CLASSIFICATION OF GPR DATA USING PRINCIPAL COMPONENT TRANSFORMATION AND DETECTION OF BURIED OBJECTS

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ABSTRACT: Ground penetrating radar (GPR) constitutes a form of geophysical technique, which uses radar pulses over a range of 10MHz to 2.5GHz of the electromagnetic spectrum. It is used extensively in geology, geomorphology, geotechnical engineering and related areas. This paper deals with a typical application in geotechnical engineering. At sites, where existing buildings are demolished and new structures are erected, there is a need to examine the presence of existing buried objects, if any. Detection of these objects prevents their accidental damage during excavation for foundation of the new building.

In the present work, using 200MHz GPR antenna, a survey was done at a construction site, where a two-storeyed building existed and was demolished. Data was collected over an area of 21 X 30 m in a grid so as to get a 3D view of the surveyed area. The initial settings were based on the prior knowledge of the subsurface that, there is a fill layer followed by a weathered basalt layer underlain by fresh basalt. The data collected was post processed to improve quality. Using Hilbert transform (HT), the data was decomposed into instantaneous magnitude and phase components. Using these HT components, five attributes, viz. envelope, double envelope, envelope of time domain energy, envelope of slope reflection strength and envelope of DB based reflection, were derived. These attributes bring out different properties of the subsurface. Using the combination of these attributes the GPR data has been classified into footing and non-footing regions using Principal component transformation (PCT.)

The study revealed that buried utilities like pipes and conduits were absent at the site and only isolated concrete footings existed, which was useful information for planning of excavation. The present work demonstrated the suitability of 200MHz for detection of buried shallow concrete footings and the usefulness of HT and PCT in automatic classification.

1. INTRODUCTION

The terms Ground penetrating radar (GPR) also known as 'ground-probing radar', 'sub-surface radar' or surface-penetrating radar refer to an electromagnetic technique designed primarily for the location of objects or interfaces buried beneath the earth's surface or located within a visually opaque structure. The word surface-penetrating implies its applicability to a variety of situations including buildings, bridges etc as well as probing through the ground. The technology of GPR is largely applications-oriented and the overall design philosophy, as well as the hardware, is usually dependent on the target type, material of the target and its surroundings. The techniques for signal processing, the hardware capabilities and the range of applications for GPR technique are becoming increasingly sophisticated (Daniels, 2007).

GPRs have been finding extensive applications in archaeological investigations, borehole inspection, bridge deck laminations, building condition assessment, utility mapping, foundation investigations, mine detection, contamination mapping, evaluation of reinforcement of concrete, road condition surveys, snow, ice, glacier mapping, integrity monitoring of tunnel linings and planetary explorations.

The study described here deals with a geotechnical application which is fast gaining acceptance especially in densely populated metropolises. The main issue is that, very tall buildings are coming up in place of existing old buildings and there is a need to assess the presence of buried objects which might serve as obstructions to erecting foundations of the new buildings.

The objective of the study is to evaluate the potential of medium frequency GPR and digital data processing using Hilbert transform (HT) and Principal component transformation (PCT) in non-invasive detection of buried impediments to piling. Application of GPR of frequency 200MHz, in the investigation of buried footings and pipes, if any, at a site where a building had existed and was demolished, is presented. The collected GPR data is processed by HT and classified digitally using PCT. The study shows that 200MHz GPR can map the buried footings and can fairly detail them and PCT can enhance the GPR data and help in digital classification and buried object detection.

2. STUDY AREA AND GPR DATA COLLECTION

The study area is a typical construction site in a metropolitan city, where an existing old two-storeyed building is demolished and a high-rise structure is being erected. In this process, as is quite common, the foundation maps of existing building are misplaced and knowing locations of buried foundations and important underground installations, which is very crucial for excavation and piling, has become difficult. Layout of the study area is given in Figure 1. With a view to map the shallow buried footings and pipes / utilities, if any, 200MHz GPR antenna was used, which can penetrate upto a depth of 8-10m subject to subsurface conditions. Data was collected over an area of 21m x 30m, in a grid format with 7 X transects and 8 Y transects, to get a 3-Dimentional picture of the subsurface. The grid is shown in Figure 1.

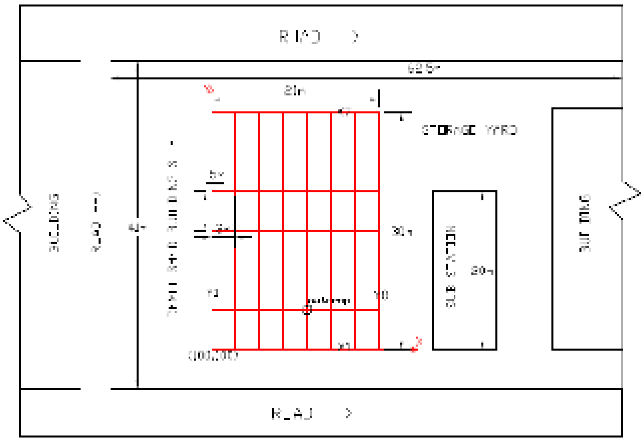


Figure 1 : Layout of the study area

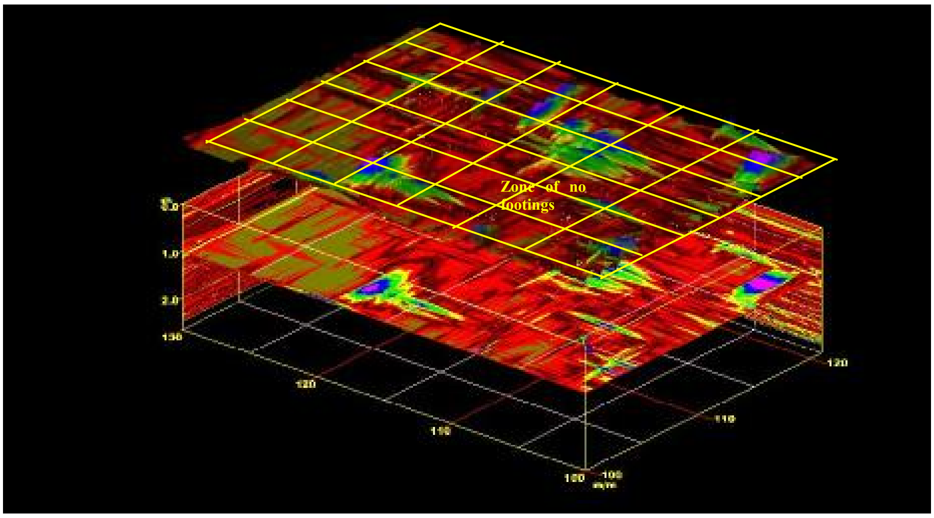


Figure 2 : A slice of 3-Dimensional of GPR data showing footing and no-footing zones

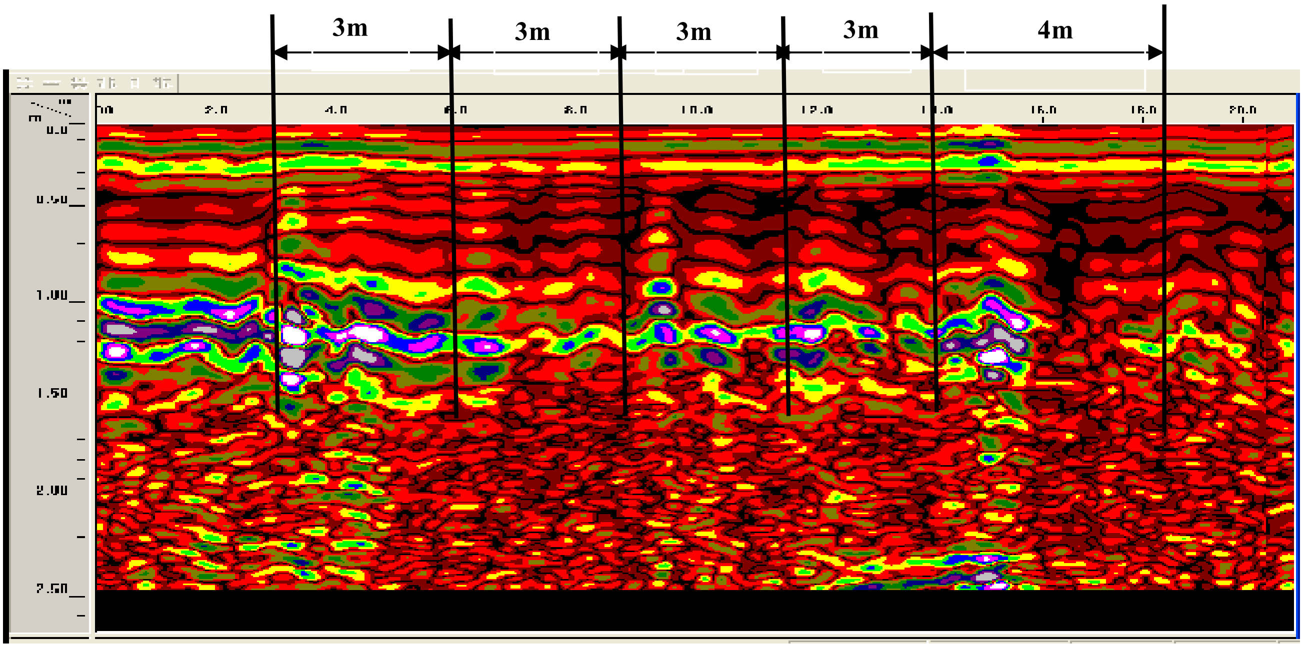


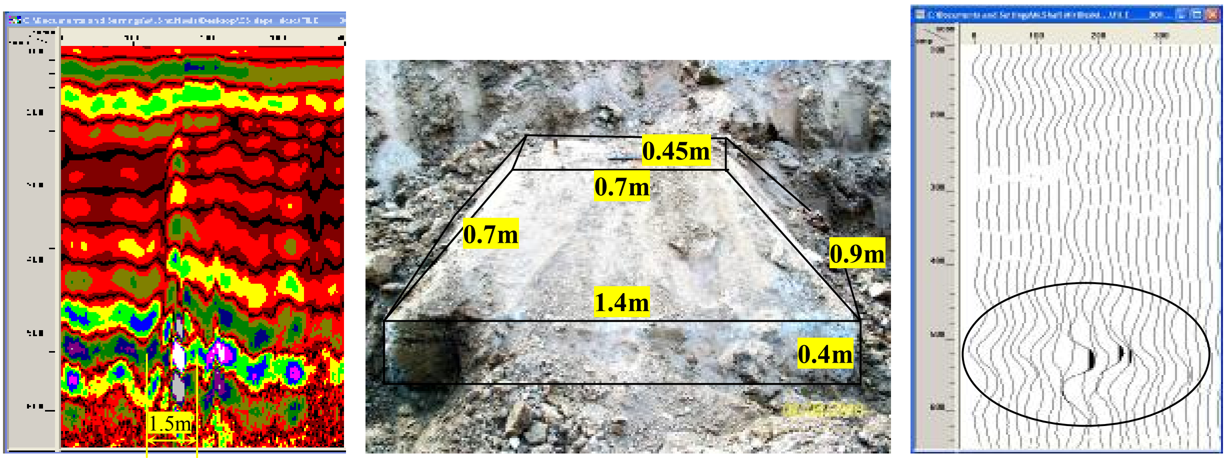
Figure 3 : 2-Dimensional GPR data along 1st X transect after post processing

3. INTERPRETATION OF GPR DATA

GPRs generate radar pulses at a given central frequency and send into earth through a transmitting antenna. The pulses get scattered back at electromagnetic discontinuities of subsurface, mainly dielectric contrasts between soil and buried objects or different layers etc. The back scattered pulses are collected by a receiving antenna and radargrams are produced. A slice of 3-Dimentional GPR data obtained is given in Figure 2. A 2-Dimentional so-called B-scan of the GPR data collected along 1st X transect (post processed) is given in Figure 3. The visual and digital interpretation of GPR data collected (Figures 2 and 3) are presented in following subsections.

3.1 Visual Interpretation

Patterns or geometries and amplitudes are the primary types of information used to make interpretation of GPR data. Patterns/geometries may be interpreted visually. Amplitudes need digital techniques for interpretation Figure 2 gives a good picture of extent of the surveyed area. It clearly shows the zones of footing region and non footing region and hence facilitates in excavation/piling. Data of 1st X transect (Figure 3) shows similar and symmetrical sloping patterns. These indicate clearly that isolated footings of the old building are present at a depth of 0.8m to 1.5m and first four footings are spaced by 3m and last one is placed at a spacing of 4m from the rest.



(a) (b) (c)

Figure 4 : Further detailing of GPR data - (a) Part of GPR data along 1st X transect, (b) A typical excavated footing along with its dimensions and (c) Data of (a) in back scattered signals form

Further, Figure 4(a) presents a windowed out part of the 1st X transect GPR data, where width of the sloping and symmetrical pattern is 1.5m which is approximately equal to the width of real footing presented in Figure 4(b). Figure 4(c), gives the GPR data of Figure 4(a) in back scattered signals form, where there is a change in pattern of signals indicating the contrast in materials i.e. interface of soil and concrete. These visual observations regarding depth, spacing and widths of footings are corroborated during the excavation at the site.

3.2 Digital interpretation

Digital techniques are used for interpretation based on amplitude values of GPR signals. The time domain radar data consists of back scattered signals from the subsurface, and signals may be defined as time vs. amplitude graphs of the reflected pulses. Another way of defining the data is to transform it into its instantaneous magnitude, phase and frequency information.

3.2.1. Hilbert transform : This well known technique is used for decomposition of radar pulses into its instantaneous components. HT expresses the relationship between the magnitude and phase of a signal, or between its real and imaginary parts. It allows the phase of a signal to be reconstructed from its amplitude (GSSI, 2007). The instantaneous phase information is sometimes more sensitive to important subsurface (dielectric) changes than the amplitudes e.g., presence of contaminants. The instantaneous magnitude display is useful for indicating the raw energy reflected from an object or layer. The radar wavelet itself may not always be a clear indicator of energy levels because it consists of several cycles. The instantaneous frequency indicates how the earth is filtering the radar signal.

A signal *s(t)* may be written in terms of its real and imaginary components *f(t)* and *h(t)* as in Equation (1). The measured real component *f(t)* can be represented by its instantaneous amplitude/ envelope/reflection strength *a(t)* and phase *δ(t)* as in Equation (2) and HT of h(t) is given in Equation (3).

$$s(t) = f(t) + i * h(t) \tag{1}$$

$$f(t) = a(t) * \cos(\delta(t)) \tag{2}$$

$$\text{Hilbert transform of } f(t) = h(t) = a(t) * \sin(\delta(t)) \tag{3}$$

From Equations (2) and (3) instantaneous amplitude *a(t)* and instantaneous phase *δ(t)* can be calculated. The instantaneous amplitude and phase include information about the subsurface like dielectric constant and conductivity. With the use of wave attributes, depending on *a(t)* and *δ(t)*, it is possible to distinguish between contiguous strata or objects of different electrical properties. A set of attributes (A1 to A5), extracted from the basic wave attributes (Instantaneous Amplitude and Phase) as suggested by Ehret (2009), are helpful in better interpretation of GPR data. Attributes A1 to A5 are as follows.

1. Envelope of the trace

$$\boldsymbol{A1} = [\boldsymbol{f}^2(\boldsymbol{t}) + \boldsymbol{h}^2(\boldsymbol{t})]^{1/2} \tag{4}$$

2. Double Envelope

$$\boldsymbol{A2} = \boldsymbol{env}[\boldsymbol{env}\,(\boldsymbol{f}(\boldsymbol{t}) * \boldsymbol{cos}(\boldsymbol{\delta}(\boldsymbol{t}))) \tag{5}$$

3. Envelope of time domain energy (square of amplitude)

$$\boldsymbol{A3} = \boldsymbol{env}[\boldsymbol{f}^2(\boldsymbol{t})] \tag{6}$$

4. Envelope of slope reflection strength

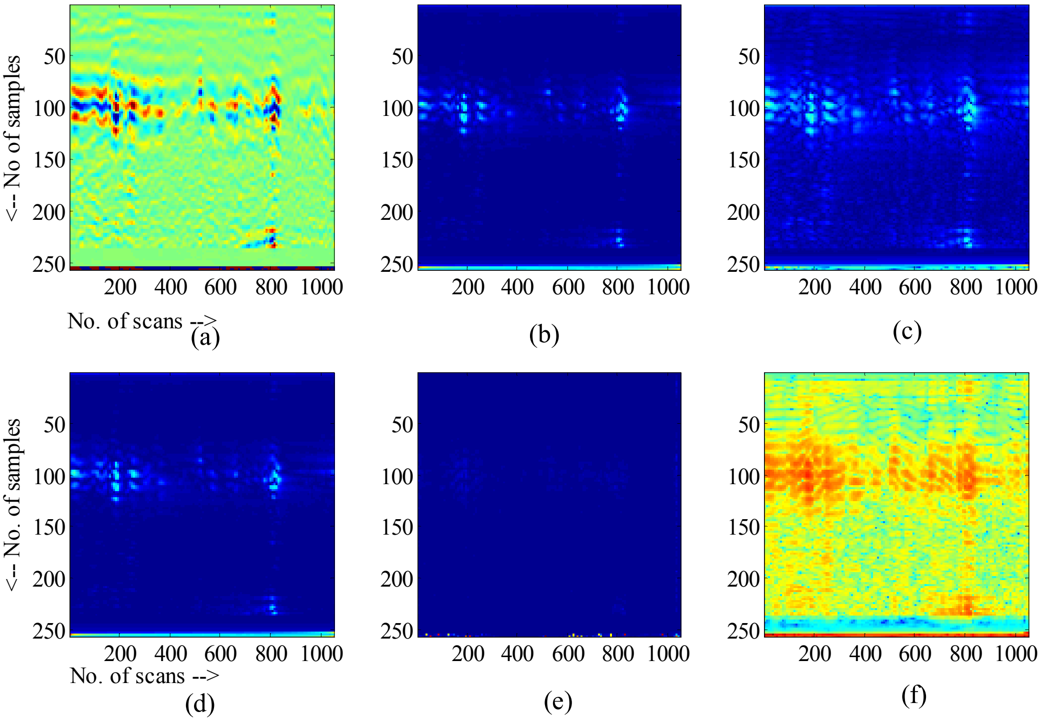
$$\boldsymbol{A4} = \boldsymbol{env}[\boldsymbol{d}(\boldsymbol{a}(\boldsymbol{t}))/\boldsymbol{dt}] \tag{7}$$

5. Envelope of dB based reflection strength

$$\boldsymbol{A5} = \boldsymbol{env}[\mathbf{20} * \mathbf{log_{10}}(\boldsymbol{a}(\boldsymbol{t}))] \tag{8}$$

Figure 5(a) gives the GPR data along 1st X transect. Figures 5(b) to (f) give the attributes A1 to A5 of 1st X transect data. From Equations (4) to (8), A1, A3, A4 and A5 depend on instantaneous magnitude which indicates amount of reflected energy from the subsurface. A2 consists of instantaneous phase, which brings out subtle features like layers and edges.

Even visually it can be seen that, A1 is bringing out the footing region clearly; A2 is bringing out the footing region along with the columns/stems of the foundation blocks. A3 is again bringing out the footing region clearly. A4 has not given any useful information. A5 has given footings as well as columns out. Hence every attribute is reflecting the features differently. But, digital delineation helps to take into consideration the combined information from all the attributes. In the next section, PCT is used to produce a single output out of these attributes.



(a) (b) (c) (d) (e) (f)

Figure 5 : 1st X transect and its attributes - (a) 1st X transect, (b) A1 -Envelope of the trace, (c) A2 - Double Envelope, (d) A3 - Envelope of time domain energy (square of amplitude), (3) A4 - Envelope of slope reflection strength and (f) A5 - Envelope of dB based reflection strength.

3.2.2. Principal component transformation : Principal component is applied to the attribute images A1 to A5 presented in Figure 5. These images consist of 256 rows and 1051 columns (a total of 269056 pixels). The variance covariance matrix of the original images is given in Table 1.

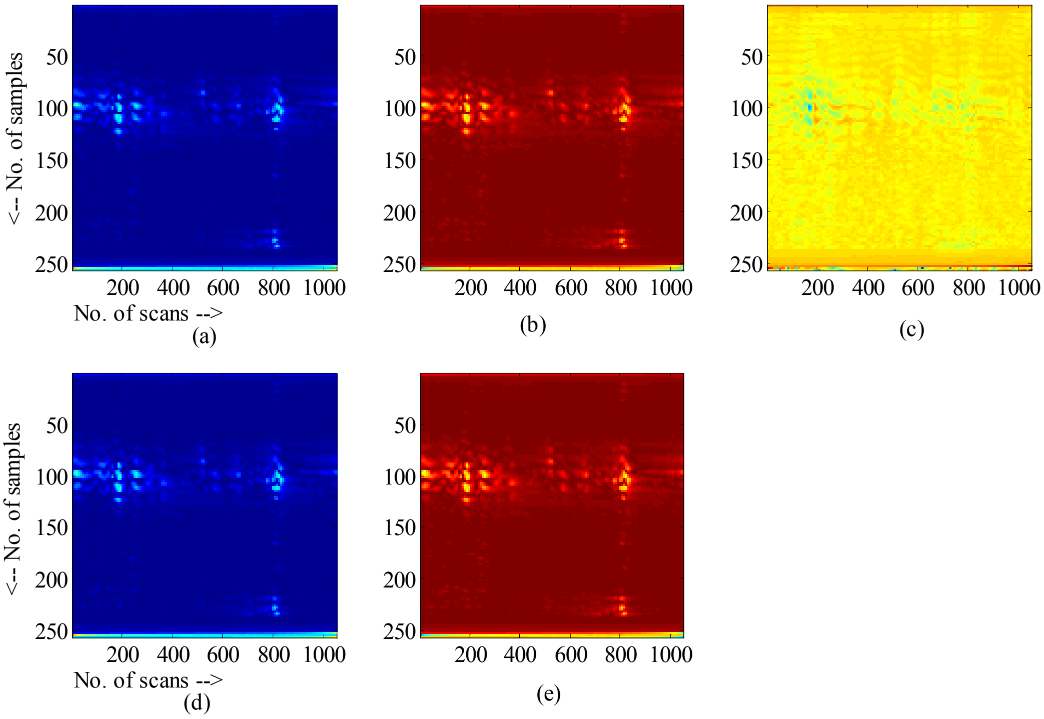
Table 1: Variance – covariance matrix for attributes A1 to A5

	A1	A2	A3	A4	A5
A1	38013157	23355748	7.16E+11	984363.1	41983.81
A2	23355748	31235261	8.05E+11	475741.6	25095.17
A3	7.16E+11	8.05E+11	2.52E+16	1.82E+10	5.81E+08
A4	984363.1	475741.6	1.82E+10	98968.12	736.662
A5	41983.81	25095.17	5.81E+08	736.662	82.14044

PCT is essentially a variance maximization technique that enables one to transform the original data into a new data set of same dimension. The variances are redistributed such that the first Principal component has the maximum variance and others progressively lesser, with the condition that covariance is zero. Thus, in this case, the new variances (which happen to be eigenvalues of the original data) are given in Column 1 of Table 2. The corresponding eigenvectors or loadings for computing transformed data are presented alongside in the same Table. As can be seen, there are five eigenvalues and five eigenvectors corresponding to each eigenvalue. The principal component images PC1 to PC5 are depicted in Figures 6(a) to (e). It may be noted from the magnitudes of eigenvectors that, the principal components PC1 to PC5 are getting their major contributions, respectively, from A2, A3, A1, A4 and A5. Therefore, except for PC3, all other components have clearly enhanced the original data by removing noise and delineated the foundation part from the medium. Thus it may be concluded that, 200 MHz GPR data, if suitably post processed, can yield useful information about the subsurface footings below a demolished building. This information is very useful for identifying the problematic areas from point of view of piling operations.

Table 2: Eigen values and Eigenvectors for A1 to A5

Eigenvalues arranged in descending order	Eigenvectors				
2.52E+16	2.84E-05	-0.9989	0.038166	-0.02708	0.0015
17712979	-3.20E-05	-0.03877	-0.999	0.022074	0.000996
5474093	-1	2.96E-05	3.08E-05	-6.59E-07	-4.91E-08
70784.09	-7.23E-07	-0.02621	0.023096	0.999384	-0.00323
25.05082	-2.31E-08	-0.00145	-0.00101	-0.00325	-0.99999



(a) (b) (c)

(d) (e)

Figure 6 : PC1 to PC5 for X1 transect data – (a) PC1, (b) PC2, (c) PC3, (d) PC4 and (e) PC5

4. CONCLUSIONS

1) GPR data gives information in two ways viz. in terms of patterns or geometries and amplitudes. Patterns or geometries can be interpreted visually whereas amplitudes need to be further processed using sophisticated techniques.

2) 200MHz frequency GPR can map buried foundations, 3-Dimentional GPR data can be used to delineate footing and non footing regions in the given extents of surveyed areas and 2-Dimentional data can be used for further detailing like depth, spacing and dimensions of footings

3) Attributes A1 to A5 derived from Hilbert transformed components of signals can bring out the features of buried objects separately.

4) PCT helps to enhance the footing region and digitally delineate them from the soil.

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