ARTICLE IN PRESS

Construction and Building Materials xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Comparative measurements of ground penetrating radars used for road and bridge diagnostics in the Czech Republic and France

J. Stryk [a], R. Matula [a], K. Pospíšil [a], X. Dérobert [b], J.M. Simonin [b], A.M. Alani [c]

[a] *Centrum dopravního výzkumu, v.v.i., Líšeňská 33a, 63600 Brno, Czech Republic*
[b] *French Institute of Science and Technology for Transport, Development and Networks, CS4, 44344 Bouguenais, France*
[c] *University of West London, School of Computing and Engineering, St Mary's Road, Ealing, London W5 5RF, UK*

HIGHLIGHTS

- In-situ comparative measurements of GPR systems.
- Accuracy of measurements: pavement layer thickness and reinforcement position.
- Recommendations for performance of GPR comparative measurements.

ARTICLE INFO

Article history:
Received 8 December 2016
Received in revised form 21 May 2017
Accepted 18 June 2017
Available online xxxx

Keywords:
GPR (Ground Penetrating Radar)
Non-destructive diagnostics
Pavement layer thickness
Reinforcement
Cement concrete pavement
Comparative measurement

ABSTRACT

The paper describes the current situation regarding the comparative measurement and accuracy of ground penetrating radars (GPR). GPR measurements are used for non-destructive diagnostic of roads and bridges, specifically for measuring pavement layer thickness and determining the location and position of reinforcement in concrete. The information used in the paper is based on the performed in-situ measurements. The conclusion includes recommendations of how to perform and evaluate the in-situ GPR comparative measurements.

1. Introduction

Ground Penetrating Radar (GPR) is traditionally used in diagnostics of transport infrastructure. It can either be used for one-off structure condition diagnostics or comparison of a development over a time period. At present, GPR is commonly used for diagnostics of roads at the project level (i.e. evaluation of shorter road sections) and rarely used at the network level.

One of the first applications of GPR in road engineering was to determine road layer thickness [1–4]. In this case, measurements are performed on both asphalt and cement concrete pavements, each with their own specific features. Given that, roads are line structures, accuracy of the localization measurement play an essential role. The measurements are usually performed on a longitudinal basis and under high speeds, so that road traffic is not restricted. In this case, the measurement is performed using a single or several horn antennas, or GPR device designed for 3D measurements [5–8].

An extended application of GPR is the localization of built-in reinforcement. For pavements, the elements in question include dowels and tie bars in jointed unreinforced concrete pavement (referred to as concrete pavement [9,10]). For bridges, the cover of reinforcement in bridge decks are evaluated more frequently [11–16]. For these applications, a cart with a single or more dipole antennas and measurements at walking speed are most commonly used.

The paper analyses a situation concerning in-situ comparative measurements of ground penetrating radars used for road and bridge diagnostics. Technical regulations and situations in individual countries are described in Chapter 1.1 and 1.2. Comparative measurements of GPR systems carried out in the Czech Republic and France with conclusions formulated on the basis of performed measurements are mentioned in Chapters 2 and 3. Recommendations for performance of GPR comparative measurements focused on two applications, pavement layer thickness and reinforcement position in concrete, are presented in Chapter 4.

E-mail addresses: josef.stryk@cdv.cz (J. Stryk), xavier.derobert@ifsttar.fr (X. Dérobert), amir.alani@uwl.ac.uk (A.M. Alani)

http://dx.doi.org/10.1016/j.conbuildmat.2017.06.134

1.1. Technical regulations

There is currently no European standard addressing the diagnostics of roads and bridges by GPR. No creation or adoption of any standards from ASTM D6432-11 [17], ASTM D4748-10 (2015) [18], ASTM D6087-08 (2015) [19] is currently expected within CEN.

However, on the national level within Europe there are guidelines and regulations targeting the diagnostics of transport infrastructure conditions using GPR. The most detailed ones are English DMRB 7.3.2 (2008) [20] and DMRB 3.1.7 (2006) [21], German Merkblatt B 10 (2008) [22] and recommendations produced within the European project MARA-NORD in 2011. More recently, European GPR Association has published guidelines for pavement structural surveys GS1601 (2016) [23] and the Belgian Road Research Centre has produced a recommendation guide ME91/16 for pavement applications [24].

A European project COST TU1208: Civil Engineering Applications of Ground Penetrating Radar has been in progress since 2013 to 2017. The planned outcomes of the project include recommendations for the design of a new European standard. Among these, one recommendation guide is devoted to flexible pavements and another to concrete structures.

The calibration procedures and verification for different types of GPR systems are always stated by manufacturers. Four basic procedures are specified in ASTM D6087-08 (2015) [19].

There is no standard or official recommendation of how to perform comparative measurements of GPR, for diagnostics of transport infrastructure conditions.

1.2. Situation in individual countries

Representatives from 13 European countries were contacted as part of project COST TU1208. At least one comparative measurement of GPR on roads was confirmed in two cases, with one business partner reporting a comparative measurement on a railway. All partners reported having no technical specifications, methodology or operational manual available for comparative measurements of GPR.

None of the 13 countries require a certificate to be issued by a relevant state administration body or road administrator from companies carrying out GPR diagnostics.

Of the 13 countries, 4 use their own specific technical specification, methodology or operational manual for the measurements by GPR. Obtained accuracies for the applications determining pavement layer thicknesses and location (depth) of reinforcement in concrete pavements range from 3 to 15%, depending on specific layer thickness and its location.

The determination of electromagnetic signal propagation speed is performed using different methods including usage of table values for corresponding pavement layers, method of reflective coefficient for horn antennas, CMP method (Common Mid Point)/ WARR (Wide-Angle Reflection and Refraction) as well as measuring relative permittivity, e.g. with the use of Percometer. The most commonly used method is using drilled cores, measuring layer thickness in isolation joints, and measuring height before and after the laying of pavement layers. When determining the reinforcement depth location, software analysis of hyperbole shapes from measurement reports is used.

There are only few documented results of GPR comparative measurements performed in-situ, e.g. project reports of MARA-NORD and American research programme SHRP: Strategic Highway Research Programme.

Some papers point out the importance to develop a methodology for calibrating GPR devices and to verify their proper operation. Results of several tests carried out in order to evaluate the stability of a GPR system working with different antennas was described [25,26], a relationship between GPR frequencies, optimal thresholds, and signal accuracy was analysed [27]. Other papers focus directly to signal processing techniques in relation to the quality of the acquired data and the purposes of the surveys [28].

The results of comparative measurements of pavement layer thickness are also reported by sources outside Europe. An American paper [29] describes a comparison of four non-destructive methods: GPR, IE (impact echo), MIRA (ultrasonic pulse-echo) and MISW (multiple impact surface waves). Layer thickness was measured on concrete roads and asphalt pavements. The measurements of GPR using different producers were performed with the use of different central transmission frequencies and antenna types (dipole antennas, horn antennas, 3D device). Some of the stated GPR measurement accuracies are alarming. In comparison with core drilling, the relative error for the determination of concrete pavement thickness by GPR ranged from 6% to 83%.

The above emphasises that accuracies reached by GPR measurements need to be specified in greater details, ideally detailing comparative measurements with a larger number of GPR systems from different manufacturers and operators.

2. Comparative measurements of GPRs

There are several ways to approach in-situ comparative measurements. We can find inspiration from other NDT methods that are used for pavement diagnostics, e.g. measurement of longitudinal unevenness of pavement surfaces (IRI parameter), skid resistance of pavement surfaces (friction coefficient), and bearing capacity of roads (deflections under loading). The replicability of measurements produced by different devices directly measuring the same road pavement parameter are determined. Comparative measurements of these parameters are performed at both national and international level, for example through the Dutch programme CROW (bearing capacity), European projects ROSANNE (skid resistance), and FILTER (unevenness).

In the case that it is possible to compare the measured results of the real condition, a comparison is done with the results of measurement performed by a reference device with higher accuracy (e.g. in case of unevenness).

In the case this cannot be performed, the golden centre (e.g. for measurement of friction coefficient and pavement deflections) is determined for results of individual devices involved in the comparison. However, this method is more complicated and may lead to a higher error.

After participating in the comparative measurement, the owners of devices that met the set requirements of repeatability and reproducibility receive a certificate for measuring the particular parameter from a relevant body of the state administrator/ administrator of transport infrastructure.

Regarding GPR, the comparative measurement should include at least 2 applications:

- Pavement layer thickness measurement (including bound and unbound layers from different materials).
- Localization of built-in reinforcement (e.g. in cement concrete).

Examples of comparative measurements performed in the Czech Republic and France are described in the following three chapters.

2.1. Comparative measurement of GPRs in the Czech Republic – pavement layer thickness determination

Comparative measurements of devices used for measuring variable pavement characteristics are performed in the Czech Republic in accordance with technical specification of the Ministry of Trans-