The geo-radar in the service of concrete durability

K.HADJA and F.KHARCHI

Abstract— Concrete has became a universal building material. Its mechanical resistance was considered as a basic criterion. It appears today that the concrete can be affected by its environment. Its performances decrease when it is exposed to moisture, pollution and other aggressive substances such as chlorides and sulfates. Therefore, the concrete degrades and the steel bars corrode**.** Aggressive substances are generally conveyed by water. Thus, the water content is a good indicator of the durability of concrete.

Non-destructive methods has been developed for diagnosing the state of a structure at any time, which allows monitoring and preventive maintenance work. The Radar technic is one of the buildings auscultation techniques which can be used. It is an application of electromagnetism and was mainly used to find buried objects in concrete and for the recognition of discontinuities or geometries. Relatively recent research has shown that the radar can also be used as a tool for characterizing the state of the material. This enables new application fields.

The radar signal is analyzed in terms of mitigation and speed, by the use of different reflected signals and also the direct wave signal between transmitter and receiver. The measurements made in the laboratory or on site indicate the sensitivity of this signal to the desired settings. The radar allows locating steel bars, measure concrete cover and estimate moisture concrete. The propagation speed is directly related to the dielectric constant. This measure gives an idea about the actual concrete moisture condition.

Analyses of radar profiles obtained by immediate auscultation of structures, Provides an idea about the anomalies related to the concrete: corrosion, presence of chlorides and other anomalies related to improper repair of the concrete or an accumulation of water above the element studied.

Keywords—concrete, durability, geo-radar, non-destructive methods, moisture, profiles, corrosion.

I. Introduction

The mechanical strength of concrete was considered as a basic criterion for the concrete but, experience shows that this material can be weakened by the environment. Pathologies such as the steel reinforcement corrosion and shattering of the concrete appear. The presence of water is an essential parameter leading to these pathologies. For this, several techniques for auscultation of used constructions has been developed, among them, the Radar technique (Radio Detecting And Ranging). It is an application of electromagnetism as support of measures; it was mainly used in finding objects buried in the concrete as frames, or for the recognition of discontinuities or geometries. Recently, research [1], [2] and [3] showed enough that the radar may be used as a characterization tool of the state of the material. This opens up new applications for the evaluation of some sustainability indicators of reinforced concrete structures.

KAWTHAR HADJA Doctor candidate Built Environment Research Laboratory LBE, civil engineering faculty, USTHB, Algiers, ALGERIA. kaw.hadja90@yahoo.fr

FATTOUM KHARCHI (Professor Research Director, Built Environment Research Laboratory LBE, civil engineering faculty, USTHB, Algiers, ALGERIA.

kharchi.fatt@gmail.com

II. Principle of Measurement

The radar technique is based on the use of electromagnetic pulse emitted by an antenna. The pulses spread in the material but, a part of the pulse energy is reflected back to the surface at each interface between two electromagnetically different materials.

In practice, an antenna (transmitter), emitting electromagnetic waves, is moved on concrete elements (slab, wall, column), another antenna on the same support (receiver) receives the reflected signals. There is an attenuation phenomena, to every initial signal correspond two waves, one direct and one reflected. The successive echoes are recorded in a time signal by the receiving antenna. The output signals are in the form of images in grayscales called the GPR profiles

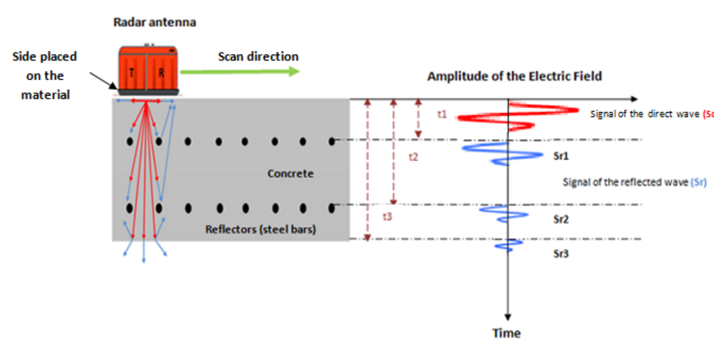

Fig. 1 Principle of measurement by Radar

Figure 1 shows a reinforced concrete element auscultated by radar. The gray part represents the concrete and black dots represent the steel bars.

In this study, the two types of wave are analyzed, the surface wave and the reflected waves , for the two parameters of sustainability .

- The surface wave allows the analyses of the water content parameter as durability indicator knowing that the large part of pathologies of the reinforced concrete is due to the water presence in the material.

- The reflected waves giving radar profiles allow the analysis of the steels bars quality to estimate the concrete bedding and the corrosion state.

III. ANALYSIS OF THE MOISTURE CONTENT BY THE RADAR TECHNOLOGY

The analyses is performed by measuring the speed of the surface wave .The spread of EMW is assimilated to the propagation of a progressive monochromatic plane wave propaging in a defined direction [4]. The propagation is affected by the conductivity and the permittivity of the medium (the dielectric constant). It has been shown that the dielectric constant affects only the speed of propagation; the attenuation is mainly due to losses [5].

The relation between the speed and the permittivity ε is given by the following formula:

$v = \frac{c_0}{\sqrt{\varepsilon}} \Rightarrow \varepsilon = \frac{c_0^2}{v}$ (1) / Such as $c_0 = 3\,x\,10^8\ m.s^{-1}$ Speed of light.

In addition to the electro - magnetic parameters (EM), it has been observed, that the spread of EMW in concrete is influenced by the amount of water present.

We analyzed the influence of variation in the speed of the direct wave based on the material humidity. We performed the measurement on samples of concrete taken from a wall. The sample is cut by a cylindrical sawing. These types of samples are commonly called "carrots concrete." The study of samples allows characterizing the state of the material. This also has a necessary calibration operation for future on-site measurements. the radar system has been used (CRS 20 GSSI) with antennas frequency 1.5 GHZ. The sample was studied at two states, humid and dried.

Fig. 2 concrete core Fig. 3 Measure system
Fig. 4 Antennas 1.5 GHz

A. Measuring device

The device is composed of two vertical square screens of 1m from the side. They are covered by a self-adhesive aluminum foil to have reflectors character. The screens are drilled in the middle to receive the concrete core which is also covered with aluminum in order to ensure a linear propagation of electromagnetic waves and avoid wave reflection to the contour. The transmitter and receiver are applied to each end of the core.

This measurement system requires defined conditions to the core: it must have a height of 150 mm and a diameter of 75 mm to fit the experimental device. Otherwise it was completed by polystyrene.

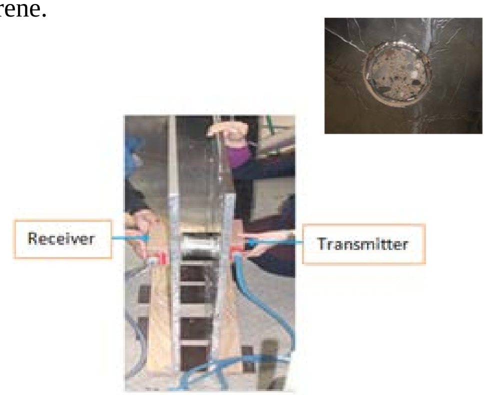

Fig. 5 Experimental device (LMDC)

The measure is affected on core of concrete and full air core to determine the initial time of propagation.

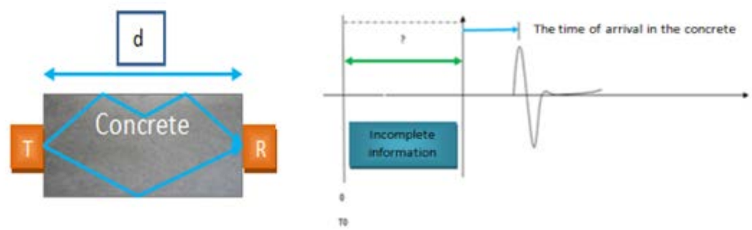

Fig. 6 Measure on the concrete core

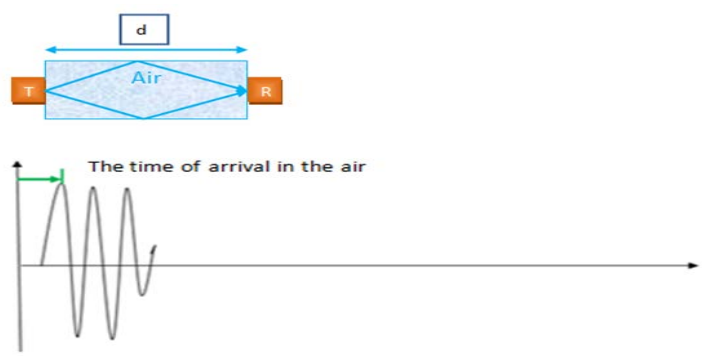

Fig. 7 Measure on the air

B. Results

From the measurements taken above, we have obtained radar profiles which corresponds to signal of the direct wave in the concrete core and in the air core are respectively in fig 8 and 9.

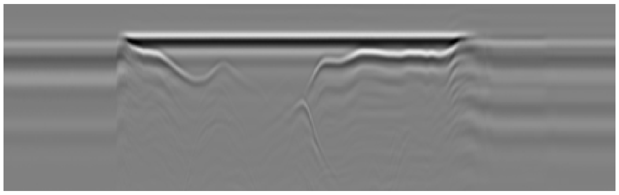

Fig. 8 profile of the direct wave in the concrete core (RADAN)

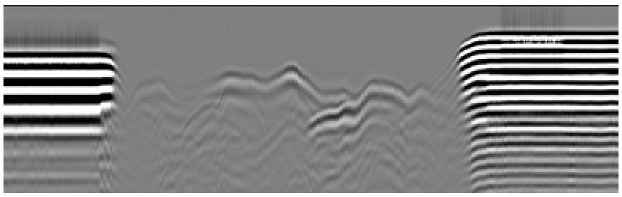

Fig. 9 profile of the direct wave in the air core (RADAN)

The radar profiles obtained are then treated by excel program.

The two graphs obtained (brown and gray) represent respectively the signal in the concrete and the signal in the air. Fig 10

From these graphs we determined: the arrival time of EMW in the concrete and the initial time t_0

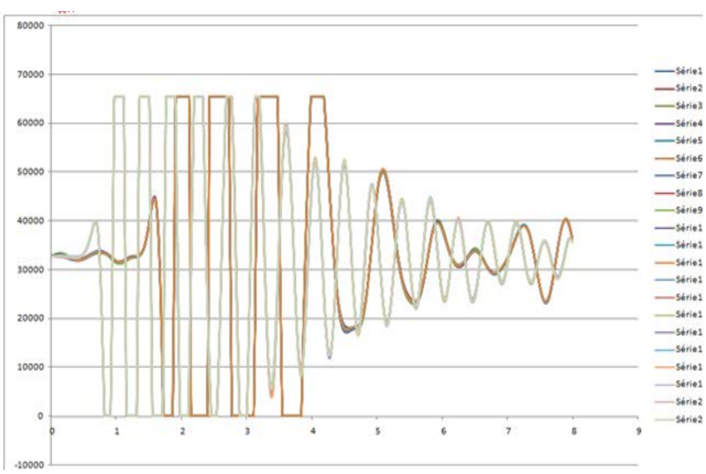

Fig. 10 Radar signals in the concrete and in the air

The velocity in concrete is calculated using the following equation:

$$v_{concrete} = \frac{d}{t_{concrte} - (t_{air} - \frac{d}{v_{air}})} \qquad (2)$$

With: $t_{concrete}$ = 1.58 ns and t_{air} = 0.68 ns
$v_{concrete}$ = 10.58 cm/ns

From this speed value, we deduced the value of the permittivity by using relation (1).

The dielectric constant is equal to 8.2, this corresponds to a concrete more or less wet (8.2 ≥ 8 knowing that ε = 8 is the limit value of a normal concrete which is limited 6 < ε < 8) [6].

The same operation was performed on the same core oven dried at 80 ° C to constant mass, the results are as follows:

$t_{concrete}$ = 1.02 ns, t_{air} = 0.39 ns and $v_{concrete}$ = 13.06 cm/ns

This speed value corresponds to a dielectric constant equal to 5.27 (corresponded to dry concrete). Therefore the EMW propagation speed is directly related to the moisture content of the material. More concrete is dry over the speed of propagation of electromagnetic waves; the higher the dielectric constant is low.

In the literature, the direct wave is propagated directly from the transmitter to the receiver. The sensitivity of the direct wave in the moisture condition of the concrete has been studied by many authors [7] and [8].

Increasing water content of concrete leads to a sharp variation of the radar signal parameters. This is usually due to the increase of permittivity and conductivity of concrete. Thus the presence of water and / or water-filled cracks can affect the behavior of the radar signal. The influence appears on the speed of the direct wave.

In this topic the researches [9], [10] use large specimens with controlled and evenly distributed water content.

The specimens were used to measure the propagation speed in bi-static mode. [9] Two concrete compositions have been used with respective water / cement ratios of 0.66 and 0.48 and porosity accessible to water of 14.7% and 12.5%. Figure 10 shows the speed changes depending on the volume of water related to the volume of the sample (volumetric water content) for both tested concretes.

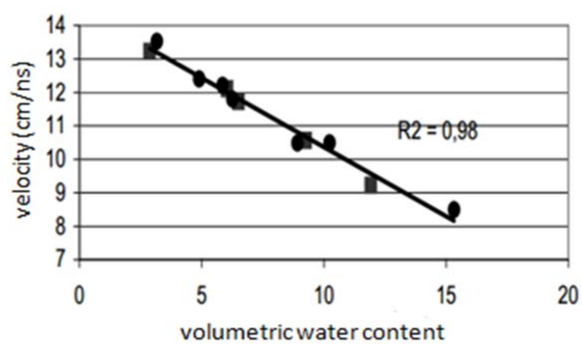

Fig. 11 Speed variation of direct wave with water content.

The test shows that the variation of speed of the direct wave depends only on the volume of water and not on the type of concrete or of its intrinsic porosity, Fig. 11.

The attenuation, it is function of the amplitude. The amplitude decreases and the attenuation increases when the water content increase. Fig.12.

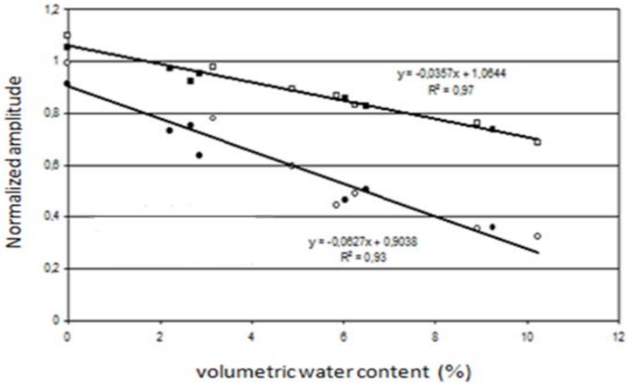

Fig. 12 Relationship between the amplitude of the direct wave, the reflection on steel bar and the water content of the concrete

Researches were conducted [11] at the same topic they have shown that the permittivity (dielectric constant) of the concrete is proportional to the volumetric water content. Fig.13

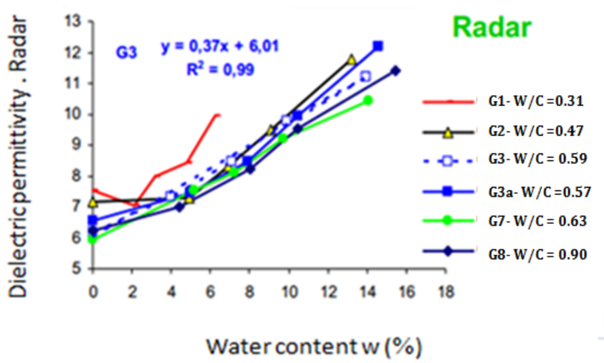

Fig. 13 Variation of the concrete permittivity with water content.

IV SENSITIVITY OF RADAR TECHNOLOGY TO THE QUALITY OF STEEL BARS OF THE REINFORCED CONCRETE

In the reinforced concrete, the quality of reinforcement steel bars is appreciated by the depth of the coating (concrete bedding), the diameter of bars and their position and the absence of corrosion.

A. Determination of concrete bedding

Fig.14 is a GPR profile, it shows the different phases and elements obtained as a result of changes in EM properties. Hyperbolic shapes showed the position of steel bars in the concrete

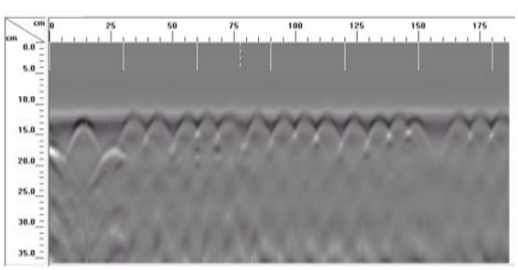

Fig. 14 Profile radar indicating the position of the reinforcements in a reinforced concrete wall (Radan 7)

Using the method of Kirchhoff migration, the information X-T are convert to X-Z, from the knowledge of the speed radar waves in concrete.

The identification of reinforcement allows to determine position of steel bars and concrete bedding.

This allows transforming hyperboles obtained in radar imaging to rounded shapes corresponding to reinforcement of concrete.

This method helps to monitor the depth of the coating over time.

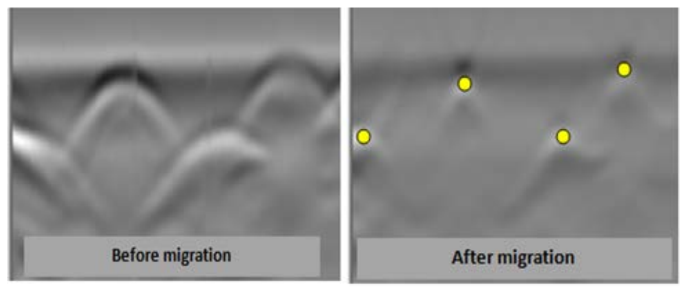

Fig. 15 Kirchhoff migration

B. Identification of corrosion in the radar profiles

The identification of the steel bars corrosion is performed by visual analysis of the GPR profiles taking into account: the Attenuation of the signal, the amplitude, and of the deformation of hyperbole under the element studied A linear image analysis is also used to map corrosion [12].

We analyzed using GPR profile a construction which has two different areas, the first one corresponded to relatively sound concrete Fig .16-a, and the second area corresponded to degraded concrete. Fig .16-b.

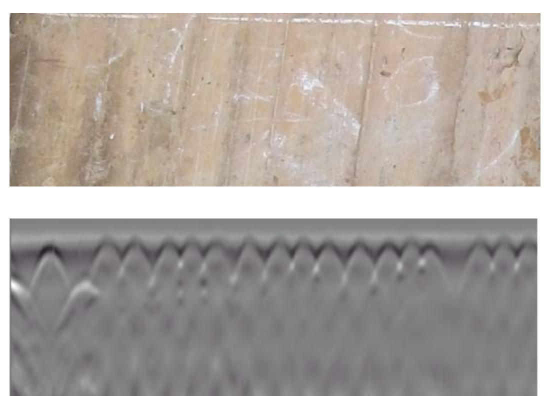

Fig.16-a The relatively sound concrete area with its radar profile

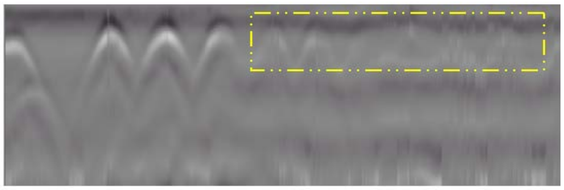

Fig.16-b The damaged concrete area (the right side) with its radar profile (present bars strongly corroded)

The horizontal radar profiles show the presence of a severe corrosion specially in the right side of the construction which is strongly damaged characterized by its low reinforcement cover and some bars are without coating .

Similar results have been demonstrated by Thikra Dawood and all [13], they have studied the probability of existence of the corrosion and its intensity in the GPR profiles. they judged that the concrete is likely sound when the reflection of the steel bars is high with clear form and uniform hyperbole, the corrosion is likely moderate in case we have relatively low reflection of the bar, but their hyperbole form is visible and finally if we have a severe corrosion likely, the radar profile show that the attenuation is high in level of higher steel bar, the hyperbolic shape of the reflection of the reinforcing bar is distorted or virtually invisible, Fig 17.

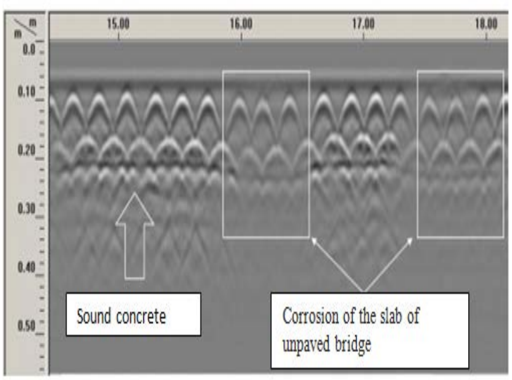

Fig. 17 Attenuation of signal caused by corrosion of the steel bar in a concrete slab

C. Presence of chlorides in a radar profile

The profiles can also indicate the presence of chlorides, the fig 18 shows that in areas where there is a sound concrete (protected by asphalt) , the signal presents a visible hyperboles , the left area (unprotected) present a uniform and high attenuation due to the saturation of chlorides in this zone.

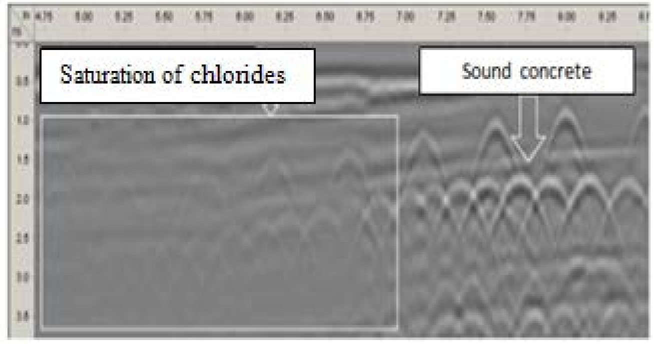

Fig. 18 Attenuation of signal due to the presence of chloride in the concrete

D. Subsequent repair concrete

Figure 19 represents in the marked location, GPR profile of a slab bridge repaired. It is interesting to see the signal attenuation below the repaired zone which indicates the existence of remainder deterioration either because the repair or because a subsequent deterioration.

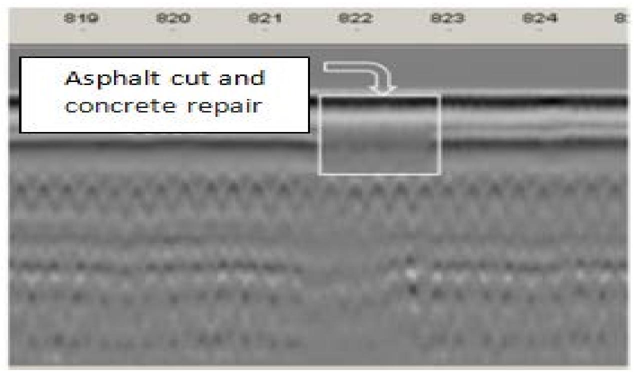

Fig.19 Old repair bridge; some damages are remaining damage (or appeared later) under part repaired

E. Accumulation of water under the upper part of the structure

In Figure 20, the rectangle of the left shows a disturbance in the ground penetrating radar signal because a cut in the layer of asphalt and repair in concrete. While the rectangle on the right shows signal attenuation due to accumulation of water under the asphalt off. This figure shows that signal attenuation can be due to different causes, which are not necessarily linked to defects caused by corrosion in concrete.

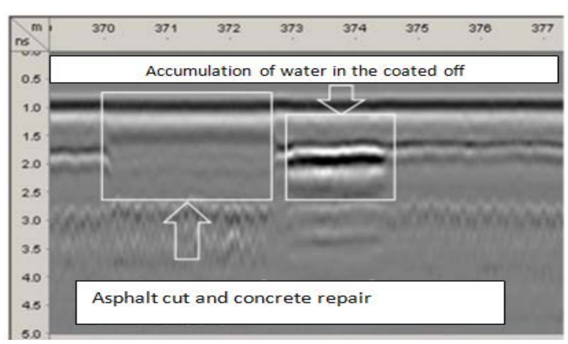

Fig.20 Attenuation of signal due to different anomalies in the concrete

V. CONCLUSION

By the relationship with the electromagnetic radar waves and some characteristics of materials, it is possible to estimate parameters informing on concrete durability because:

The speed of the direct wave (surface wave) is a function of physical characteristics of the material (moisture and salinity).

The analysis of the reflected electromagnetic waves allow the determination of some characteristics of the material: detection bars, determination of concrete cover and identification of corrosion related to the steel bars.

The visual analysis of radar profiles allows to identify some anomalies and parameters of the durability of reinforced concrete like detecting areas where the steel bars underwent corrosion, the areas which are infected by chemical aggressions (exp : chlorides) and identifying authors anomalies related to the steel bars and the concrete in the time. thereafter and by using analysis software called Radex according to the analysis, we can drew mapping of areas where w have a sound concrete , moderate corrosion and a severe corrosion of the studied the reinforced concrete element .

REFERENCES

[1] Laurens S., "Aptitude de la technique radar à la caractérisation du béton d'enrobage _ Aide au diagnostic de la corrosion des armatures", Thèse de Doctorat, INSA Toulouse (France), Université de Sherbrooke (Canada), 2001, pp 211.

[2] Garciaz J.L., Perrin J.L., "Application du radar géophysique pour l'évaluation des antennes spécifique et traitement de données", Journées Scientifiques ENDGC 2, Bordeaux, Novembre 2001.

[3] Dérobert X., "Techniques radar appliquées au génie civil", LCPC, n°J1050343, ISSN 1167-4865, 2003.

[4] Balayssac. J-P, Kringkai.V , Sbartai M , Klysz G , Laurens S and Arliguie G. Contribution au développement du radar pour la caractérisation non destructive du béton .Actes des 25e rencontres de l'AUGC, Bordeaux ,23-25 mai 2007.pp 3.

[5] Klysz G, Balayssac J-P .Determination of volumetric water content of concrete using ground-penetrating radra. Laboratoire Matériaux et Durabilité des Constructions, INSA-UPS Toulouse (France) ,april 2007.

[6] Cassidy N, Ground penetrating radar theory and applications, chapiter II: electrical and magnetic prosperities of rocks, soils and fluids. 2009.pp158.

[7] Lataste J.-F.(2002). Évaluation Non Destructive de l'état d'endommagement des ouvrages en béton armé par mesures de résistivités électriques, Thèse de doctorat, Université Bordeaux I, pp 295.

[8] Greaves, R.J, Lesmes, D.P, Lee, J.M, Toksöz. N. (1996). Velocity variations and water content estimated from multi-offset, ground-penetrating radar, Geophysics, 61 (3), pp.683- 695.

[9] Klysz G. « Caractérisation du béton d'enrobage par technique radar : exploitation de l'onde directe émetteur-récepteur » Thèse de doctorat, Université Paul Sabatier – Toulouse III, 2004, pp240.

[10] Sbartaï M., «Caractérisation physico-chimique des bétons par radar –approche neuromimétrique de l'inversion », Thèse de Doctorat, Université Paul Sabatier Toulouse (France), Université de Sherbrooke (Canada), 2001, pp244.

[11] Dérobert X et al .Complémentarité de techniques non destructives pour déterminer les propriétés de différents bétons hydrauliques, Laboratoire Central des Ponts et Chaussées (LCPC) - Centre de Nantes.2008. pp6.

[12] Tarussov A, Vandry M. and De La Haza, A. Condition Assessment of Concrete Structures Using a New Analysis Method: Ground-Penetrating Radar Computer-Assisted Visual Interpretation. Journal of Construction and Building Materials, Elsevier Vol. 38, 2013, pp. 1246–1254.

[13] Dawood T, Abouhamad M, Shami A, Zayed T, Dept. of Building, Civil, and Environmental Engineering, Concordia Univ., 1515 Sainte Catherine St. W., Montréal, QC, Canada H3G 1M7 and Dinh K ,Center for Advanced Infrastructure and Transportation (CAIT), Rutgers, The State 11 University of New Jersey, 100 Brett Rd, Piscataway Township, NJ 08854- Rapport Progrès récents dans la cartographie de la corrosion des dalles de pont en béton . 22E Colloque sur la progression de la recherche québécoise sur les ouvrages d'art ,5 et 6 mai 2015.pp9-10-11.