International Journal of Engineering and Geosciences

https://dergipark.org.tr/en/pub/ijeg

e-ISSN 2548-0960

Determining the buried concrete amount using GPR/GPS combination method

Celalettin Uçar [*1], **Füsun Balık Şanlı** [2]

[1]*Turkish Airlines, Yesilkoy, Istanbul, Turkey*
[2]*Yıldız Technical University, Civil Engineering Faculty, Geodesy and Photogrammetry Department, Istanbul, Turkey*

Keywords
Concrete
GPR
NDT
EM Wave Field
GPS

ABSTRACT

This paper investigates the possibility of describing location based NDT (Non-Destructive Testing) samples for an officially finalized project of a buried concrete layer beneath the İstanbul-Millet Street, by the combination of high frequency GPR and CORS-GPS. For this purpose, field works and laboratory studies were performed. First, data acquisition was carried out over the asphalt surface along the construction route of the street. Reflected/scattered electromagnetic wave fields was studied over the processed radargram of the concrete layer. Hence, the upper and lower boundaries of buried concrete layer were determined as a value of depth and coordinate based on spatial dataset, where there was no information about the current amount of constructed concrete. According to the measurement results, the marked location of reflected/scattered wave field on the processed radargrams defined the newly constructed concrete layer. The vertical distance between upper and lower boundaries of the layer defines the thickness of concrete layer. All types of buried layers such as C-25 road concrete, plaster or asphalt have been extracted from the entire data using the amplitude differences.

1. INTRODUCTION

GPR (Ground Penetrating Radar) is a geophysics method, which is used in searching objects in shallow depth of Earth layers. In the light of the developments in the field of electronic engineering, during the last three decades, it is now more affordable, fast, and precision measure the speed of light, which was expensive and troublesome earlier. These developments not only provided to have precise measurements of the speed of light, but also provided researchers to be able to measure all the signals that are closely moving as fast as the speed of light underground in a detail of nanometre, and made it possible to reach accurate results in shallow geophysics. These studies and improvements lead to the GPR applications. GPR was first developed to measure the thickness of the ice. By the help of seismic data acquisition techniques, data that had been measured in natural ground conditions reached to the depth of 10-20 metres. Today, GPR method is widely used in researches of shallow ground and archaeometry. GPR, which was started to be used in mining and geologic studies in the beginning of 70's, was used to investigate shallow depths in 80's giving better resolutions with the 500 MHz -1GHz antennas. In the beginning of 1990s, low (10, 20 and 50 MHz) and high (2.5-3 GHz) frequency antennas were used in the working area (Millet Street). Finally, GPR was started to be used in the fields of studies related with the mining, stratigraphy, inspection of road covering, structures, constructions and water detection etc (Alp et al. 2003).

GPR method is based on the propagation of electromagnetic waves into the ground and recording the signals of those reflected waves that are back to the radar antenna as a function of time. As the signal of the radar propagates deeper, every chemical or physical change results in a different reflection of the energy back to the surface. This procedure goes on until the energy is attenuated. Reflections that are caused by variations in the ground layers occur according to the differences of electrical and magnetic features of all the reflective layers such as rocks, sediments, soil, and various mixtures of those, and change in rocks or stratigraphic differences in intensiveness in between layers. Radar reflections are produced while radar energies are getting through all the archaeological structures and layers surrounding them. Because all the structures; cemeteries, tunnels, burials and pipes, that the radar

* **Corresponding Author**

*(ucar_c@hotmail.com) ORCID ID 0000-0002-1742-4796
(fbalik@yildiz.edu.tr) ORCID ID 0000-0003-1243-8299

Cite this article

Ucar C & Sanlı F B (2022). Determining the buried concrete amount using GPR/GPS combination method. International Journal of Engineering and Geosciences, 7(1), 59-66

Research Article / DOI: 10.26833/ijeg.876310

Received: 07/02/2021; Accepted: 05/04/2021

came across, result in changes in the spreading of the radar waves, they produce significant radar reflections. Lots of wave forms that are overlapping each other are recorded as they were one serial in the same location of different depths. That is called the radar reflection trace of that location (Van Dam and Schlager, 2000).

While the resistivity of the underground structures increase, which means a decrease in conductivity, the quality of GPR images increase as well. The area of the target implementation area of GPR should be as dry as possible. Electromagnetic waves get into a fairly more conductive area when they reach to the level of underground water level. Relative di-electric permittivity contrast occurs at this specific humid level. It also occurs a decrease in dilatation of electromagnetic waves based on the absorption in high frequency content because of the sudden increase in the conductivity of the electricity (Alp et al. 2003).

Nowadays, GPR technology is used in various fields for different purposes such as;

Geographic studies, road condition inspection, remote detection from planes or satellites, pipe and tube inspection, ground research (road, airport, dam, water canal, settlement area research), tunnel research (railways, roads, tubes, mining gallery research), structure research (ceiling, ground and wall research, restoration research), archaeological research (antic city, temples, cemeteries, walls, base, galleries, and for finding similar historic remnants), industrial waste, leakage, and environmental pollution research (finding old or off record industrial waste areas, determining leakage in factories, gas stations, and water paths; waste discharge areas), searching old or off record city underground structures (finding old sewages, water paths, tunnels, tubes, shelters, electric and phone lines), mining research in ground and galleries (searching for mining in close to ground layers and improving reserves, coal search via exiling galleries, search targeted first aid in collapsed and mining diggings). (MTA Natural Resources Economy Bulletin, 2012)

There are several studies in the literature for each topic mentioned above that uses GPR technology such as; determining stratigraphic order close to the ground (Davis and Annan, 1989), determining geological units close to the ground (Koralay et al. 2007), mapping discontinuities as geological faults and fractures (Grandjean and Goury,1999; Green et al. 2003; Kadıoğlu et al. 2008), determining carstic emptiness (Kadıoğlu and Kadıoğlu 2006), determining underwater levels (Harrari 1996; Dannowski and Yaramancı 1999; Aspiron and Aigner 1999), researching liquid hydrocarbon close to the ground (Changryol et al. 2000). Besides these; in archaeological studies, finding temples, cemeteries, walls, base, and as such historical remnants (Sambuelli, et al. 1999; Daniels 2000; Hammon et al. 2000; Kadıoğlu et al. 2008), metallic item search, determining buried tubes underground, pipe lines, water or gasoline tanks and areas of old industrial waste (Kadıoğlu and Daniels, 2008), determining robustness of roads, railways, water tunnels, tubes, wall facades in mining galleries, searching degradations of areas and ores in galleries, to determine gallery headway directions, (Cardelli et al. 2003), searching archaeological sites and contexts from investigations into Roman era burial tombs in Egypt (Shaaban et al. 2009), detecting clandestine burials (Unterberger 1992; Mellett 1992; Miller 1996; Nobes 2000; Davenport 2001; Ruffell and McKinley 2005; Morgan and Bull 2007; Schultz 2007; Schultz andDupras 2008; Billinger 2009; Novo et al. 2011; Pringle et al. 2008), determination of the influence of soil parameters and sample density (Linck and Fassbinder 2013), near surface soil water content (Moghadas et al. 2014).

The purpose of this study is to determine buried concrete level under New-Jersey* productions which is bordering Bağcılar-Kabataş Light Metro Lines in Istanbul metropolitan city. This project went out to tender as a restoration of pavement for 1.803.797,25 USD to the contractor company by İstanbul Metropolitan Municipality under the law of tender on 7/12/2011, 540 number of the ruling of the court. As production is continuous for 24 hours per day, considering the traffic jam in the specific area, there seems unsatisfactory information about night productions. Therefore, it was decided in the beginning to search the level of the concrete by providing with destructive testing samples, however, the price of the authorized company of BIMTAS was 13.135,857 USD for destructive test at intended interval.

However, the amount of the payment to the company through model profile is 16.091,426 USD. Because the certain meterage of the production is not known, paying complete through model profile is considered to be a crime of public injustice, on the other hand paying deficient or any cut will also be a crime of misconduct and prejudice the company intentionally. Therefore, by preferring Non-destructive Testing Method, GPR-GPS combination measurements were done along the 5277 m at the pavement level in the path of New-Jersey. Then the data was analysed and 511 Non-destructive Testing samples acquired for the path. By the help of this method, the real thickness of the concrete construction was determined at a very short time period compared to the destructive testing method.

The difference of this study from others is, instead of destructive testing, by using Non-destructive Testing technique with GPR-GPS combination composed of CORS-GPS integration which has ± 0,02meter precision and GPR of 1200/1600 MHz central frequency system Mala Pro-Ex Series; to uncover the truth that a public law problem could be resolved at a much shorter time (5 days) and at a much lower cost (3.251,125 USD).

1.1 Preliminary Research

The main problem of research was distinguishing the new concrete construction part from non-concrete area, and determining the amount of concrete construction. Before surveying, model profile of the project was examined in order to decide for an appropriate location of profile line for the GPR surveying design. As a result of the preliminary works, it is understood that the New-Jersey borders are situated on the left and right sight of the Bağcılar-Kabataş Light Metro route as a double row. As can be seen in Figure 1, there are three different buried layers under the New-Jersey borders as asphalt (0,08m), plaster (0,07m) and concrete (0,10m). It is seen that the layer of buried C-16 class concrete layer is situated under the New-Jersey-asphalt and plaster (Figure 2). It was constructed on top of the C-25 class road concrete layer that already exists. So it has a variable thickness because of keeping the elevation on the road surface. When model profile of the project was studied, it is understood that concrete layer was produced as 60 cm wide, which is 15 cm wider than the New Jersey (45.5 cm wide) blocks.

As can be seen in Figure 2, it was understood that C-16 class concrete with an approximately 10 cm width is lying under the intersection line of the asphalt boundary and New Jersey border. Furthermore, the bottom depth of C-16 concrete layer is approximately 0,4 m under the surface. Because of this shallow depth, it was decided that the frequency of GPR system must be chosen as high as possible. Thus, it is aimed to differentiate C-16 concrete road layer from C-25 concrete by using the amplitude differences. After deciding on the spatial location of GPR profile, it was time to solve the second problem of the project, which was differentiation of concrete and non-concrete locations with the location based Non Destructive Testing (NDT) samples by using GPR-GPS combination methodology.

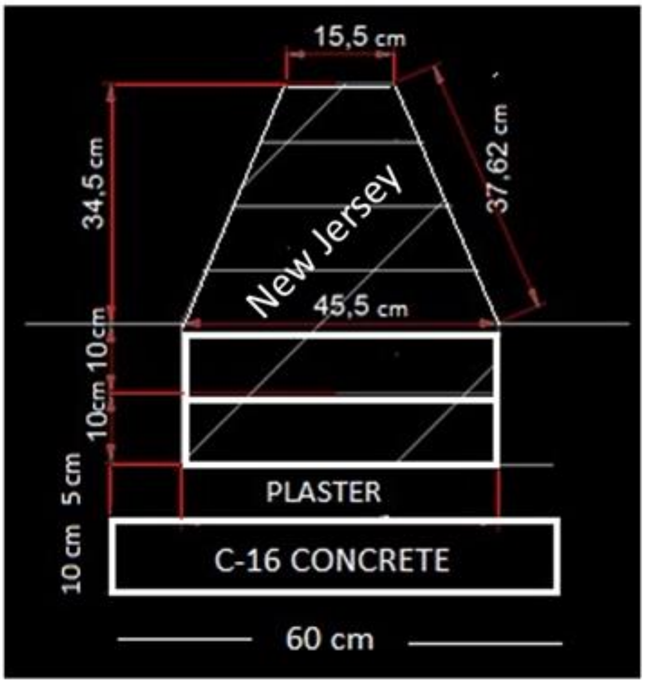

Figure 1. Model Profile of the construction project (Unit of length in centimetres)

Figure 2. New-Jersey borders and their boundaries, which used as a profile line

2. METHOD

Surveying was carried out on the Millet Street, which situated in Fatih region of İstanbul (Figure 3). The New Jersey border stone flooring construction, constructed on the boundaries of Bagcilar-Kabatas Light Metro, which was awarded and controlled by İstanbul Metropolitan Municipality with the responsibility of contractor company. According to the model profile of New-Jersey; the thickness of buried concrete layer must be 10 cm. The concrete layer was overlapped on the C-25 road concrete, to prepare a smooth surface for the flooring of New-Jersey borders. Despite the width of concrete construction is stable, the thickness of concrete could not be constructed as 10 cm that is stated in a project standard due to the variations of the elevation of C-25 road concrete layer. Since, it was a 24 hours' nonstop work, it was impossible to follow night time production by classic surveying methods such as geometric levelling, trigonometric levelling, or any other optic based surveying methods. So, the real volumetric amount of concrete construction could not be calculated.

The primary objective of the study is to detect the concrete construction whether it exists or not, and to determine the value of concrete thickness with spatial location of detected concrete layer. In order to reach this goal, GPR/GPS combination technique was used for determining the amount of concrete and defining the coordinates of the non-destructive testing samples' position. Mala-ProEX series GPR system with a compatible 1200/1600 MHz antenna unit was integrated with Trimble R-8 series CORS-GPS system for achieving the synchronized data acquisition. Using this combined system, previously defined 36 GPR profiles are precisely positioned on the map (Figure 3).

As a result of velocity analysis, the electromagnetic wave velocity of field was measured at 0,0995 m/ns. The radargrams of the sample profiles indicating the concrete layer is depicted in Figure 4 and Figure 5.

Figure 3. Profile lines on left and right sight of the Millet Street - Fatih region of İstanbul

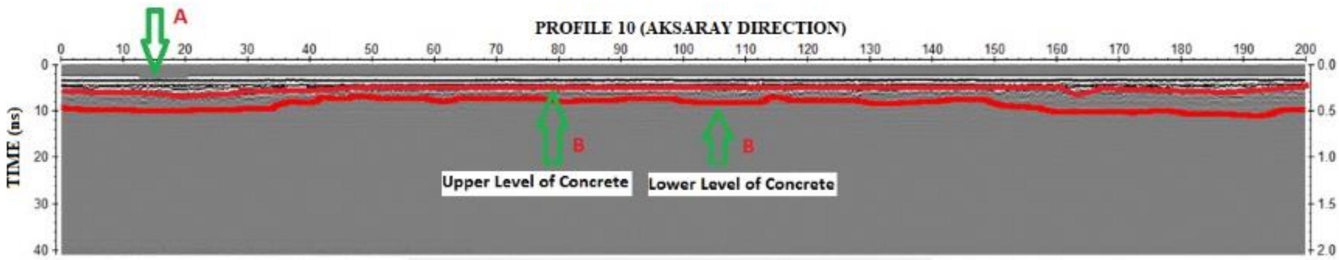

Figure 4. New concrete construction was detected on entire radargram of profile 10 - Upper and lower boundaries of the concrete layer – Amplitude Scale - Direct Propagating Wave Field (A) – Reflected/Scattered Wave Field (B)

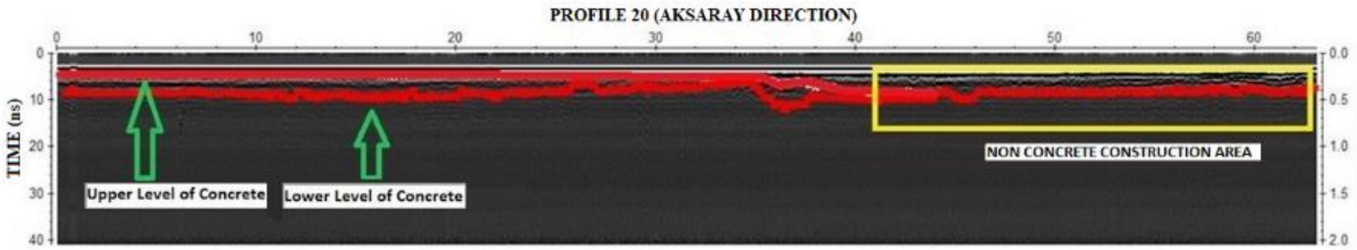

Figure 5. Boundaries of new concrete construction and non-concrete construction area shown on the radargram of profile 20

2.1. Data Processing

Reflex-Win v.3.5 (Sandmeier 2004) software was used for the collected data processing.

The order of applied data processing steps are;
1) Time Zero Correction,
2) Dewow,
3) Substracting Average,
4) Gain,
5) Frequency Band Pass,

Formations of the field generates artificial reflection anomaly deep down the surface, which has different contrast of formation. These effects were eliminated from the collected data using a special logarithmic negative amplitude functions. In this way, shadow effect of metal plumbings and equipment elements could have been removed. In final step of the data processing, migration filter used for determining the boundaries of concrete layer. CORS-GPS unit integrated with the GPR and the GPR/GPS combination model was used for data collection Horizontal positioning error measured as ±2 cm for CORS-TR referenced GPS system. Reflex-Win software used for the data integration between GPR and GPS. As a result of velocity analysis, the electromagnetic wave velocity of concrete layer was calculated as 0,0995 m/ns.

Electromagnetic wave velocity of hyperbola was verified with super positioning with another hyperbola anomaly, which has a known velocity as mathematically.

Radargram's velocity and time period data was used to calculate the depth information as;

$$d = (v \times t)/2 \quad (1)$$

d: Distance; v: Velocity; t: Time

On the processed 2D radargrams, horizontal axis direction and vertical axis direction correspond to the distance and the roundtrip time period of the signal, respectively (Figure 4). Since the working area is one of the busiest streets in İstanbul, surveying was started at 00:30 am in 25.04.2015 assuming that the traffic density would be relatively less in the night. The surveying was delayed on 26.04.2015 for avoiding the negative effects of heavy rain on measurement result. It was started again on 27.04.2015 at 00:30 am and completed in the same day. A flashing vehicle was used as a security precaution to ensure the safety of surveying team during the period from 25.04.2015 to 27.04.2015 (Figure 6). In this study the location, size and variety information of buried layers/objects were determined from radargrams gathered using GPR and GPS data (Figure 7).

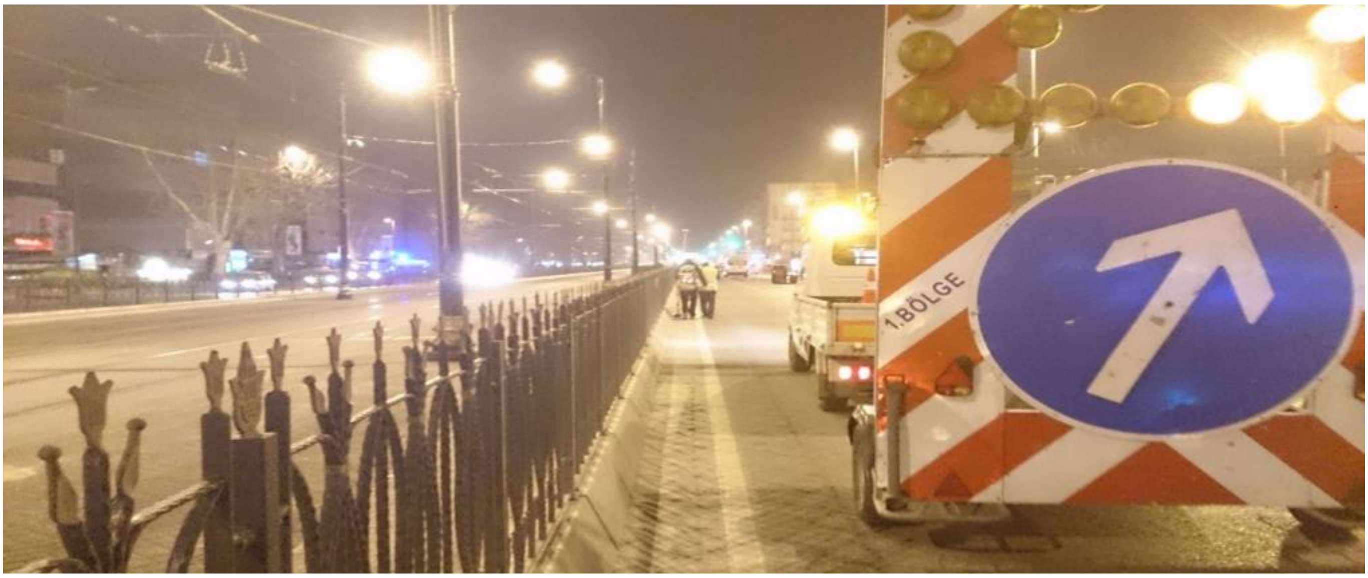

Figure 6. Flashing vehicle was used as a security precaution during the study

3. RESULTS

GPR and GPS data are used together for determination of radargrams, which obtained as a result of the study (Figure 7).

The average distance between upper and lower boundaries of concrete layer is measured on radargrams using the same amplitude value of radar trace to determine the varying thickness of concrete layer of radargrams in the processing step. The main goal of the study is determining the vertical average thickness of target object point on the concrete layer picked on the radargram. The measurements have a horizontal position error caused by the distance between transmitter and receiver antennas as theorically, however, this horizontal error in decimetre level is ignored in this study.

On the other hand, there is no vertical geometric deviation in the depth of concrete layers in different profiles i.e., same depth values were measured on the consecutive profiles on the intersection lines. Amplitude and polarity research are the most effective method ever for classifying the buried layers. If amplitude/reflected wave is positive, the polarity will be positive. If the first value of amplitude is negative, the polarity will be negative. First, electromagnetic wave's polarity must be determined to get the polarity of field (A), which shown in Figure 4. If the amplitude value of direct propagating wave field is positive at zero time, the polarity will be positive. If it is negative on the scale of amplitude, the polarity will be negative. So that, the polarity of direct propagating wave was determined positive as result of the laboratory analysis of our study. Next step of the study is defining the polarity of electromagnetic waves reflected/scattered from buried objects. The value of amplitude was found on amplitude scale table. If the polarity of direct propagating wave is same with reflected/scattered wave polarity, the polarity will not change. On the other hand, if the polarity of direct propagating wave is different from the polarity of reflected/scattered wave, the polarity will change. Searching the amplitude constant of the wave reflected from concrete layer, is the easiest way to explain why the polarity is the same or not.

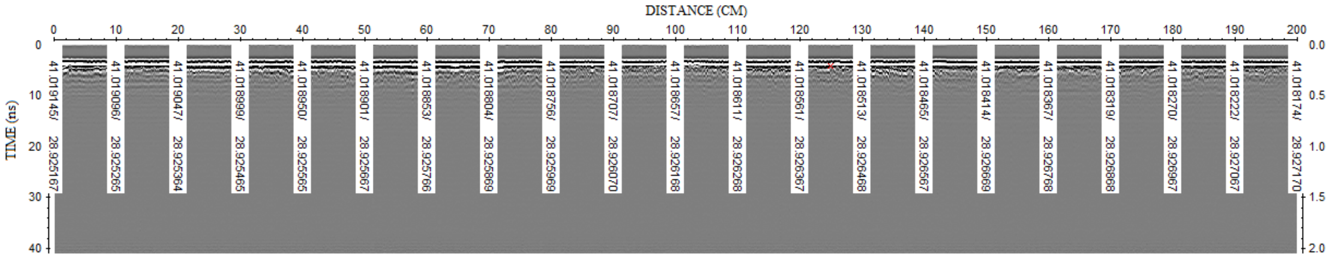

Figure 7. Radargram sample of a GPR/GPS combination

Reflection constant for a direct wave is defined with equations given below (Annan 2000).

$$R = \frac{V2-V1}{V2+V1} = \frac{\sqrt{\mathcal{E}1}-\sqrt{\mathcal{E}2}}{\sqrt{\mathcal{E}1}+\sqrt{\mathcal{E}2}} \tag{2}$$

V1 and $\mathcal{E}1$ represent the velocity and the di-electric constant of the electromagnetic wave of field, respectively. V2 and $\mathcal{E}2$ represent the velocity and the di-electric constant of electromagnetic wave for concrete layer, respectively.

As soon as the propagating waves hit the concrete layer, the wave is scattered/reflected back with an amplitude calculated as the multiplication of propagating wave's amplitude and the reflection constant, and then recorded for all receiver points as a function of arriving time. These scattered/reflected waves are also called as electromagnetic wave fields. If the velocity of electromagnetic wave in concrete layer is higher than the velocity of wave in field, the reflection constant will be positive. In this case, there will be no change on the polarity of reflecting/scattering wave, and then it will be the same as the polarity of direct propagating wave. On the contrary, if the velocity of electromagnetic wave in field higher than the velocity of concrete layer (V1>V2), then polarity of reflected/scattered wave will change to negative values. Defining the amplitude values and polarity of reflected/scattered wave field is the most effective method for the classification of buried layer. Electromagnetic wave in fields is usually less than the velocity of electromagnetic wave within the concrete. It is known that, the wavelength of an electromagnetic wave of 1000 MHz is 0.122 m in the concrete layer with the RDP value of 6 (Conyers L B 2004). Since the concrete has a higher velocity then the velocity of other layers (such as dry sand and asphalt) in the field, theoretically a polarity change in the concrete layer is expected. Hence, the overlapped concrete layer in the field, which was 0,26-0,45 m deeper from the surface, has a higher amplitude and a contrast (-) polarity as compared to the other layers. In this study, for distinguishing the concrete layer from different type of layers, amplitude and polarity differences were also used.

In this study, for the purpose of NDT the spatial location based radargram samples were generated for the buried concrete layer. Radargrams were determined asa result of multiplying the amplitude by reflection constant, hence the amount of reflected/scattered energy could be determined for the arriving time of direct propagating wave to the concrete layer, which was recorded as a time function, and position based radargram samples. Although there is no negative interactive field such as decomposition zone or electromagnetic wave absorber, it was also detected too many buried installations, which was affecting the condition of measurement under the ground surveying. Such irrelevant elements or objects, which are out of focus, were removed from the results of radargram analysis in the processing steps, and focused only on to the research of the concrete layer. The average depth could be measured as 1.6 m at the end of the data processing steps by applying the filters to the radargrams, elevation correction and eliminating the exterior effects from the measurement.

Upper level of concrete layer on the 2D radargrams, which continued in a row, was picked using manual and automatic phase fallow method to check the contract layers' depth and geometry on successive radargrams.

As the result of GPR analysis; C-16 concrete layer was detected through the area, which situated under the New-Jersey borders and the layer has a variable thickness between 0,07 to 0,15 meter.

Another high amplitude layer was detected between the depth of 0,3 – 0,4 meter, which is overlapping with some part of the C-16 concrete layer, and it has the same amplitude value and polarity. It is interpreted as an old road concrete layer belonging to the C-25 concrete class. According to the model profile of the project C-16 concrete, layer takes place between the depths of 0.15-0.25 m. As the concrete layers with irrelevant depth related with the old C-25 concrete layer, it was removed from the results.

Buried concrete layer of 4900 m was detected/mapped along the 5277,56 m surveying profile. This means, no concrete layer was detected on 377,2 (5277,2-4900= 377,2) meter part of the total surveying profile. However, the 735 (15%) meter part of this 4900 meter concrete layer detected in the depth of 0,5 meter was belonging to the C-25 road concrete, which was constructed in the past as defined previously. So, there is no new concrete construction in the 735 meter part of the profile.

As a result, the length of new concrete construction in the effective research depth (0,4 m) on Millet Street was calculated as (4900-735) = 4165 meter. Average thickness of concrete layer was calculated as 13,47 cm with using the 511 Non-destructive Testing samples that were generated on the profile line with 10 meter intervals (Figure 8).

Figure 8. NDT samples on the GPR surveying line

GPR/GPS combination method helps to improve accuracy of locations of all NDT samples, ±2 cm horizontal positioning error in UTM coordinates.Due to having same amplitude value and relative di-electric permittivity (RDP) of C-25 and C-16 concrete layers, the average thickness of new concrete construction (C-16) could be measured with ±3 cm vertical precision. Since the average thickness of concrete layer is calculated as 13,47 cm, ±3 cm vertical measurement precision, the thickness of concrete is varying between 10,47 cm and 16,47 cm. Thus, the minimum value (10,47) is enough to verify the existence of the new concrete construction. Because the concrete layer is defined as 10 cm on the approved model profile of construction project. Instead of minimum concrete thickness (10,47 cm) calculated from radargram analysis, the controller engineering group of Istanbul Metropolitan Municipality calculated the amount of the payment to the construction company based on the model profile as 10 cm, for the use of public interest. The aim of the C-16 concrete construction was preparing a smooth area for flooring the New-Jersey borders. So the width of construction on the model profile is 0,6 meter. Finally, all the parameters are ready for calculating the volume of concrete construction as;

$$4165 \text{ m (Length)} \times 0{,}6 \text{ m (Width)} \times 0{,}10 \text{ m (Thickness)} = 249{,}9 \text{ m}^3$$

In this study; the amount of buried concrete construction, which could not be measured by classical surveying methods in the construction duration, is determined by this research. The result of the calculation is used for defining the amount of payment to the company. Furthermore, profile lines and Non-destructive Testing samples were attached an official document to the project folder for the first time.

4. CONCLUSION

The results of this study help to improve calculation accuracy for the amount of buried concrete construction using Non-destructive Testing technique (GPR) combined with CORS-GPS. By the help of this study, the certain level of the concrete construction was determined in a very short time efficiently and economically compared to the destructive testing method. Thus, it was prevented the unlawful profit or the loss of contractor in the judicial process according to the public law. Additionally, a public law problem could be resolved at a much shorter time i.e. in 5 workdays instead of 20 workdays, and at a much lower cost i.e. 3.251,125 USD instead of 13.004,500 USD comparing with destructive testing method. Since the actual concrete distance was found, the payment was done for 4165 m instead of 5277.56 m for buried concrete layer.

As a case study, location-based NDT samples generated for the first time for determining the volume of buried concrete layers using GPR-GPS combination methodology in Istanbul Metropolitan Municipality.

Author contribution

Celalettin UÇAR: Supervisor, Conceptualization, Methodology, Software. **Fusun BALIK SANLI**: Data curation, Writing-Original draft preparation, Validation.

Conflicts of interest

The authors declare no conflicts of interest.

REFERENCES

Alp K, Gelişli K, Yılmaz A O, Kaya R & Çavuşoğlu (2003). Mermer İşletmeciliğinde Yer Radarı Uygulamaları, MRSEM, Türkiye IV. Mermer Semposyumu. Bildiriler Kitabı, 37-48.

Annan A P (2000). Ground Penetrating radar workshop notes, Sensors and Software Inc., Canada.

Aspiron U & Aigner T (1999). Towards realistic aquifer models: Three dimensional georadar surveys of Quaternary gravel deltas (Singen Basin, SW Germany), Sedimentary Geology, 129, 281-297.

Billinger M S (2009). Utilizing ground penetrating radar for the location of a potential human burial under concrete, J of Forensic Sciences, 42(3), 200-209.

Cardelli E, Maronne C & Orlando L (2003). Evaluation of tunnel stability using integrated geophysical methods, Journal of Applied Geophysics, 52, 93-102.

Changryol K, Daniels J J, Guy E, Radzevicius S J & Holt J (2000). Residual hydrocarbons in a water-saturated medium: A detection strategy using ground penetrating radar, Environmental Geosciences, 7(4), 169-176.

Conyers L B (2004). Ground Penetrating Radar for Archaeology-Altamira Press-ISBN 0-7591-0772, 23-55.

Daniels J J (2000). Ground penetrating radar for imaging archeological objects in the subsurface, Proceedings of the New Millennium International Forum on Consideration of Cultural Property, Kongju, Korea, 247-265.

Dannowski G & Yaramancı U (1999). Estimation of water content ant porosity using combined radar and geoelectric measurements, European Journal of Environmental and Engineering Geophysics, 4, 71-85.

Davenport G C (2001). Remote sensing applications in forensic investigations, Historical Archaeology, 35(1), 87-100.

Davis J L & Annan A P (1989). Ground Penetrating Radar for high resolution mapping of soil and rock stratigraphy,Geophysical Prospecting, 37, 531-551.

Grandjean G & Gourry J C (1999). GPR data processing for 3D fracturemapping in a marble quarry (Thassos, Greece), Journal of Applied Geophysics, 36, 19-30.

Green A, Gross R, Holliger K, Horstmeyer H & Baldwin J (2003). Results of 3-D georadar surveying and trenching the San Andreas Fault near its northern landward limit,Tectonophysics, 368, 7-23.

Hammon W S, McMechan G A & Zeng X, Forensic (2000). GPR: finite-difference simulations of responses from buried human remains,Journal of Applied Geophysics, 45(3), 171-186.

Harrari Z (1996). Ground penetrating radar (GPR) for imaging stratigraphic features and groundwater in sand dunes, Journal of Applied Geophysics, 36, 43-52.

Kadıoğlu S & Daniels J J (2008). 3D visualization of integrated ground penetrating radar data and EM-61 data to determine buried objects and their characteristics,Journal of Geophysics and Engineering, 5, 448-456.

Kadıoğlu S & Kadıoğlu Y K (2006). Yer radarı yöntemi ile bir mermer sahasındaki kırıkların, sağlam ve bozuk alanların belirlenmesi, Selçuk Üniversitesi, Mühendislik Mimarlık Fakültesi Dergisi, 2(1-2), 127-135.

Kadıoğlu S, Kadıoğlu Y K & Akyol A A (2008). Geoarchaeological research of the mid-Age Ilyasbey Complex buildings with ground penetrating radar in Miletus, Aydın, Western Anatolia, Turkey. Donald Harrington Symposium on the Geology of the Aegean, IOP Conference Series: Earth and Environmental Science, 2, published online.

Koralay T, Kadıoğlu S & Kadıoğlu Y K (2007). A new approximation in determination of zonation boundaries of ignimbrite by ground penetrating radar: Kayseri, Central Anatolia, Turkey, Environmental Geology, 52(7), 1387-1397.

Linck R & Fassbinder J W E (2013). Determination of the influence of soil parameters and sample density on ground-penetrating radar: a case study of a Roman picket in Lower Bavaria, ArchaeolAnthropol, 6, 93-106.

Mellett J S (1992). Location of human remains with ground penetrating radar, Fourth international conference on ground penetrating radar. Geological Survey of Finland Special Papers, 16, 359-365.

Miller P S (1996). Disturbances in the soil: Finding buried bodies and other evidence using ground penetrating radar, Journal of Forensic Sciences, 41(4), 648-652.

Moghadas D, Jadoon K Z, Vanderborght J, Lambot S, Vereecken H (2014). Estimation of the near surface soil water content during evaporation using air-launched ground-penetrating radar, Near Surface Geophysics, 12, 623-633.

Morgan R M & Bull P A (2007). Forensic geoscience and crime detection: Identification, interpretation and presentation in forensic geosciences, Minerva Medicolegale, 127, 73-89

MTA Doğal Kaynaklar ve Ekonomi Bülteni (2012).

Nobes D C (2000). The search for "Yvonne": A case example of the delineation of a grave using near-surface geophysical methods, Journal of Forensic Sciences, 45(3), 715-721.

Novo A, Lorenzo H, Rial F I & Solla M (2011). 3D GPR in forensics: Finding a clandestine grave in a mountainous environment, Forensic Science International, 204(1-3), 134-138.

Pringle J K, Jervis J, Cassella J P & Cassidy N J (2008). Time-lapse geophysical investigations over a simulated urban clandestine grave, J of Forensic Sciences, 53(6), 1405-1416.

Ruffell A & McKinley J (2005). Forensic geoscience: Applications of geology, geomorphology and geophysicst criminal investigations, Earth-Science Reviews, 69. 235-247.

Sambuelli L, Socco L V & Brecciaroli L (1999). Acquisition and processing of electric, magnetic and GPR data on a Roman site (Victimulae, Salussola, and Biella), Journal Applied Geophysics, 41, 189-204.

Sandmeier K J (2004) Scientific Software, REFLEXW ver.3.5 program for processing and interpretation of reflection and transmission data.

Schultz J J & Dupras T L (2008). The contribution of forensic archaeology to homicide investigations, Homicide Studies, 12(4), 399-413.

Schultz J J (2007). Using ground-penetrating radar to locate clandestine graves of homicide victims, Homicide Studies, 11(1), 15-29.

Shaaban F A, Abbas A M, Atya M A & Hafez M A (2009). Ground-penetrating radar exploration for ancient monuments at the Valley of Mummies -Kilo 6, Bahariya Oasis, Egypt, Journal of Applied Geophysics, 2, 194-202.

Unterberger R R (1992). Ground penetrating radar finds disturbed earth over burials, Fourth international conference on ground penetrating radar, Geological Survey of Finland Special Papers, 16, 341-357.

Van Dam R I & Schlager W (2000). Identifying causes of ground-penetrating radar reflections using time-domain reflectometry and sedimentological analysis, Sedimentology, 47, 435-449.