Opponent review

Dissertation thesis; author Ing. Salih Serkan Artagan

Use of Ground Penetrating Radar in Condition Assessment of Railway Ballast

Overall dissertation extent is 194 pages excluding attachments. Dissertation is divided into several parts. First part addresses generally to railway substructure and superstructure. In the second part dissertation objectives are described. Third part deals with GPR history, basic principles and GPR applications in transport engineering. The fourth part contains the state of the art on the use of GPR on the railway infrastructure. In the fifth part, the used GPR equipment is mentioned. Sixth part deals with laboratory and field experiments. The following section is the most important part, which comprises results of dissertation. The final part is the conclusion.

- **Topicality of the thesis;**

There is currently a great development in the GPR application on the railways. This technology is very suitable for quick assessment of the railway track and GPR is already used in many countries. The presented work is thus a contribution to a wide range of research results in this field. For these reasons, I consider the aim of dissertation to be very up-to-date.

- **Selected methods of writing;**

Formal adjustment, clarity and language level of the text parts fit well with the requirements.

- **Fulfilling the objectives;**

The mail goal of the dissertation was to specify electromagnetic properties, determine differences in relative permittivity of the ballast with different fouling levels, humidity, type and orientation of antenna and solve the influence of sleepers and rails. Next task was to realize a field study on the actual railway track section with different types of sleepers and verify the laboratory measurements. Final objective was to compare available GPR systems from different producers on the identical track section.

To conclude, the objectives of the dissertation were successfully fulfilled in all respects.

- **The novelty of the results**

Above all, I appreciate new findings in part which deals with GPR performance compliance tests of antennas. There are four compliance tests: Signal-to-Noise Ratio, Signal Stability, Linearity in the Time Axis and Long-term Stability test. The reason of performing these tests is stated by the author in dissertation, I quote: „*Each antenna has unique parameters and performance. Performance of antennas may change over time. Prior to initiating the measurement with an untested GPR system, it is appropriate first to test its stability and performance in data collection. This could eliminate mistakes and interpretation of unexpected distortions in the data*." The performance of 400MHz, 900MHz and 2000MHz antennas was examined. It was found that some antennas did not meet the criteria according to the proposed threshold values. Further research in this area will be necessary.

- **Impact on scientific development and practical demand;**

This thesis provides useful information for both researchers and practitioners. Concerning the fact that the most beneficial parts are as follows,

  - Antenna compliance tests
  - Comparison of laboratory and field data
  - Laboratory tests of ballast with different fouling materials, fouling level and amount of water,

the presented work is definitely add a beneficial value on the GPR for railway diagnostics.

I appreciate the collaboration with the Università Roma Tre, Italy and his involvement in the EU funded COST programme, which directly focuses on GPR research in engineering applications. It can be assumed that the author will contribute by his dissertation work to the solution of this European project.

- **The extend and quality of the published works related to the dissertation;**

I believe that published papers on conferences and articles meet with the requirements of the obligation to publish the results of the dissertation.

- **Fulfilling the requirements for scientific work**

Dissertation thesis meets the requirements for scientific work for getting Ph.D. title.

Own assessment of dissertation

Remarks to the individual parts of dissertation:

Page 31 and 32: Presented figures have low resolution

Page 74: The sand, fine-sized gravel and their mixture as a fouling material were used in the experiments performed in University of Pardubice. It would be recommended to use real fouling materials like a fine-grained soil (i.e. silt) as it was carried out in the experiments in Università Roma Tre, Italy.

On the page 151, it is written that: *metal sleepers did not allow to image underneath the sleepers due to multiple reflections caused by them*. In my opinion, the main problem is the presence of highly fouled ballast because of similar characteristics of fouled ballast and silty sub-ballast. The similar parameters of soils do not allow the reflection on the layer interface.

On the page 151 author comments: *Although the wooden sleepers may cause problems due to highly organic compounds that can develop inside with years, in this case, wooden sleepers made of oak tree did not cause any significant problem to image beneath the sleepers.* The author probably assumed that the interface between the ballast and subgrade is visible under the part with wooden (oak) sleepers. This assumption is partly true, on the other hand, when checking the data with scan rate of 100 scans/m, the interface can be detectable only in crib places (space between sleepers filled only with ballast). Wooden sleepers probably cause strong reduction of electromagnetic waves, which makes the interface beneath rather undetectable. This reduction can be probably caused by organic compound in sleepers.

SŽDC data were recorded with scan rate of 100 scans/m and the author scanned with the rate of 90 scans/m and used 8 stacks on traces as a processing step, which is good for overall assessment of the railway track. However, the use of original scan rate with more scans could lead more detailed evaluation. For example, the interface between the ballast and subgrade in crib places can be detectable with stacking but there is no apparent and clear reflection under the sleepers.

Advantages of dissertation:

For the field measurement in Rozhovice, the railway cart made of glass-fiber reinforced plastic square profiles and polyamide wheels was used. This design is very good for trial tests of horn antenna. Generally, it is recommended to have no metal objects in close proximity of the antenna and this trolley fulfill this characteristics for horn antennas.

On the page 152, the difference of 100MHz in the real frequency spectrum was found between 400MHz GSSI and 400MHz IDS antenna.

For real measurement on railway, it is very important to know the ballast permittivity before, during and after the rain. In current study, the author measured permittivity variation by the time by trying to change water amount in the ballast. I found this laboratory experiment greatly useful.

Laboratory compliance tests are also very interesting and beneficial for GPR applications.

The majority of the text is well written and the facts described in the text are explained very clearly.

I consider that the dissertation addressed all objectives and I recommend it for the defense. The comments stated above do not significantly reduce its positive contribution.

V Pardubicích dne 20.7.2018 **Mgr. Aleš Fleischmann**