REBAR DETECTION USING GPR: AN EMERGING NON DESTRUCTIVE QC APPROACH

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ABSTRACT

Civil infrastructure especially the rigid pavements have been increasingly covering a huge part of the infrastructure around us with the demand of rapid urbanization. The quality and condition assessment of it after its construction is an important issue with the engineers. The need for defect diagnosis and verification of their various design parameters is vital and important for quality control and decision making steps because of various economic, quality and safety reasons. In India, the pavement evaluation is done solely by conventional destructive methods involving a lengthy procedure of core drilling, sampling and laboratory testing which, due to the same reason, is time consuming, costly and traffic disturbing in nature. An innovative non-destructive high resolution subsurface imaging technique (ground penetrating radar 'GPR') has been used to monitor the RCC (reinforced cement concrete) pavements parameters at IIT Roorkee, India, to overcome the existing difficulties. It has substantially reduced manpower requirement, time, money and traffic disturbances. In this paper a successful attempt has been made nondestructively using 1000 MHz antenna based GPR to verify the presence and array size of rebars used in RCC roads along with its depth, concrete thickness and the masking effects of rebars on deep features.

Key words: Reinforced cement concrete, rebar detection, GPR, subsurface imaging tool, rigid condition assessment.

1. INTRODUCTION

Now a days the quality and condition assessment of the constructed infrastructure like pavements, whether rigid or flexible is getting more importance as the cases of premature failure of pavements are frequently appearing and resulting into road sinking events. These events are mainly noticed where the roads are constructed over the big sewer lines, water line and over the huge tunnels constructed for metro train as can be seen in New Delhi, India Aug 27, 2010 [1]. In fact, in July, 2010, eight times the road between AIIMS and IIT crossing Aurobindo Marg, which is passing over the Metro tunnel, was dug up to repair the leaking pipelines and that had lead to cracks on the road surface. Now the issue of concretizing the roads has been raised by the NDMC 'New Delhi Municipal Corporation'. The damage of subsurface pavement layers is the combined effect of inadequate material composition, adequate compaction, improper layer thicknesses, washing away of subsurface layers by water induced soil erosion which is due to leakage in underground pipe lines and the rapidly growing traffic load. The mater of quality is a big issue for the safety and comfort of the road users. At several places the reinforced concrete is seen as a good solution where strong structure is required like bridge decks but mostly these concrete layers are covered by asphalt layers. There, the visual inspection of the reinforced concrete pavements is not possible and so its damages are also not visually detectable. As a result, the planning of rehabilitation of such places (bridge decks) is based on a small number of probes by conventional approaches and consequently its assessment is of lower certainty [2].

The common practice for quality evaluation of concrete structures is the application of intrusive testing, applying drilling, sampling and laboratory testing [3]. These are costly and time consuming methods. A more rapid and inexpensive methodology is to apply the use of nondestructive testing (NDT) techniques. Several nondestructive methods for testing concrete have been standardized by American Society for testing and Materials (ASTM), American Concrete Institute (ACI), the International Standards Organization (ISO) and the British Standards Institute (BSI). Among the various NDT techniques for concrete evaluation, ground penetrating radar (GPR) provides an ideal technique in the sense that it has the highest resolution of any subsurface imaging, non-invasive method and is far safer than other methods such as X-ray technology [4]. GPR based concrete evaluation has already gained popularity out side India. However, it is relatively new in India and is at an early stage and needs beginning institutionally as well as commercially.

According to the extensive literature review on the background and current state of art on GPR testing of rebar in concrete by Xian [5], detecting the location of reinforcing bars is an important and popular application and that has received particular attention with emphasis on the effects of bar size, spacing and depth upon the ability of GPR to detect individual bars and the problems caused by masking of deeper features. Having been inspired from the existing concrete related structure failure and the need for its quality and condition assessment in India, the assessment of reinforced concrete structures (RCC slabs) on pavements have been initiated in the IIT Roorkee campus with the prime objective of detection and verification of thickness of concrete slab, detection of rebars with its proper reinforcement plan (map) quantification and the effect of rebars on the deeper features. The parameters are important because it is useful for calculating the load bearing capacity of concrete pavements which depends greatly on their thicknesses, placing consolidations and reinforcements.

1.1 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. PRINCIPLE OF GPR OPERATION

The RADAR (RAdio Detection And Ranging) is a well established technique that uses radio waves to detect objects and determine their distance from echoes they reflect [6]. The GPR is a special kind of radar which moves on ground and sends electromagnetic pulses to penetrate the ground The RADAR (RAdio Detection And Ranging) is a well established technique that uses radio waves to and collects back the backscattered signals from the ground. This technique is used for the detection and locating the targets in the structures. By monitoring the amplitude and time delays between the signal peaks from different layers, it is possible to evaluate both layer dielectrics and thicknesses. A variety of GPR systems are available for the purpose of survey but the primary components of all the GPR systems are the same as shown in the figure 1.

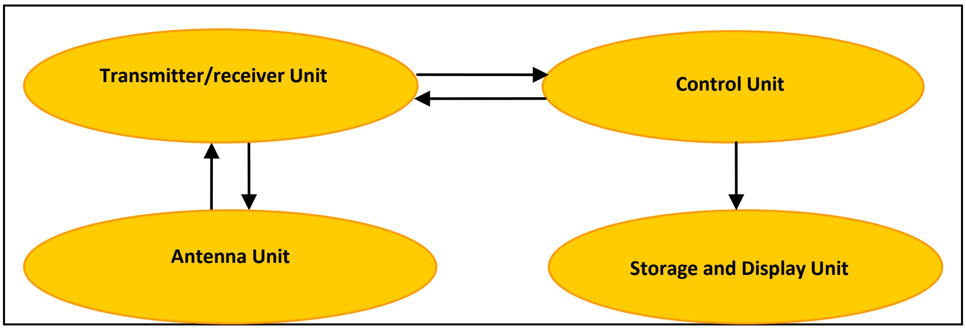

Figure 1: Basic components of a GPR system

The antenna unit of the GPR system transmits and receives radar signals. The transmitter/receiver unit consists of a transmitter for signal generation, a receiver for signal detection and timing electronics for synchronizing the transmitter and the receiver. The control unit controls the overall operation of the GPR system and sends the received data to the data storage and display unit [6]. For pavement evaluation purposes, air-coupled and ground-coupled antenna systems are used. Ground coupled antenna based GPR is shown in figure 2a and figure 2b at two different sites.

Figure 2a: 1000 MHz ground coupled antenna based GPR. Figure 2b: 1000 MHz GPR survey

The drawback of ground coupled antenna based GPR is that it acquires data at lower speed as it is moved by operator. Whereas, the drawback in the air coupled GPR is that the penetration depth is limited in comparison to that of ground-coupled GPR. The thickness of each layer can be accurately known if the dielectric constant of the corresponding layer is known. The estimation of the dielectric constant of pavement layers can be computed using the amplitudes of the reflected pulses collected by the GPR system [7].The majority of today's GPR technology is based on ultra-wideband (UWB) impulse radar principles due to its high time resolution and because of the depths at which most targets are located [8].

3. DATA COLLECTION AND ANALYSIS

Data have been collected from various sites 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.

3.1 GPR survey of reinforced cement concrete pavement at New Lecture hall IIT Roorkee campus

Data has been collected in grid format of dimension 2 m x 2 m with inter line spacing of 10 cm 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 27 cm between two adjacent rebars. GPR profiles of both vertical cross section and horizontal cross section are collected and are shown in figure 3a and figure 3b. The photograph of the site while taking data is also shown in figure 2a. 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 figure 3a. 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 figure 3a. The soil layer is clearly visible because of its distinct signature which is seen at the bottom of the figure 3a, 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 figure 3a.

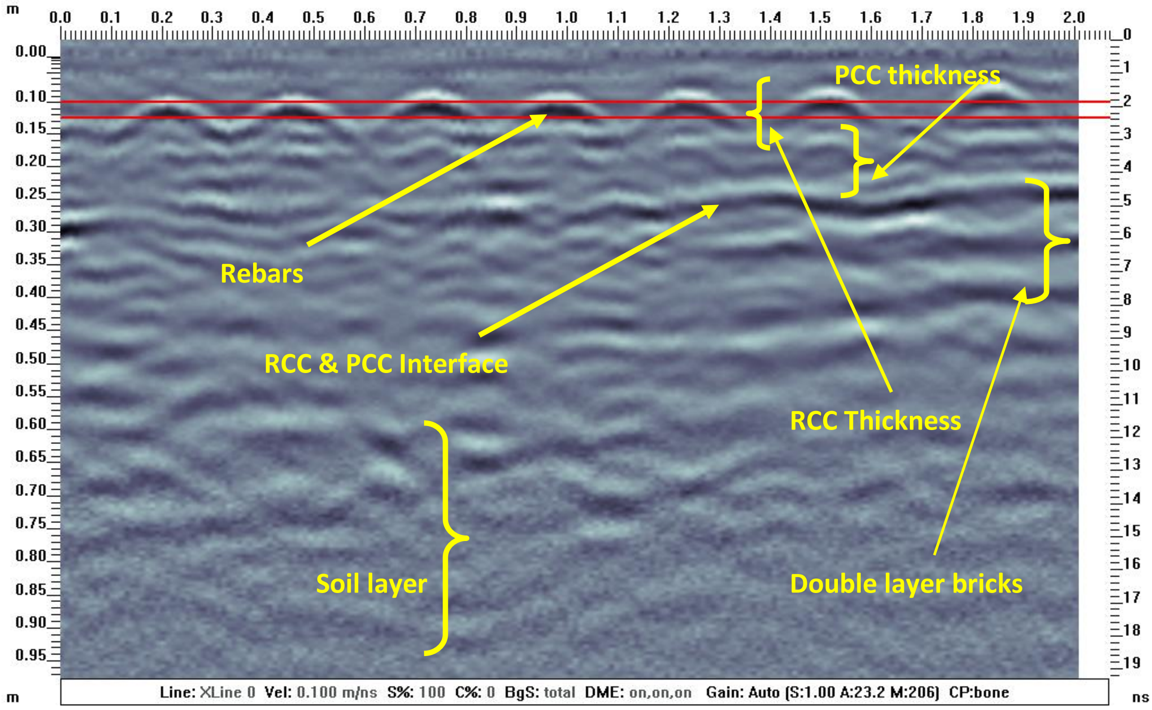

Figure 3a: RCC pavement profile collected by 1000 MHz antenna based GPR.

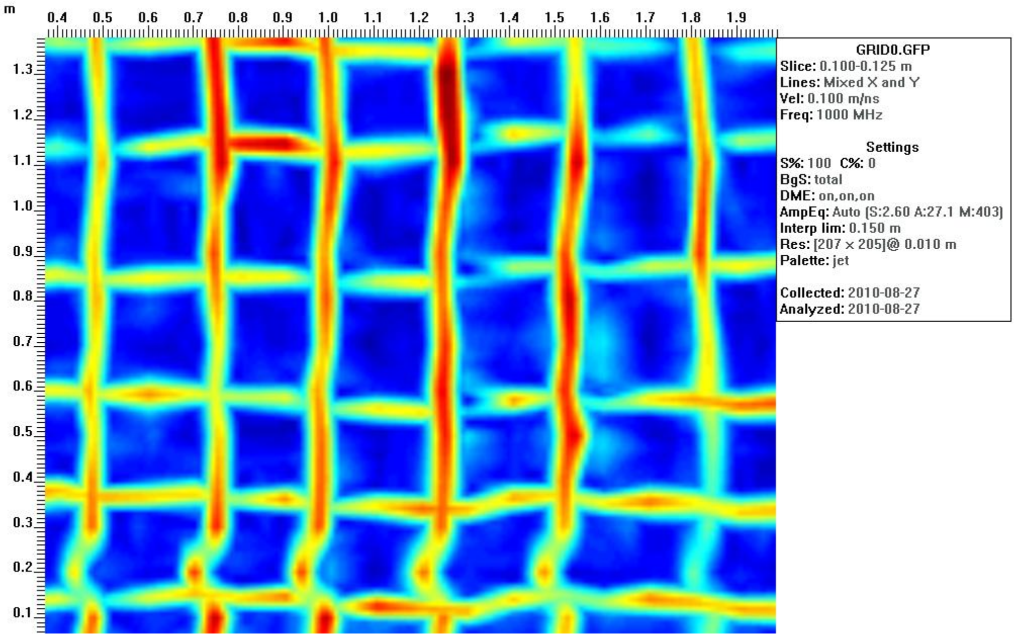

Figure 3b: 2D horizontal plot of rebar array in RCC pavement collected by GPR.

3.2. GPR survey of RCC pavement at Rajeev Gandhi bhawan IIT Roorkee campus

Another RCC road has been studied 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 figure 4a and figure 4b and the 2D plan view of pavement cross section showing rebar plan with clear dimensional details have been shown in figure 4c. The photograph of the site while taking data is also shown in figure 2b. The pavement is having double layers of rebars, which indicates that two slabs are used for the pavement.

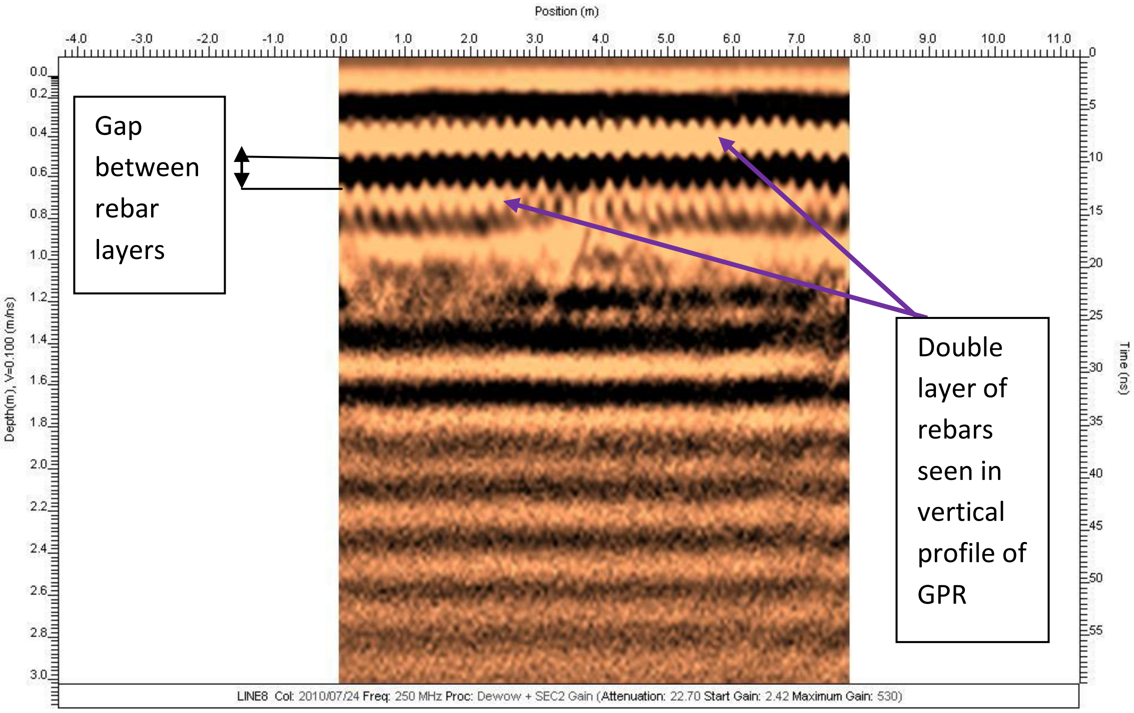

Figure 4 a: GPR profile of double layers of rebar. Data taken by 1000 MHz antenna based GPR.

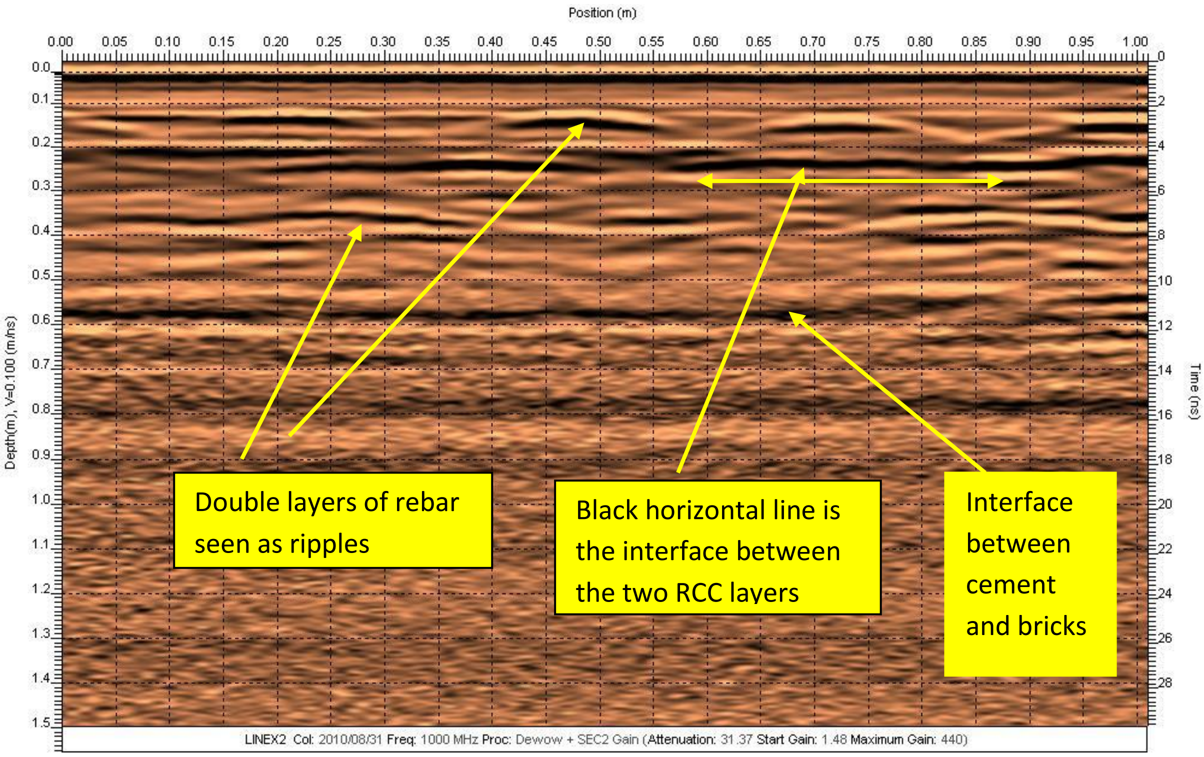

Figure 4 b: RCC profile having double layers of rebar. Data taken by 1000 MHz antenna based GPR

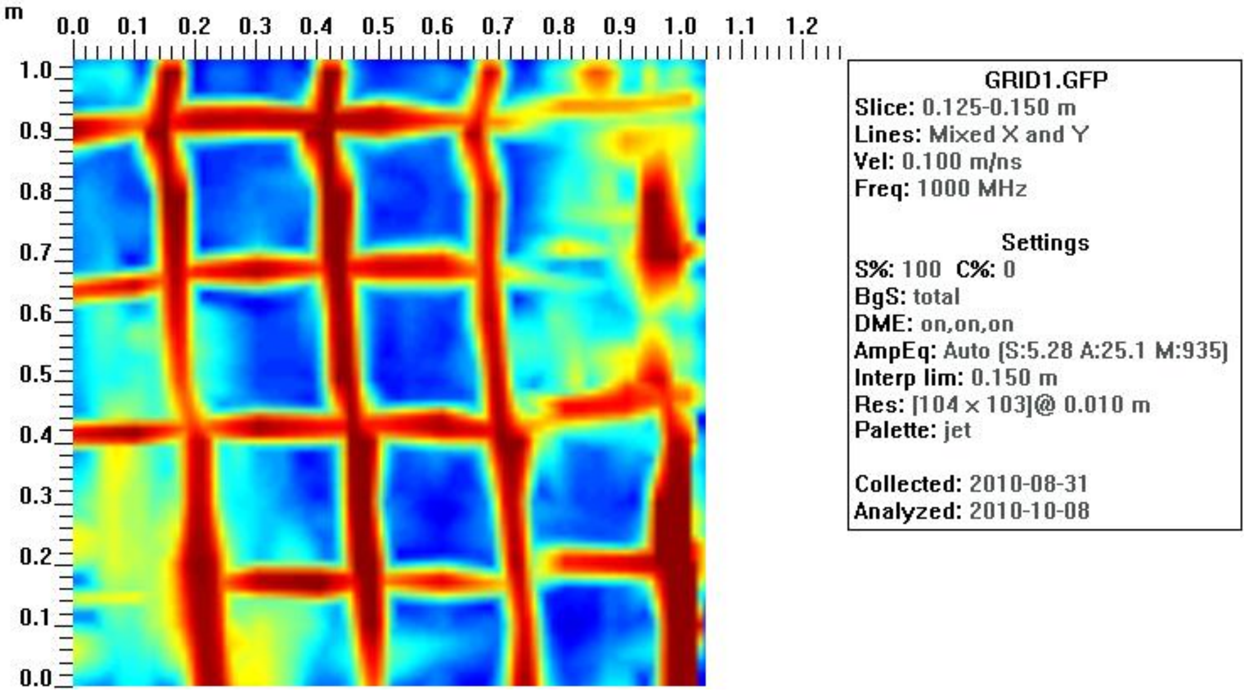

Figure 4c: Cross sectional RCC profile having rebar. Data taken by 1000 MHz GPR. (Grid1x1)

From the images obtained as in figure 3a and figure 4b 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.

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.

1. 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 figure 3a.

2. The rebar plan map with its array dimension (27 cm by 27 cm) is non-destructively detected and which can be seen in the figure 3b and figure 4c. Therefore, there isn’t any need of physically excavating the road to observe the presence and measure their array size.

3. The position of rebar from the top surface is seen at 0.1 m in the depth profile of pavement as can be seen in the figure 3a.

4. Two layers of rebar could also be detected as seen in figure 4a. 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.

5. The masking effect of rebars on the relatively deeper objects is observed clearly in figure 4a 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 pay back 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 [9] use electromagnetic principle based ferroscan rebar scanner [10] 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.

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