GPR Application – Case Studies

Case Study-1: Understanding the Relationship between GPR & Rebar Corrosion

[Excerpts from the paper published in R. N. Raikar Memorial International Conference and Dr. Suru Shah Symposium on "Advances in Science & Technology of Concrete" organized by India Chapter of American Concrete Institute,2013,p.140-144]

1.0 Introduction

Non-destructive testing (NDT) methods are often used to quantify damage on bridge decks, and this case study focuses on two of the more commonly used methods: half-cell potential (HCP) and ground penetrating radar.

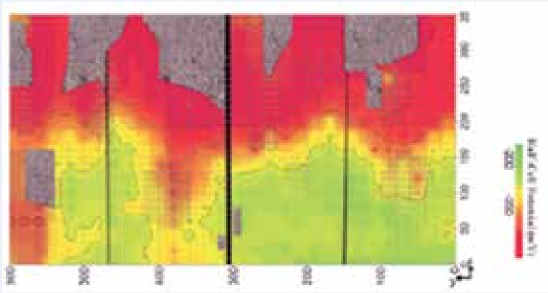
(GPR) conducted in one of the bridge deck slab in Maine, USA. The half-cell potential method is a slower, point by-point method used to identify areas of active corrosion within a bridge deck by using measurement thresholds provided in ASTM C876. This method uses a reference electrode, which sits on top of the concrete surface and is connected to the positive terminal of a voltmeter, with the negative terminal connected to an exposed rebar. The idea is to measure the electrochemical potential difference which develops as a part of the corrosion process.

2.0 Assessment by NDT

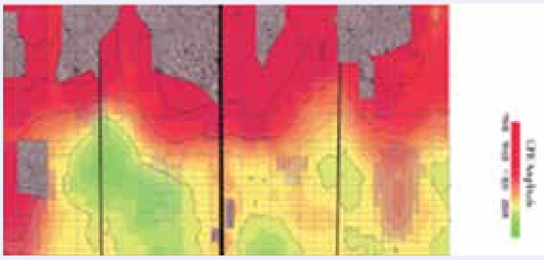
GPR data was collected using a 2.6 GHz GSSI ground coupled antenna and a SIR-3000 controller. Scans covered the entire wearing surface from curb to curb with a 300 mm offset between scans lines. Half-cell potentials were collected over the entire wearing surface as well, but on a 1.2 m grid. A visual inspection was also conducted on bridge deck, and the boundaries of all patching locations visible on the deck surface were mapped. All of the data was taken with reference to the same origin and grid so that during the processing of the data sets, the researchers retained the ability to overlay sets of data for comparison.

In deck slabs of the bridge the amplitudes associated with the rebar locations and the HCP measurements were contour plotted on plan area maps (Fig. 1a and 1b). In order to determine the correlation between the methods, and an associated GPR threshold, the contour plotting program was used to determine a depth corrected GPR amplitude and HCP measurement was taken at every 400 mm, over the entire area of the slabs. This was done so that the methods could be compared spatially since they were obtained on separate grids.

A qualitative assessment of the GPR and HCP by contour plots for the two heavily patched bridge decks demonstrates the ability of these technologies to expose the patched regions. It is expected that the patches areas with newer concrete would have higher half-cell potentials (indicating lower corrosion), and higher GPR amplitudes than the original bridge deck (because chlorides have more time to penetrate older concrete), but this isn't true for every patch.



(a) Half-cell corrosion potentials



(b) GPR rebar level attenuation

Fig. 1b: Contour plotting of half-cell potential (1a) and GPR attenuation (1b) of deck slab of a bridge

A qualitative assessment of the colour contour plots of the deck slabs demonstrates that both methods expose deterioration in the same area. In general, the upper half of the slabs can be considered corroded because this area has the lowest potentials and the most rebar level GPR attenuation. Additionally, the strong similarity between the methods suggests that GPR is a good indicator of active rebar corrosion.

To quantify the deterioration of bridge, the GPR and HCP plot for the deck slabs was generated based on data extrapolated and interpolated every 400 mm spatially throughout the slabs (Fig. 2).

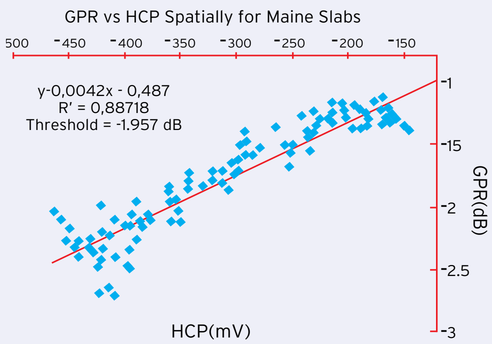


Fig. 2: Correlation curve between half-cell potential readings and GPR attenuation

Once the data was plotted for each deck, a line of best fit was determined for each plot using a least squares approach. Additionally, a correlation coefficient and an associated threshold were computed for each deck as well. The threshold was computed based on the equation of the line of best fit. According to ASTM C876, areas of concrete where HCP measurements are below -350 mV have a 90% probability of experiencing active corrosion.

Therefore, -350 mV was the HCP threshold used in the regression equations to compute each GPR rebar level threshold. Each of the computed thresholds is displayed on their respective plot.

3.0 Conclusion

The correlation coefficient for the decks for the Maine slabs was 88%. These coefficients show that GPR can be indicative of areas which are actively corroding, and those areas can be distinguished using the computed GPR thresholds. In other words, GPR rebar level measurements below the computed threshold will be considered corroded and those above the threshold will be considered healthy. If the measurements are displayed in a colour contour plot, those values below the threshold would be placed in red (corroded), and those above would be placed in yellow and green (healthy).

Based upon the NDT report where severe corrosion of reinforcement was established, the bridge deck in Maine was demolished in October 2010, after 28 years of service, and replaced with a new deck.

Case Study-2: Radar for the Evaluation of Concrete Structures– Influence of Reinforcements and Ducts

[Excerpts from the paper published in Proceedings of International Conference on "Rehabilitation and Restoration of Structures" held at IIT Madras, Chennai", 2013, p.541-542]

1.0 Introduction

A reinforced concrete slab of a building was evaluated with the GPR using 1.6 GHz antenna. The slab was divided into grids of 100 X 100mm in plan and the radar data was collected in both the directions. Fig. 1 shows the line scan obtained over a line. The inverted hyperbolas indicate the presence of the reinforcements. From Fig. 1, it can be seen that the cover to the reinforcement is not uniform. The data was processed using.

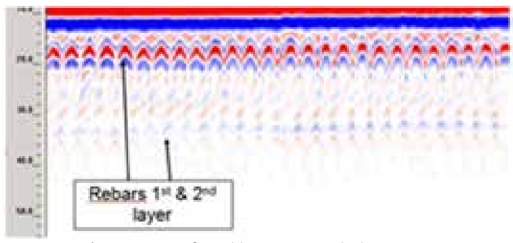


Fig. 1: Line scan for the RCC slab

RADAN software and the C-scans, i.e., the sections parallel to the reinforcements were obtained. Figs. 2 and 3 show the presence of top and bottom layers of reinforcement. The second layer is not clear because of the reflection of the radar signals from the first layer. The spacing of the reinforcement obtained is 150 mm and was correlating well with the actual provided in the slab.

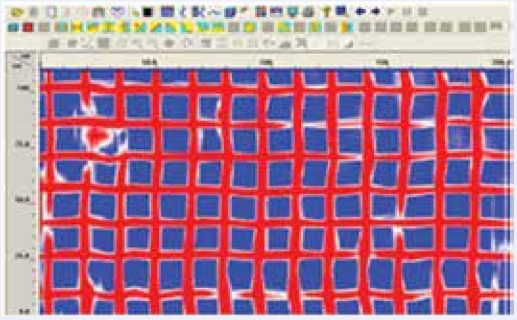


Fig. 2: C-scan – Top layer of rods

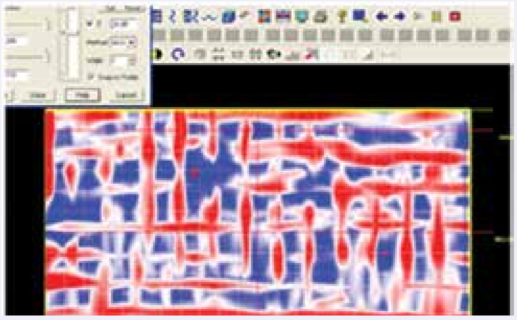


Fig. 3: C-scan – Bottom layer of rods

The B-Scan and C-scan images obtained using radar demonstrated that GPR is the best NDT method for the determination of reinforcements and ducts in concrete structures.

Various parameters were considered namely reinforcement meshes, ducts and voids. These were located effectively and the efficiency of GPR in locating buried targets was proved experimentally.

2.0 Conclusion

- Top and bottom layer of the specimen were obtained using the RADAR technique effectively, but the second layer was not as clear as the first layer. This was due to the fact the intensity of waves was initially lost due to reflection from the 1st layer itself.
- For determining the location and position of the duct, reinforcement spacing and location with respect to duct influence the output images were obtained.
- Grid spacing for collecting data is also another important parameter influencing the data. From the processed data, it can be inferred that grid spacing ranging between 100 mm to 200 mm was found to be effective.
- It can be concluded that a minimum spacing of 4 cm for

32 mm diameter bar and 5 cm for 8 mm diameter bar is possible with radar technique.

- When two metal targets such as two layers of reinforcement or a combination of duct and reinforcements are closely spaced, the results obtained are not clear and accurate due to multiple reflections.

Case Study-3: Rebar Detection using GPR An Emerging Non Destructive QC Approach

[Excerpts from International Journal of Engineering Research and Applications (IJERA),Vol. 1, Issue 4, pp. 2111-2117]

1.0 Scope in India

The use of GPR for road survey is in use for the last three decades in different parts of world but in India this concept is very new and currently not in use for routine survey purposes for the evaluation of flexible and rigid pavements. As a result it has got enormous scope of implementation for various survey purposes efficiently and cost effectively. It will be helpful as a diagnostic tool for early forecasting of road and structure damage and destruction. At the same time the verification of various design parameters can be assessed non-destructively after the construction which is a new approach for structural quality control.

2.0 GPR survey of reinforced cement concrete pavement-1

Data have been collected from various sites at New lecture Hall at IIT Roorkee campus in grid as well as line format with the objectives to accurately detect the presence and depth of rebars and estimation of slab thickness of the reinforced rigid pavements using 1000 MHz ground coupled antenna based GPR. The obtained image is clearly able to delineate the subsurface information with different layer information. The interface between the various layers and the width of the individual layers are quite clear.

Data has been collected in grid format of dimension 2 m x 2 m with inter line spacing of 100 mm between two adjacent lines in both the X as well as Y directions. The details of the pavement cross section as per documents are (1) top layer reinforced cement concrete (RCC) layer of thickness 100 mm (2) second layer is Portland cement concrete (PCC) layer of thickness 100 mm (3) third sand layer of 30-40 mm for leveling (4) fourth layer of bricks of thickness 100 mm – 150 mm and the last layer is soil layer as per the documents. Rebars are arranged in an array form having separation of 270 mm between two adjacent rebars. GPR profiles of both vertical cross section and horizontal cross section are collected and are shown in Fig. 1a and Fig. 1b. The rebars have been observed clearly and non-destructively with the exact dimension of spacing between the two adjacent rebar lines. The dimensional measurements have been found significantly correct matching to the dimensions present in the construction drawings. 2D analysis of the obtained data has been conducted by the dedicated software (EKKO_VIEW and EKKO_Mapper) for processing of ground data. Different sections of the RCC road with their different material and their thicknesses have been shown in Fig. 1a. If such information is available without digging, it can become boon in next generation quality checks. The interface between the RCC and PCC layer is clearly seen in Fig. 1a. The soil layer is clearly visible because of its distinct signature which is seen at the bottom of the Fig. 1a, wherever there is a difference of electrical properties (dielectric constant) between different layers. It is reflected in the images in terms of dark lines or fringes between the two layers which can be seen in the same Fig. 1a.

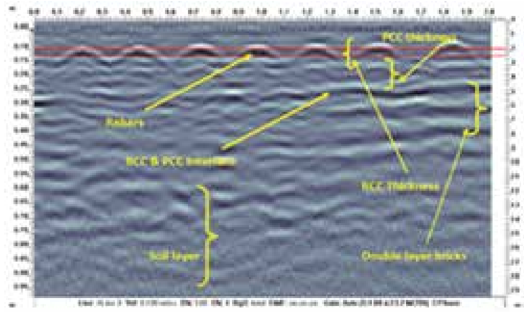


Fig. 1a: RCC pavement profile collected by 1000 MHz antenna based GPR

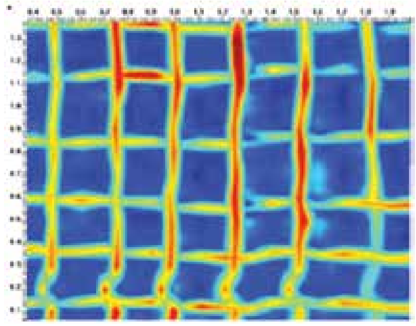


Fig. 1b: 2D horizontal plot of rebar array in RCC pavement collected by GPR

3.0 GPR survey of reinforced cement concrete pavement-2

Another RCC pavement has been studied at Rajeev Gandhi bhawan IIT Roorkee campus to obtain the rebar image. This area has been chosen to check the ability of GPR in the region having closely spaced service lines/ rebars. Clear rebar image is obtained with the correct dimension of its array. The correctness of dimension is because of high resolution of antenna used and proper velocity calibration. Data has been collected in grid format of dimension 1 m x 1 m with inter line spacing of 10 cm between two adjacent lines in both the X as well as Y direction. Then the data had been processed using dedicated softwares, EKKO_View and EKKO_Mapper. Two GPR profiles of the same vertical cross section are shown in Fig. 2a and Fig. 2b and the 2D plan view of pavement cross section showing rebar plan with clear dimensional details have been shown in Fig. 2c.The pavement is having double layers of rebars, which indicates that two slabs are used for the pavement.

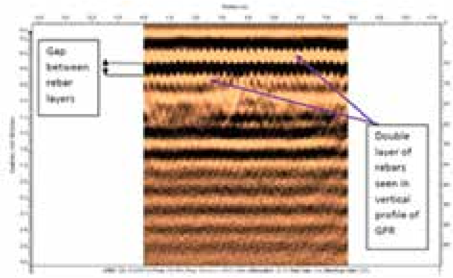


Fig. 2a: GPR profile of double layers of rebar. Data taken by 1000 MHz antenna based GPR

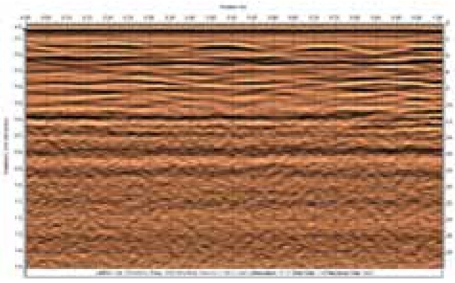


Fig. 2b: RCC profile having double layers of rebar. Data taken by 1000 MHz antenna based GPR

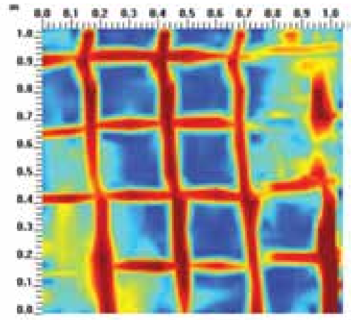


Fig. 2c: Cross sectional RCC profile having rebar. Data taken by 1000 MHz GPR. (Grid1x1)

4.0 Discussion

From the images obtained as in Fig. 1a and Fig. 2b after the survey of the RCC roads using 1000 MHz antenna, it can be seen that the GPR is capable of identifying the interfaces between the different layers having substantially different dielectric constant (an electrical property). And because of this, GPR can be utilized for the estimation of the thicknesses of these layers with appropriate correctness. It has been seen that the GPR gives very good images of the metal objects like rebars in the RCC roads. The gap between the rebars lines can also be identified with ease. Greater resolution is obtained due to the use of high frequency 1000 MHz antenna. If the same study would have been carried out using a lower frequency antenna like 250 MHz, then there could be a possibility that the small rebars might have been skipped during detection process. On should never go for line data acquisition when small pipe lines or thin telephone cables are present under the ground as generally these service lines are skipped by the operators; grid format provides larger probability of identification of these features. And if data is being obtained in grid format then also the line spacing between two consecutive GPR survey lines must be kept small so that the smallest of the small service lines are not skipped.

The image is to be observed carefully when two layers of rebars are present one below the other in order to detect both the rebar layers simultaneously. Because it is a well known fact that metals reflect the radar signals so it becomes difficult for the signal to penetrate further into the deeper levels making the deeper objects unclear

5.0 Conclusion

Non-destructive approach of GPR has been successfully implemented to detect the subsurface anomalies and ground layer structures, using this approach; it has been possible to monitor the various pavement features as given below, without digging the pavement surface.

- The presence of rebars, which were covered with the RCC layer, could be detected clearly with ease and this is noticeable in the pavement profile collected by GPR in the form of ripples as shown in Fig. 3a.
- The rebar plan map with its array dimension (270 mm by 270 mm) is non-destructively detected and which can be seen in the Fig. 1b and Fig. 2c. Therefore, there isn't any need of physically excavating the road to observe the presence and measure their array size.
- The position of rebar from the top surface is seen at 100 mm in the depth profile of pavement as can be seen in the Fig. 1a.
- Two layers of rebar could also be detected as seen in Fig. 2a. It can be seen in the form of triangular shaped ripples separated by second black thick strip. Though double layer rebar detection is little difficult if the antenna frequency is lowered as its resolution becomes poorer.
- The masking effect of rebars on the relatively deeper objects is observed clearly in Fig. 2a in which some utility objects lying below the second layer of rebar and in the middle of the depth profile is not identified clearly.
- GPR provides an efficient and versatile means for detecting rebars in the reinforced cement concrete slabs in rigid pavements along with their real depths and rebar array dimension. Single layer and double layer rebars have been successfully detected due to the use of advanced hardware and software features of the system being used. The rebar features have been easily identified without disturbing the road users, without destruction of the pavement and in shortest possible time leading to a

cost effective solution for the pavement evaluation. This is the reason why the developing countries like India must use GPR for routine pavement monitoring and hence its use can be recommended for this purpose. Its payback period will be short if its cost of purchase is compared with the equivalent economic gain during each evaluation work on the huge road networks in the country. But GPR technology is still not in use for pavement related work in India. In fact, road construction agencies in India like, National Highway Authority of India (NHAI) under Ministry of Road Transport & Highways, Public works Departments (PWD) under state government and other private construction companies of India still rely on drilling, sampling and testing for both flexible as well as rigid pavements. Although, few private companies use electromagnetic principle based ferroscan rebar scanner for building wall, roof and floor investigation in terms of presence of rebars but they do not investigate rebars for pavement as that can scan up to only a few meters, so not useful for kilometers of highway lengths.

Case Study-4: Application of GPR for detection of cracks in basement slab

[Excerpts from International Journal of Engineering Research and Applications (IJERA),Vol. 1, Issue 4, pp. 2111-2117]

1.0 Introduction

Non-destructive testing is one of the most important means which supervisor, diagnose and evaluate the quality of the reinforced concrete. The testing results will be important gist of preservation and maintenance of the concrete structure. In view of the complicated property of the reinforced concrete and the limitation of testing site environment, some routine testing method such as, for example, ultrasonic testing, pulse-echo testing and infrared ray testing, can't be put to use or obtain scheduled testing purpose. Ground penetrating radar (or GPR for short) is non-destructive testing technique of non-metallic structure and it has been widely applied in engineering and environment surveys.

There was seepage phenomenon of groundwater in concrete soleplate of the Shanghai Jinwantan Square, China. The thickness of the soleplate was 2.1 m, all the concrete was simultaneous paved and the total area is 8000 m^2. Because of the temperature changing during the solidification, parts of the concrete soleplate came into being small cracks. It was necessary to make sure the outstretched depth and the crack extend direction in concrete soleplate.

GPR data were collected using pulse EKKO-IV and pulse EKKO-1000 systems that were manufactured by Sensor & Software Inc. (Canada). Equipment components include a system unit enclosure case (250 x 160 x 160 mm), a set of shielded antenna having 25-1200 MHz center frequency and 20 m antenna control/power/data optical fibers. The antenna was connected to the GPR system unit via the fiber, allowing the antenna to be towed by a small simple tractor-trailer across the test plots.

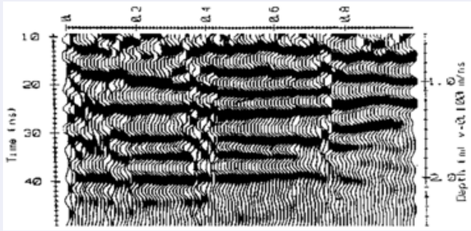


Fig. 1: GPR testing image of the cracks

2.0 Testing the GPR on crack of the concrete

A pulse EKKO-1000 GPR from Sensors & software Inc. was used for non-destructive testing. The antenna had center frequency of 900 MHz. All of the data were acquired using common-offset reflection profiling method. A series of single line tests was completed to optimize acquisition parameters, and used these results to design 3-D surveys. The step size data is 0.01 m and the transmitter-receiver separation data is 0.17 m. Fig. 1 is one of the GPR testing images. The GPR reflection images were analyzed to make sure the position and outstretched depth of the cracks.

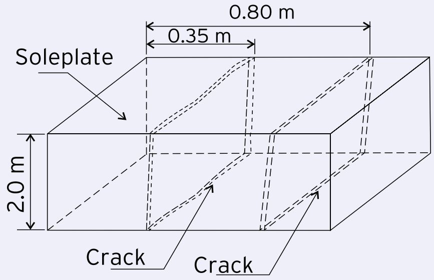


Fig. 2: 3-D representation image of the cracks

In Fig. 1 the in phase axes of the reflected wave were unbalanced on the horizontal position of the 0.38 m and 0.78 m, which showed that the two parts of the concrete existed cracks. In the vertical direction the unbalance didn't disappear until 40ns (~2.0 m depth), which showed that the cracks had extended to the bottom of the concrete soleplate. Fig. 2 is the 3-D representation image acquired by synthetically analysis with other testing line results.

3.0 Conclusion

Ground penetrating radar has widely used in geophysical surveys. GPR was primarily focused on mapping structures in the ground; more recently GPR has been used in non-destructive testing of the non-metallic structures. The application in non-destructive testing of reinforced concrete is a new task and study field. The practical engineering applications established that GPR is a better method of non-destructive testing of reinforced concrete.