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IMPLEMENTATION OF GPR AND TLS DATA FOR THE ASSESSMENT OF THE BRIDGE SLAB GEOMETRY AND REINFORCEMENT

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This paper presents a suggested approach for forensic investigation of bridge decks in which Ground penetrating radar (GPR) consisting of two antennas is used to assess the current conditions. The methodology was tested on a bridge deck in central Sicily. The acquired data were analyzed for identifying the asphalt overlay thickness, concrete cover depth and deck thickness and location of the rebar reinforcement. In the proposed approach for assessing bridge deck conditions the GPR survey was complemented with (i) a site investigation on layer thicknesses for calibration/verification purposes of the GPR response and (ii) a Terrestrial Laser Scanning system (TLS) to verify the bridge design slab curvature. The study shows that this methodology has significant merits on accurately assessing such bridge deck components when bridge design records are non-existing, and by using non-invasive methods such as laser scanning and GPR. The great advantage provided by the TLS technique is the possibility to obtain a 3D output model of the scanned element with the accuracy of the best topographic instruments in order to complement GPR data surveys for bridge inspection.

Keywords: Ground Penetrating Radar; Terrestrial Laser Scanning; Sicily

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1. INTRODUCTION

Data collected with high efficiency equipment, such as GPR, allows to get high quality and detailed information of the road and bridge assets and offers the chance to create a georeferenced database which can be used both for road maintenance and Quality Assurance/Quality Control (QA/QC) applications [1,5,6]. At the network level GPR can provide useful information on the condition of pavement layers and bridge decks for maintenance management and optimization of resources [7]. At the project level, GPR provides detailed information on layer condition, thickness, location of the reinforcement, material degradation, and other [8]. Ground Penetrating Radar can also be used in QA/QC complementing inventory data when design and construction records are non-existent or questionable. Thus, such technology can provide quantitative information for improved decision making and reduced operating costs in Pavement Management and Bridge Management Systems [6, 9, 10]. For these reasons several studies have explored the use of GPR in assessing the condition of critical infrastructure components and to identify potential improvements in GPR data analysis [11, 12].

The present paper presents a study undertaken in monitoring the condition of an existing bridge deck where limited design and construction records were available by using non destructive equipment available at the Department of Civil Engineering and Architecture of the University of Catania. The initial analysis and results indicated that GPR can provide accurate assessment of the asphalt overlay thickness, concrete cover depth and deck thickness and location of the rebar reinforcement [13]. The GPR data was also integrated with Terrestrial Laser Scanning (TLS) measurements for assessing the bridge deck curvature and geometry, using a ground-based remote sensing technique to overcome the limits of traditional and destructive surveying methods to complement GPR data.

2. EQUIPMENT AND DATA COLLECTION

Ground Penetrating Radar (GPR) is an electromagnetic-based non-destructive geophysical tool that can be used for pavement and bridge deck investigations, including layer thicknesses, location of reinforcement, and potentially deterioration (6). The working principle of the GPR technique is based on sending a short-duration electromagnetic wave and recording arrival time, amplitude and phase of the back-reflected signal. Specifically, the GPR antenna transmits short bursts of

electromagnetic waves as the instrument is moved across the pavement. When the downward-propagating GPR signal encounters an interface across which there is a change in dielectric permittivity, some of the energy is reflected back from the interface to the receiver as an echo. The rest of the energy is transmitted across the interface. GPR principles feed into the electromagnetic theory wherein the physics of the wave propagation is described by the Maxwell's equations and material properties are quantified by constitutive relationships.
Figure 1 represents a GPR output deriving from a survey layout typical of a reinforced structure. An electromagnetic wave is emitted towards the surface by a radar with a fixed central frequency using one or more antennas. Signal is then received as a function of the material properties and characteristics of the receiving antenna. A number of information is then monitored, such as the two-way travel time distance between reflection peaks at layer interfaces/target positions (e.g., rebars), the amplitude and phase of the signal.

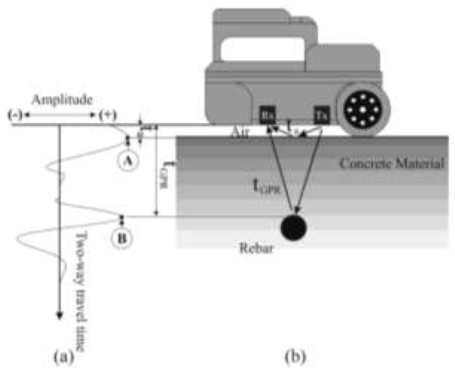

Fig. 1. (a) Amplitude variation of GPR signal; (b) Layout of a reinforced concrete structure survey [14].

The Ground Penetration Radar available at the Transport Infrastructure Laboratory of the University of Catania, (Figure 2) uses two antennas/receivers with 600 MHz and 2000 MHz frequencies. The K2_FW acquisition software is used to manage the phases of radar acquisition and to review the data acquired directly on site.

Fig. 2. Ground coupled GPR survey during the bridge monitoring.

Terrestrial Laser Scanning (TLS) is a ground-based remote sensing technique used in different geological fields to overcome the limits of traditional surveying methods. In archaeology, TLS is often used to detect architectural elements with very high precision and accuracy, and to survey archaeologic artifacts in order to obtain detailed information on its construction characteristics [2,15,16].

The TLS technique can also produce point cloud data to obtain high-resolution 3D models. In this study, a laser scanner Leica P20 (Figure 3), operating in a range of 120 m and a rate of 1,000,000 points/s, was employed. Leica P20 also provides an integrated 5-megapixel camera to produce photos during the scanning process.

Fig.3. Terrestrial Laser Scanning TLS survey during the bridge monitoring.

The bridge under investigation is located in a secondary road in Sicily and was used for the experimental case study. Since the bridge construction is not well documented, the geometry of the structure was verified by using the data collected by the laser scanner, while GPR was used in the survey to assess bridge deck layer and reinforcement characteristics.

The bridge under investigation is a multispan bridge, which consists of single span precast beams connected in upper part with continuous, cast in situ, concrete slab with expansion joints each three spans. The bridge consists of ten 32 m long spans, with a total length of 320 m.
The TLS was carried out along the overall bridge, while GPR survey was carried out between joints at 88 m and 185 m. Results of data fusion between TLS and GPR are presented for the 32 m span starting at joint located at 88 m, used as common reference for both the survey.

3. DATA INTERPRETATION

3.1. TERRESTRIAL LASER SCANNER – TLS

In order to assess bridge geometry, seven laser scans were carried out (Table 1), two of which were on the opposite sides of the upper part of the bridge. The large point cloud obtained from a TLS surveys is usually very complex and difficult to manage with traditional software for the 3D modelling. For this reason, a post-processing step for data reduction was required.
One of the procedures used during the post-processing step is called "decimation" and consists of iterative contractions of vertex pairs to reduce the complexity of the points cloud maintaining surface error approximations using quadric matrices. Using a pair contraction decimation algorithm, it is possible to contract a set of vertices into a single vertex. A pair of vertices v1, v2 is valid for the contraction if:

- $(v_1; v_2)$ is an edge;
- $||v_1-v_2||< t$, where t is a threshold parameter.

Each vertex is associated with an error metric, a 4×4 symmetric matrix, and a quadric error. So each contraction has a weight estimated by the error at each vertex [3,4].

Table 1.Main features of the seven TLS scans of the bridge.

Name	Number of points	Geometric resolution	Min intensity	Max intensity
Scan1	22,084,486	3771 × 10120	0.0048	0.9928
Scan2	1,396,546	1191 × 2673	0.0028	0.9909
Scan3	11,087,999	1344 × 10120	0.0043	0.9967
Scan4	95,083,609	7541 × 20229	0.0050	0.9913

Scan5	13,112,613	3654 × 4776	0.0048	0.9901
Scan6	10,753,106	3357 × 4591	0.0045	0.9899
Scan7	11,172,311	1349 × 10120	0.0043	0.9955

The points cloud so obtained represents a valid model to carry out measurements and extract useful information about the object detected through the use of dedicated software.

Each single scan was then analyzed and processed to generate a single 3D model of the bridge by combining the individual scans for homologous points. This final scan included 164,690,670 points. Two different views are reported in Figures 4 and 5, where different colors are due to the laser's reflection to different materials and/or surface characteristics. (i.e. concrete could be referred to a range among yellow-green and blue in function of the radiometric response of the material).

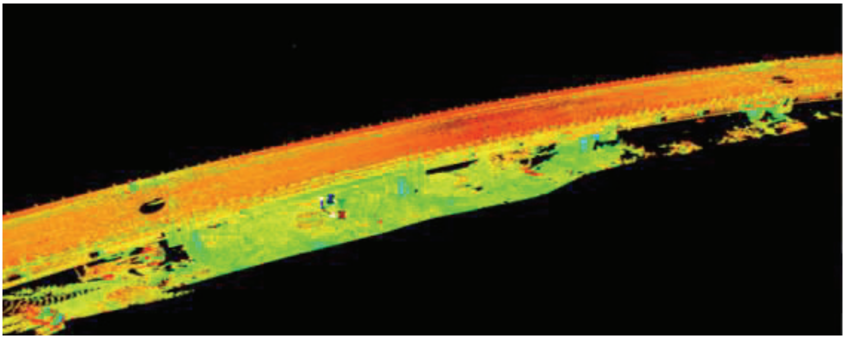

Fig. 4. View of the upper part of the entire bridge showing the pavement deck.

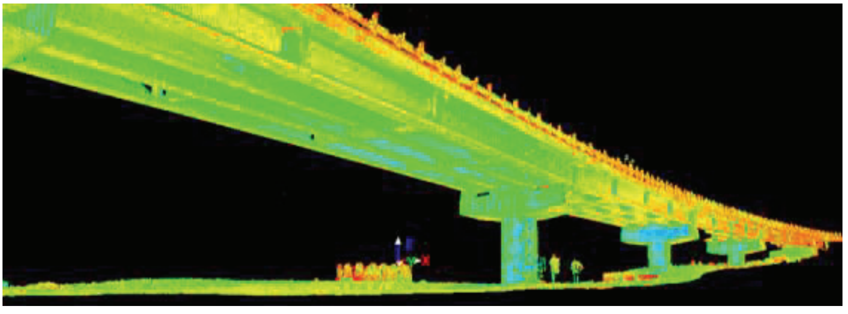

Fig. 5. View of the lower part of the bridge beams and spans.

3.2. GROUND PENETRATING RADAR – GPR

As before mentioned, the surveyed bridge has a series of decks on pillars that are about 32 meters apart from each other. Several longitudinal (A,..,E) and transverse (1,..,15) GPR runs were collected on the bridge deck (Figure 6).

At the longitudinal direction the middle of the carriageway as well as the shoulder and edge markings were surveyed. The longitudinal radagram covered a distance of 320 meters with visible transversal joints at 88 and 185 meters where pavement thickness measurements were taken for calibration and verification of the GPR data (Figure 7).

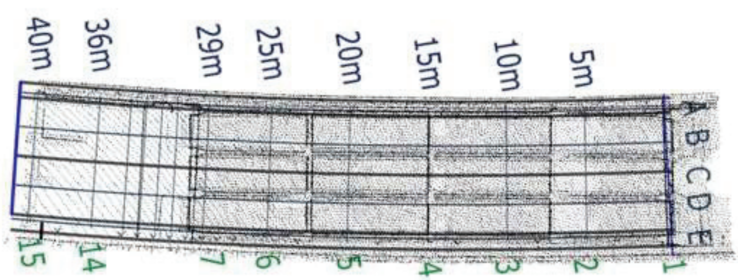

Fig. 6. Paths of the GPR survey on bridge deck scheme from laser scanner data starting at 88 mjoint.

Fig. 7. Bridge Deck, Asphalt pavement and cement concrete deck thickness at the 88 mjoint .

Figure 8 shows the radagram at the first joint, 88m from the start for the survey. As it can be seen from this radagram there is an asphalt overlay of thickness throughout the bridge deck ranging from 10-11 cm. The depth of the steel bars is variable with a curvilinear shape depending on the pre-stressed curvature of the beams. Thus, at the pillar the reinforcement has the highest depth equal to

22 to 23 cm from the surface, while such depth is decreasing away from the pillar following the curvature of the precast beams.

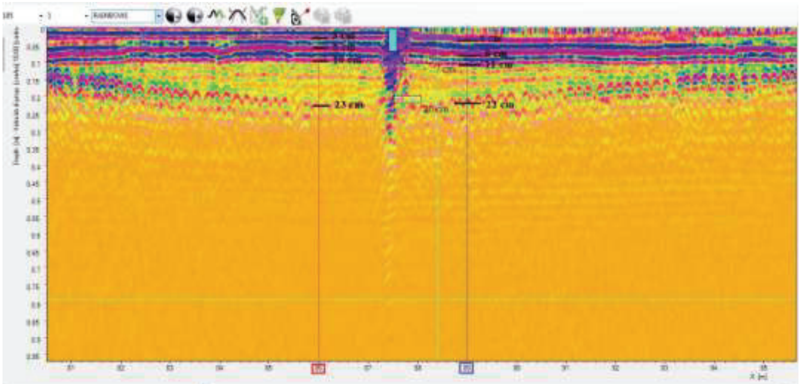

Fig. 8. Radagram at Bridge Deck Joint 1 with 2GHz antenna at 88 m joint.

Figure 9 shows the variance of signal amplitude from the top of the pavement layer in two different bridge sections. EM signal picks represent changes in the dielectric material properties encountered at the interface between pavement and slab layers (10 and 11 cm),and the reinforcement steel bars (20 and 21 cm). At higher depth (35 cm), the back surface of the bridge slab was better detected with the lower frequency antenna (600 MHz).

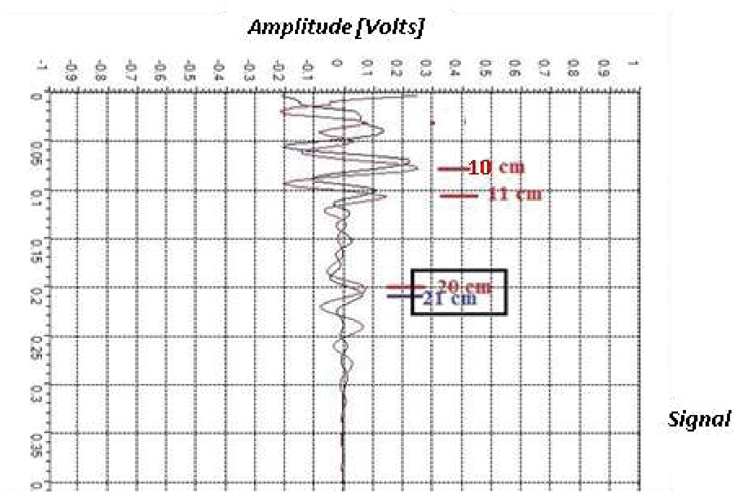

Fig. 9. GPR Signal at a distance from Joint 1 (86m and 89m).

3.3. FUSION OF TLS AND GPS DATA

TLS data were used in conjunction with the GPR analysis in order to provide accurate cover thicknesses and location of rebars (GPR) in function of the top and bottom bridge slab surfaces (TLS). TLS provided the geometry of the bridge deck in the longitudinal and transverse directions. The bridge deck geometry and alignment was then used to (i) accurately locate the variable overlay thickness and position of the rebars and (ii) assess the accuracy of the materials' dielectric properties by comparing the overall slab thickness measured by GPR and TLS. The fusion of these surveys from the two equipment TLS and GPR permits such a valuable assessment.

Figure 10 shows a schematic comparison carried out using a longitudinal section that was extracted from the overall point cloud of the laser survey corresponding to a path surveyed with the GPR. The same section detected with TLS identifies a curvature in the longitudinal direction due to the pre-stressing of the beams during construction and average thickness of the bridge slab and pavement of 35 cm, Figure 10 (top). The same curvature in the reinforcing steel bars and slab thickness are identified from the GPR survey, Figure 10 (bottom), confirming the accuracy of the data analysis providing a good agreement between the two surveys. Table 2 reports the comparison between the maximum bending at the center of the bridge in the bottom of the slab (measured by TLS) and the reinforcement bars (measured by GPR) along all the five runs. Assuming that the slab and the reinforcement have the same curvature, the average difference of 6% permits to confirm the correct assumption of the value of field propagation speed of GPR signal set equal to 10 cm/ns.

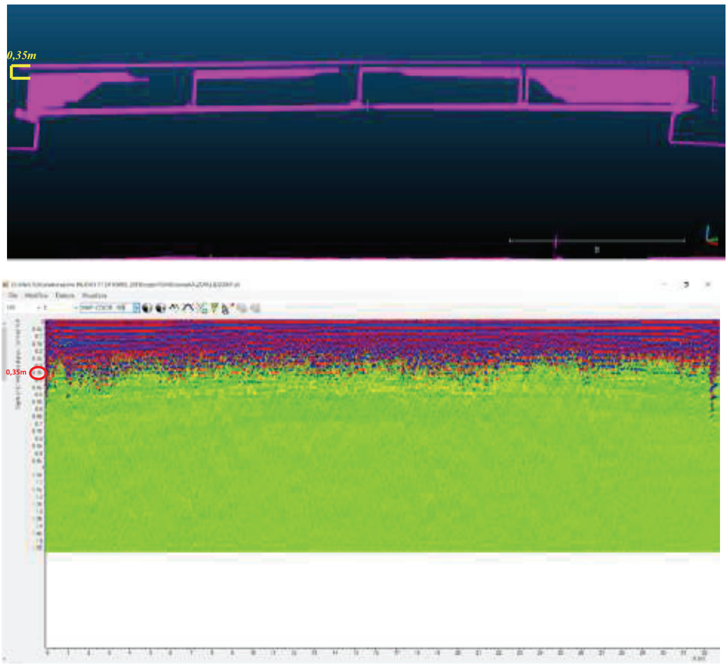

Fig. 10. Longitudinal section C detected by TLS (top) and by GPR (bottom).

Table 2. Comparison of the maximum bending [cm] at the centre of the bridge beam measured with GPR (10 cm/ns as reference speed) and TLS.

GPR track	A	B	C	D	E	average
Bottom slab (TLS) [cm]	10	9	10	9	8	9.2
Reinforcing steel (GPR) [cm]	8	11	12	9	9	9.8
Difference	-20%	+22%	+20%	0%	+12%	+6%

4. DISCUSSION AND CONCLUSIONS

The methodology approach proposed in this study is based on fusion of data collected with ground coupled GPR and TLS equipment. Results showed significant advantages for accurately assessing bridge deck conditions especially when limited or no bridge design records are available. The analysis and results indicated that GPR surveys can provide accurate assessment of the asphalt overlay thickness, concrete deck depth and location of the steel rebar reinforcement. Combining GPR data with TLS measurements can help minimize the need for time consuming and costly bridge deck inspections and coring usually carried out for data calibration and validation.

When appropriately calibrated and validated, GPR surveys can provide information about location of reinforcing bars, detection of rebar corrosion, estimation of rebar size, evaluation of the concrete cover, concrete characteristics. Fast assessment of the bridge deck characteristics with GPR can provide useful information for network screening of bridge decks. Later on, at the project level, GPR can provide detailed information for determining specific bridge deck rehabilitation strategies.

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