Informes de la Construcción
Vol. 75, 569, e476
enero-marzo 2023
ISSN-L: 0020-0883
https://doi.org/10.3989/ic.89444

Applications of ground penetration radar geophysical technology together with infrared thermography, ground electromagnetic survey and other complementary technologies, in construction. Limitations and possibilities

Aplicaciones de la tecnología geofísica de georradar junto con la termografía infrarroja, el perfilómetro y otras tecnologías complementarias, en la construcción. Limitaciones y posibilidades

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ABSTRACT

Georadar technology has proven to be highly effective in the diagnosis and analysis of soils and the most diverse applications thanks to its effectiveness and non-destructive characteristics. This article describes and analyzes the use of georadar technology supported by other complementary ones, such as the ground electromagnetic survey, infrared thermography, infrared photography and multispectral photography, all of them used together for a common objective in concrete examples related to the field of the construction. Subsequently, the characteristics of the construction systems and the environment that can condition the effectiveness of the results and reduce the advantages of the joint use of the different systems are analyzed, which will allow future actions to adjust the scope of the objectives, optimize the advantages the complementarity of the different systems and, therefore, will open a range of possibilities for future use.

Keywords: georadar; ground penetretion radar; ground electromagnetic survey; electromagnetic profiler; construction analisis; non-invasive diagnostic systems in constructions.

RESUMEN

La tecnología del georradar se ha probado de gran eficacia en la diagnosis y análisis de suelos y las más diversas aplicaciones gracias a su efectividad y sus características no destructivas. El presente artículo describe y analiza la utilización de la tecnología del georradar apoyada en otras complementarias, como son el perfilómetro, la termografía infrarroja, la fotografía infrarroja y la fotografía multiespectral, empleadas conjuntamente en ejemplos concretos de análisis de construcciones con objetivos relacionados con la detección y diagnóstico de deficiencias en los proyectos. Posteriormente, se analizan las características de los sistemas constructivos y del entorno que pueden condicionar la efectividad de los resultados y merma las ventajas de la utilización conjunta de los distintos sistemas, lo que permitirá en futuras actuaciones ajustar el alcance de los objetivos, optimizar las ventajas de la complementariedad de los distintos sistemas y, por tanto, permitirá abrir un abanico de posibilidades de utilización futura.

Palabras clave: *georradar; perfilómetro; análisis de las construcciones; sistemas de diagnóstico no invasivos; building pathologies management.*

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Cómo citar este artículo/*Citation:* Adolfo García Ruiz-Espiga, Luis Avial Bell, Manuel José Soler Severino (2023). Applications of ground penetration radar geophysical technology to-gether with infrared thermography, ground electromagnetic survey and other complementary technologies, in construction. Limitations and possibilities. *Informes de la Construcción,* 75(569): e476. https://doi.org/10.3989/ic.89444

Recibido/*Received*: 13/05/2021
Aceptado/*Accepted*: 09/06/2022
Publicado on-line/*Published on-line*: 23/03/2023

1. INTRODUCTION

The georadar is included among the non-destructive techniques used in construction, among other sectors, which allows the analysis and identification of parameters with a greater degree of efficiency, and which is experiencing a moment of study due to its wide possibilities (1).

Also called Terrestrial Penetration Radar or Ground Penetration Radar (GPR), it is a system based on the measurement of the transmission of ultra-wide band electromagnetic waves (2), in the range between 10 MHz and 2.6 GHz, in the materials being analyzed. A part of the electromagnetic wave that the system emits is reflected when approaching areas of the analyzed material where changes in its electrical properties take place. This reflected signal is recorded in the system and logged by the operator for later analysis.

The history of the georadar begins in 1904, when Christian Hülsmeyer developed the first patent on radar technology. Already in 1910 Gotthelf Leimbach and Heinrich Löwy applied this technology to locate buried objects in the subsoil, patenting a system that used surface antennas together with continuous wave radar. The system had a substantial advance when in 1926 Dr. Hülsenbeck developed and patented a pulse radar system, which allowed a significant improvement in the resolution of the results and in the depth of the range of the system, so we can say that it is the basis of current systems.

The use of the system had an example of relevance in 1929, when W. Stern measured the depth of a glacier in Austria (3). Although since then there were no noteworthy uses, until the 1970s its use for military applications was promoted, such as the location of tunnels in the demilitarized zone between the two Koreas, and later. Later the system began to be used in civil issues , such as the location and drawing up of plans for infrastructure and public services in the subsoil of cities as well as the expansion of their use for detection of ground water or saline deposits

Rodriguez Abad (4). establish the market entry of the first affordable GPR systems in the 1980s. However, today most GPR systems are designed for surface applications, where both the transmitter and the receiver are above the ground. of the surface to be analyzed, although there are systems that can be introduced into wells for analysis of grater depths.

This paper aims to analyze projects carried out by the company Falcon High Tech, a company highly specialized in the use of various technologies that, together, complement their results by leveraging of the various advantages of each of the systems to improve the scope of the final results. The analysis of these results allows us to establish parameters that limit the scope and therefore possible uses in the construction sector

2. PRINCIPLES OF DETECTION OF MOISTURE AND CAPS IN CONSTRUCTION STRUCTURES

Before studying the different technologies, it is necessary to summarize some concepts that support the principles on which the operations of the different systems are based.

Conductivity in materials is the ability they have to allow electric current to pass through them. It is also defined as the natural property characteristic of each homogeneous environment that represents the ease with which electrons (and holes in the case of semiconductors) can pass through it.

The electrochemical activity caused by electrolytes, which circulate in materials, is the basis for electromagnetic methods, both self-potential and induced polarization (5). The dielectric constant indicates the capacity of sedimentary material to hold electrical charge and partially determines the response of formations to high-frequency alternating currents introduced into the sample through inductive or conductive methods. Anomalies and incoherent elements of different conductivities, found on the surface or within a structure, affect the direction and intensity of the field that generates the transmitted electromagnetic signal. Around these anomalies in the structure of materials, a distortion or weak secondary field is generated, which is measured and analyzed, in order to be able to interpret the data obtained, for the location, for example, of cracks, holes or anomalous materials, that may contain water inside. This method allows very varied depths of investigation, ranging from a few centimeters to several meters (6).

At present, geophysical methods are the main procedures for prospecting and detecting anomalies in structures involving air or water. The chosen technique depends fundamentally on the environmental context and the materials to be used.

To know the conductivity of water you have to know what type of water we are talking about. Pure water, H_2O, does not conduct electricity. However, practically all the water with which we are in contact (in the tap, mineral, rain, sea ...) is water with a solution of salts in different concentrations. Since the salts within the water have the ability to carry electrical energy (7), it does conduct electricity. And given this very direct relationship between salinity and conductivity, the later can even be used to measure the salinity of water.

3. TECHNOLOGIES USED IN DETECTION AND ANALYSIS. FUNDAMENTALS AND PROCEDURES

Next, we analyze the technologies that will be used in the projects, both the main one, such as the georadar, and others complementary to the first, such as thermography, infrared aerial photography, multispectral and electromagnetic profiler.

3.1. The georadar (GRP)

Ground Penetrating Radar technology is based on the transmission and reflection of electromagnetic waves, that is, on their emission and subsequent reception of the different reflections that the different materials which make up the object studied.

This technology uses a balanced matrix for a pair of bistatic antennas, which allows combining the results on a grid at a fixed distance. The matrix results in a high resolution definition of the structures of different materials (8), which grants, together with geopositioning systems, greater precision in the situation of the results in plane when joining it with CAD systems or even BIM. In order to initially estimate what is to be analyzed, we must first take into account some parameters of great importance, such as the dielectric constants of the materials that we can expect to make up the sample, the size of the analysis area, the depth of the area that we intend to study and the resolution that we will need to achieve.

Once the general parameters have been established, such as the dielectric constants of the materials that we can expect the sample is made up, the size of the analysis area, the depth of the area that we intend to study and the resolution that we will need to achieve, we must proceed to choice of the most suitable antenna frequency for the objective we intend to obtain, since the lower frequency counts greater depth of penetration, but at the cost of a decrease in the resolution of the results.

When finding a zone with different electromagnetic characteristics, part of these waves are reflected and captured by the antenna. Given the cone shape of the pattern emitted by the transmitting antenna, the areas that extend with respect to the vertical will arrive with a greater delay, reflecting data that will appear to be of deeper than its reality (9). This is the case of the cylindrical objects reflection, which are represented in the trace with a hyperbolic image, in which the extremes are the records of the rebounds around the path or the antena.

The horizontal resolution of the GPR will depend fundamentally on the wavelength of the antenna used, in such a way that a 200Mhz antenna achieves a low resolution at depths of up to 10m, while a 2.4 Ghz antenna achieves a very high resolution, which reaches 20,000 points per square meter, although its penetration capacity decreases, being in this case below 0.5m (10). In these traces the diagrams of the response or rebound times are shown, which is directly related to the speed at which the waves are transmitted in the material, the depth of the detected discontinuity, as well as the difference between the electromagnetic parameters of the material and those of the one that motivates the discontinuity. In recent years, there has been an advanced development in high-resolution antennas, reaching equipment that works in frequency ranges of up to 6 GHz. However, said equipment maintains a minimum penetration capacity, around 20 cm, for what commercial equipment maintains the maximum range between 30-50 MHz.

Regarding the representation, the georadar uses electromagnetic pulses of very short duration, 1-60 nanoseconds (ns = 10-9 seconds), in the VHF / UHF band (20-1000 MHz), which are repeated with a frequency of 50 KHz. These impulses are grouped into wave packets made up of 1,000-15,000 of them. When these impulses are generated by means of the transmitting antenna, these impulses, in their trajectory through the subsoil, may encounter a change in the geological stratum, a construction, cavities, objects, humidity or water table levels, etc.; In short, although other factors such as density and relative humidity also influence , what they detect is mostly a change in the electrical properties (dielectric constant) of the media in which they propagate. This causes part of the energy to be reflected and collected by the receiving antenna, while the rest continues its way through the interior of the analyzed sample.

Residual moisture is also important, because it affects the speed of the wave (the higher the humidity, the lower the speed) which can distort the results. In metallic elements, density is also important, given that being high, the radar wave does not penetrate it. It also influences if there is salinity in the subsoil or clay, the worst enemies of the radar wave.

This energy is represented by color-amplitude windows that are usually chosen so that they are representative of the objectives of each job. The positive amplitudes correspond to the passage to a medium with a higher dielectric constant, the target being the maximum positive amplitude recorded. The negative amplitudes correspond to the passage to a medium with a lower dielectric constant, gray being the maximum negative amplitude. Since it can be considered that one works with a normal incidence when the reflecting surface is flat and in the case of working in non-magnetic media, the reflection coefficient of the georadar is given by the simplified expression (Equation 1)

$$[1] \quad r = \frac{\sqrt{\varepsilon_2} - \sqrt{\varepsilon_1}}{\sqrt{\varepsilon_2} + \sqrt{\varepsilon_1}}$$

Where ε2 corresponds to the dielectric constant of medium 2, while ε1 corresponds to the dielectric constant of medium 1. Applying the principle to studies of reinforced concrete, the existing media will be concrete and the rebar of the reinforcements, these acting as short-circuiting for the emission of the georadar. for which they are characterized by maximum amplitude. In the examples studied, the decrease in this maximum amplitude reflection that must occur in the metallic elements (rebar) should be indicative of the degree of oxidation / corrosion.

Amplification of data obtained in the trace. As the delay time is prolonged, there is a decrease in the characteristics of the signal since the energy of the electromagnetic pulse decreases as it propagates through the material, which means that as we increase the depth it will be necessary to amplify the data that are received (11).

Filter application. In most cases, signal processing will be required in order to eliminate the "noise" data that clouds the trace data and makes it difficult to identify and interpret the data that is really significant for the result that We want to obtain, for for which two main types of filters are applied, band filters for the elimination of unwanted frequencies and filters for the elimination of the background (12).

Velocity of propagation and characteristics of the materials. For the correct interpretation of the delay times in the rebound of the signals, it is essential to know the propagation speeds of the electromagnetic waves in the material to be analyzed (Figure 1). Although these speeds can be calculated empirically, as a general rule they are estimated based on the lithological characteristics of the materials that we estimate that the sample to be analyzed contains. Among these, the most relevant characteristics for the propagation of electromagnetic waves in non-magnetic materials are the Dielectric Permittivity (ξ) and Conductivity (σ), which have been used to determine the parameters that characterize the different materials (13).

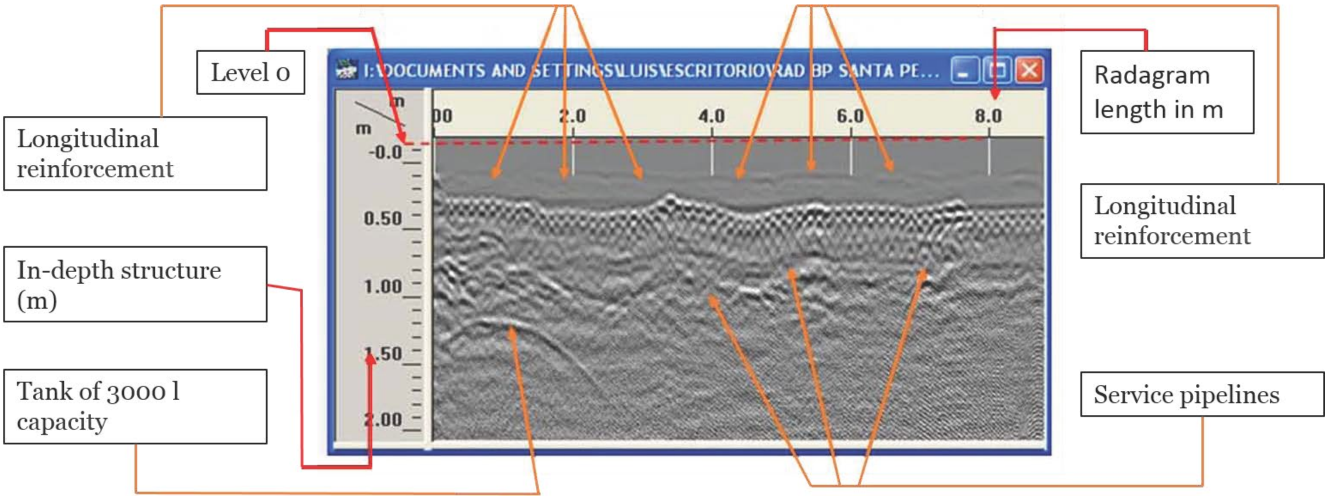

Figure 1. Radargram of a concrete flooring, without processing, as seen by the operator.

A concept that we must bear in mind is that of Electrical Resistivity (Equation 2). The electrical resistivity (ρ) of a certain material is defined as its specific electrical resistance, and it depends on the electrical resistance (R), the surface (S) and the length (l):

$$[2] \quad \rho = R\frac{S}{L}$$

The electrical resistivity of a particular conductor material is a measure of how strongly the material opposes the flow of electric current through it, and is inversely proportional to conductivity (σ). This variable parameter depending on the material and its density, is a concept used in GPR measurement, being the more effective the greater the difference between the different materials that make up the sample analyzed. In this way, sands and sandstones have resistivity values between 100 and 5000 Ωm and clays between 3 and 100 Ωm, compared to 0.0172 Ω.mm2/m for copper or 0.0971 Ω.mm2 /m for iron.

3.2. Infrared thermography (TIR)

This technology is widely proven as a non-destructive test of special efficiency for its use in the construction sector, from the verification of the thermal conditions of the building envelopes to the detection of various deterioration processes caused by physical and chemical agents in the structures and their elements. They are included as analysis tools to raise planimetries identifying their injuries (14).

The development of easy-to-use portable equipment and its popularization at affordable costs has allowed its use to be generalized. Likewise, it makes it possible to show the real temperature of an object and observe the variations in temperature and emissivity on its surface by measuring the variations in infrared radiation. The image we obtain is called a thermogram, which instantly shows the temperature at each point on the surface of the object, whether it is stationary or moving. The system can be applied in two main ways, the active and the passive technique.

Active Thermography. It uses a stimulation by means of an external infrared radiation source that heats the surface of the médium, producing a heat radiation that depends on the temperature distribution, allowing the detection of anomalies on the surface or under the surface.

Passive Thermography. In this case, the system analyzes the object's own emissions without the need for external stimulation, measuring and interpreting among other parameters the surface temperature patterns.

3.3. Infrared aerial photography

Although aerial photography systems have been used to identify and survey land uses since the mid-nineteenth century (15), nowadays technological development has made it possible to process huge amounts of data, giving rise to GIS information systems. geographic.

There are several types of aerial photos (16):

- Vertical photography, which keeps the axis of the machine vertical. They are the most used in the elaboration of maps.
- Oblique photography, in which the optical axis of the camera forms an angle with the vertical. This method covers a greater surface than the vertical, forces to make corrections that rectify the distortions of the image, preventing stereoscopic vision.
- Panoramic photography, in which the angle of view of the terrain is greater than 100º, which generates large distortions.

Among the film typology, in addition to panchromatic, which provides images similar to those captured by the human eye, and color, infrared photographs distinguish between black and white photographs, and color infrared, or false color, which have many advantages since in addition to being sensitive to the same spectrum band as black and white, they assign assigned colors to objects. with certain properties or characteristics.

In the technology of infrared color photography, the blue color is completely eliminated, thus filtering the effect of atmospheric light scattering, providing information beyond the spectrum of visible light, between 700 and 1200 nanometers. This type of photography has its origins in 1910, when the American physicist Robert W. Wood published his research to demonstrate the reflection of chlorophyll, by including

 Informes de la Construcción, Vol. 75, 569, e476, enero-marzo 2023. ISSN-L: 0020-0883. https://doi.org/10.3989/ic.89444

cryptocyanin as a dye applied to photographic plates. Later, during the First World War, the United States used plates sensitive to the infrared spectrum to detect camouflaged elements. At present, for use with a digital camera we will only have to use an infrared filter.

3.4. Multispectral photography

The evolution of systems that traditionally allowed capturing images for cartographic uses now allows us to analyze time series of physical phenomena that occur on earth. The development of complex algorithms and specific techniques and processes now allow a large amount of data about the interrelation of objects with electromagnetic radiation.

The spectrum is the distribution of the intensity of radiation as a function of a characteristic quantity, such as wavelength, energy, frequency, or mass. In this way, the spectral image is the one that reproduces an object depending on the wavelength that it is emitting or reflecting. This radiation allows a substance to be identified. Electroscopes, in addition to allowing the observation of spectra, make it possible to carry out measurements on their wavelength, frequency and intensity of radiation. The electromagnetic spectrum ranges from the lowest wavelengths of radiation, such as gamma rays, to the highest, such as radio waves. Within this spectrum, the range of radiation visible to the human eye is between 400 nm and 700 nm. Below this band is ultraviolet radiation, and above infrared.

The colors that the human eye appreciates correspond to the wavelengths that objects transmit or reflect, and not those that they absorb, being these complementary to the former. For this reason, if it is intended to observe the radiation absorbed by an object, a suitable source must be used, and study the image band covering the region of the spectrum closest to the used source.

We can then deduce the differences between a multispectral and a hyperspectral image (17), which focus on the number of spectral bands they include. The former capture images in the two spatial directions, while the latter add a Z spatial dimension to the former. The multispectral images are made up of a number of between 3 and 20 bands, not necessarily contiguous, with which we can obtain intensity values at the discrete wavelengths of the object.

While to take color photos as seen by the human eye, RGB cameras (red, green, blue) are mounted, multispectral cameras allow us to visualize radiation that goes beyond RGB, with this type of camera we will be able to capture the red edge (0.68 to 0.75 microns) and the near infrared (0.75 to 1.7 microns).

There is a wide variety of multispectral cameras and NIR (near infrared) cameras on the market. The choice will depend on the possible use that is going to be given. The use of these systems is wide, and they go as far as the search for the location of hydrocarbon deposits through the exploration of small superficial leaks, constituting a direct method of exploration (Hörig, Kühn, Oschütz and Lehmann 2001).

3.5. The ground electromagnetic survey (GEM-2)

Also call Electromagnetic Profiler, the GEM-2 is an active method that uses an electromagnetic signal (EM) to detect variations in the electrical conductivity of the surface being analyzed, providing a fast multi-frequency technique for surface geophysical explorations that allows to visualize the geomorphological and geological structure of the subsoil, and the spatial and volumetric positioning of internal anomalies, provided they have a certain entity (Figure 2). The principle is based on the detection of each conductive coefficient of the different elements that make up the sample. A receiving coil in the EM instrument allows the secondary electromagnetic field caused by the currents to be measured at the same time as the original signal being transmitted (18).

Figure 2. GEM used. Source: Courtesy of Falcon High Tech.

This secondary field is separated into two orthogonal components, which provide, on the one hand, a measure of the apparent conductivity of the analyzed area, and on the other hand, variations that indicate anomalies of different consideration.

A big advantage of the system is its portability, which linked with active GPS tracking allows an operator to collect around 20,000 data points per hour at five frequencies. The depth of penetration into the material that is achieved depends, among other factors, on the conductivity of the material and the chosen EM wave frequencies

4. REAL CASES OF THE USE OF THE GROUND PENETRATING RADAR SUPPORTED BY OTHER SYSTEMS, IN CONSTRUCTION WORKS

Two projects of special interest carried out by the specialized company Falcon High Tech are briefly described below, which, with different objectives, allow a broad vision of the capabilities of the use of the different systems, taking advantage of their complementarity.

4.1. Geophysical survey of buildings in the Residential Complex in La Moraleja, Madrid (Spain)

<u>Scope of the work carried out:</u> In this project, geophysical prospecting was carried out using infrared thermography (TIR,) infrared aerial photography (IR), Ground Penetration Radar (GPR) and Electromagnetic Profiler (GEM) on the roofs of the buildings of the complex in order to determine possible existence of water under the horizontal facing of the upper terraces, and its spatial and volumetric positioning.

The buildings presented some deficiencies in the waterproofing of the roofs caused by a concatenation of mistakes in their construction, which caused repeated pathologies. During the development of the repair work, atmospheric phenomena of an explosive cyclogenesis type occurred, which caused the formation of water pockets between the various layers of roof formation. That problem occurred in a greater and different number of buildings than those reflected in the project. of construction.

These bags produced pathologies of diverse consideration because of the leaks into the houses. The property made, with little success, an attempt to locate and eliminate the bags by opening on site test holes. The method was unsuccessful so, the work was entrusted to a specialized company with the aim of locating, spatially identifying, and, where appropriate, quantifying the possible existence of dammed rainwater.

To carry out the work, the company used the following coordinated systems:

- Thermography and infrared aerial photography (TIR / IR) on the entire surface analyzed.
- Realization of longitudinal and perpendicular profiles (X, Y) by means of GPR in the whole grid. (1.20 m thick grid mesh).
- Carrying out longitudinal and perpendicular profiles (X, Y) using a grid GEM with the same mesh pattern as the GPR.

Specific GPR and GEM Methodology: Fundamentally, it consisted of making a gridded mesh in X and Y coordinates, for detailed prospecting the hole Surface of the chosen areas. So, the data collection was carried out with a high mesh density, practically the maximum that can be done in a geo-morphological environment as complicated as a roof, through a GPR on a crutch provided odometer and GEM equipped with DGPS. Given the need for high resolution of the radagrams and electromagnetic profiles, the theoretical quality of the surveyed envelopes and the prior technical evaluations, it was agreed to use the 1.0 GHz antenna (maximum range 1 meter deep in concrete with these dielectric characteristics) and three frequencies, high, medium and low for electromagnetic profiles, with a maximum range of 2 meters deep.

The GPR equipment was used manually following the same grid mesh methodology, with the advantage of its resolution greater than 20,000 information points per square meter.

The use of the multifrequency electromagnetic GEM during data collection was carried out by means of a sweep at an approximate height of 0.20 cm above the surface. The equipment allowed to carry out an exact positioning of the anomalies that were detected, since it was equipped with a GPS differential and three frequencies, in addition the data obtained was reliable even at depths greater than 1 m for this investigation. Both technologies were carried out under very complex conditions, given the location of the prospecting.

Methodology used with the Thermography (TIR) and Infrared Aerial Photography (IR) equipment: The methodology consisted of taking a battery of aerial photographs by means of UAV equipment, with an infrared (IR) and thermographic (TIR) digital camera, following the grid determined, under pre-programmed working conditions (IR, sensitivity, emissivity, etc.). Likewise, a specific oblique orientation was determined, following previous parameters and in a preconceived daylight schedule, morning in this specific case, to take advantage of thermal dissipation.

The thermal differences in the analyzed grid were an indicator of the existence of deficiencies inside different geo-morphological structures (contamination, cavities, water, decay, etc.), since the facing acts as a heat collector during the day and from dusk it radiates the energy by thermal dissipation to the colder air. As there is a layer of different density and composition, a variation in the temperature of the facing could be detected in these areas. The presence of moisture on the surface and / or shallow levels would delay thermal dissipation and, in any case, would considerably lower the detected temperature (Figure 3).

During the collection of thermographic data, the daytime atmospheric temperature remained at very low thermal values, so there was no great difference in thermal dissipation, which slightly impaired the thermal differentiation capacity of the structure of the area.

Data collection process: The data collection with the GPR and GEM equipment was carried out according to an imaginary grid established in the field, managing to prospect 86% of the surface by means of GPR, 94% by GEM and 100% by infrared sensors. In this way, the total area analyzed covered an area of 1,520 square meters.

TIR analysis: Once thermograms of shadows and surface elements had been filtered by removing the basic primary anomalies, slight anomalies of negative category were detected (radiation shielded by the presence of water in the structure), in several areas of the grid, associated with the existence of high residual humidity in the roof structure compared to thermograms in other areas.

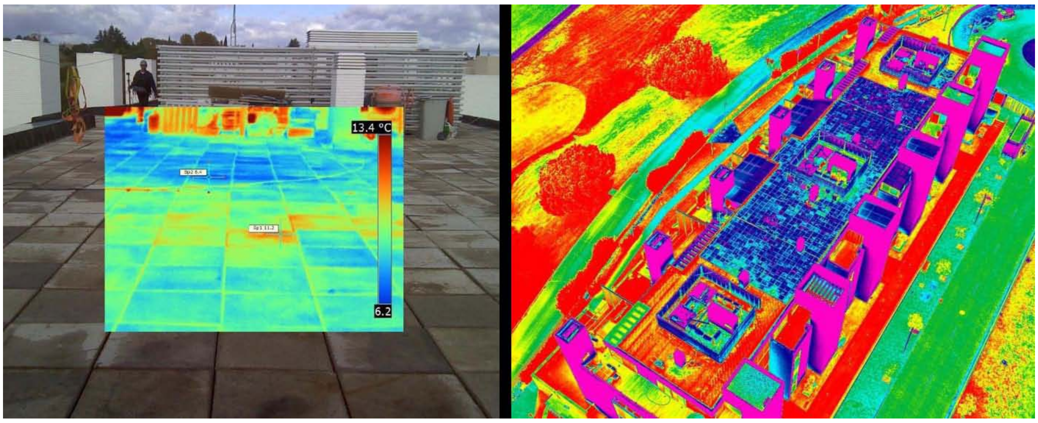

Figure 3. Thermographic surface image and Aerial infrared photography from 60 m. Source: Courtesy of Falcon High Tech.

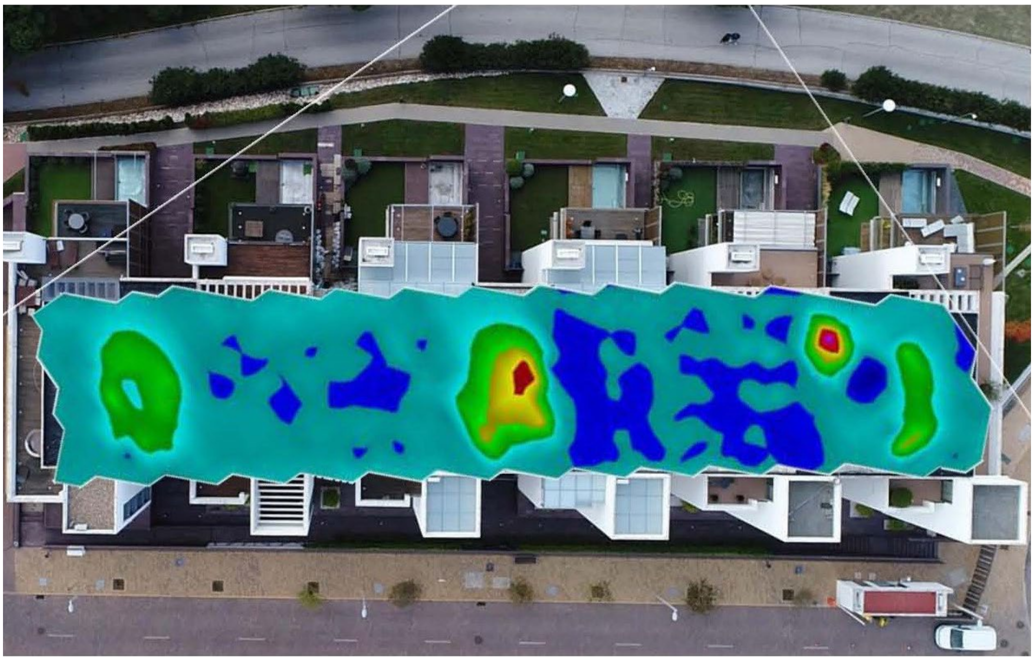

Figure 4. Schematic result of the GEM analysis performed on the mesh of the directions (X and Y).

The primary anomalies were verified using high-resolution ground geophysical methods. In general, the surfaces presented a very low profile gradient and a heterogeneous thermal level.

IR analysis: The infrared image analysis of the spectrum closer to the visible was processed to detect geomorphological surface changes as density, corrosion or presence of water due to exogenous conditions, positioning the sub and superficial structure of the area, where significant surface contrasts were detected, clearly associated with the presence of high residual humidity on the surface. and inside the enclosure. The different surface composition of the roofs, with areas welded with insulating extruded polystyrene slabs with surface protection of porous mortar and others only with asphalt layer, significantly impaired the ability to differentiate infrared. In asphalt layer and enclosures, shades of yellow-green with points of maximum concentration were appreciated, in the area soaked with insulating plate, dark blue and magenta tones were appreciated.

GEM analysis result: In this analysis, points with maximum internal accumulation of water were detected, with indication AE (in yellow) and AP (in red color) concentrated in the areas closest to the three internal enclosures identified with the exits to the exterior of the three stair cores.

Final Result and Conclusion of the joint data analysis: Infrared thermography and infrared photography provided primary but basic data to visualize the extension of the areas with probable involvement by residual humidity, with the verification of thermal signs of existence on the surface and structure of different thermal and infrared anomalies associated with the current presence of water inside the composition of the envelope roof, but the massive presence of residual moisture on the surface and the existence of a differentiated geomorphological structure, with areas with tiles differentiated from the areas with only asphalt layer, prevented the clarification of accumulation areas (Figure 4).

Likewise, both the GEM and the GPR detected electromagnetic anomalies associated with the existence of water inside the roofs of the building envelopes, most of them grouped in the upper and central layers, between 0 and -30 centimeters deep, medium-sized and current in nature, very difficult to identify due to the presence of rainwater on the surface. The areas with the greatest accumulation were positioned, showing maximum accumulations of water in the free phase of up to 2 cm.

However, the accumulation of constitutive layers of the roofs, with a very marked difference in their dielectric constants and their geophysical properties, significantly hindered the interpretation of the final data, and therefore the determinations of the conclusions.

4.2. Geophysical Prospecting for the National Highway Directorate on the bridge over Arroyo Saladino, RN9 highway. Buenos Aires

Scope of the work carried out. The objective of the project was the verification by non-intrusive techniques of the structural situation of the reinforced concrete bridge over the Arroyo Saladino (Argentina), and the detection and spatial and volumetric positioning of the different pathologies that could be detected. The structure showed visual signs of deficiencies, such as cracks and deformations, necessitating its detection, evaluation and analysis. Likewise, it was intended to detect possible anomalies in the geological layers found in the subsoil of the bridge and stream and the preparation of a location plan, so that later, they serve as a guide for subsequent repairs and / or in the event that If the highly relevant detected were interpreted, the rectification works considered appropriate by Dirección Nacional de Vialidad, which is a State company for management of the highway network, were planned. Next, a summary of the work carried out was developed that illustrates both the methodology and the results obtained.

Specific methodology. The fundamental methodology consisted of planning and making a grid in X and Y coordinates, to prospect in detail the areas chosen by the national company that owns the structure. Given the importance of the fact to be investigated, data was collected with a high mesh thickness, practically the maximum that can be done in a geo-morphological environment as complicated as a bridge with a circulation of 3,000 vehicles / hour, without disturbing the circulation, located in restricted access areas of an International Highway, through a radar equipped with an odometer and GEM with DGPS. The need for high resolution in the radagrams and electromagnetic profiles, together with the theoretical quality of the surveyed soil and the previous technical evaluations, led to the decision to primarily use the 900 MHz antenna (maximum range between 1.5 and 2 meters of depth in concretes with these dielectric characteristics) and assess deeper layers also with the profilometer and five frequencies (maximum range between 9 and 12 meters deep in subsoils with these dielectric characteristics).

Once the field work was finished, the data was dumped into a computer for subsequent export, treatment, representation and interpretation, using specific software for each task. The GEM-2 software: WinGEMv3 was used for the data dump and export, while the Surfer9.0 and Matlab6.5 programs were used for the treatment and graphic representation. Within the data processing, several processes were carried out. Depending on the results that were obtained, decisions were made in the processing of the records, that is. Ranges of values were eliminated, certain contrasts or zones were accentuated, filters, operators were applied, using various color scales, etc. In this way, maps of magnitudes were obtained in which we will be able to appreciate, in the best possible way depending on the sedimentary environments, the most interesting contrasts or anomalous areas according to the analysis objectives.

Ground Penetrating Radar: The GPR used was the GSSI SIR-3000 with a SmartCar trolley equipped with an odometer, a radarteam crutch, and as auxiliary material, a measuring tape, signaling cones and an independent photographic sketch of each section. It was intentionally chosen not to know the data or hypotheses about its constructive structure prior to carrying out this survey by means of georadar so that its knowledge did not influence the layout, volume and spatial positioning of the possible pathologies that were detected.

Infrared Photography: The methodology consisted of taking a series of photographs by means of a digital infrared (IR) thermographic (TIR) and visual spectrum (RGB) camera of the bridge structure, under previously programmed working conditions (IR, sensitivity, emissivity, etc.) and with an oblique orientation determined by previous parameters and in a preconceived sunlight schedule, specifically at dusk, so that it was possible to take advantage of the thermal dissipation. This action was designed to detect and position possible internal anomalies associated with pathologies on the surface or within the structure and is included solely for the purpose of demonstrating the capabilities of thermography in this area.

GEM and Side Scan Sonar. To analyze the geo-morphological and geological structure of the terrain. As important as auditing the structure of the bridge itself was analyzing its integration with the terrain on which it sits, including the flooded area when in doubt about the possible existence of a current in the subsoil of the stream, given the close relationship in the detection of internal moisture in the structure, and its internal corrosion problems. The geological structure of the subsoil was extremely important so the work included detecting the possible existence of discontinuities or internal cavities, which could affect the stability of the construction, as well as its degree of hardness and flexibility to avoid resonance problems. For this purpose, the analysis was carried out using an acoustic torpedo drawn from a small inflatable boat. This system is capable of detecting and positioning any object and / or geo-morphological structure at the bottom of rivers / swamps, graduated with pre-established parameters and without the need for dives. The profilometer, is placed on the rubber band and equipped with various frequencies, penetrates under the river bottom, showing in plan the geological structure of the ground under water up to a maximum level of approximately -15 m depth.

The data obtained was treated by the specialized company with its own system for its processing, mostly by using the following commercial software:

Georadar: Radan 6.6 And Radan 7.0. Surfer 10.0
Electromagnetic Profilometer: Magmap, Surfer 10.0
Proton Gradiometer: Magmap, Surfer 10.0
Infrared-Multispectral Sensors: Flir Reporter 8.0, Flir Quick Report, Adobe Photoshop, Pix 4-D

Results Obtained by the different systems.

Aerial Infrared Thermography (TIR) and Aerial Infrared Photography (IR): The exploration area was carried out using a mi-

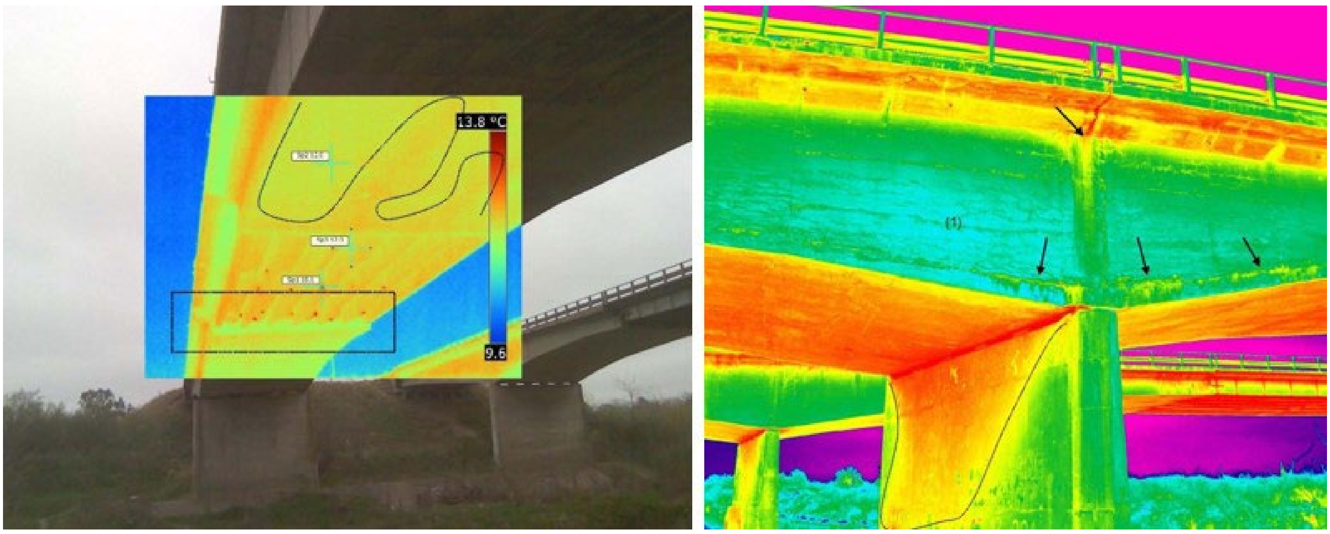

Figure. 5. Infrared (IR) aerial photography showing various deficiencies. Source: Courtesy of Falcon High Tech.

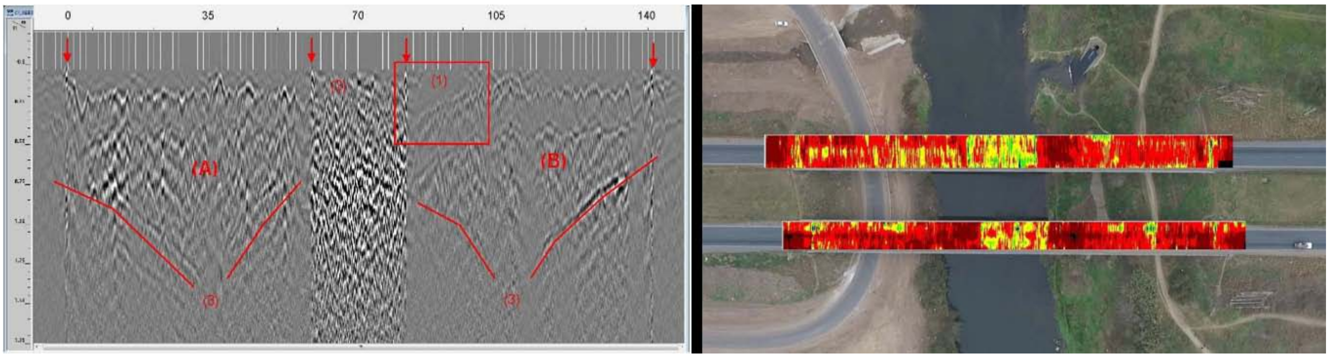

Figure 6. Radargram 202. 1.75 m deep. It shows deficiencies close to the central isostatic zone, and 3D geo-radar of both boards, with detection of the dielectric constant associated with fractures, fissures and discontinuities. Source: Courtesy of Falcon High Tech.

crodrone between 6 and 90 meters high, from various points located in front of the surveyed area (red dots), using a FLIR VUE PRO 336 camera, DJI 20 Mpx, and Canon IXUS 180 IR. On the ground, using a FLIR T-400 thermal imager and a FUJI IS-1 infrared camera. The entire structure of the bridges and even attached areas have been completely covered (Figure 5).

<u>TIR analysis:</u> The result showed a heterogeneous thermal level, once shadows and vegetation thermobars were filtered, inhomogeneities were detected in the central left area of the bridge deck "O", as well as a change in longitudinal density, and a large thermal difference between areas N and S Saladillo stream margin marked area structurally altered by geomorphological change.

<u>IR analysis:</u> The infrared processed by stratigraphic surface changes, positioning the sub and surface structure of the area, detecting exogenous radiometric changes, contributed from inside bridge decks (dark blue color) of different entities. However, they were primary anomalies, which required verification with higher resolution geophysical means, as the angle and distance were insufficient.

<u>GPR:</u> 2D and 3D radagrams were made. In the set of tests, the internal structure was clearly detected, more importantly the negative repositioning and deficient internal density in the connection areas with isostatic section, due to poor construction and water entry and subsequent internal corrosion and decay. It includes heavily damaged areas in the lower part of the bridge, of an irregular shape and very poor internal density, with radar "shadow" points caufsed by a high degree of residual humidity.

In one of the supports of the isostatic central slabs, a serious accumulation of residual moisture was detected that caused advanced internal corrosion and delamination, recommending the adoption of immediate safety measures, as well as the realization of intrusive analysis, since it could not be ruled out the sudden collapse of that point, given the degree of its structural affection (Figure 6).

<u>Conclusions</u>

As a brief summary of the study's conclusions, we can point out that the analyzes carried out are conclusive in that both slabs are clearly differentiated in their degree of internal density, and even in the internal composition of concretes and rebar. Significant electromagnetic anomalies were detected in both bridges, very marked in the decks, and less important in the piers and abutments, associated with internal corrosion, delamination and fractures, due to the erosive action of residual moisture.

In relation to the main points with anomalies and / or pathologies, the main problem detected was internal corrosion, a decrease in the density of the concretes due to the massive entry of residual moisture, particularly serious in three of the four connection areas between the concreting and the two isostatic zones. These isostatic areas are in good condition except for the almost superficial layer, where corrosion is beginning to act.

5. CONCLUSIONS - LIMITATIONS AND POSSIBILITIES IN THE SCOPE OF THE USE OF THE SYSTEM IN CONSTRUCTION WORKS

We can summarize that the GPR has a limited penetration capacity, approximately between 4 and 5 meters of maximum depth in a medium soil, in relation to the high resolution antennas used, the only ones capable of detecting dielectric constant associated with anomalies or internal pathologies in a structure, as well as areas affected by hydrocarbons, water, heavy metals or exogenous chemical compounds. In this way, the data obtained can be interfered with, and therefore its readings altered, by strong electromagnetic fields or the massive presence of saturated clays in the subsoil, or the presence of salt water.

In the case of the GEM, its penetration capacity is limited, approximately between 8 and 10 meters maximum depth in a medium soil, in relation to the high resolution frequencies used, between 50,000 Hz and 1,000 Hz, the The only ones capable of detecting dielectric constant associated to the affection of hydrocarbons, water, heavy metals or exogenous chemical compounds, and in the same way as in the georadar, the readings can be interfered with and altered by electromagnetic fields of great intensity.

As for the TIR and IR, they have a limited penetration capacity, approximately between 1 and 2 meters of maximum depth in medium soil. Their readings can also be interfered with and therefore altered by architectural structures in the subsoil, cavities with air or water, service pipes and pipes with fluids under pressure or high temperatures or dense geological layers such as rock outcrops.

The GPR is the geophysical system with the highest resolution, and the profilometer is a complement through conductivity.

The two systems together are unbeatable as non-intrusive and non-destructive methods (European GPR Association). The georadar basically detects the dielectric coefficient of the analyzed element, and in the event that the sample presents internal pathologies, such as fractures, fissures, repositioning, decay, etc., the constant of its dielectric coefficient varies, as there are other compounds (air, water, etc). The use of the Profilometer system is completely complementary, since it indicates the conductivity values. And although it provides a lower resolution, it has the great advantage of being easy to deploy in the data collection phase.

While some materials used in construction have ranges of variation of their electromagnetic parameters that we can qualify as small, such as asphalt with a dielectric permittivity (ξ) between 3 and 8 and a conductivity (σ) between 0.1 and 1 mS / m, or a metal pipe with values of 1 and 108 respectively, in the case of concrete (19), the dielectric permittivity can vary in the same sample up to 50% over small distances, up to 10 centimeters, so it can be misleading as it can produce speed variations of up to 35% in a material that we traditionally consider homogeneous, and consequently induces thickness and depth corrections. Likewise, for the relative dielectric permittivity of air, the unit value is usually taken, which is the same value as that of vacuum (ξ = 1), although its real value varies slightly and reaches 1,0003.

On the other hand, the porosity of the material and the fluid contained between the pores largely determine the electromagnetic parameters of the material to be studied, which affects the speed of propagation of electromagnetic waves (20).

Although water also has differences in the parameters of its relative permeability depending on its state and even on the temperature, a value of 0.81 is usually taken to simplify the calculation of the speed, which corresponds to an ambient temperature. of about 18o. Ice and snow present lower values due to the percentage of air they contain.

The presence of water will therefore be decisive for the determination of speeds (21), so the material will have a wide range of values depending on the degree of its content. We see that in the examples discussed that when there are several materials with different dielectric characteristics added to accumulations of water both saturating materials such as geotextile, such as sheets impounded at the interfaces, it causes great disturbances in the results that cause a drastic decrease in the effectiveness of the results obtained.

The thermal differences in the analyzed structures are an indicator of the existence inside of a different geo-morphological structure (cavities, water, contamination, decay, corrosion, etc.) since the facing acts as a heat collector during the day and from at dusk they radiate the energy by thermal dissipation to the colder air. When there is a layer of different density or a pathology, a variation in the temperature of the facing is detected in these areas. The presence of moisture on the surface and / or shallow levels delays thermal dissipation and always considerably reduces the detected temperature. The existence of internal cavities in a concrete structure causes an increase in temperature in these layers, which can be detected and differentiated by infrared.

During the collection of thermographic data, it is important to highlight that a difference in daytime and nighttime temperatures and humidity benefits the thermal differentiation capacity of the structure of the area to be analyzed, the better the greater the difference in thermal dissipation or thermal gradient.

As it is an eminently practical infrared, GPR, sonar and GEM inspection, prior but closely linked to a specifically technical interpretation and remediation of the problem suffered by the sample, and with the purpose of showing that the results of a GPR inspection and / or GEM are easily usable by professionals outside Geophysics, the reports do not include explanations of a mathematical and technical nature about their theoretical operation, methodology and post-processing techniques used.

The GPR and GEM technology, used in a complementary way, are non-intrusive and non-destructive technical instruments to analyze concrete structures and detect possible pathologies such as cavities, corrosion, internal fractures or delamination. The deterioration of the external and internal structure of the constructions is the cause of the combination of several complex phenomena, the physically induced (thermal gradients, volumetric changes, abrasion, erosion, cavitation,) and the chemically induced (chlorides, carbonates, sulfates and attacks acids) that cause internal corrosion, generally due to the entry of moisture. The internal corrosion of the bars also causes the deterioration of the concrete structure, and is detected by these systems due to the increase in its conductivity.

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