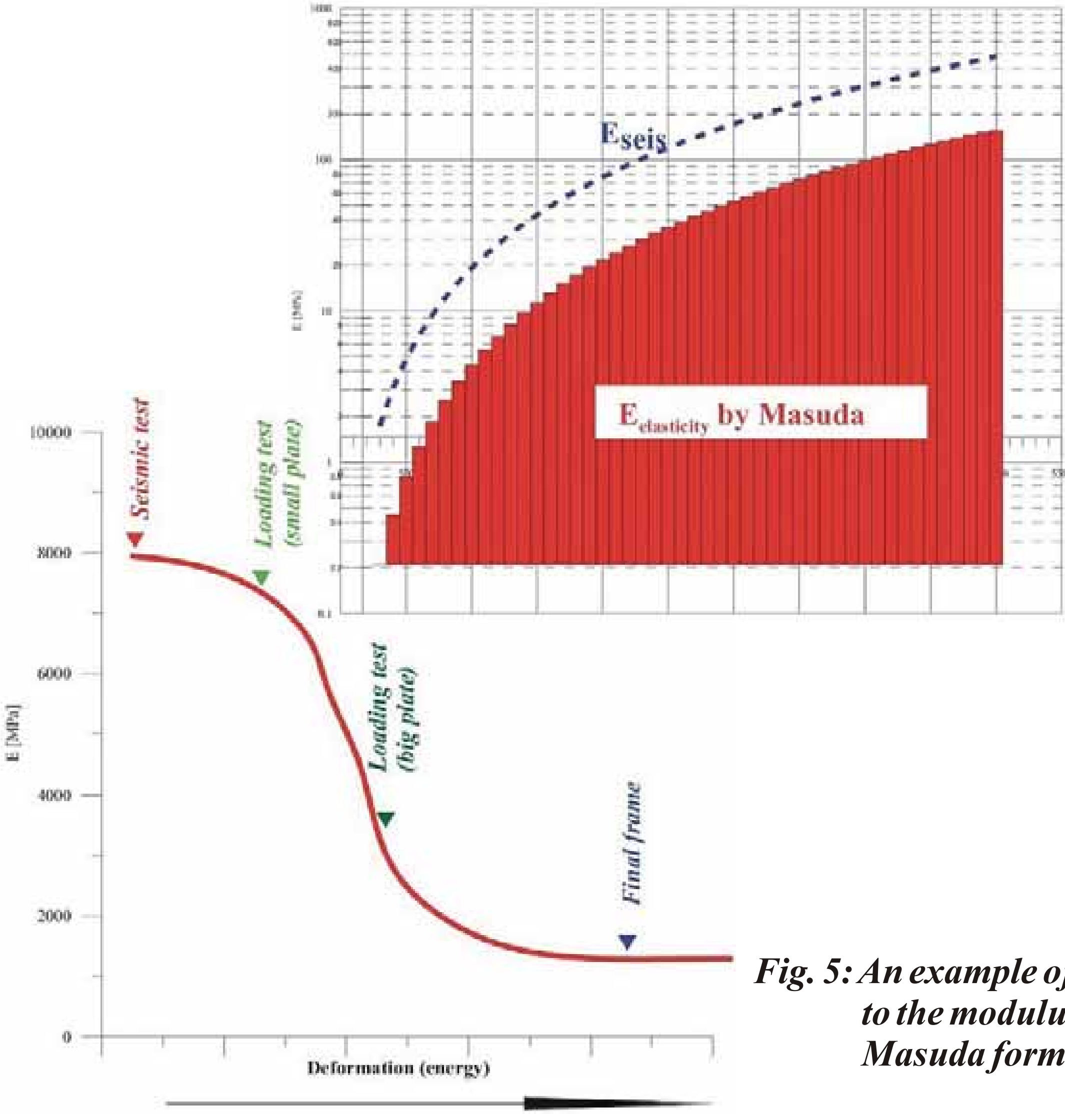

Fig. 5: An example of conversion of the magnitude of longitudinal seismic velocities to the modulus of elasticity E seis. This is followed by correction according to Masuda formula.

Fig. 6: The measurement using the seismic apparatus Terraloc. Montmélian, France.

be applied. This formula corrects the moduli determined by the seismic way to the values corresponding, for example, to the test with a standard loading plate, which is given by the respective regulation of the railway company.

Fig. 6 shows a fieldwork moment, characterizing the specificity of work on the railway track. The geophysical team must be trained to secure work safety and follow the local regulations. The photo is taken over from the measurement in France.

3. Conclusions

From the preceding chapter 2 it is shown that geophysical data provide information which can be further interpreted for the purposes of geological, hydro-geological and particularly geotechnical investigations. Deformations of rails as well as degradation of track ballast bed and other structure layers are primarily very frequently associated with underestimating of a complicated geological setting at a place in question. We talk about phenomena, such as the adverse effect of tectonic pattern, landslide showings near railway track or groundwater level fluctuation. Care for safe and trouble-free railway traffic is associated, among others, with conducting reliable geological investigation and subsequent geological surveillance. The complexity of the geological services also includes the geophysical measurements. The geophysical investigation is of particular importance in the following work phases:

- At the moment of starting to study the occurring difficulties when there is lack of essential information and when it is necessary to quickly gain, without larger financial and organizational measures, first findings on the geotechnical properties of the studied place.
- In the period after the standard geological investigation, when it is necessary to refine certain issues using detailed measurements.
- In the period after completing the remedial action we recommend to apply the geophysical monitoring of the structure to ensure, in the event of repetition of adverse effects, the timely identification of these facts (at the beginning of the difficulties).

The measurements performed at the localities in Sweden, France, Spain and the Czech Republic allowed to compare the application of geophysics under different conditions. By this, we mean conditions of the geological setting and also the practice of railway traffic management by various European railway companies. In none of the cases, the geophysical group encountered problems, which would be specific to a certain territory. Applications of the geophysical methods were similar for all localities and organization of work did not have to be much adapted to the local requirements. This means that the general applicability of geophysical methods in the European territory can be stated. Experienced geophysical group may perform work not only in domestic conditions, but also elsewhere in Europe.

The measurements presented in chapter 2 have performed a certain basic model of how to proceed economically and effectively in organizing the geophysical measurement. This model can of course be modified and adapted to the needs of a specific situation. Nevertheless, it has been proved that initial work can largely be organized as follows:

- if from the area of interest earlier measured radar data are available, we recommend to study and possibly reinterpret the data. A radar survey provides first information, based on which it is possible to delimitate areas requiring more detailed investigation by means of other geophysical methods.
- in the following phase we recommend that a geophysicist should propose the extent of the area to be measured. The extent of the measured area generally exceeds by approximately two thirds the extent of the place with the track defect itself. A common layout consists of two geophysical profiles running in parallel with the railway track. Measurements situated on profiles running beyond the track allow conducting the geophysical investigation independently of traffic. In such case, traffic interruptions are not necessary. If it is possible to perform the geophysical works at the time of traffic interruption, it is recommended to situate at least one geophysical profile also in the track. As the basic complex of the geophysical methods we recommend a combination of the seismic method, the method of resistivity tomography and gravimetry. As an integral part of the seismic method there has to be also a seismic tomography between the

profiles running on left and right sides of the track. In this way we acquire also the information on the geotechnical conditions directly below the track.

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