Journal of Applied Geophysics 97 (2013) 27–36

Contents lists available at ScienceDirect

Journal of Applied Geophysics

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

GPR abilities in investigation of the pavement transversal cracks

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ARTICLE INFO

Article history:
Received 17 October 2012
Accepted 23 March 2013
Available online 6 April 2013

Keywords:
GPR
Pavement crack identification
GPR indications of cracks
Bituminous pavement
Concrete pavement

ABSTRACT

This paper describes the results of an investigation into the capabilities of the GPR technique within the field of pavement crack diagnostics. Initially, laboratory tests were performed on prototypes simulating idealized cracks. Next, long-term visual observation and repeated GPR scanning were performed, on three roads of semi-rigid construction, several hundreds of meters long and subjected to heavy traffic. Furthermore, a road of rigid construction was tested, having a more than 70-year history of use. In several cases the cracks were probed by drillings, in order to recognize structures responsible for signal generation, or to explain reasons of signal lacking.

The main result of this work is a list of GPR indications of cracks, which can be noticed on echograms. It was created through a correlation of the visually-observed cracks with the corresponding echograms, with decimeter accuracy. Several types of GPR responses were classified and linked to possible categories of crack structures, or to processes associated with the presence of cracks (as crumbling, erosion, and lithological alterations). The poor visibility of cracks was also studied, due to small crack size, or to the blurred character of the damaged area, or else to masking effects related to coarse grains in the asphalt mixture.

The efficiency of the proposed method for the identification and localization of cracks is higher when a long-term GPR observation is performed.

1. Introduction

The cracking that occurs in pavements is a fundamental area of concern in the field of pavement use and maintenance. Cracks can represent some construction failures or some properties of the construction materials, but first of all they are a direct manifestation of the fundamental process of road deterioration in result of exploitation (e.g. alligator cracking developing along the wheel tracks) and environmental influence (like transverse cracking due to contraction during temperature drops). The possible origins of cracks in pavements are fatigue, shrinkage, movements of subgrade soil, constructional defects and ageing. Occurrence of different types of cracks depends on pavement structure and it is different for rigid, semi-rigid and flexible pavements.

Loss in bearing capacity and subsidence of the subgrade will lead to slab breakage and single transverse line cracks in rigid structures. These cracks will be fine or medium-wide and their edges may stagger in the failure plane direction. For semi-rigid structures, the phenomenon may result in cracks of the same type or in block patterns of longitudinal and transverse cracks. In flexible pavements the affected area will be damaged with alligator cracking in the end.

Transverse cracks are generally caused by thermally induced shrinkage at low temperatures. When the tensile stress due to shrinkage exceeds the tensile strength of the asphalt pavement surface, cracks occur. Shrinkage cracks are most often spaced between 5 and 15 m apart and are often single-line cracks when they become visible at the surface, but may develop into double and branched cracks under traffic (Vanelstraete and Francken, 1997).

Another type of transverse cracks is reflective cracks. Usually, an earlier existing crack is being reflected in a newer overlay. The phenomenon is due to the fact that as a result of various factors the edges of an existing crack are subjected to movements which are transferred to the bottom of overlay, where they induce a concentration of stresses.

Considering the mechanism of transversal cracks development, the types of cracks can be as follows:

- crack with initial vertical propagation — fine or medium-wide, curved, with full bounding between layers, and
- crack with initial horizontal propagation — wide and straight, with debounding effect occurring with the crack.

GPR is considered to be a viable method of inspection for the purposes of studying the mechanisms of cracking within pavements. The method is of some use in estimation of crack's propagation depth or localization of hidden cracks (Birtwisle and Utsi, 2008; Saarenketo, 2009). In particular cases, it helps to clarify reasons of cracking and

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http://dx.doi.org/10.1016/j.jappgeo.2013.03.010

to choose proper methods for road treatment. Nevertheless, detailed researches on GPR response to cracks in bituminous pavement which try to formulate explicitly diagnostic criteria (Diamanti et al., 2010) or to study the relation with the real crack structure are not numerous (Al-Qadi et al., 2009).

Two general approaches can be distinguished in GPR crack inspection: profile scanning and pseudo three-dimensional (3D) imaging. The profile scanning uses echograms corresponding to vertical cross-section along the profile as the main method of visualization (Saarenketo and Scullion, 2000). The large singular structures (like cracks or local inhomogeneities) inside locally planar and horizontal road structure are manifested on echograms as diffraction hyperbolas. The lateral continuation of the structures, being an important feature of cracks, distinguishing them from local inhomogeneities of the medium, can be studied using several mutually parallel profiles. The transversal cracks (perpendicular to the road direction) were investigated here, as particularly convenient ones for profile scanning. The method can be applied to other common crack types (longitudinal cracks or not very dense network) as well. From the profile scanning point of view, it is important that crack should be perpendicular to the profile and then the electric field polarization should be parallel to the crack. Such configuration is necessary in this approach.

The pseudo 3D imaging needs dense data acquisition on the investigated surface area and uses special methods of spatial synchronization of the large data set (Benedetto et al., 2012). As a result, pseudo 3D imaging also allows for the fine visualization of data in the form of horizontal slices, essentially enhancing study of the lateral continuation of the singularities of the medium structure (Krysiński and Sudyka, 2012a). These advantages are specially useful in studies of systems having complex geometry, like network of expansion joints in concrete pavement. Although the idea of this approach is formally more general and it has potentially larger possibilities of lateral scan correlation than the profile methodology, the 3D imaging has also some practical disadvantages related to the current state of resolution, efficiency of data collection and signal processing quality. Thus the present paper, which is dedicated to detail study of the signals generated by cracks, was based mostly on profile measurements and the 3D imaging is only mentioned here.

The use of GPR technique for investigation of pavement transversal cracks seems to be promising, but numerous paradoxes occur. Sometimes, well visible cracks more than ten millimeters thick doesn't generate noticeable GPR response, while ones being thinner at the surface may produce strong response, but located more deeply inside the pavement. Thus, some general questions arise. When are cracks detectable by GPR? Which crack features can be extracted from GPR images? What can GPR technique tell about cracks? Paradoxically, the object of investigation (i.e. internal crack's structure) is usually very difficult for direct examinations in drillings and outcrops. The most interesting cracks are those occurring in roads subjected to heavy traffic, where possibilities of drilling are very limited.

The main aims of the present study are related to the real cracks occurring in pavements; in particular, the following objectives are pursued:

- recognition of GPR manifestations accompanying visible cracks, with special attention to cases of weak GPR manifestation,
- determination of echogram features types that can be helpful in crack identification or investigation,
- recognition of geometrical and material features of drilled cracks, which can be responsible for generation of a distinctive diffracted signal, and
- recognition of conditions that can be responsible for the lack of signal or for difficulties in crack detection.

The described problems were studied within long-term observation. Repeatable GPR measurements, careful echogram analysis and some drillings were performed, on several road sections. These field observations were supported also by laboratory tests and some numerical simulations.

2. Material and methods

The detailed study of the GPR signals characteristic for real cracks, conditions of generation of these signals, and visibility and features of the crack structure responsible for the signal generation and visibility, were the main aims of the present work. Thus, the high resolution measurements were made using High Frequency (2.2 GHz), air-coupled antenna collecting data along profile with high density (preferably 50 scans/m or more in some cases) and using at least three parallel profiles. Further measurements were performed, using antennas with a lower central frequency, for comparison.

2.1. Field GPR measurements and synchronization of GPR data

In GPR measurements of roads some specific problems with distance correlation occur, which are related to large length of the profiles, large velocity of the measuring vehicle, difficulties connected with heavy traffic, latency of the measuring system and parallax effect. The GPR equipment registers its own distance related to rotation of the vehicle wheel, and the position of some anchor points (cracks or some reference objects) can be assigned manually on the echogram during measurement. But the effective imprecision of the anchors location in terms of the GPR distance is of about several meters (up to 10 m and never less than 1 m). Difficulties may arise, when we try to confirm the presence and position of a visible crack on the relevant echogram. In practice, a plenty of different situations occur with visible cracks interpretation: cracks visible on the surface sometimes have clear GPR response, they can have weak response, being interpretable only because of their visibility on the surface, frequently they have no clear response distinguishing them from the surroundings, etc. Similar problem occurs when visible GPR manifestations of different intensity do not correspond to any visible cracks. Standard GPR anchor points are not sufficient for the identification of crack position or confirmation of its identity on echogram. For investigation of crack GPR response, at least decimeter precision is necessary.

Several methods of distance correlation were applied in this study. The basic method consists in precise measurement of the distances where the cracks occur along the measuring profile with the use of other equipment like the measuring wheel or profilograph. The new distance usually differs from the GPR distance and the difference varies along the profile. For this reason, the calibration function has to be constructed by using these rare cracks (or other reference objects), which are well manifested on the echogram.

The main part of the present study consisted of a long-term observation of 6 roads of semi-rigid or rigid construction using GPR scanning and visual observations. The echograms were correlated with visual observations with decimeter precision to find exact spatial correspondence between cracks and their potential but not ever visible manifestations. The recognized GPR manifestations allowed to formulate classification of echogram diagnostic features (section 4). The classification is first of all a necessary language for expression of observations being a consequence of the extensive echogram analysis. The proposed classification (name system) can be useful in communication, but it is also helpful in practice, when echogram analysis is directed to crack identification and investigation, especially in cases of weak crack manifestation. Some provisional scale of the manifestations intensity was defined for purposes of statistical analysis and correlation with visual cracks intensity. The list of diagnostic features and intensity scale were tested again to check their efficiency in crack identification on the base of echogram analysis in the investigated 6 roads. There was also one additional, successful test showing a possibility of identification of an invisible crack in concrete road covered by a new