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GPR INVESTIGATION ON DAMAGED ROAD PAVEMENTS BUILT IN CUT AND FILL SECTIONS WITH RETAINING WALL

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Abstract

We present the GPR results dealing with flexible road pavements located on cut and fill sections with retaining wall. The aim is to evaluate the road damage (particularly the ramified cracks) taking into consideration also other parameters (cut and fill section height and traffic load). The GPR evaluation was carried out on 20 sites selected in the secondary urban road network of L'Aquila, a medium-size urban area representative of the Abruzzi Region (Central Italy). Stress induced by traffic load generally affects a road section thickness of about 1.0 m from the ground; so a monostatic GPR antenna, with a nominal frequency of 2000 MHz, was used given that its maximum inspection depth corresponds to 1.0 m from the ground. The 2000 MHz antenna has also a quite high-resolution when inspecting road damage. The GPR acquisition was carried out in damaged and adjoining undamaged road sites, to compare the GPR data of the two areas. GPR data analysis was based on the sweep-rectified power approach to evaluate the radar signal attenuation curve vs. depth, which permitted us to single out different road types of damage and to discuss the factors which caused them.

Keywords: damaged road pavements, GPR, durability performance of road pavements, inspection, maintenance strategies

1 Introduction

We report the results carried out by using GPR (Ground Penetration Radar) technique on flexible road pavements built in cut and fill sections with retaining wall. The goal was to find correlations between the types of paving deterioration, the cut and fill section height, the traffic load and the results obtained from the GPR campaign. Previous studies have always evaluated different types of paving deterioration with a reduced number of GPR scans. The results were interesting but not definite, due to their extremely small number [1].

During the current research, to increase our data we acquired five GPR measurements for each variable evaluated (cut and fill section height, traffic load). With regards to the type of deterioration inspected, the survey was conducted only on the ramified cracks (also called spider or alligator cracking) that represent one of the five types of bearing capacity structural defects regarding flexible road pavements [2].

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2 The research goals

The research goals were to carry out a survey with the GPR technique of degraded road pavements with a single type of deterioration, carried out on the cut and fill sections with retaining wall. The ramified cracks (RC) deterioration analyzed were selected to represent the worst conditions. Longer fractures measuring 5 m and wider than 5 mm were identified and, regarding the extension of degraded areas, more than 5 m^2 extended pavements were identified.
Regarding the influence of the height of the cut and fill section with retaining wall were considered pavements consisting of high cut and fill sections with retaining wall (HCF), a height of › 4 m and wall height › 3 m, and on low cut and fill sections with retaining wall (LCF), a height of ‹ 2 m and wall height ‹ 2 m.
Regarding the influence of the intensity of the traffic were considered pavements subject to heavy traffic load (HT), with average daily traffic › 4000, and low traffic load (LT), with average daily traffic ‹ 1000. Once again dealing with traffic loads, a further verification was performed which took into consideration the diversity of the flow of vehicles in transit on the roads surveyed, in order not to neglect the effect of heavy traffic. This verification was not focused on the average daily traffic load, but rather on the equivalent standard axle loads (ESALs - each of the 120 KN) per year. The evaluation confirms the results obtained in the first study and identified the following traffic load classes: heavy traffic load (HT) with › 400,000 ESALs/yr and low traffic loads (LT) with ‹ 4,000 ESALs/yr.
Therefore, the inquiry was performed on twenty sites chosen to be representative of the different combinations of the variables analysed. The same sites were identified on the secondary urban road network located into L'Aquila (Central Italy). Be informed that the studied area is placed at an altitude of 700 m above sea level and is characterized by cold winters.
The superstructures of the evaluated roads are constituted by flexible road pavements which have similar layers, with the following thicknesses: layer of foundation in granular mixture: 30 cm, base layer in bitumen mixture: 10 cm, binder layer: 6 cm and surface layer: 4 cm, both consisting of a bituminous concrete. Therefore, the superstructures on average have a total thickness of 50 cm.
The GPR surveys were carried out to perform a quantitative analysis through the examination of the GPR signal attenuation curves with the depth (the rectified power method). An antenna module with a nominal frequency of 2000 MHz was used, which is a type of evaluation that is quite reliable if directed at a depth of up to 1.0 m. This choice was made based on the effect, due to the stresses induced by traffic on cut and fill sections with retaining wall, to a maximum depth of about 1.0 m, developing, however, in the most accentuated form on an average in the first 50 cm of the superstructure [3]. In this current study, we used a 2000 MHz butterfly antenna manufactured by Systems Engineering - IDS (Pisa). It is a portable, monostatic type, non-dispersive antenna and is characterized by linear polarization, low directivity and limited bandwidth.

3 Analysis with sweep rectified power method

As it is known, the propagation of an electromagnetic field is described by the Maxwell equations, in which the constant of attenuation α appears, which expresses the amount of energy that is absorbed by the intersected layers. Please remember that the larger the void ratio of the evaluated material the greater the attenuation of the radar signal and the lower the attenuation constant is α [4]. Therefore, by determining precisely the α attenuation constant, it is possible to obtain a positive evaluation of the depth of the signal penetration itself. Since the goal of our study is to evaluate the importance of structural defects, we decided to focus the evaluation on a maximum depth of 1.0 m from the road pavement. This choice was made because the effect, due to the stresses induced by traffic on cut and fill sections with retaining wall, to a maximum depth of about 1.0 m, developing. However, in the most accentuated form on an average in the first 50 cm of the superstructure and spreading, with a still evident and easily seen result, for an additional 50 cm. Therefore, the theoretical reference road section was schematized in two portions: the first, 50 cm (S1), representing the superstructure and the second, an additional 50 cm (S2) representative of the portion of section formed by the ground which is still affected by the traffic [5]. This choice was in line with the demands that the antenna resolution of GPR had adopted (2000 MHz). Another fundamental assumption adopted in the model was that layers S1 (road pavement) and S2 (subgrade) are considered homogeneous on average. This assumption does not accurately reflect the reality, especially for the S1 layer, given the granulometric variety, specific weight and form that characterize the materials used in road pavements.

The sweep rectified power analysis, carried out in our study using software created by IDS-Gred (© 2004 IDS Ingegneria Dei Sistemi SpA, Pisa), graphically represents the average trend (straight line attenuation) energy absorbed by the ground portion of the cut and fill section with retaining wall placed between 50 and 100 cm (S2).

Through this interpretation of the rectified power diagrams, you can trace the α attenuation angle that graphically represents the angle that envelopes the R^2 regression line of power, forms with the x-axis which, in turn, indicates the depth from the road surface. Regarding the surveys carried out in our study, please note that the analysis was carried out considering two contiguous stretches in length equal to 1.5 m belonging respectively to a damaged area and an undamaged area from degradation and it not present specific abnormalities, for not vitiating the comparison. The relative diagrams for the two contiguous sections surveyed (both damaged and undamaged area) were included in the same graph to highlight their differences. The red coloured diagrams are related to the degraded road sections, while those of green coloured diagrams belong to the intact portions [6]. By making comparisons between attenuation corners of damaged areas (α_d) and undamaged (α_u), it is expected that if the difference between these values ($\Delta\alpha = \alpha_d - \alpha_u$) tends to zero, then the probable cause that generated the deterioration of paving is attributable to phenomena of fatigue or thermal shrinkage. These phenomena are due to horizontal tensile stresses that develop in the S1 layer of the road pavement (Figure 1a). In fact, in this case, in the S2 layer the energy curves are almost coincident, which means that the subgrade terrain relating to the two examined road sections, display the same degree of densification and there are no compactions in place (Figure 2). Moreover, the breaking of the surface layers in S1 may depend on deep settlement (rotation and translation), which originate on the base of the detecting portion of the embankment on the side of the retaining wall of the cut and fill section.

If instead, $\Delta a \neq 0$ the probable cause that triggers the degradation of the road pavement is attributable to the change of soil compaction portion of the section present in the S2 layer due to the action exerted by vehicular traffic. In this circumstance, we must make a further distinction between the case in which $\Delta a > 0$ and the case in which $\Delta a < 0$. In the first, the energy curves for the damaged areas (red) are at a lower energy content than those undamaged (green). This means that the deteriorated areas are more compacted of the not deteriorated areas. More precisely, the energy curves for the damaged areas (red) are positioned beneath those undamaged (green), and this confirms the fact that a lower power consumption level corresponds to an index of lesser void ratios (Figure 3). Therefore, the degradation process is no longer in place in the deteriorated area, while the areas that are not deteriorated will tend, over time, to assume the same level of densification of damaged areas; then the entity of degradation will tend to not remain confined in the deteriorated area but to expand in the neighbouring areas (Figure 1b). In the second, the energy curves for the damaged area (red) are at a higher energy content than those which are undamaged (green), and that the deteriorated areas are less compacted than non-deteriorated areas. More precisely, the energy curves for the damaged areas (red) are positioned above those undamaged (green), and this confirms the fact that at a power level absorbed corresponds a higher void ratio greater (Figure 4). Therefore, the degradation process is still going on in the deteriorated area and continues until it reaches the level of densification of the area not deteriorated; for this, the degradation will remain confined in the area affected by deterioration (Figure 1c).

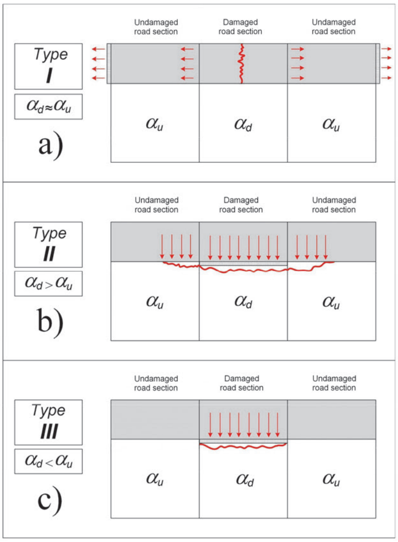
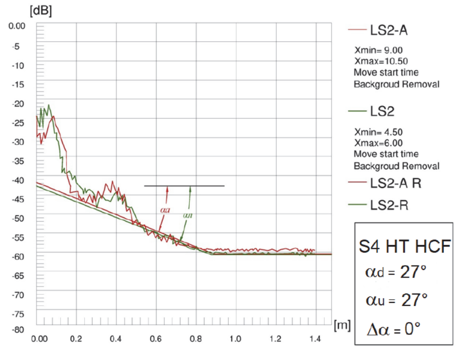


Figure 1 Diagram illustrating the three types of deterioration



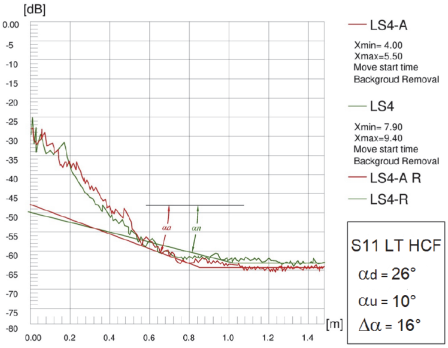


Figure 2 Example of the Δa @ 0 case

Figure 3 Example of the Δa › 0 case

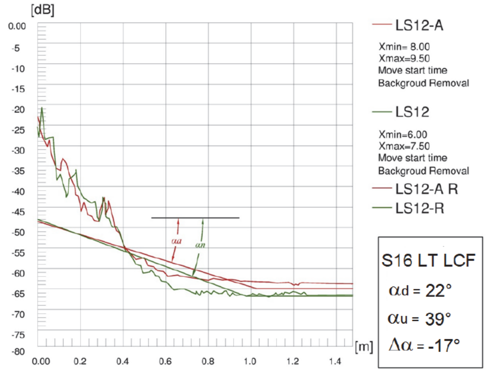


Figure 4 Example of the Δa ‹ o case

4 Survey results

We analyse the results of surveys carried out with GPR in the twenty sites chosen which are representative of the various combinations of the variables studied.
In this regard, it is noted that the accuracy in the interpretation of radargrams is a function of the antenna resolution and sampling the electromagnetic signal; in our case they are respectively of 1 cm and of 1024 samples per second. Furthermore, the resolution in the power sweep diagrams is of 1 dB for the signal attenuation (y-axis), and of 4 cm from the road surface to the depth (x-axis). This approach provides a detailed resolution to be able to evaluate areas up to 1 cm^2 in a thickness of road pavement/cut and fill section up to the depth of 1.0 m (Figures 2, 3, 4).
With the assistance of the sweep rectified power analysis, we proceeded to the evaluation of signal attenuation angles is in damaged sections ($α_d$), and in those undamaged ($α_u$), to which was followed by the evaluation of the variation of the attenuation (Δa). In Table 1 we report, the various combinations tested, the values of the attenuation constant a and the index Δa calculated. Please note that any survey is characterized by a code indicating, for the type of deterioration evaluated (ramified cracks RC), the height of the cut and fill section with retaining wall (HCF, LCF) and traffic load (HT, LT), according to the preceding paragraphs.
The analysis of the results made it possible to divide the types of degradation in two categories: the first consists of the resulting deterioration due to problems inherent in the road pavement layer (layer S1), and the second consists of the interesting deterioration of the subgrade layers (layer S2).
The deterioration in the first category (breaking in S1 layer) have provided values of Δa content in a range, respectively, of -2 ‹ Δa ‹ +2.
In this regard, the analysis of the values reported in Table 1, it was found that for road sections characterized by high traffic (HT), both high cut and fill sections (HCF) and low cut and fill sections (LCF), we were obtained the same types of results concerning the rupture in layer S1, both with 3 sections out of 5. For the findings, we can state that, in the light of the considerations set out in the preceding paragraph, the deterioration caused in the S1 layer (Figures 1a, 2) are normally generated by horizontal tensile stresses due to fatigue or thermal shrinkage affecting the surface layers of the road pavement. Generally, the rupture of the road pavements depends from the undersize of layers respect to traffic loads. But the traffic can also generate sagging of the supporting wall (rotations and translations) due to fatigue stress caused by the repeated passage of vehicles (Figure 5).
As said, we can deduce that the soils present in the cut and fill sections (up to 1.0 m deep) are not, in this case, the cause of no damage of the cracking type. From the analysis of the results

in the first category (breaking in S1 layer), it is clear a high repeatability resulted from the values obtained from the measurements with the GPR (both 60 % with HCF and LCF sections with HT), demonstrating that GPR is reliable for evaluation of deteriorated road surfaces and provides good results. Regarding the deterioration of paving in the second category (rupture in the S2 layer), they were recorded values of Δa included in a large interval of $-17 < \Delta a < +16$. As found, it can be said that the deterioration regarding the layer (S2) are generated by the sudden change in density from the subgrade terrain produced by the action exerted by the vehicle traffic (soil compaction).

Table 1 Different values of α_d and α_u measured and the index Δa calculated

Traffic load	Height	α_d	α_u	$\Delta\alpha$	Damaged layer
HT	HCF	30	32	-2	S1
HT	HCF	28	33	-5	S2
HT	HCF	26	33	-7	S2
HT	HCF	27	27	0	S1
HT	HCF	27	27	0	S1
HT	LCF	22	31	-9	S2
HT	LCF	27	27	0	S1
HT	LCF	31	29	2	S1
HT	LCF	28	30	-2	S1
HT	LCF	23	32	-9	S2
LT	HCF	26	10	16	S2
LT	HCF	25	15	10	S2
LT	HCF	10	13	-3	S2
LT	HCF	12	15	-3	S2
LT	HCF	21	21	0	S1
LT	LCF	22	39	-17	S2
LT	LCF	27	34	-7	S2
LT	LCF	35	36	-1	S1
LT	LCF	31	37	-6	S2
LT	LCF	27	40	-13	S2

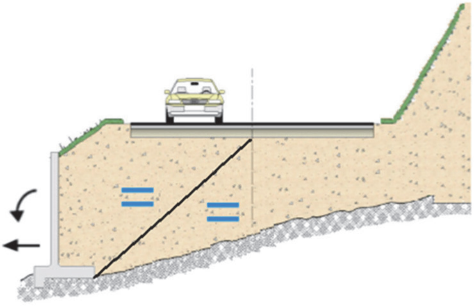


Figure 5 Cut and fill section with retaining wall and traffic

In this case please note that if $α_d$>$α_u$ the deterioration will tend to expand in neighbouring areas; if instead, $α_d$<$α_u$ the deterioration will remain confined to the already degraded area. It is noted that, in the case of low traffic (LT) and both high cut and fill sections (HCF) and low cut and fill sections (LCF), for 4 sections of 5 were recorded the highest values of Δa and 6 with a negative sign. This means that the problems inherent in the compaction are limited to the layers close to the substrate and not extend throughout in the neighbouring damaged area of the cut and fill sections. Generally, the rupture depends from landslides that interest the subgrade terrain of the roadway. Maybe this shows that the road damaged are conditioned by unpredictable external factors such as, for example, the influence of the subgrade composed of natural terrain positioned close to the road pavement.
Also, in this case the results obtained show a high repeatability with 80 % in the case of homogeneous results HCF and LCF with LT showing that it is a reliable methodology for evaluation of road pavements deteriorated even with different conditions of traffic and sections.

5 Conclusions

The results of a GPR survey conducted on degraded road pavements built on cut and fill section with retaining wall is presented. It was evaluated only one type of deterioration (ramified cracks) and was carried out a survey on a large sample (five surveys) for each of the evaluated variables (sections height and traffic load). These pavements have been identified on secondary roads of the urban area of the city of L’Aquila (central Italy). The evaluation of the attenuation curves of the radar signal detected from the road pavement, performed by the sweep rectified power method, allowed us to determine the attenuation constant a. Through the comparison of the attenuation of constant a, detected on two adjacent longitudinal sections belonging respectively to a damaged portion ($α_d$) and to an undamaged stretch ($α_u$), made it possible to trace the causes of the degradation of the analyzed pavements. The results, taken from a large sample, showed high repeatability to demonstrate that the methodology can be trusted to evaluate deteriorated road pavements with different traffic conditions and sections heights with retaining wall.

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