GPR based Detection of Structurally Weak Zones of Road Pavement

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Abstract. The application of ground penetrating radar ‘GPR’ for pavement evaluation is relatively new concept in India and can be considered to be in its natal stage as far as its survey, analysis and prediction is concerned. This is mainly due to (a) lack of skilled manpower i.e. technical expertise and (b) limitations on financial front. These issues combinedly put a big impact on the use of the emerging technologies and as a result GPR has not been able to gain popularity and confidence in India. As a matter of fact enormous scope of GPR based pavement related work can be simply expected in India. Thus, to initiate such studies, GPR survey of a major district road is conducted and an attempt has been made in the form of a paper to address the findings of GPR survey output based on analysis of the GPR image data for a heavily trafficked, structurally deteriorated, weak and potentially accident prone road which is adjacent to National Highway-58 passing through Roorkee city, and consequently which calls for the urgent need of maintenance and rehabilitation work of the road. This work can provide technical assistance to the beginners involved in the GPR based manpower development programmes.

Key words: GPR survey, pavement evaluation, maintenance and rehabilitation of pavement.

1. Introduction

Ground penetrating radar (GPR) technology has been used to assess pavement performance and damage detection for the past 30 years in a variety of ways. Currently the GPR based inspection of road pavement is actually becoming a standard technique for monitoring and maintenance program for the problems largely related to the structural damage of the infrastructures. Few studies also quantitatively showed that the pavement damages impact crucially on road safety and they are often the main causes of accident [1, 2]. Till today most of the transportation agencies are dependent upon destructive methods to evaluate layer thicknesses and the properties of pavement layers which include digging test-pits and extracting cores from the pavements. These methods provide relatively accurate thickness measurements, but at the same time, these are time consuming, hazardous and require traffic control yet provide limited information (as core samples are taken at discrete locations of road) [3]. GPR based survey provides significant advantages over the traditional methods as (a) this is the only technology that can be used at highway speed to provide subsurface information about the pavement structure (using air coupled antenna) and can be considered very safe with respect to the static traditional measurements and (b) GPR methods are not destructive especially when compared to the traditional drill core methods, therefore, they can be considered cost effective.

In spite of that, it has the limitations in terms of interpretation of GPR data which is mainly because of the fact that the backscattered signals collected by GPR depend largely on the unknown dielectric properties of the structural materials and also it cannot detect different layers unless they have sufficiently dissimilar dielectric constants [4, 5]. In the present study, GPR has been chosen for the evaluation of a road section about 125 m long which connects the old city market to National Highway-58 (NH-58) in Roorkee. This road is heavily trafficked and because of the excessive growth of traffic volume, it has become structurally...

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inadequate to serve the future transportation needs, which is self evident as two damaged road spots are found sinked and structurally deteriorated causing the removal of subsurface supporting layers up to a few meters and leading to hollow subsurface space or big voids under the road.

2. Principles 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 [4]. The GPR is a special kind of radar which moves on ground and sends electromagnetic pulses to penetrate the ground 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](image)

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 [4, 6]. For pavement evaluation purposes, air-coupled and ground-coupled antenna systems are used. 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 [7, 8]. The velocity of electromagnetic waves propagating through a media is a function of its dielectrics.

3. GPR data collection

Because of the advantages of the GPR survey over the traditional approaches i.e. (a) high rate of data acquisition, (b) sensitive to water and chloride contents, (c) insensitive to environmental conditions, and (d) three dimensional image construction, GPR survey is carried out to the intended road segment with Noggin 250 MHz shielded ground coupled antenna based GPR system for data acquisition and Ekko_Mapper, Ekko_View and Ekko_View Deluxe softwares have been used to view, analyze and predict the data. Two pits have been observed on the road being surveyed. Grid1 of size 10 m × 6 m has been taken to map bigger pit (shown in Fig. 2a) while grid2 of size 4 m × 2 m has been taken to map smaller pit (shown in figure 2b).

![Figure 2a: Pit 1](image) ![Figure 2b: Pit 2](image)
Data around the pits have been acquired in grid formats with interline spacing of 1m, that means the spacing between two consecutive parallel lines is equal to 1m. Grid means collecting data in two perpendicular directions as in our case one along the road and other across the road. First, data along all the lines across the road is collected using the instrument and then data along all the perpendicular lines i.e. along the road is collected. X-axis has been assumed along the length of the road and Y-axis has been assumed across the road width. The velocity $= 0.1 \text{ m/ns}$ has been taken as average velocity of wave propagation through the road sub layers. The GPR instrument should be calibrated for velocity in situ, since the depth values are only accurate if the system has been properly calibrated to determine the velocity of the wave in the material being scanned. The depth is given by $D = (T/2) \times V$, where $D =$ depth, $V =$ velocity & $T =$ two way travel time recorded by GPR.

Velocities can be determined or calibrated in one of the four ways - (a) hyperbola fitting (matching), (b) target of known depth, (c) selecting a media and (d) input of a velocity value. The best method is the hyperbola fitting method. In this method if GPR detects any metallic pipe under the ground whose characteristics response is a hyperbola, then using the fitting option available with the instrument which creates another hyperbola. This is superimposed over the actual hyperbolic signature and then using hyperbola fitting option the dimensions of both the hyperbolas can be matched. After matching the hyperbolas the calibrated velocities can be obtained. The calibration procedures have been performed and calibrated velocity of approximately $0.1 \text{ m/ns}$ is obtained which is used as average velocity for the study. Besides these grid surveys, two line surveys have also been performed Line1 and Line2 along both sides of the same road. Line1 is about 125 m long and the data is acquired from Church end wall to Bharat Sanchar Nigam Limited (BSNL) end wall (site description) on the same road. Line2 is about 85 m long and data is taken from Vishal Megamart parking to Church end wall (site description). The grid observations are taken to identify the damaging situations under the road layer around the pits. Line observations are taken to identify the structural deformity throughout the length of the road.

4. Observation and discussions

Survey of the road under consideration is carried out using 250 MHz Noggin GPR system (250 MHz system means antenna central frequency is 250 MHz) in grid format and the data interpretation is done manually. The instrument is set in grid format with line spacing equal to 1 m, depth setting as 5 m although it is understood that the images up to 3 m depth is clear and below that the reflected or backscattered signals are weak. Velocity calibration is set at 0.1 m/ns. There are two pits found on the road which are formed as road sank down after heavy rain, because of the loss of support due to erosion of the soil under the road surface which caused the formation of big cavity as shown in figure 3. (pipe line is visible under the road cavity). Therefore, it has been considered necessary to examine the road health from the point of view of structural adequacy and also to assess the requirement of maintenance and rehabilitation works to serve the pavement management system efficiently at planning level. The dimension of bigger pit is around (1 m x 0.5 m) and the smaller one is a circular pit having radius around 15 cm. Grid1of dimension (10 m x 6 m) is drawn around the bigger pit covering the pit 4.5 m on either side along the length of the road (x-axis) and 2.5 m on either side of pit along the width of the road (y-axis).

Figure 3: Water pipe seen through the pit1
The GPR profiles of the road on the basis of visual interpretation have been identified into five major types as (i) identification of different layer segments of road and utility items, (ii) identification of moisture/water content, (iii) identification of damaged layers, and (iv) identification of dips i.e. sinking of road. But before any kind of interpretation of the GPR data is made, it must be ensured that unwanted hyperbolic reflections caused by the objects above the ground like trees, fence, overhead wires etc. are identified which appear in the GPR profile of subsurface image. As some hyperbolic reflections can be caused by the objects such as mentioned above that are not in the subsurface region but they may cause interference with the objects under the road by showing their false presence in the subsurface region and are reflected in the GPR profile of the subsurface [9]. Thus, these need to be identified and omitted, otherwise they will represent the false presence of targets under the surface and the result of interpretation will be wrong. It can be easily identified by using a simple concept, as it is known that the velocity of electromagnetic waves in air is of the order of $3 \times 10^8$ m/s and in the ground is of the order of 1.0 m/s. So, if an object is in air the velocity shown by GPR will be of the order of 3.0 m/s and if the object is inside the ground its velocity will be of the order of 1.0 m/s. So, an important part of data interpretation is learning to recognize these unwanted “air” events and differentiate them from the desired subsurface events. Good field notes are indispensable for help in identifying unwanted events on the data. This method is used to verify the authenticity of the targets seen. Now the interpretations of the GPR profiles are as follows-

(i) Identification of different layer segments of road and utility items

In almost all the X and Y, B-scan lines (plot between depth profile vs horizontal distance covered by GPR) four distinct transverse sections of the road can be identified as can be seen in figure 4a., (a) the first segment is varying between 1-40 cm which indicates the top layer consisting of bitumen, aggregate and bricks and this can be seen visually too, (b) the second segment that is just below the first segment layer is consisting of soil of almost uniform composition roughly in the depth range starting from (40-60) cm to 160 cm, (c) the third segment which is the hard supporting layer generally consisting of stones and bricks, starts at a depth range starting from 1.5 m-1.6 m and goes up to 2.5 m to 2.6 m. This segment of image has been observed to be consisting of about four to five lines as identified from the strong reflections which correspond to the interfaces in this region, and finally (d) the fourth segment of the image of the road is the whole region below 2.6 m and at some places below 2.8 m. This is the sub-grade region which is nothing but the soil. All the above layers are shown by arrow lines in the figure 4a. Additionally, a hyperbola sign or signature is visible in the y0-line at a horizontal distance of 4.5 m to 4.8 m starting from the reference point (beginning) corresponds a metallic water pipe under the road surface of nearly 20 cm of diameter and which is validated by visual inspection of the pit1 and is shown here by referring to figure 3 again.

(ii) Identification of moisture/water content

Interestingly, the presence of water is seen before and after the pit area location and can be seen in figure 4b corresponding to line x2. This line falls along the pit axis and shows presence of water along the same axis (shown as ‘m’) which strongly recommends the possibility of formation of cavity due to water induced erosion of soil. The presence of water is supposed to be the main reason of soil erosion in the sub-surface region leading to sinking of sub-layers and thus the road structure is gradually getting damaged and pits are formed. The reason of extension of the cavity under the pit is supported by the existence of the slope in the road and so the cavity extends down the lane where water flow is maintained due to slope. Here, it will be worthwhile to mention that how could water come in significant amount in the observed pit area, and the possible reason is that there are water pipes under the road layers and thus the strong chances of their leakage can not be ruled out. There is a second possibility that a drain running by the side of the road which is over flowing during rainy seasons may wash away soil of the adjacent side of the road. In the present study both the reasons are found valid after site visit.

(iii) Identification of damaged layers

The damaged sub-layers can be observed right from top layer through the sub-base layers, and can be seen in the line Y7-line of figure 4c. The layers between top layers to the depth up to 1.2 m exhibit this signature. Layers having weak intensity of image show damaged or washed away layers or having tendency of being washed away. This makes the road structurally weak.
Figure 4a: Water pipe signature ‘p’ and different subsurface layers shown as a, b, c and d. Line-(y0)

Figure 4b: Presence of water shown by ‘m’ and washed away layers by low intensity areas. Line-(x2)

Figure 4c: Layer sinking down shown by ‘s’ and here washed out soil showing damage. Line- y7
(iv) Identification of dip/sinking

Further, some regions of layers can be observed dipping down (line Y7 of figure 4c.) which is represented by ‘s’ and here the washed out soil layers creating cavities are visible. This shows the tendency of the road sub-layers to sink down after a short period of time. Its time estimation for complete sinking is subjected to the knowledge of the traffic load and present strength of the road structure. It is clearly seen that the density of the layers at the location shown by ‘s’ is lower as compared to that of other locations of the same layers. This makes this location sinking or weak.

From the above discussion the potential strength of the GPR based road survey can be easily made out, i.e., it can identify the conditions of hidden and unseen layers of road with its associated defects that are under the surface, which otherwise can not be identified by simple surface inspection. Water, the enemy of road, which can adversely affect the load bearing capacity of the pavement by water induced soil erosion, can also be detected using GPR. By monitoring the road condition by GPR its premature failure can be avoided by assessing the weaker sections of the road, both structurally and functionally. Thus, suitable maintenance and rehabilitation actions can be taken beforehand for the roads considered unsafe and accident prone for the transportation purposes before the sudden collapse of the pavement take place.

5. Conclusion

As GPR based survey provides significant advantages over the traditional methods as already described. On the basis of the GPR based investigation of the road under consideration to evaluate the road health and the corresponding need of maintenance and rehabilitation work, it can be summarized that some portion of the road specially between grid 1 and grid 2 which is about 23 m long and also some length of road adjacent to the bigger pit down the length nearly 3 m to 4 m in length is found structurally inadequate to meet the rapidly expanding traffic load. This road may become more dangerous during rainy seasons as the same road had collapsed six months back after two days’ heavy rain causing two cavities or pits to form on the road. The presence of water, sinking sub-layers and some big cavities or voids are noticed during the investigation based on visual interpretation of the GPR profiles of the road segment under consideration, specially around the pits. On the basis of the analysis this segment of the road can be marked as potentially damaged, weak, structurally unsafe and accident prone zone. And as a suggestive remedy, the above mentioned facts call for the urgent need of the maintenance and rehabilitation work to be initiated. And till such time the heavy traffic must be avoided on this road.

6. References


