

# Identification of deep-rooted transverse cracks using Ground Penetrating Radar

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**Executive summary.** Transverse cracking is a surface distress resulting from various mechanisms appearing in the pavement and their occurrence proves improper action of the structure, which, in a long run will be subject to accelerated degradation. The proper evaluation of the progress of cracking is certainly helpful in finding out the origin of this type of damage; therefore, also in the correct selection of the repair technology.

The use of GPR (Ground Penetrating Radar) as an auxiliary tool in assessing the structural condition of the pavement in terms of identification of transverse cracking is not a new practice. However, it is still a complicated task due to many external factors which may distort the result or even prevent analysis of data, especially in terms of interpretation of the obtained radar images.

This article presents the case study for the practical use of the method of GPR inspection of the transverse cracks structure to analyse the process of restoring transverse cracks in bituminous pavement. This procedure is based on the earlier catalogue of the GPR manifestations of the elements of deep cracking structure and requires precise synchronization of the GPR measurement with cracks observed on the pavement. Explicit manifestations are only visible in expanded cracks, where the zone of material changes in the vicinity of the cracking surface has a width of at least one decimetre. Such defects usually result from the long-lasting operating process, and their presence in the deeper layers of the structure is an evidence of breaking continuity of mechanical consistency of the foundation under the cracking line.

**Keywords:** road pavements, cracking, GPR radar, identification of cracks

## 1. Method of GPR evaluation of intensity and advancement of the cracking process

The GPR diagnostics of the pavement cracks is a discipline arousing great interest due to practical significance resulting from identification of characteristics of the process of formation and development of cracks. The possibilities of the GPR (Ground Penetrating Radar) method apply to identification of the detailed structure of cracks i.e. their geometrical composition together with certain material characteristics of that structure, which are demonstrated in the electromagnetic properties [1, 2, 3].

One of the practical benefits of the development of the methodology for the GPR identification of cracks is the possibility of the evaluation of the rooting depth of the cracking structure and the extent of their development. These characteristics are treated in the analysis in a semi-quantitative and descriptive manner as the characteristics of the degradation process. This procedure aims, inter alia, at finding the possible evidence for the presence of deep-rooted cracks understood as weakening of the



pavement and its subgrade in the crack vicinity, resulting primarily from long-term mechanical activity of the cracks, though perhaps inspired by earlier local features of the subgrade. The negligible visibility of the underdeveloped initial cracks in the GPR method is a feature so favorable in the practical assessment that the acquisition of visible traits of the cracking structure proves that the defect is very developed and is related to its long-term, intense mechanical activity.

The GPR traits of the cracking structure are intensively tested in terms of phenomenology [4] as well as in terms of laboratory and numerical [3, 5] modelling. The practical interpretation of echograms may be in particular assisted with the catalogue of typical elementary traits and the notes concerning the diagnostic significance of synchronous occurrence of those traits at the various levels or in approximate parallel measuring profiles [4]. The key examples of elementary traits include *diffraction hyperbola*, the *Chi pattern* together with their reduced variants, such as nearly *point form* (a spot of local scattered emission). Among the particularly spectacular traits is the *Christmas tree form* composed of several hyperbolas or chi patterns occurring one above another. The catalogue of traits also includes the significant considerations and observations concerning the typical structures of the medium generating those traits. The GPR image is not a simple representation of the geometrical structure, because its nature is diffractive, which is particularly visible in the case of edges, linear or nearly-point elements, or other step changes of the structure. What's more, this image indirectly expresses the contrasts of certain electromagnetic properties of the material, the interpretation of which requires knowledge in typical properties of the medium encountered in the specific test area (for example in the area of pavement testing). The interpretation of echograms may be, in particular, assisted with the list of frequently encountered architectural arrangement of the cracks' surroundings generated in relation to the activity of the cracks, as the features suggesting local subsidence of the structure (collapses, breaks). The list is accompanied by vast reflections on the typical changes in materials (mostly in the main crack crevice and its close vicinity) and on the phenomena (processes) responsible for those changes [6].

In numerous cases that method may be used in a completely non-invasive variant for testing of a large number of cracks in the selected section subjected to an intense cracking process. Testing requires a thorough surveying of the cracks visible on the surface, as well as arduous synchronization of their visual position with the GPR image. The presence of numerous traits of cracking visible on the echogram allows to reliably interpret them, for example as the hallmarks of long-term mechanical activity leading to local material changes of the medium. The assessment may include the depth of occurrence of the elementary traits, their intensity (mostly if these are clearly typical traits) and the manifestations of the horizontal stretch of the damage zone. It should be noted whether there are material changes in the base course, which are strictly correlated with the cracking position. The echogram is analysed also in terms of presence of the evident traits of cracking which are not so evident on the surface. The summary of that procedure includes the quantitative characterization of the tested group of cracks to answer the question what is the share of cracks of a very well developed structure in the population of the visible cracks, are most of them deep-rooted and whether more or less all the cases of the evident GPR traits of cracking are also already visible of the surface. Such a method of characterization of the population of cracks allows for formulating the realistic view on certain characteristics of the course of the cracking process, which are significant from the technological point of view.

## **2. Methodology of measurements and preparation of data for interpretation**

The below-described project uses the GPR method (a GSSI device, an air-coupled antenna with the central frequency of 2 GHz) and two visual observation methods: surveying of cracks with manual measurements of cracking positions (measuring wheel) and marking of that position on the roadway edge, as well as continuous photography of the surface using the SPDE measuring system (Fig. 1). The perfect synchronization of all three measurements is a key element of the procedure presented in this paper and these works usually require major efforts. The procedure leads to removal of large errors of the single observations and the often encountered faults of the individual distance defining

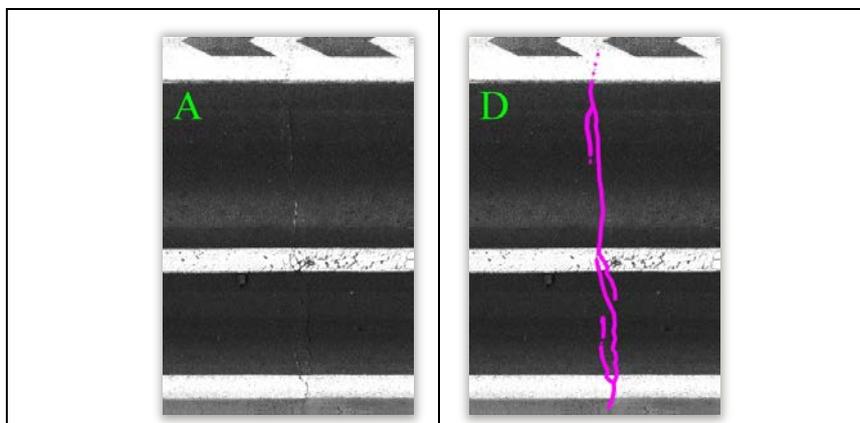
methods (such as skips or changes in distance calculation trend). The essence of these effects is the relative identification of cracks, i.e. making sure that in the specific case all those observations apply to exactly the same crack. In practice, this means that the precision of the mutual synchronization of distance from the various methods is situated at the level of single decimetres.



**Figure 1.** Multifunctional SPDE measuring system for measuring surface characteristics of the pavement and photographic recording of damages.

Marking of positions of cracks on the roadway edge during preliminary visual surveying is a very important part of the synchronization procedure. It allows for accurate location of manifestations of specific cracks on an echogram (initial identification) through an arduous correlation of the distance of GPR traits with visual observations. This procedure will allow for a precise synchronization of the measuring distance with an official chainage of the road or other working chainages, or other local methods used for defining the distance. Direct observation also facilitates the initial identification of cracks on the photographs taken with a surface analyser and further synchronization of the measuring distance of SPDE with the measuring distance of GPR.

The photographs taken during the continuous measurement provide a very good documentation of the position and the exact route of the cracking line which could not have been obtained using other methods of field measurements. It is possible or even mandatory to use the graphical transformations highlighting lineations and edges (Fig. 2D) during layout. Then these images reveal their huge diagnostic potential. A precise synchronization of photos with measurements of other diagnostic methods present new possibilities in the field of analysis of pavement structure and in particular the structure of defects.



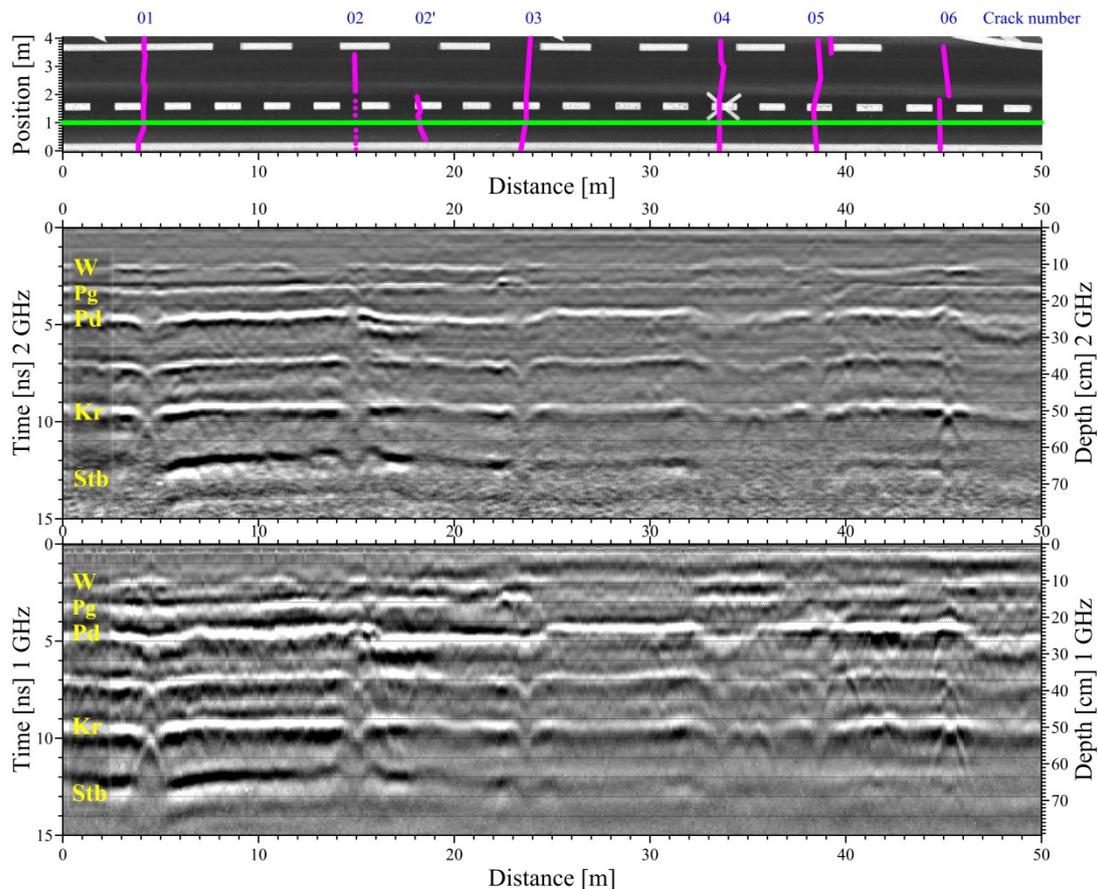
**Figure 2.** Identification of transverse cracking based on the photo. A) Original form of the photo, D) course of the cracking line marked on the original photo.

### 3. Characteristics of the population of cracks and characterization of the degradation process

Approximately 85 discontinuities in the form of transverse cracks were found in the tested road section with a length of 1,000 m. About 65 of them may be characterized as intersecting the profile of GPR measurement, presenting interpretable GPR traits of the presence of cracking. For practical reasons, 56 cracks intersecting the entire width of the tested traffic lane were selected for further consideration as a group representative for characterization of the cracking process.

Among this test group, only two cracks did not have a clear GPR response, six from the other cracks provided a weak or a very weak response, while the remaining ones, i.e. 48 cases (86% of the test group) included cracks with a well developed (8 cracks) and a very well developed structure (40 cracks), providing a clear or even spectacular GPR response. Nearly all of their GPR images indicate the presence of changes in the medium related to the advanced cracking evolution process up to the depth above 50 cm (and even up to 80 cm in extreme cases), that is to the diagnostic limits of the used equipment. More than 30 cracks are accompanied by spectacular GPR manifestations (Fig. 3). In many cases (22 cracks), the changes in the deeper layers of the structure, i.e. in the sub-base (aggregate “Kr”) and in the mechanically stabilised layer (“Stb”) have a significant transversal size (i.e. in the profile direction), covering the strip along the crack with a width of above 1 m (rarely above two metres). At the same time the tendency to increase the width of the zone covered by changes in the structure and the material together with increase in depth is very visible.

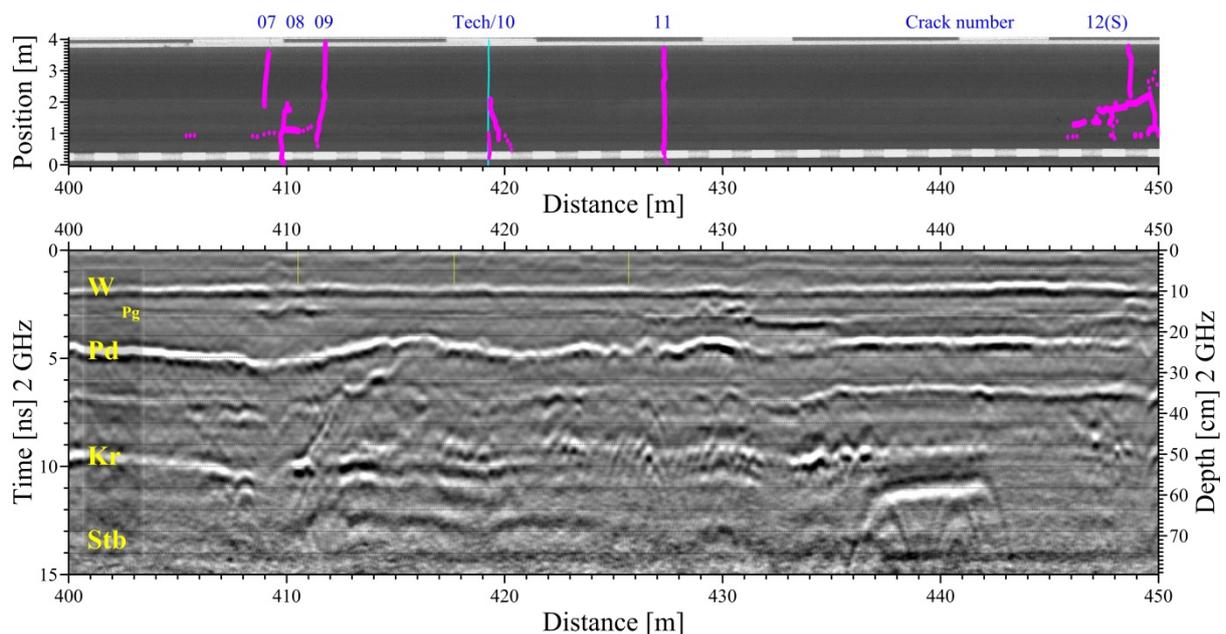
The cracks identified in the photos were marked with a violet line and were afterwards compared with a fragment of the echogram corresponding to that section, on which spectacular and well-located manifestations of cracks inside the pavement structure are visible (Fig. 3). They have very well developed forms that are variants of the Christmas tree layout [4]. This combination shows that the GPR manifestations of the cracking structure, and more precisely their axial planes, occur synchronously with their surface manifestations, with accuracy to one decimetre. It is worth mentioning the crack marked with number 02, that line is observed on the surface during the measurement and which does not intersect the line of the measuring profile yet, but very intense internal manifestations of the crack appeared below the profile at the point where it intersects with the extension of the axial plane of the crack. This is characteristic of very developed cracks recently covered with a new layer of asphalt, when this restoration process is not yet very advanced. The cracks visible in that figure have a very developed structure. Their presence in the structure is obvious based only on echograms, without confirmation with visual observations. The intensity of manifestations and their width (stretch along the profile) increase together with the depth, so that their presence in the sub-base and deeper courses is beyond doubt. The width of the zone with structural and material changes in these deeper levels reaches values greater than one metre. The forms of scattering caused by the structure of the cracks at the levels of inter-layer borders differ considerably from the pattern of the hyperbola, and take the shape of a Chi pattern, which proves wide zones of structural change.



**Figure 3.** An example of an excellent correlation of the position of cracks visible on the surface with their very distinct and well located manifestations on a GPR image. The above figure presents the photographic map of the pavement with the cracking lines visible on the surface marked with a violet line and the route of the measuring profile marked in green. Synchronously compared echograms obtained using antennas with the central frequencies of 2 GHz and 1 GHz are presented below. The reflection levels corresponding to the lower surfaces of the structural layers are designated as W (binder course), Pg (asphalt roadbase), Pd (asphalt sub-base), Kr (sub-base), Stb (mechanically stabilised layer).

Another part of the tested pavement section (Fig. 4) may be indicated as a comparative example presenting less obvious cases requiring a more complicated discussion. The image of the layered structure should be in this case defined as heavily distorted. The base course structure is especially distorted. Here one can see numerous elementary characteristics of potential presence of cracks, but they are not arranged in vertical groups clearly suggesting the specific locations of cracks. What is more, the defects and disorders of the layered structure of the packet are not numerous (three short ranges) and do not present conclusive evidence of piercing of the packet by cracking. Three cracks found on the surface of this section are accompanied by certain GPR traits of the potential presence of cracks, providing a chance to determine the probable position, but which alone are not the basis for suggesting its probable presence. In the case of crack 11, with precise synchronization with photography it is possible to recognize which elementary traits are the manifestation of the crack and what's more they form a typical Christmas tree pattern; however, it is masked by a multitude of elementary figures in its surrounding. Crack 12(S) and the group 07, 08 and 09 constitute two examples of branched cracking systems, which suggest the early stage of development of alligator cracks. Those areas in the asphalt packet present defective interlayer connections, whose range of occurrence strictly corresponds to the area subject to cracking. In this regard particularly significant

are defects in asphalt base. These defects have a form characteristic for debonding, but a chaotic scattering pattern is visible in those areas in the packet, which even leads to weakening and partial masking of structures located below, which is visible in the echogram in a form of a vertical zone called the *masking umbrella*. This irregular scattering suggests that the lower layers of the packet may be significantly mechanically degraded. An accurate view of the image of layers underneath the asphalt packet allows for determining that Chi patterns forming a Christmas tree arrangement are visible there and the axial plane of that arrangement corresponds to one of the transverse cracks (449.5 m in the case of network 12(S), while the cases of group 07, 08, 09 correspond to crack 08 of 410 m). The initial crack 10 which appeared in the vicinity of the construction joint (Tech, 419.2 m) may be regarded as not having the clear manifestations of deep-rooted cracking apart from the generally disturbed structure of the base course.



**Figure 4.** An example of a section with a disturbed structure suggesting occurrence of cracks, the precise location of which in the echogram is however difficult. The above figure presents the photographic map of the pavement with the cracking lines visible on the surface marked with a violet line, and the construction joint marked with a blue line. An echogram obtained using an antenna with the central frequency of 2 GHz and synchronously compared with the map is presented below. The reflection levels corresponding to the lower surfaces of the structural layers are designated as W (binder course), Pg (asphalt roadbase), Pd (asphalt sub-base), Kr (sub-base), Stb (mechanically stabilised layer).

Due to the varying degree of severity of the interpretable GPR manifestations of cracks and the varying degree of visibility of the cracks on the surface during identification of the extent and intensity of the phenomenon, it is good to describe the size of the individual groups of the process manifestations. This initial presentation make it possible to indicate the typical traits of cracking (depth of rooting, width of the zone of structural and material changes, tendency to intersect upper layers and other structural characteristics) which are the premises to draw a conclusion about the route of the process and the level of its advancement.

The echograms also show the traits of cracks not belonging to the defined test group. Those include cracks (about 20, including many with strong GPR manifestations) which, although intersecting the measurement line, have not yet intersected the entire traffic lane and have not been included in the test group. There are also less numerous manifestations of the possible cracks — generally weaker and

without the apparent deep rooting, where it is difficult to assign to them the clear traits of surface cracking or where inconclusive initial characteristics occur on the surface in those locations. The process of piercing of the new overlay by the underneath, old yet active weak zones, is by no means complete, but it may be assumed that the majority of the most developed among those structures is already visible on the surface.

The described deep traits are characteristic for the very well developed cracks, which are accompanied by material changes of a width of 1 dm (or more) in the vicinity of the cracking gap and much more extensive structural changes (to the more than a dozen of decimetres in width) visible in the disturbed system of layers, mostly the layers of the sub-base. The cracks intersect into the whole structure; in some cases suggesting the presence of material changes also under the structure. In many cases, the form of deformation of the layered system points to the loss of the bearing capacity of the structure under the cracking.

#### 4. Summary

A common use of photographs of the pavement taken using the surface analyser and the GPR inspection of its structure is a combination indeed providing new possibilities of structural diagnostics of cracking. Great potential of this method is revealed during the synchronous comparison of photos with echograms at the precision of synchronization at the level of single decimetres. The primary benefit of this method is the possibility of a very precise and reliable assignment (identification) of the corresponding transverse cracks visible on the surface to the GPR characteristics of cracks. The second benefit of this combination is the ability to develop a structural discussion in situations more complicated than a transverse crack (e.g. alligator cracks), when a single measuring profile does not provide sufficient insight into the complexity of the structure. Particularly convenient is the analysis of the relationship between the cracks not intersecting the measuring profile on the surface and the deep manifestations of cracking, which may appear under the profile at the extension of the cracking plane.

Moreover, the presented case study shows practical possibilities of the presented method used for characterization of the pavement cracking process. This method allows for inspection of the structure of cracks and assessment of the depth of their rooting, as well as for the assessment of the process advancement. This insight is possible in the case of very well developed cracks.

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