SUBSURFACE LITHOLOGY MAPPING BY USING GROUND PENETRATING RADAR

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ABSTRACT

The main aim of this thesis is to demonstrate the applicability of the Ground penetrating radar (GPR) to identify the sub-surface lithology of the ground having the cross-section profile.For this purpose four different places were selected where there is a known differences in lithology among the layers. For the interpretation of the GPR profiles the cross-section images of the subsurface layers were photographed for comparison with the GPR data. The study was conducted in different places by taking two profiles on bitumen layer and two profiles on soil layer by using GPR with 100 MHz antenna.

After the data collection post-processing of the data is done with the RADAN 7 software to remove the noise from the various sources. After processing with the RADAN 7, GPR profiles is correlated with the field data.

From the experimental results of the four profiles of the Ground penetrating radar data and field information, it is found that the lithologic layers of the subsurface could be correlated reasonably to the image of the GPR profiles. This information can be used to interpreting GPR data for mapping subsurface lithology.

INTRODUCTION

Ground penetrating radar (GPR) also known as Geo-probing radar or Geo radar is one of the instrument that can produce an image of subsurface by totally a non-destructive method and can give a subsurface cross-section profile without any drilling or trenching the ground. GPR profiles are normally used for the identification of the depth and location of the buried objects such as civil utilities, to identify the presence and continuity of the natural features and subsurface conditions.

Ground penetrating radar (GPR) is a geophysical method which uses radar signals to image the ground. This non-destructive geophysical method works on the principle of Electromagnetic wave propagation theory usually in the range of the microwave band in the radio frequency spectrum to investigate the continuity and disposition of the natural subsurface conditions. Most of the GPR methods can gather the great information about the subsurface in the non-destructive way, allowing large set of data to study efficiently and accurately, under the favourable conditions.

FUNDAMENTALS OF GROUND PENETRATING RADAR

Ground penetrating radar works on the principle of scattering of Electromagnetic theory, whenever Electromagnetic wave radiated from the transmitting antenna incident into the ground they get reflected back to the receiver depending on the dielectric properties and electrical conductivity of the subsurface materials. GPR is used to detect the target or its interfaces covered under the opaque substances and to map its structure under the subsurface.



Schematic diagram of overall GPR system

The depth of penetration of the EM waves decreases as the frequency increases with increase in resolution/accuracy. In the same way the depth of penetration of the EM wave increases as the frequency decreases with decrease in accuracy. Therefore antennas with low frequencies (20 to 250 MHz) can obtain the reflections from deeper depths (more than 10 meters) with low resolution. These low frequency antennas are used to study the geological information of site, such as to locate the fractures and to locate the deep buried utilities. Antennas with high frequencies (>250 MHz) obtain the reflections from shallow depths (0 to 10 meters) with high resolution. Hence these high frequency antennas are used to for civil engineering applications, non-destructive techniques (NDT) applications and for smaller objects detection in the subsurface.

FREQUENCY	DEPTH	APPLICATIONS		
2.6 GHz	Up to 0.03 m (Approx)	Structural concrete, Roadways, bridge decks		
1.6 GHz	U to 0.05 m(Approx)	Concrete evaluation, Roadways, bridge decks		
900 MHz	Up to 1 m(Approx)	Concrete evaluation, void detection, shallow soils		
400MHz	Up to 4 m(Approx)	Utility detection, void detection, environmental, archeological		
270 MHz	Up to 4 m(Approx)	Utility, engineering, geotechnical		
200 MHz	Up to 10 m(Approx)	Geotechnical, engineering		
100 MHz	Up to 20 (Approx)	Geology, geotechnical engineering, mining		
16 – 80 MHz	Up to 35 -50 m(Approx)	Geology, Geotechnical engineering		

Table 1.1 Frequency of Antenna with depth range and its application areas

1.3 Applications areas of GPR

GPR can be applied to various fields such as geological, hydrogeological studies. In addition to the subsurface profiling or mapping, mapping of bedrock topography, identification of water table, locating the buried targets or objects, identification of cavities, pipes, tunnels, to find the leakage in the dam structure, land mine detection can also be done by GPR. By using the GPR techniques we can identify the unexploded ordinance and mines and these are studied. GPR survey can also be used for the engineering applications like civil constructions (road pavements, bridges, foundations) and the GPR data can be analyzed for the reference purpose in order to identify the structural geology. Now a days Forensic department and law enforcement agencies are also using the GPR for finding the graves, sometimes human bodies remains and murder of victims in the ground. Investigations of archeological sites is one of the major applications of GPR.

1.4 STATEMENT OF THE PROBLEM

In the urban environment, constructing rail, road, bridges and buildings is a common feature. It is very important to know the subsurface soil structure along with other utilities and geologic surprises (boulders) to plan well in advance for making foundations. GPR is a versatile equipment to map the subsurface features without trenching or drilling.

It is very important to validate the GPR signals at sites excavated for foundations of high-rise buildings, fly over pillar foundations to know the subsurface soil structure by using 100 MHz antenna, it is probably the best tool to map subsurface formations to reasonably accuracy at the near surface. Therefore in the present study GPR images are taken at sites excavated for foundation and these are validated through actual profiles observed at sites.

LOCATION OF THE STUDY AREA

In the present study two sites have been choosen in and around Hyderabad where the excavation is done for the fly-over or some other construction purposes. One of the excavated site is situated near Hi-tech city railway station, izzathnagar, kothaguda with the coordinates of latitude 17°28'23.08 and longitude 78°22'52.97 and the other excavated site is situated opposite to the Manjeera majestic commercial complex, kukatpally for the construction of fly-over with the coordinates of latitude 17°29'30.61 and longitude 78°23'35.28. (Fig 1.2 and Fig 1.3)



Fig 1.2 First excavated site for the bridge near Hi-tech city railway station



Fig 1.3

Second excavated site for fly-over at opposite to Manjeera mall

THEORETICAL BACKGROUND

Ground penetrating radar is a geophysical method that uses electromagnetic waves to image the subsurface by the principle of electromagnetic theory. This non-destructive method uses electromagnetic radiation in the microwave band (UHF/VHF frequencies) present in the radio spectrum usually having the higher frequency radio waves usually in the range of 30 MHz to 300 MHz, Ground Penetrating Radar transmitter emits the electromagnetic waves into the ground, when the waves are encounters an object or boundary between materials having different permittivity gets reflected or scattered back to the receiver present in the GPR and it can be observable on the control unit digitally and records the variations in the reflected signal. The principle involved in the GPR is similar to the seismology, except GPR uses electromagnetic energy instead of acoustic energy, and the energy may be reflected at the boundaries wherever the sub-surface material properties changes rather than the sub-surface mechanical properties as in the case of seismics. However, the transmitted and reflected signals in the GPR depends on the dielectric property of the sub-surface materials. Because subsurface itself is having consisted of different material properties, each material has its own conductivity levels for which they produces a certain velocity for travelling EM waves.

Using the reflections of the waves and two-way travel time of the Electromagnetic pulses a cross-sectional profile is generated. The cross-sectional profile can be observed in real time by the control unit where the collection of reflected EM signals are obtained. (Fig 3.1)





and the time required to return the reflected signal. Reflections are produced when the waves enters into the different material properties which are based on the dielectric properties of different materials. And the strength of the reflections are also based on the contrast in the dielectric properties of the materials (Fig 3.2). Which means, a wave which moves from dry sand to wet sand will produce a strong reflection, while moving in same way from dry sand to limestone will produce a relatively weak reflection. The loss of signal varies widely based on the properties (dielectric constant and conductivity) of materials through which the waves are passing.

EM waves in the subsurface material can be described by Maxwell's equation and the behavior of the EM waves in subsurface material is dependent on is electrical conductivity and dielectric constant (ε_r) and we have the relation between the electric and magnetic fields as in equation 3.1

$$\Delta \mathbf{x} E = -jw\mu \mathbf{H}$$

$$\Delta \mathbf{x} \mathbf{H} = E\sigma + w\varepsilon E \qquad (3.1)$$

Where

 σ : electrical conductivity

Relative permittivity is defined as the dielectric properties of the material relative to that of free space as in equation below 3.2

$$\varepsilon_r = \frac{\varepsilon}{\varepsilon_o}$$
 (3.2)

Where

 ε_r : Relative permittivity

^E : Dielectric constant of material

 ε_o : Relative permittivity in the free space (8.8541×10⁻¹² F/m)

Travel time is defined as the sum of the time taken to reach the material and time of reflected back signal from material to the receiver. So that we will call it as two-way travel time. We need to find out the velocity of the EM wave in the material, therefore to measure the velocity of the wave, a relation between time & depth of the sub-surface material is given in below equation 3.3

$$V = \frac{2d}{t} \tag{3.3}$$

Where

d: depth of the sub-surface boundary

t : time travel (ns)

V: velocity of the EM wave (m/ns)

The velocity with which the EM waves passes through a material mainly depends on the materials' dielectric permittivity. The velocity of the wave in the sub-surface is less relatively when compared with the air as a medium. The dielectric constant of the material is inversely proportional to the velocity of that material. This relation is given by the equation 3.4

$$\mathbf{v} = \frac{c}{\sqrt{\varepsilon_r}} \tag{3.4}$$

where

 ε_r : Dielectric constant of the material

c: EM wave velocity in vacuum (0.3m/ns)

V: EM wave velocity in material

The EM waves are reflected whenever they get interaction with the different material, some amount of energy is absorbed by the material, and some travels towards the deeper ground. The reflected proportion of the energy depends on the dielectric properties of the materials at the interface, this relation is generally described as the reflection co-efficient.

The reflection co-efficient is the ration of the amplitude of the reflected energy to the amplitude of the original energy. For a normal incident signal the reflection co-efficient is given as in equation 3.5

$$R = \frac{(\sqrt{\varepsilon_2} - \sqrt{\varepsilon_1})}{(\sqrt{\varepsilon_2} + \sqrt{\varepsilon_1})}$$
(3.5)

Where

$$R = \frac{(\sqrt{\epsilon_2} - \sqrt{\epsilon_1})}{(\sqrt{\epsilon_2} + \sqrt{\epsilon_1})}$$
(3.5)
R: reflection co-efficient

 $\boldsymbol{\varepsilon}_1$ = dielectric constant of medium 1

 $\boldsymbol{\varepsilon}_2$ = dielectric constant of medium 2







Fig 3.3 Frequency of antenna Vs depth of penetration for comparison

From the above Fig 3.2 and Fig 3.3 it is observed that as the frequency of antenna decreases, the depth of penetration increases in addition to the decrease in resolution of the data or accuracy and vice-versa. With increase in electrical conductivity will attenuate the intruding property of electromagnetic wave, consequently the depth of penetration comes down. Because of the frequency dependent attenuation condition, the higher frequency radars will not penetrate into the deeper depths compared to lower frequencies. However the higher frequency of antennas provides high resolution or high accuracy data with lower depth of penetration. Based on the area of interest or application we need to adopt the suitable frequency of antenna for data acquisition

COMPONENTS OF THE GROUND PENETRATING RADAR

The GPR instrument has the following components

- 1. Control unit
- 2. Antenna
- 3. Battery



Software Control Buttons Fig 3.4 GPR control unit (SIR4000)

3.3.2. Antenna

The 100 MHz shielded antenna is normally suitable for deep sub-surface applications, geology, geo-technical engineering, mining and archeological applications (Fig 3.5). This antenna is compatible with SIR 4000 and SIR 30 control unit systems. Even though we have multiple applications we are supposed to use the suitable antenna according to application.



Fig 3.5 GPR 100 MHz antenna

3.3.3. Battery



3.4 BASIC GPR OPERATIONS BEFORE SURVEY

The following are the two simple connections need to be performed before doing survey.

1. The male end of the antenna control cable need to be connected to the port of 19 pin analog antenna of the control unit SIR 4000. The other end of the cable need to be connected to the antenna.(Fig 3.7)

2. The survey wheel calibration cable is to be connected to the survey port provided on the top of the antenna. However by default the cable is connected to the antenna but we need to check before doing survey.

3.5 INTRODUCTION TO THE GSSI SIR 4000 CONTROL UNIT SCREEN

By pressing the power button on the top left corner of the control unit of SIR 4000, the system gets switched-ON, by having the LED lights of green and red illumination for turning ON condition and other purposes. This screen allow us to select the following options and modes while switched to ON condition.



Fig 3.8 Introduction to screen

3.5.1 Expert mode: By using Expert mode the user can customize all the parameters of overall 2D data collection. (Fig 3.8)

3.5.2 Last used settings: This option allows the system to recall the last used settings on the control unit for data collection. Until unless we change the settings, the settings are not going to be changed. (Fig 3.8)

3.5.3 New project: In this option we can create the new project name for the data collection to be done for the new data. (Fig 3.8)

3.5.4 Play back: In this option one can reopen or play back the previous files stored in the control unit. (Fig 3.8)

3.5.5 Tool bar: Tool bar which is provided to customize the universal options provided in the control unit. Provides different options to change the data appearance during setup, data collection and play back mode. It contains the options such as Language, Units, Antenna, GPS, Theme and settings. (Fig 3.9)



Fig 3.9 Introduction to Tool bar

3.5.5.1 Language selection: There are six (6) languages on the SIR 4000 which contains English, French, Chinese, Japanese, Spanish, Portuguese, we can select our priority language by using control nob or navigation buttons. (Fig 3.9)

3.5.5.2 Units: There are two types of units available on the control unit, those are English units and Metric units. We can select it by using control nob or by buttons provided. (Fig 3.9)

3.5.5.3 Antenna: In this option we can select the antenna frequency, antenna model and antenna transmit rate from the list of options available. (Fig 3.9)

3.5.5.4 GPS: In this option the SIR 4000 will allow us to configure the GPS to record the coordinates of the real time data collection in the site. Make the following settings to enable the GPS for SIR 4000.



3.5.5.5 Theme: In this option we can change the theme settings based on our choice and select the preferred color theme once it is selected it will be default for the next time. (Fig 3.11)



Fig 3.11 Theme settings in tool bar

3.5.5.6 Settings: In this option we have the settings of Calibration, configuration, date and time and firmware. (Fig 3.11)

3.6 DESCRIPTION OF MENU BARS OF SIR 4000 CONTROL UNIT

The GSSI SIR 4000 has the following main menu options and these options are directly visible on the screen, can navigate through the control nob by rotating it to be worked out for the changes in settings.

I. Radar II. Process

III. Output

IV. System

3.6.1 Radar: The following are the options that can be customizable under the radar settingsusing control nob or navigation buttons.



Fig 3.12 Radar menu settings **Dielectric constant:**

Dielectric constant or Relative permittivity is the velocity of the Electromagnetic waves with which it travels into the subsurface material. The dielectric constant values are differ with the velocities of the electromagnetic waves in the subsurface geologic conditions or features. If we know the dielectric constant of the materials that we are surveying through we can give it manually to the control unit. Dielectric constant and velocity are inversely proportional to each other, which means the higher the dielectric constant the material is having, the lower is the velocity of EM wave through material which leads to shallow depth of penetration.

The relation between velocity and dielectric constant is given by

$$\varepsilon_r = \left(\frac{c}{v}\right)^2$$
 \longrightarrow Dielectric $= \left(\frac{Speed \ of \ light}{Velocity}\right)^2$

Speed of light = 11.811 in/ns (0.3 m/ns)

S.No	Material	Dielectric constant	Velocity (mm/ns)
1	Air	1	300
2	snow	2.2	225
3	PVC	3	173
4	Clay soil (dry)	3	173
5	Polar ice	3.15	168
6	Asphalt	4	153.5
7	Sand stone (wet)	6	112
8	Concrete	6.5	110
9	Granite	6.5	113
10	Dolomite	7.5	111
11	Basalt (wet)	8	106
12	limestone	8	107
13	Silt (wet)	10	95
14	Clay (wet)	12	98
15	Agricultural land	15	77
16	Sand (wet)	28	58
17	Water (fresh)	81	33
18	Coal	440-490	4-5
19	Sea ice	5.25	118
20	marsh	12	86

Table 3.2 Dielectric constant values for different materials



Fig 3.13 Variation of dielectric constant with velocity

From the above graph (Fig 3.13) it is observed that velocity of the EM wave increases as the dielectric constant of materials decreases and vice versa.

Soil type: Generally survey is to be performed in different soil conditions like rock, pavement, soil etc. We can select the soil type directly in this option accordingly it can select appropriate dielectric constant. (Table 3.3)

Material	Dielectric Constant
Snow/Ice	3.0
Dry Sand	4.0
Pavement	6.0
Rock	8.0
Dry Soil	9.0
Ave. Soil	14.0
Wet Soil	20.0
Wet Sand	25.0
Water	80

Table 3.3 Soil type and Dielectric Constant

Depth range: it is the vertical scale displayed on the control unit, we can choose the units to be displayed on the vertical scale. (Fig 3.12)

Time range: it is the vertical scale of depth in nanoseconds to be displayed on the control unit, we can choose the scale to be displayed.

Position mode: it deals with the position of the Time-zero. Time-zero is the location of the beginning of the scan.

Offset: it is an internal system parameter, that describes the time lag in nano seconds from the control unit till we consider it to have transmitted from the antenna itself.

Surface (%): The term surface represents the ground surface that should set to 0.0

3.6.2 PROCESS:

In this process menu, the following settings need to be changes based on our preferences by using control nob or navigational buttons.



Fig 3.14 Process menu settings

Gain mode: gain is the artificial addition of the signal to amplify or impede the natural effects of attenuation, it will make the weaker signal into stronger relatively.

Whenever the signal is transmitted into the ground some portion of the signal is reflected, some absorbed by material and remaining some goes to deeper until it is completely absorbed so that it becomes weaker. In order to amplify those signals, Gain mode is used by using the Gain curve in the O-Scope that can be seen in the Fig 3.14 on the setup screen. Gain mode is applied to the signals to make the small variations in weaker data to be visible on the control unit.

It is applied using Time-variable Gain curve represented by a red line in the O-Scope on the setup screen and location of the gain points is as shown in the above Fig 3.14. By using those points only we can change the Gain curve accordingly.

Edit gain curve: it is the option used to modify the gain points either by adding or removing gain points to change in time-variable gain curve for strengthening or weakening purposes.

IIR BG removal: It is a filter which can be used to remove horizontal bands of noise present in the data.

During data collection none of the filters are used in the SIR 4000. Even though we will use the post processing of data using RADAN 7 software.

Signal floor: It is the option that overlays a green field on the line scan display. It indicates that the effective depth of each signal is based on the analysis of noise to signal loss.

3.6.3 OUTPUT:

The following are the options that can be customizable settings while conducting the survey.



Fig 3.15 output menu settings

Select Data path: the locations of files need to be stored in the SIR 4000 control unit. In this option we can modify the project name, file location also.

Vertical scale: Vertical scale is the option that the units of depth of penetration of EM waves into the subsurface. It must be selected either in Depth or time scale units whichever is convenient to us.

Vertical units: Vertical units is the option that can choose the depth of penetration units either in depth (cm or m) or in time (ns) in the vertical scale of the data. (Fig 3.15)

Horizontal units: Horizontal scale is the option that the horizontal units of the data can be choosen in the units either in cm or m.

Scale color: In this option we can change the text or background colors like gray, red, green and yellow etc.

Show O-Scope: it is the option that used to display the gain curve during the data collection.

Color map, Color stretch: These are the options that can change the background color of the screen. **3.6.4 SYSTEM:**

The following are the options that can be customizable settings such as brightness, auto save, volume and etc.



Fig 3.16 System menu settings

Brightness: it is the option that can change the brightness of the screen. (Fig 3.16)

Volume: It is the option that can change volume of the control unit. (Fig 3.16)

Auto save: The auto save option should set to ON while during the survey, after the data collection, the file is saved automatically otherwise it get erased. (Fig 3.16)

Recall setup: in the SIR 4000 we can save the required settings before doing the survey. So that we can recall the same setting during the survey of the particular field.

Calibration of survey wheel:

The survey wheel calibration need to be calibrated whenever there is a change in ground surface. This has to be done by the survey wheel mode, within that quadrature is selected and the instructions are followed as given below.

3.7 DIRECTION OF SURVEY

Direction of survey is one of the most important thing in the survey during data collection in the case of identification of underground utilities because on the direction of survey only the shape of hyperbola is depended. Normally survey is conducted perpendicular to utility alignment. But in case of interpretation of sub-surface layers is not that much important thing.

3.8 DATA DOWNLOADING FROM SIR 4000 TO A COMPUTER

After the data acquisition in the field, USB is connected to SIR 4000 control unit. The option Playback is clicked, then Choose path is selected, then the saved files are opened, the files have to process is to be selected and then copy/move is clicked to download the files to USB. After the USB is connecting to a computer to copy the files for the post-processing.

3.9 DATA PROCESSING STEPS IN RADAN 7 SOFTWARE:

RADAN 7 software is one of the most advanced software among the remaining available soft wares for processing of GPR data. RADAN 7 is the windows based software, will provide easy and familiar to use for all levels of experience and processing for improving data by removing background noise, applying different filters, stretching the files etc.

All the sequential steps of processing are as follows.



Opening of RADAN 7 software:

Fig 3.19 RADAN 7 software introduction screen

The file that we need to process is opened by clicking on the OPEN option present in the top left of the toolbar in the introduction screen of RADAN 7 software. Once a file is selected it is double clicked on that to open the file. (Fig 3.19)

Horizontal scaling: Horizontal scaling is the one of the option that is used to stretching the file or to enlarge the profile in horizontal direction to our required units.

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Option processing is clicked then we can see the option called Horizontal scaling is available (Fig 3.20). When we click on that one can see the operation type then we select the stretching option and the number of times to be stretched is entered and apply is clicked. Now the file is enlarged to required times. (Fig 3.21)



Fig 3.21 File after Horizontal scaling (stretched file)

Background removal: Background removal is a filter which is used to remove the horizontal band of noise present in the data and is also called as Horizontal background removal for FIR filter. Then Easy processing (Fig 3.19) is selected. Then Background removal option is selected, then Full pass filter is selected and Apply is clicked (Fig 3.22).



Fig 3.22 Background removal

Changing Transfer to Abs value: In raw data it shows the subsurface information in the form of positive & negative peaks to differentiate the difference among the layers in the form of black and ash colors in the data. But in the case of subsurface layers we need the extreme boundaries of the layers instead of differentiation.

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Fig 3.23 Changing Transfer to Abs value (before applying)

For transfer option right button is clicked on the screen as we can see in the Fig 3.23 then Abs value is clicked. Then the raw data changes to the Abs value data indicating all positive peaks. (Fig 3.24)



Fig 3.24 Changing Transfer to Abs value (After applying)

Edit block: it is the option used to crop the image to our required size, so that we can adjust the raw data to our required size. (Fig 3.25 and Fig 3.26)

Processing is clicked then the option Edit Block is selected, after that we can rearrange the block to our required size.



fig 3.25 Edit block (after applying)

In this study the site photograph are less in size when we compared with the GPR raw data available in the field. Therefore we need to crop the GPR raw data to our required site photograph size, then we can compare the both images easily.

Exporting the processed image to JPEG format:

GSSI button is clicked, then Export is clicked, then Export to JPEG image is clicked to save the current raw data file to image format. (Fig 3.26)

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Fig 3.26 Exporting to JPEG image

3.10 COMPLETE GPR PROCESS

The following are the steps we have worked out for complete GPR survey in the form of flow chat. (Fig 3.28)



Fig 3.28 Flow chart of GPR process

RESULTS AND DISCUSSIONS 4.3 PROCEDURE FOR DATA ACQUISITION:

1. To start the GPR instrument for data collection, the green button is clicked once to on the control unit.

2. The required settings in the control unit is changed to perform the survey at the given site like soil type, scans/sec, scans/meter, dielectric constant suitable to field condition. Before this survey wheel calibration is to be done.

3. While moving the 100 MHz antenna over the surface, the EM waves are transmitted and received the radar pulses when it encounters a change in dielectric constant in the subsurface, the received pulses are recorded by the control unit SIR 4000.

4. The GPR control unit will save the received pulses against two-way travel time (ns) for further processing.

5. The data collection process is continued until it reaches to our destination mark, then one can decide either to save or discard the file, and then for the next profiles data collection can be started. (Fig 4.1) 6. After the field data collection is completed, then the instrument is stopped. (Fig 4.1)

7. Raw data is collected from the control unit SIR 4000 and then post processing is done by using RADAN 7 software.

8. After the interpretation of data the layers of the subsurface section are deciphered and compared with the real image of the site. (Fig 4.2)



Fig 4.1 Data acquisition in the field



Fig 4.2 Cross-section images of filed sites 4.4 DISCUSSION OF THE GPR PROFILES IN THE STUDY AREA

In this study we have chosen the two sites where there is an excavation is done for the construction purposes like flyover and bridge. These are the places suitable for the GPR survey for the identification of the sub-surface layers and cross-checked with lithology of the subsurface present in the field.

One of the site is located near the Hitech city railway station of Hyderabad excavated for the construction of the bridge. In this site we collected and interpreted the GPR data for the three cross-sectional profiles.

Second site is located opposite to the Manjeera majestic complex opposite to the JNTUH campus excavated for the construction of the flyover. In this site we collected and interpreted the data for one cross-sectional profile.

GPR profile 1:

The first profile is taken on the site, located near the Hi-tech city railway station. The processed and interpreted profiles of the lithological mapping of the sub-surface having the horizontal length of 6.20 m and 2.8 m in depth is shown in Fig 4.3. These images are reduced and adjusted to the scaling when GPR data and field photographs can be compared.



Fig 4.3 Interpreted GPR profile 1

In the Fig 4.3 we can see the layers of the sub-surface profile (left side image) by using GPR data after the post-processing is almost similar with the real image of the site (right side image) photographed. From the results of the above mentioned image we can say that the top bitumen layer depth is varying from 0-10 cm, below which the layer of almost 10-40 cm in depth is road laying material. Below is the soil with a depth is 40-60 cm. It is followed by weathered layer up to the depth of 150 cm and then followed by weathered rock. These are the broad lithologic layers identification,

one can see that GPR has shown each and every minor variation in the lithologic deposition as well as layers in road.

GPR profile 2:

The second profile collected from the site near the Hi-tech city railway station is having the horizontal length of 5.1m, and the depth of 2 m. The processed and interpreted sub-surface image is as given below.



Fig 4.4 Interpreted GPR profile 2

In the Fig 4.4 we can see the layers of the cross-section of the GPR profile 2 in a less conspicuous manner. From the results of the above mentioned image we can say that the top red soil depth is varying from 0-50 cm, and the below soil depth has varied from 25-100 cm and the bottom soil depth varies from 100-180 cm approximately. Weathered rock is seen beyond the depth.

PRESENTATION OF RESULTS OF GPR SURVEY:

From the GPR subsurface profiles and their comparison with actual field profiles reveals that the GPR profiles one representing the subsurface formation almost in a detailed phasion. Layer boundaries are well demonstrated with their thicknesses almost coinciding with the real field measurements. This information is more useful for civil engineering.

CONCLUSIONS

Based on the experimental results of the four profiles collected by using GPR in the study areas following conclusions are made

(i) The GPR profile has clearly demonstrated the varying bed boundaries.

(ii) The thickness of the beds are almost comparable with the actual thicknesses

RECOMMENDATIONS FOR FUTURE RESEARCH

It is advised to map the subsurface with lower frequencies such as 25 MHz to penetrate the deeper layers.

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