Süleyman Demirel Üniversitesi
Fen Bilimleri Enstitüsü Dergisi
Cilt 26, Sayı 2, 305-313, 2022

Süleyman Demirel University
Journal of Natural and Applied Sciences
Volume 26, Issue 2, 305-313, 2022

DOI: 10.19113/sdufenbed.1000547

Determination of Highway Pavement Layer Thickness and Layer Anomalies with GPR in Burdur Section of D330 Highway

Sercan SERİN*[1], Mehmet SALTAN[2], Serdal TERZİ[2]

[1]Osmaniye Korkut Ata University,Faculty of Engineering,Civil Engineering Department,80100,Osmaniye, Turkey
[2]Süleyman Demirel University, Faculty of Engineering, Civil Engineering Department, 32260, Isparta, Turkey

(Alınış / Received: 24.09.2021, Kabul / Accepted: 25.05.2022, Online Yayınlanma / Published Online: 20.08.2022)

Keywords
Ground Penetration Radar (GPR),
Non-destructive testing method (NDT),
Pavement,
Highway,
Quality control

Abstract: Ground Penetration Radar (GPR) is an important non-destructive testing method used in quality control studies on highways. In this study, the GPR device was used to determine the pavement layer thicknesses and to reveal the anomalies that occurred during the manufacturing on the highways. Within the scope of the research, field studies were carried out in a certain part of the Antalya-Burdur-Isparta highway (17 km). Scanning was performed at two different frequency rates (600 and 1600 MHz) using the GPR device. Two consecutive GPR scans were performed in the year the highway was renewed and the following year. In the first year GPR scans, it was determined whether the planned layer thicknesses were reached or not and abnormal conditions arising from the construction of the highway. In the second year GPR scans, the changes that occur on the highway after one year under the traffic load were determined. With this study, it has been demonstrated once again that the GPR test method is an alternative to destructive testing methods and is a test method that can collect information about the highway without damaging.

D330 Karayolu Burdur Kesiminde GPR ile Karayolu Üstyapı Tabaka Kalınlığı ve Tabakalardaki Anormalliklerin Belirlenmesi

Anahtar Kelimeler
Zemin Penetrasyon Radarı (GPR),
Tahribatsız test yöntemi (NDT),
Üstyapı,
Karayolu,
Kalite kontrol

Öz: Zemin Penetrasyon Radarı (GPR) karayollarında kalite kontrol çalışmalarında kullanılan önemli bir tahribatsız test yöntemidir. Bu çalışmada, üstyapı tabaka kalınlıklarının tespiti ve karayollarında imalat esnasında oluşan anormallikleri ortaya koymak için GPR cihazı kullanılmıştır. Araştırma kapsamında Antalya-Burdur-Isparta karayolunun belli bir kesiminde (17 km) arazi çalışmaları yapılmıştır. GPR cihazı kullanılarak iki farklı frekans hızında (600 ve 1600 MHz) görüntüleme yapılmıştır. Karayolunun yenilendiği yıl ve bir sonraki yıl üst üste iki kez GPR taraması yapılmıştır. İlk yıl yapılan GPR taramalarında yapımda planlanan tabaka kalınlıklarına ulaşılıp ulaşılmadığı ve yolun yapımından kaynaklı anormal durumlar tespit edilmiştir. İkinci yıl yapılan GPR taramalarında ise trafik yükü altında bir yıl sonrasında karayolunda meydana gelen değişimler belirlenmiştir. Bu çalışma ile GPR test yönteminin tahribatlı test yöntemlerine alternatif ve karayoluna hasar vermeden bilgi toplayabilecek bir test yöntemi olduğu bir kez daha ortaya koyulmuştur.

1. Introduction

The asphalt pavements are distressed by high volume of traffic, increase of heavy vehicle, and environmental effects [1-3]. The pavement forms an important part of the highway. It performs many positive tasks, from safety to fuel consumption. In this case, the quality of the coating is very important. The pavement can be affected by many factors and subject to deterioration. Therefore, some precautions should be taken [4-7]. The effects of the deterioration will vary in different sections of the highway depending on the class of the highway, the quantity of traffic and the loading situation on the highway. Therefore, different maintenance and repair strategies and programs can be developed for each highway [4-7].

Many non-destructive test methods have been studied by researches for long times to prevent the disaster in highway due to the fatigue crack or settlement of

*Corresponding author: sercanserin@osmaniye.edu.tr

asphalt pavement in advance [1-3]. Traditionally, the thickness of asphalt layers was evaluated by measuring the strain and pressure of highway or by collecting the core samples directly [1, 8-9]. Although these methods are reliable by giving accurate results, they are expensive, time consuming and provide local information compared to non-destructive test methods. To overcome these limitations, the use of non-intrusive techniques is often recommended [10-11].

There has been a continuous increase in the use of non-destructive testing (NDT) to evaluate civil engineering structures recently [12]. Ground Penetrating Radar (GPR) is one of the most frequently used NDT on highway inspections because it is relatively fast technique that gives overall internal image of the shallow subsurface [1]. GPR is a pulse NDT method for locating structural objects and assesses pavement material layer thicknesses and properties [13-14]. There are different studies carried out using the GPR method in the literature.

Saarenketo et al. carried out the quality control of the asphalt pavement using electromagnetic measurement methods and created deterioration maps. Until that time, the same author carried out a series of studies for the determination of crack widths, transverse and longitudinal cracks and layer thicknesses in the Scandinavian region. Thus, they have been instrumental in including the GPR technique as a quality control tool in this region. [15-20].

Al-Qadi et al. carried out experiments on flexible airport pavements in a study called on-site determination of the densities of asphalt pavements with the GPR technique. In order to determine the pavement density, the dielectric and density data were compared with the GPR based on the dielectric coefficients of the pavement. At the end of all studies, it has been determined that density determination with the GPR method is easier and gives better results than traditional nuclear methods [21].

Colagrande et al, examined the deteriorations in flexible pavements with GPR. Researchers studied forty different paths with and without distortion at 1600MHz and 600MHz GPR frequencies. They also supported their studies statistically and revealed the causes of deterioration [22].

Ahmad et al. conducted a study on the feasibility of detecting cracks in asphalt pavement with GPR. Researchers did not use traditional destructive methods for the detection of cracks due to their time consuming and high cost, instead they investigated the usability of the non-destructive GPR method [23].

Mardeni et al. carried out pavement density analyzes with the GPR technique. They used the distortion estimation as a factor to determine the density of the pavement using the GPR frequency range of 1.7 – 2.6 GHz. As a result of the study, they found that pavement density was predicted more successfully with low GPR frequencies of 1.7 GHz [24].

Al-Qadi et al. used the GPR method to evaluate railway ballast conditions quickly, effectively and continuously. They evaluated the ballasts of the smooth railway with the same characteristics and the ballasts with deterioration, using the GPR data, scattering analyzes were carried out to detect the railway ballast deterioration. As a result of the study, they presented a new methodology showing that 2 GHz GPR antennas can be used to evaluate railway ballast material [25].

Zhou and Scullion, in the report they prepared in 2007, stated that non-destructive testing methods can be used for the evaluation of flexible pavement coatings. In this report, the results are presented by using the GPR, FWD and compression dynamic deflectometer (RDD) together. The GPR was used to determine the layer thicknesses of the existing pavement and the moisture zones where potential deterioration would occur [26].

Kim et al. combined two GPR systems operating in different frequency bands at the same time and applied them to evaluate the asphalt pavement. The layer thicknesses of the asphalt pavement, the air spaces therein, the groundwater close to the substrate and the defects caused by these were monitored with GPR [1].

In this study, reconstructed layered system with 17 km highway section was investigated by using the Ground Penetration Radar (GPR) which is one of the nondestructive test methods (NDT). In this way, pavement layer thickness and anomalies occurred in time and during construction stages were investigated.

2. Material and Method

2.1. Method

Ground Penetration Radar (GPR). GPR is an important test method designed to determine the content of both natural and man-made materials. It can also be used to locate buried objects underground [15-16]. GPR technology was first used in transportation engineering applications in the mid-1970s [21,27]. Since then, it has been used frequently in different applications in this field [21]. GPR test equipment enables continuous and fast data collection in direction of the same profile. The most important parts are antennas, data acquisition equipment and distance measuring devices [21].

Figure 1 shows the signals sent from GPR antennas in a three-layer structure. The signals reflect from the interfaces and reach the antenna again. The data of the records are processed and taken from the GPR screen. Then, the images are analyzed and information about the structure is revealed [28].

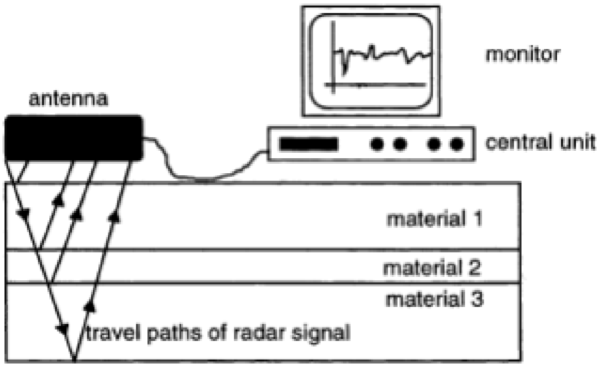

Figure 1. The working principle of GPR [28].

GPRs are grouped in two ways. This grouping is called depending on how the antenna is mounted. These are air-coupled systems or ground-coupled systems [21]. In this study, an air-coupled GPR antenna system capable of collecting data 150 to 500 mm above the ground is used. Figure 2 shows the amplitudes obtained directly from GPR data.

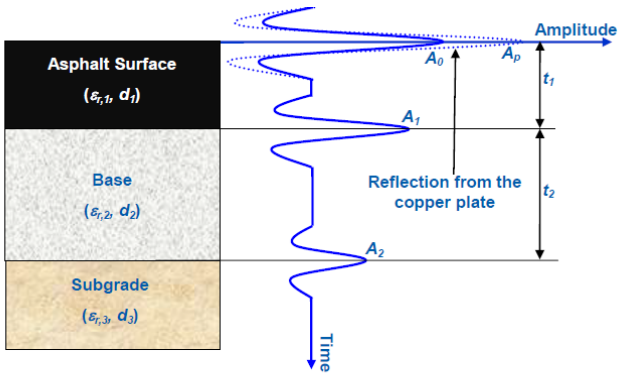

Figure 2. GPR signal reflections in highway layer interfaces [21].

The velocity of the electromagnetic wave decreases with an increase in the dielectric constant. The speed of electromagnetic wave is approximately:

$$v = \frac{c}{\sqrt{\varepsilon_r}} \tag{1}$$

Where: v, signal velocity; c, velocity of light (0,3 m/ns); and ε_r, relative dielectric constant.

The depth of a layer of material is determined from the time it takes the reflected wave to be detected at the receiver. The depth is calculated as:

$$d = v\frac{\Delta_t}{2} \tag{2}$$

Where: d, thickness of layer; v, velocity of electromagnetic wave through the layer; and Δ_t, time between reflections [29].

2.2. Study area and material properties

In the current study, the performance of GPR to measure the thickness and anomaly of asphalt pavement layer in the newly constructed Antalya-Burdur-Isparta highway in Turkey were tested. The tests have been carried out along with 17 km section of 100 km highway [30].

The highway was constructed by adding 4 new layers on the existing pavement and subgrade layers. These layers include wearing course, binder course, bituminous base, plentmix layer and subgrade layer. A real section illustrating the layers and layer thicknesses of the highway are given in the Figure 3. In this study, wearing course, binder course and bituminous base layers have only been examined. The maximum thicknesses of these layers are determined in the design project as 5 cm, 8 cm and 13 cm, respectively [30].

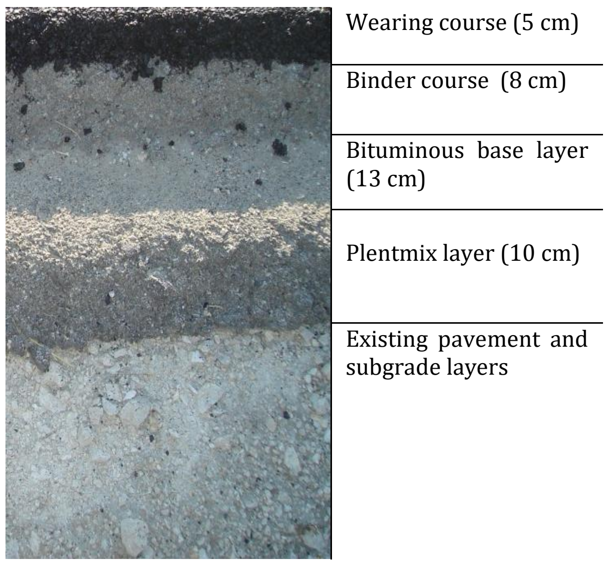

Figure 3. A real section showing the layers of the highway.

The basic physical properties of these layers are presented in the Table 1. These physical properties are optimum bitumen content (%), density, Marshall Stability, Voids (Vh), bitumen flow values, voids filled with bitumen (Vf), VMA of the layers. Also, the aggregate gradations used in these three layers are given in the Table 2.

Table 1. The basic physical properties of the layers.

	Wearing Course	Binder Course	Bituminous Base
Optimum Bitumen Content %	4.80	4.30	4.00
Density, Dp (t/m3)	2.407	2.418	2.418
Marshall Stability, MS (kg)	1380	1370	1380
Voids, Vh (%)	3.93	4.42	4.67
Bitumen flow values, (mm)	3.25	3.50	3.75
Voids filled with bitumen, Vf (%)	72.3	67.0	64.2
VMA (%)	14.2	13.1	13.1

Table 2. Aggregate gradation of the layers.

Sieve Diameters		Bituminous Base	Binder Course	Wearing Course
mm	inch			
37.5	1 1/2"	100.0	100.0	100.0
25	1"	91.5	100.0	100.0
19	3/4"	78.0	89.7	100.0
12.7	1/2"	64.9	69.4	88.7
9.5	3/8"	57.2	58.3	81.5
4.75	No.4	40.8	40.9	47.5
2.00	No.10	29.2	29.2	33.2
0.425	No.40	12.5	12.5	13.9
0.177	No.80	8.4	8.4	8.6
0.075	No.200	4.2	4.2	5.3

3. Results

In this study, GPR surveys on Antalya-Burdur-Isparta highway (D330) were conducted as soon as the highway was put into service and next year. The antennae were air-coupled to avoid damage from obstacles along the track. In this context, the highways layers were scanned immediately after the reconstruction with 40 ns display speed up to 3.5 m depth by the help of different GPR antenna having 600 and 1600 MHz frequency. The data were collected at a speed of 40 km/h. The GPR equipment setup is shown in Figure 4.

Figure 4. Installation of GPR antenna on vehicle and instant data transfer to PC.

GPR data was passed through eight different processes using the Reflex program for clearly view of the layers and detection of layer thicknesses. These consist of filtering and amplitude changing processes. After all these processes, it was found that the best imaging frequency was obtained at 1600 MHz. Different researchers have made similar studies for layer thickness estimation in other GPR frequency ranges [22-24]. Figure 5 shows GPR images obtained with 600 MHz and 1600 MHz antenna.

Time and depth indicators were created on GPR images with Reflex program depending on amplitude of the air zone, the reflection time and the velocity of electromagnetic wave. These indicators are shown on the right and left of the GPR images.

The distance between the point where the GPR antenna is fixed and the layer of the first reflection is determined. Thus, the first reflection distance of the air zone has been determined. And then, the air zone displays have been cleaned by the help of the analysis program from the GPR image. Thus, the layers forming the pavement were identified. Figure 6 shows the layers of existing pavement, subgrade layer and new highway layers. Layer changes points are clearly seen in the figure. GPR images are divided into 100-meter sections because the imaging distance is very long.

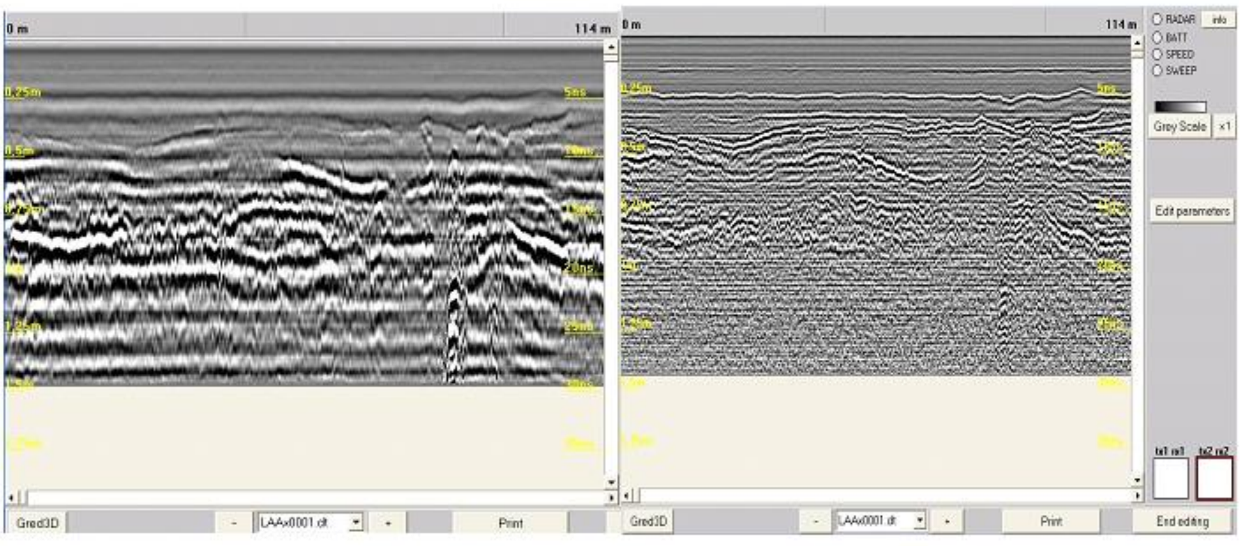

Figure 5. GPR images obtained with 600 MHz and 1600 MHz antenna.

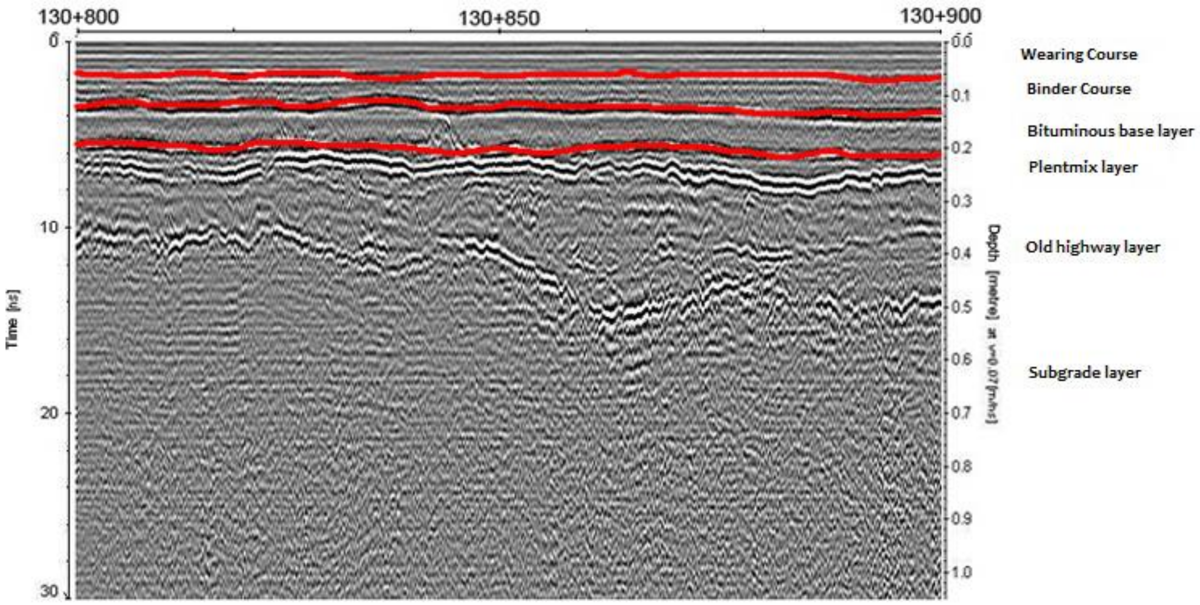

Figure 6. Layered structure of pavement for first year GPR measurement (130+800-130+900 km).

This figure shows wearing course, binder course, bituminous base and plentmix layer of the new highway. Furthermore, it shows existing pavement layer and subgrade layer. It was found that large parts of the existing pavement were damaged.

Analyzes were carried out to determine the thicknesses of the layers of the new highway. The reflection times (t and Δt) and velocity (v) for each layer were determined. Then the thicknesses of the three layers (d) were calculated. The measurements determined by the GPR were compared with the actual project data given in Table 3.

Table 3. Comparison of actual project layer depths and GPR results

	Wearing Course	Binder Course	Bituminous Base
Reflection time (Δt) ns	1.6	2.0	2.2
Layer thickness determined by GPR (d) (cm)	5.6	7.0	8.75
Layer thickness of the project (cm)	5.0	8.0	11.0

As aforementioned, GPR surveys were conducted in the first year and the next year, after the building of highway. GPR images taken from the same highway section for two years are presented in Figure 7.

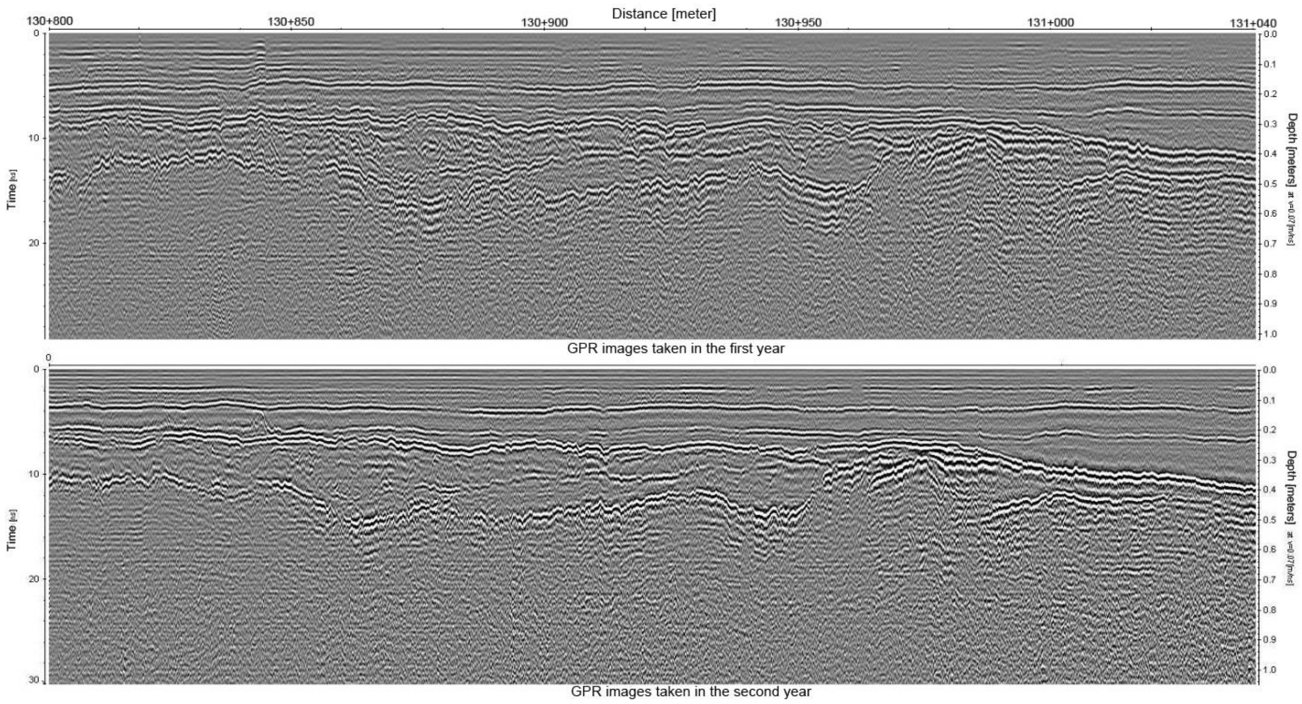

Figure 7. GPR images taken from the same highway section for two years.

When all of the images are examined after filtering, it is seen that some regions haven't a boundary between the wearing course and binder layer and between the binder and the bituminous base layer. In addition, the collapsed and swollen old highway layers are striking in the views (Figure 8).

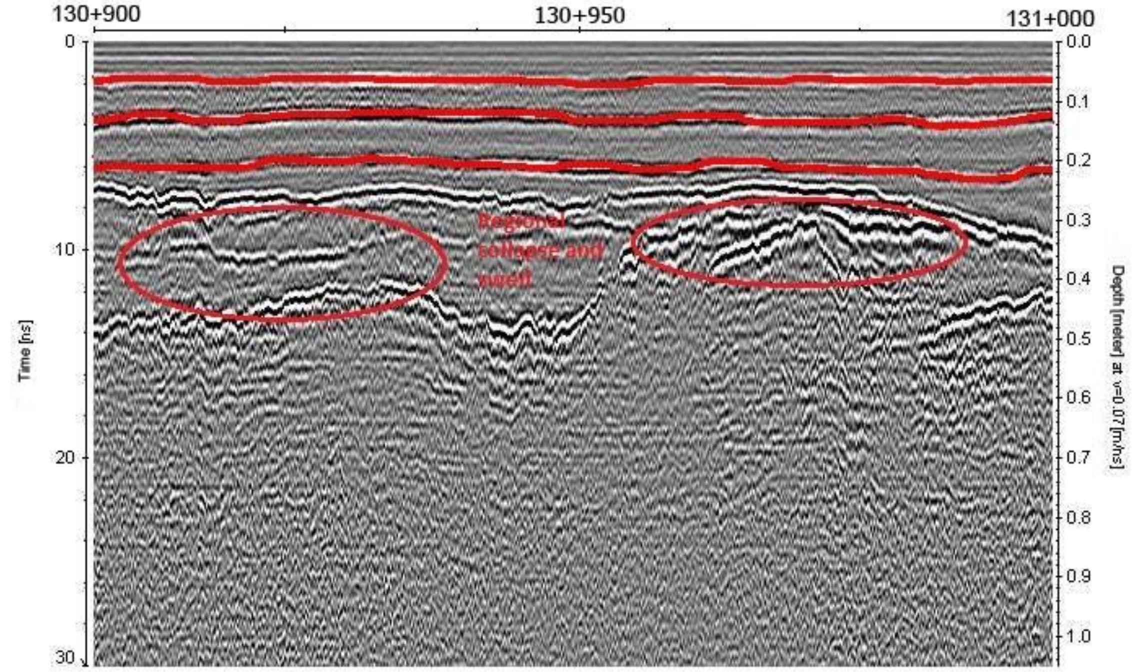

Figure 8. The distinction between layers and anomalies in layered structure (130+900-131+000 km).

Also, artifacts such as ditches, culverts and bridges on the route were clearly seen in the GPR images. The layers and layer changes of the natural ground were also seen below the old highway layer. When the figure below is examined, it can be seen that there is a clear collapse in natural ground (Figure 9).

Another important finding of all GPR images is the observation of obvious changes in layer thicknesses even at very short distances. The differences in the thicknesses of the layers due to the construction of the highway are standing out. These details provide important information to control the quality of highway in first and after years (Figure 10

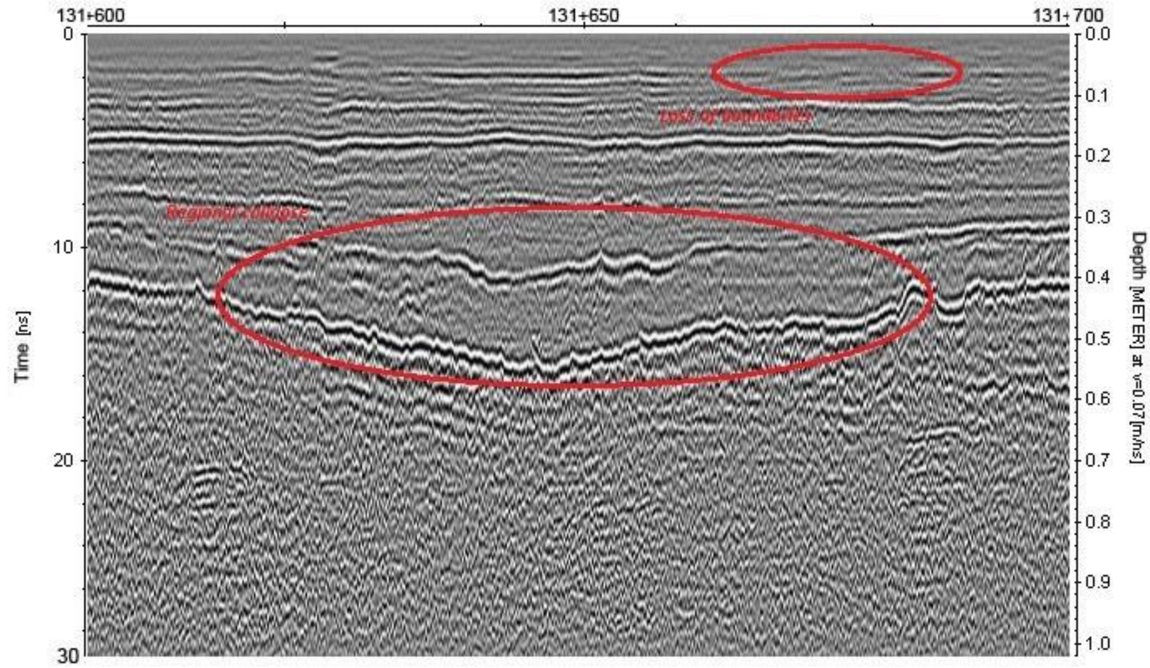

Figure 9. Anomalies in the layered structure (131+600-131+700 km).

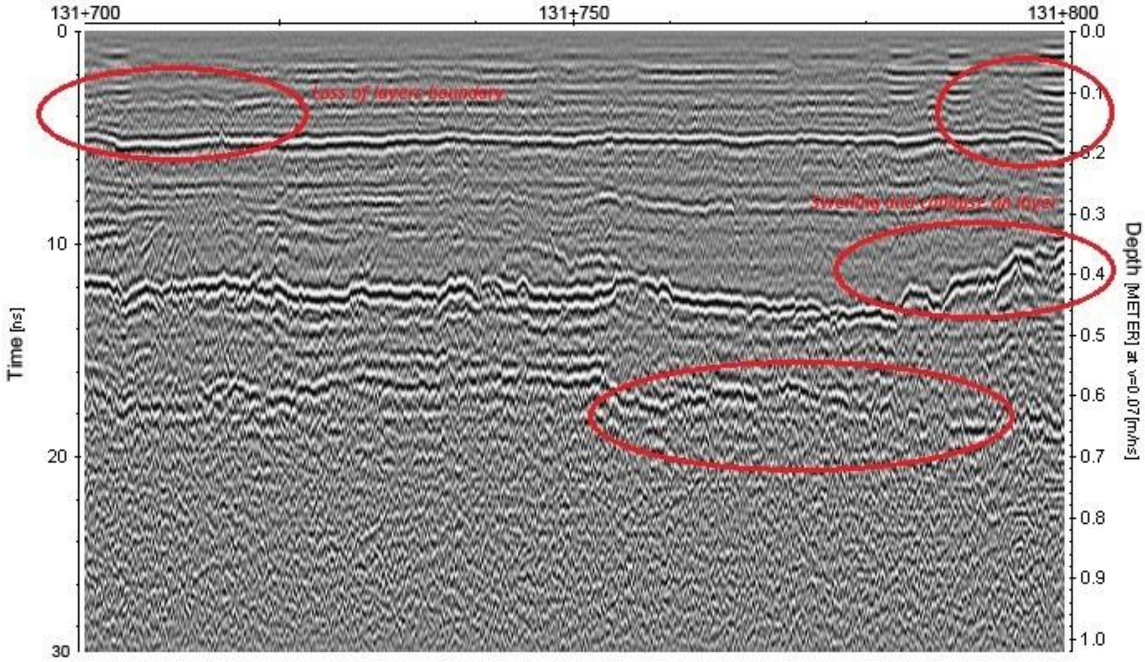

Figure 10. Anomalies in the layered structure (131+700-131+800 km).

When the images taken in the second year were carefully examined, collapses were observed in the lower layers. It was also found that the layers seen immediately below the plentmix layer were the old highway layers in the images obtained for every two years. It is clearly seen that these layers are damaged for the first and second year.

It is stand out that in the second year GPR images, the boundaries between the layers do not appear clearly in some highway sections. In addition, the layer thicknesses of some highway sections have changed due to the vehicle loads that have been passing by for a year.

4. Discussion and Conclusion

In previous studies with GPR, either the layer thicknesses on the highway were determined or the deteriorations in the pavement were determined. In this study, on the same highway section, both the layer thicknesses and the deteriorations on the highway are presented together. On the other hand, taking two measurements on the same highway with one-year intervals and comparative analysis distinguishes the research from other studies.

In this study, it is presented differences in the thicknesses of the layers by using GPR method. The results obtained from the study reveals that GPR method is suitable for determining layer thicknesses. The highway layers were scanned immediately after the reconstruction with 40 ns display speed up to 3.5 m depth by the help of different GPR antenna having 600 and 1600 MHz frequency. It is seen that the most suitable scanning frequency is 1600 MHz. It also helped to identify construction faults. These details provide important information to control of the highway quality for first and after years. Thus, it can be determined whether the layer thickness has been reached on planning the design or not.

In other respects, it was possible to determine if there was sufficient compaction in the layers. With this method, anomalies on the pavement layers and between these layers were also determined. In addition, this method is very useful to predict the highway defect location in advance. The deteriorations such as collapse and decomposition were detected with the data especially taken in the second year. Consequently, GPR is a non-destructive method that does not damage the highways and all these informations are easily presented to the user.

Acknowledges

This work was supported by Scientific Research Projects Coordinator of Suleyman Demirel University with the projects numbered 3408-D2-13 and 2666-M-10. The Authors also special thanks to COST (European COoperation in Science and Technology) Action TU1208 “Civil Engineering Applications of Ground Penetrating Radar”.

Declaration of Ethical Code

In this study, we undertake that all the rules required to be followed within the scope of the "Higher Education Institutions Scientific Research and Publication Ethics Directive" are complied with, and that none of the actions stated under the heading "Actions Against Scientific Research and Publication Ethics" are not carried out.

References

[1] Kim, S. W., Hyun, S. Y., Cho, J. H., & Kim, S. Y. (2011). GPR monitoring system for evaluation of asphalt pavement. Resistor, 900, 20.

[2] Wensel, M., Shalaby, A., Thiessen, M., & Mah, V. (2002, June). Investigation of asphalt pavement rutting at two Canadian airfields. In 4th Transportation Specialty Conference of the Canadian Society for Civil Engineering, Montreal, Canada.

[3] Spagnolini, U. (1997). Permittivity measurements of multilayered media with monostatic pulse radar. IEEE Transactions on Geoscience and Remote sensing, 35(2), 454-463.

[4] Solla, M., Lagüela, S., González-Jorge, H., & Arias, P. (2014). Approach to identify cracking in asphalt pavement using GPR and infrared thermographic methods: Preliminary findings. Ndt & E International, 62, 55-65.

[5] Brownlee, T. J., Finnie, S., & Wightman, D. (2007, August). Identification of potential highways maintenance schemes. In Proceedings of the Institution of Civil Engineers-Transport (Vol. 160, No. 3, pp. 139-146). Thomas Telford Ltd.

[6] Ferreira, A. J. L. (2011, September). Briefing: New developments in pavement maintenance. In Proceedings of the Institution of Civil Engineers-Municipal Engineer (Vol. 164, No. 3, pp. 153-155). Thomas Telford Ltd.

[7] Benedetto, A., & Pensa, S. (2007). Indirect diagnosis of pavement structural damages using surface GPR reflection techniques. Journal of Applied geophysics, 62(2), 107-123.

[8] Park, H. M., Kim, J. W., Hwang, S. D., & Lee, H. J. (2005). Determination of the layer thickness for long-life asphalt pavement. International Journal of Highway Engineering, 7(2), 23-31.

[9] Subagio, B. S., Cahyanto, H. T., Rachman, A., & Mardiyah, S. (2005). Multi-Layer Pavement Structural Analysis Using Method of Equivalent Thickness Case Study: Jakarta—Cikampek Toll Road. Journal of the Eastern Asia Society for Transportation Studies, 6, 55-65.

[10] Plati, C., & Loizos, A. (2013). Estimation of in-situ density and moisture content in HMA pavements based on GPR trace reflection amplitude using different frequencies. Journal of Applied Geophysics, 97, 3-10.

[11] Goel, A., & Das, A. (2008). Nondestructive testing of asphalt pavements for structural condition evaluation: a state of the art. Nondestructive Testing and Evaluation, 23(2), 121-140.

[12] de León Izeppi, E., Flintsch, G. W., & McGhee, K. K. (2008). High-speed, noncontact digital imaging system for inspection of hot-mix asphalt pavements. Journal of transportation engineering, 134(6), 246-254.

[13] Loizos, A., & Plati, C. (2007). Accuracy of pavement thicknesses estimation using different ground penetrating radar analysis approaches. NDT & e International, 40(2), 147-157.

[14] Morey, R. M. (1998). Ground penetrating radar for evaluating subsurface conditions for transportation facilities. Transportation Research Board.

[15] Saarenketo T. (1992). Ground Penetrating Applications in Road Desihn and Construction in Finnish Lapland. Geological Survey of Finland, Special Paper 15, pp. 161-167.

[16] Saarenketo T, Scullion T. (1994). Ground Penetrating Radar Applications on Roads and Highways. Research report 1923-2F, Texas Transportation Institute, College Station, Texas, 36 pp.

[17] Saarenketo T. (1997). Using Ground Penetrating Radar and Dielectric Probe Measurements in Pavement Density Quality Control. Transportation Research record 1997, pp. 34-41.

[18] Saarenketo T, Roimela P. (1998). Ground Penetrating Radar Technique in Asphalt Pavement Density Quality Control. Proceedings of the Seventh International Conference on Ground Penetrating Radar, May 27-30, 1998, Lawrence Kansas. 2, pp. 461-466.

[19] Saarenketo T, Scullion T. (2000). Road Evaluation with Ground Penetrating Radar, Journal of Applied Geophysics 43, 119-138.

[20] Saarenketo T. (2008). NDT Transportation. Chapter 13 in text book. Ground Penetrating Radar: Theory and Applications. Ed- Harry M. Jol. Publisher Elsevier, 524 p.

[21] Al-Qadi IL, Leng Z. Al Larkin, (2011). In-Place Hot Mix Asphalt Density Estimation Using Ground Penetrating Radar. Technical Report of Research, Federal Aviation Administration Under Cooperative Agreement, DOT 05-C-AT-UIUC, ICT Report No. 11-096.

[22] Colagrande, S., Ranalli, D., Tallini, M., (2011). Ground Penetrating Radar Assessment of Flexible Road Pavement Degradation, International Journal of Geophysics, Article ID 989136, doi:10.1155/2011/989136

[23] Ahmad. N. Lorenzl H., (2011). Crack Detection in Asphalt Pavements, How useful is the GPR?. Wistuba Braunschweig Pavement Engineering Center (ISBS), Technische Universität Braunschweig, 978-1-4577-0333-1/11/2011 IEEE

[24] Mardeni, R., Raja Abdullah R.S.A., Shafri, H.Z.M., (2010). Road Pavement Density Analysis Using A New Non-Destructive Ground Penetrating Radar System, Progress In Electromagnetics Research B, 21, 399-417.

[25] Al-Qadi IL, Wei Xie, Roger Roberts, (2008), Scattering analysis of ground-penetrating radar data to quantify railroad ballast contamination, NDT&E International 41, 441– 447

[26] Zhou, F., & Scullion, T. (2007). Guidelines for evaluation of existing pavements for HMA overlay (No. FHWA/TX-07/0-5123-2). Texas Transportation Institute, Texas A & M University System.

[27] Black, K., & Kopac, P. (1992). The application of Ground-Penetrating Radar in highway engineering. Public roads, 56(3).

[28] Morcous G, Erdoğmuş E. (2009). Use of Ground Penetrating Radar for Construction Quality Assurance of Concrete Pavement. NDOR Project Number P307, Final Report, Principal Investigators, University of Nebraska – Lincoln.

[29] Gordon, M. O., Broughton, K., & Hardy, M. S. A. (1998). The assessment of the value of GPR imaging of flexible pavements. NDT & E International, 31(6), 429-438.

[30] Serin S. (2014). Modelling of the Physical and Mechanical Properties of Flexible Pavements by Means of Non-Destructive Testing Methods. Süleyman Demirel University, Ph. D. Thesis.