# NDT for Pavement Exploration using GPR

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**Abstract:** ***Assessment of pavement is an salient task as it plays a pivotal contribution to economic development and growth which bring social benefit. Due to modernization and increased traffic, in addition to maintenance the expansion of network and widening of existing road has become primarily important. It is foremost to have a non-destructive testing (NDT) to restrict the use of core sampling. Ground Penetrating Radar (GPR) has wide application in subsurface exploration which can be operated rapidly and without traffic interruption. This paper presents the evaluation of different layers and thickness of pavement using GPR having air horn antenna of center frequency 2 GHz and its comparison with 400 MHz antenna. The data obtained does not provide direct information which is to be processed and analyzed further. Test was conducted with different materials used in pavement and with different combinations so as to be familiar with patterns which different material give under varying dielectric constant.***

**Keywords:** GPR, NDT, Pavement, Frequency, Thickness

## 1. Introduction

Road infrastructure provides a fundamental foundation to the performance of all national economies. Recently a large emphasis is put on diagnostic methods which are simple, safe, non-invasive and time efficient from the viewpoint interference with traffic flow of particular road. Road users require safe, economical and comfortable driving. Vehicle technology, traffic mix and road conditions have necessitated the research on road user cost to be reviewed and updated periodically so as to adequately represent the changed conditions. It is felt prudent for proper assessment of road projects to develop a uniform method and new techniques for pavement layer which are non destructive. GPR is an non destructive evaluation technique that has been successfully used in several transportation applications such as subsurface exploration and condition assessment. An accurate anticipation is required for pavement management system. GPR can be used for the estimation of structural capacity of existing pavement to predict their remaining life. The design of overlay and quality control can be assured [1]. The error is minimized in the statistical analysis as most of the available quality measurement methods such as testing the field cores in laboratory can only provide information of discrete test locations. The risk involves in the measurement as the tested random sample is only a small fraction of the population. GPR is a rapid testing method that covers a large area and enhances the confidence level of data [3]. GPR can be further provide the various parameters for distress in pavement including cracks and their propagation, rutting, segregation, stripping, moisture and asphalt air voids content with the possible corrective actions. The location of the distress can be monitored in the radar data [10].

## 2. GPR System

The GPR system mainly consists of three parts control unit, antenna and distance measuring instrument (DMI). The control unit for this system is SIR-20 which is a computer for storage and analysis of data. The housing of antenna consists of transmitter and receiver assembly. The system generates a continuous short electromagnetic pulse which is transmitted through the medium of interest and get partially reflected on encountering a change in electrical properties. The reflected energy is collected and displayed as a waveform showing amplitude variation. The frequency of the antenna plays an important role in the penetrating depth of GPR signal and the data resolution [1].

In case of GPR with high frequency the distortion of the shapes in original incident pulse and reflected pulse does not have significant difference. It may be because the antenna with 1 GHz and 2 GHz penetrates through short depth and henceforth the target encountered are less. The antenna with low frequency penetrates through long depth which exceeds 2 m length. The travel time in this case is more and encounters more targets and reflection while propagating resulting into change in shape of the pulse [7].

## 3. Basic Principle of GPR System

The principle of GPR system in this study is based on sending the electromagnetic pulse into system which may be air horn or ground coupled type antenna. The pulses are reflected back from internal surfaces with dielectric discontinuity by measuring the amplitude and arrival time of pulse [4]. Electromagnetic waves travel at specific velocity that is determined primarily by the relative permittivity ($\varepsilon_r$) of the material. The relationship between the velocity of wave and material properties is the fundamental basis for using GPR to investigate subsurface. By monitoring time delays between the peaks of reflected signals, it is possible to evaluate layer thickness (h),

$$h = \frac{c\Delta t}{2\sqrt{\varepsilon_r}} \quad (1)$$

where $c$ is the speed of light in free space ($3 \times 10^8$ m/s), $\Delta t$ is the two way travel time between the layer interfaces. The dielectric constant of the top layer( $\varepsilon_{r,1}$) which may be HMA or concrete can be estimated from equation (2),

$$\varepsilon_{r,1} = \left( \frac{1 + \frac{A_0}{A_p}}{1 - \frac{A_0}{A_p}} \right)^2 \qquad (2)$$

Where $A_0$ is the amplitude for surface reflection and $A_p$ is the amplitude of the incident GPR signal which is determined by collecting GPR data over a large scale and flat copper plate placed on the pavement surface. This equation assumes that the material should be homogeneous and have uniform dielectric constant [5]. The constant values of various materials are shown in Table 1 [8] ranging from 1 to 81.

**Table 1:** Dielectric Constant

| Material | Dielectric Constant |
|---|---|
| Air | 1 |
| Dry sand | 3-5 |
| Asphalt | 3-6 |
| Limestone | 4-8 |
| Clays | 5-40 |
| Concrete | 6-11 |
| Saturated sand | 20-30 |
| Water | 81 |

## 4. Traditional Methods

The destructive method of testing includes core sampling and field sampling. Drilling a core decreases the structural capacity and affects the strength and durability properties of the pavement. After extracting the core the filling process with the binding material is time consuming and an monotonous operation [2].

There are different technologies for NDT for evaluation of structural capacity and to determine various parameters such as modulus of elasticity of concrete, modulus of subgrade reaction, load transfer efficiency and presence of voids. The NDT includes GPR, ultrasonic tomography, Benkelman Beams, Seismic Pavement Analyzer, falling weight deflectometer, dynaflects, etc. From the above methods available GPR is the most resourceful and multifaceal [1].
There are certain importance for existing and old pavement. The details are necessary to model the pavement maintenance and rehabilitation strategies. The measurements of thickness of layer are usually unavailable for older pavement due to poor documentation [7].

## 5. Applications of GPR

The GPR consists of antenna of different frequencies and the selection is done depending on the penetrating depth and type of work. The numerous applications of GPR include the following:

1) Inspection of concrete structures for any distress and location of steel reinforcing bars in the member.
2) Mapping of pipes, cables or any other buried object.
3) Mapping the difference in soil type or fill layers for geotechnical applications.
4) Monitoring the condition of ballast so as to avoid instability of the track [6].
5) Detection of illegal dump deposit and to identify hazardous waste for the decision making of land retrieval [9].
6) To locate buried archeological structure before carrying out the digging operation to prevent heir accidental damage [7].

## 6. Testing

The testing were carried out using two different antennas having frequency 400 MHz and 2 GHz respectively. The testing of 400 MHz antenna was performed on concrete pavement in VJTI campus. The survey cart was used with the DMI for measurement of horizontal distance. The data was acquired at the rate of 40 scans per second. The analysis was performed using a specialized software. In case of underground utilities like pipeline the low frequency antenna shows hyperbola when the target is detected. The result obtained is shown in Figure 1. We can observe formation of multiple hyperbolas up to certain depth after which the pattern changes their shape. Further test were conducted on concrete pavement in different location and the results obtained were same. From this we can predict that the pavement shows multiple small hyperbolas on reflection

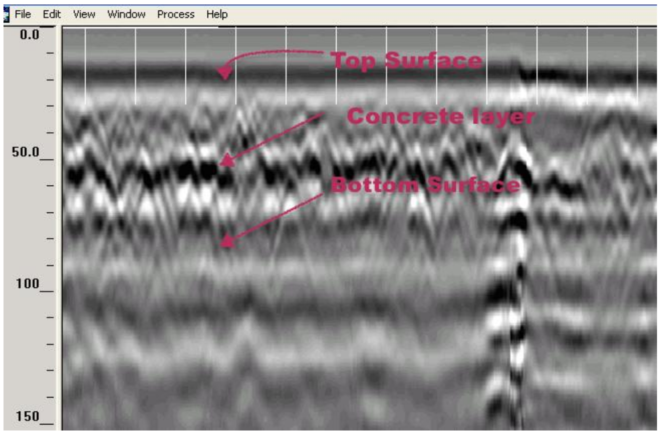


**Figure 1:** Result obtained for concrete pavement using 400 MHz frequency antenna

Concrete is a heterogeneous mixture consisting of cement, fine aggregate and coarse aggregate. Analysis depicts that when a pulse hits the individual target which may be aggregate in a concrete it forms one small hyperbola. In such a way entire result is obtained. The outcome is same for the flexible pavement using 400 GHz antenna. The drawback of using low frequency antenna in pavement analysis is that it shows large variation in size of depth and detects numerous patterns of objects up to additional depth. Thus high frequency antennas are used for pavement evaluation and further tests are conducted on flexible pavement on field and in workshop using 2 GHz antenna.

### 6.1 Field Testing

The readings were taken on road having flexible pavement near D bock of VJTI campus in Mumbai. The vehicle were not used for the measurement of horizontal distance and the instrument was operated under free run command. The time required to setup the instrument is not more than 6 min. The length of the road was 50 m. The antenna was allowed to travel over test location. Data were acquired at the rate of 40 scans per second with 512 samples per scan. The time required was approximately 3 min.

The same procedure were repeated with 80 and 160 scans per second. The storage size of the data increase but the time required for acquisition reduced to 2 min. The data were put for analysis after collection of suitable samples. If the dielectric constant of two materials have value with less difference then the readings obtained has less variation. In the process of analysis using RADAN it is difficult to identify the layer. There were chances of presence of void pockets which are onerous to detect by taking the core of pavement. It is necessary for the researcher to be familiar with all the patterns so as to have interpretation of data with less effort and more accuracy.

### 6.2 Workshop Testing

To have the knowledge about the analysis the test was conducted in a transportation department workshop of VJTI campus. A pit was constructed using a wooden plank of dimension 1m ´ 1m´ 0.3m. The base of the mechanism kept open and the ground surface was assumed as a sub grade. The depth was divided into three parts comprising height of 0.1 m each. The first part which is a base layer filled and compacted with aggregate of size 40mm. The readings were obtained using GPR with free run having center frequency 2 GHz. The analysis can be predicted with less effort as it comprises of single layer. The analysis rather becomes difficult when subsequent layers of different sizes are added. Sometimes the reading may appear as homogeneous if the heavy weight compaction is carried out.

In this case the dielectric constant plays an important role to identify various surfaces. In the final combination of arrangement of layer the top 10 cm is filled with bitumen. To distinguish the different layer two thin metal piece were kept between the surface interface. The reading acquired were changed to different colour code so as to distinguish the surface. It was observed that the metal reflection shows different colour as shown in Figure 3 and hence forth the interfaces were identified and the layers can be identified. The pattern changes its colour when metal is detected. In section A the gap can be observed which is due to the removal of metal piece.

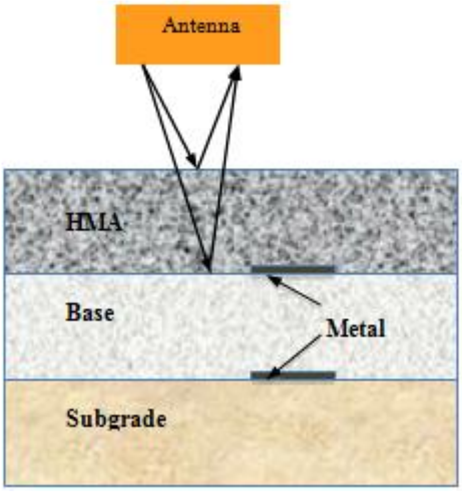


**Figure 2:** Mechanism used in site testing for flexible pavement

The left corner calibration shows the depth of pavement in 'cm'. The topmost layer begins from approximately 22 cm. The bitumen layer can be calculated considering the section B which is approximately 10 cm and matches with the true value. There are multiple colour combinations and one of them can be selected which can be best suited using trial and error method. The main focus has been kept on the analysis of data as the 2 GHz antenna does not produce large variations such as multiple hyperbolas which is in the case of low frequency antenna used for underground utilities.

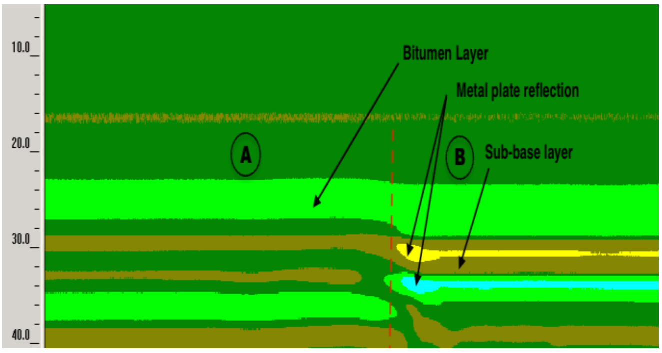


**Figure 3:** Result obtained from 2 GHz frequency antenna for flexible pavement

## 7. Conclusion

The research aimed to differentiate various layer in pavement along their thickness under various settings. The field experiments validated the applicability and effectiveness of GRP approach. This enables performing a non-destructive and quick assessment of the structure and subgrade. Considering environmental precaution and efficient implementation, GPR is one of the most competitive techniques available. The centre of attention was kept on analysis of data. The comparison was made between the two antenna with different frequency. The result signifies that low frequency antenna can be used for pavement evaluation but the analysis is not accurate and are subjected to more error. The 2 GHz antenna serves better for pavement analysis with high resolution data. This outcome is not the rule, as the differences could be significant in case of variation due to different material property. GPR applications can be serviceable in the field of management as it saves time and improve quality without damaging the structure.

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