

# ESTIMATION OF REBAR DIAMETER IN CONCRETE STRUCTURAL ELEMENTS USING GROUND PENETRATING RADAR

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## Abstract

The objective of the present study is to locate the rebar and estimate the rebar diameter in reinforced concrete (RC) structures non-destructively, using Ground Penetration Radar (GPR). Laboratory studies have been carried out on specially cast concrete block specimens with known rebar diameter. Radargrams have been collected using GPR with 1.6 GHz antenna. The collected radargrams have been converted into ASCII files that contain the amplitude values of the reflected signals at every interface. The key function of the process is converting the analog signals into digital signals. The digital signal is represented by numerically encoded values corresponding to the amplitude of the electromagnetic waves reflected from the concrete-steel interface. Based on the available procedures, a methodology is proposed to get the relation between the power reflectivity and length of the scan. Based on the available procedures and limited laboratory studies, it is found that the estimated rebar diameter is in close agreement with the actuals.

**Keywords:** Non-destructive testing (NDT), Ground Penetration Radar (GPR), Radargram, Power reflectivity, Rebar diameter

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## 1.0 INTRODUCTION

Non-destructive testing (NDT) techniques are increasingly gaining popularity for the assessment of important structures such as bridges, roadways, tunnel linings, nuclear structures, etc [1,2]. The commonly used NDT methods for the evaluation of quality and integrity are rebound hammer, ultrasonic pulse velocity, core sampling & testing etc. [3]. In recent times, techniques such as impact echo (IE), pulse echo (PE), ground penetrating radar (GPR), infrared thermography, etc., are gaining popularity in the field of civil and structural engineering for determining the thickness and identification of defects [1-2]. GPR is a relatively modern non-destructive testing method that helps in providing information about buried objects, internal details, mapping of rebars in concrete, etc. Many researchers reported about the applicability of GPR techniques for the thickness measurement, mapping of reinforcement, locating tendon ducts, moisture distributions, etc. [4-8]. In the present study, efforts have been made to locate the rebar and estimate the rebar diameter in the laboratory cast reinforced concrete (RC) block specimens with known parameters.

## 2.0 GROUND PENETRATING RADAR (GPR)

### 2.1 General

Ground penetrating radar (GPR), sometimes called ground probing radar, georadar, subsurface radar, or earth sounding radar is a non-invasive electromagnetic geophysical technique for subsurface exploration, characterization and monitoring. In civil engineering applications, inspection depths are relatively shallow and only short pulses of electromagnetic waves (microwaves) are generally used [9,10]. For this reason, the technique is often called short-pulse radar or impulse radar. It may be deployed from the surface by hand or vehicle, and from aircraft or from satellites. GPR generally consist of operation-unit along with a computer (usually a handy laptop) and the antenna(s). The computer has software for the operation of the radar. There are generally separate software for collection and processing of the data [10]. Typical instrumentation for GPR includes the following main components: an antenna unit, a control unit, a display device, and a storage device [11,12]. A typical photograph of GPR is shown in Fig. 1 (a). Now-a-days, compact or portable GPR with built-in antenna is also available (Fig. 1 (b)). The antenna emits the electromagnetic pulse and receives the echos. The length of the pulse is largely controlled by the antenna design. Longer pulses are associated with longer wavelengths (or lower frequency) and have more penetrating ability, but poorer resolution (poorer ability to detect small objects), than shorter pulses. Table 1 shows antenna frequency, approximate depth of penetration and appropriate application [10].

## 2.2 Working Principle of GPR

GPR works by sending a pulse of energy into a material and recording the strength and the time required for the return of any reflected signal. A series of pulses over a single area make up what is called a scan. Reflections are produced whenever the energy pulse enters into a material with different electrical conduction properties (dielectric permittivity) from the material it left. The strength, or amplitude, of the reflection is determined by the contrast in the dielectric properties of two materials. This means that a pulse which moves from dry sand (dielectric constant ( $\epsilon$ ) of 5) to wet sand ( $\epsilon$  of 30) will produce a very strong, brilliantly visible reflection, while one moving from dry sand ( $\epsilon$  of 5) to limestone ( $\epsilon$  of 7) will produce a very weak reflections. While some of the GPR energy pulse is reflected back to the antenna, energy also keeps travelling through the material until it either dissipates (attenuates) or the GPR control unit has closed its time window. The rate of signal attenuation varies widely and is dependent on the dielectric properties of the material through which the pulse is passing. Materials with high electrical conductivity (high dielectric) attenuate the electromagnetic wave signal and thus the penetration depth decreases [13]. Water saturation dramatically raises the dielectric of a material, so a survey area should be carefully inspected for signs of water penetration. Radar surveys should never be conducted through standing water, no matter how shallow it is. Depth of penetration through a material with a high dielectric will not be very good.

## 2.2 Application for condition assessment [10,14,15]

For condition assessment, GPR can be effectively used for finding the following:

- Measurement of structural elements thickness
- Location and spacing of reinforcement bars (rebars)
- Measurement of cover depth to rebars
- Foundation materials shift or settlements
- Detect presence of delamination, voids, honeycombing etc.
- Detect corrosion indirectly, as the strength of reflections is decreased
- Detect position and profile of pre-stressing cables
- Detect different layers of materials if used in construction

### **2.3 GPR for Rebar Detection**

Steel reinforcing bars are the most common targets in concrete structures. Transverse rebar (i.e., rebar oriented perpendicular to the scanning/survey line) produce clean and strong hyperbolas [16]. Fig. 2 shows radargram with hyperbolas showing rebar locations of a typical RC slab. The strength (amplitude) of a rebar reflection increases with rebar size. On the other hand, it decreases with depth and/or presence of corrosion. A steel pipe (conduit, for instance) looks exactly the same as a steel rebar of the same diameter. The radar signal does not penetrate metal, so there is no difference between reflections from a solid rod or a hollow metallic pipe [16].

### **2.4 Rebar Diameter Estimation**

Theoretically, rebar size can be estimated from reflection strength on a comparative basis, but cannot be accurately measured [16]. This means, if two rebar are located at exactly the same depth and in exactly the same concrete, and one is brighter than the other, the brighter one is larger. How much larger is impossible to determine. In structures with two layers of rebar, visibility of the second layer depends on the bar spacing in the first layer and on the amount of attenuation and scattering in the concrete.

#### **2.4.1 Methodologies for studying hyperbolic signatures**

For studying the hyperbolic signatures different researchers adopted different methodologies for estimating the rebar diameter/radius. Shaw et al. [17], proposed a methodology which use a neural network to automate and facilitate the post-processing of GPR radargrams. The results showed that the use of neural network approach could be quite effective in automating the identification and location of embedded rebars from a radar investigation. Accurate estimation of depth, or cover, requires a reliable knowledge of the dielectric properties of the concrete. The GPR signatures of cylindrical targets are characterized by a number of parameters, most notably the depth, diameter and orientation of the target, as well as the relative permittivity of the medium surrounding the target. Shihab et al. [18], attempted to mathematically model the GPR signatures to evaluate different parameters from the shape of the detected radargrams (hyperbola), by subjecting to a series of image processing stages followed by a curve-fitting procedure. For the analysis and simplification of GPR signatures, transforms like Hough transform, Stationary wavelet transform (SWT) and Discrete wavelet transform (DWT) have been reported in literature [19]. Zhan et al. [20] developed a method for estimation of rebar radius by studying the hyperbolic signatures using SWT. Chang et al. [21] developed a methodology, which allows rebar radii to be quantitatively detected through GPR radargram, resulting in a more accurate estimation of the power reflectivity of the surrounding concrete and depth of the bars, in addition to the radius estimation. In the present study, the same concept is adopted, which uses the electromagnetic principles to analyse the GPR signature. The collected radargrams have to be converted into ASCII files that contain the amplitude values of the reflected signals at every interface. The key function of the process is converting the analog signals into digital signals. The digital signal is represented by numerically encoded values corresponding to the amplitude of the reflected electromagnetic waves. At each point of location, traces (Wiggle plot) are to be plotted and then the power-reflections of each trace are generated. The entire process has been carried out by developing a graphical user interface, which will take the digital file (ASCII) as input and will plot the power reflectivity graph over the length of the scan. The proposed

methodology of finding the rebar diameter/radius involves the sequence of steps to be followed and are presented below (Fig. 3).

### **3.0 EXPERIMENTAL STUDY**

#### **3.1 Laboratory Study**

To demonstrate the methodology, GPR data has been collected on specially cast concrete specimens using 1.6 GHz frequency antenna. The specimen is a square block of dimension 39cm×39cm×30cm. Fig. 4 shows the photograph of two specimens (i) rebar of diameter 8mm and (ii) rebar of diameter 16 mm. Line scan data has been collected on each concrete block (refer Fig. 5). The collected radargram is converted into ASCII format consisting the amplitude values of reflected signals. A user interface is developed to get the plot between the power reflectivity and length of the scan. Figs. 6 and 7 show power reflectivity graphs on a concrete specimen of 8mm and 16mm diameter rebars.

For estimating rebar radius, the energy radius of the cone (E) and power reflectivity length (L) are needed. E depends on the wavelength of the penetrating radiation and the vertical position of the rebar (H). Using migration analysis, the dielectric constant of concrete is estimated and finally the energy radius is computed. Power reflectivity length can be measured based on the number of scans and the scanning length. Following equations (Eq. (1) and Eq. (2)) have been used in estimating the rebar radius. The radius of the rebar estimated using the above procedure is 3.77mm and 7.87mm, respectively for 8mm and 16mm diameter rebars. The results are presented in Table 2 and the difference in estimation of rebar diameter is 1.6% to 5.75%. Further elaborative studies are required in estimating the rebar diameter on concrete structural elements with multiple rebars by considering the effect of spacing of rebars, interference effect, scattering of signals, etc. [8].

$$\frac{E}{2} = \frac{\lambda}{4} + \frac{H}{\sqrt{\epsilon_r + 1}} \quad (\text{Eq. 1})$$

where: E = long dimension radius of the energy footprint  
 $\lambda$  = wavelength of the radar energy  
 H = depth from the surface to the reflection surface  
 $\epsilon_r$  = average relative dielectric permittivity of the material for the depth (H)

$$r = \frac{L - E}{2\pi} \quad (\text{Eq. 2})$$

where: r = radius of rebar  
 L = power reflectivity length

### **4.0 CONCLUSIONS**

Following conclusions can be drawn from the limited experimental study:

- In RC structural components, rebar location can be identified easily by using GPR technique
- A methodology has been demonstrated for estimating the rebar radius in concrete by studying the electromagnetic wave reflections. The diameter estimated from the trails is in the range of  $\pm 10\%$ .

- Further elaborative studies are required in estimating the rebar diameter on concrete structural elements with multiple rebars by considering the effect of spacing of rebars, interference effect, scattering of signals, etc.

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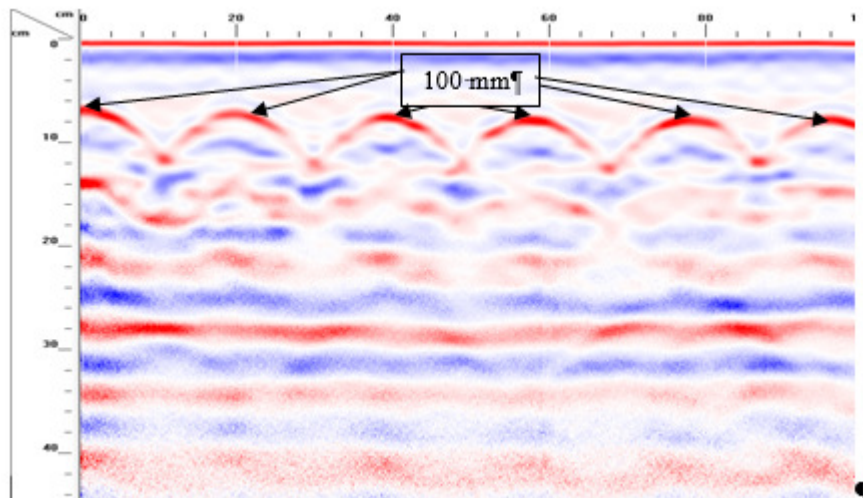
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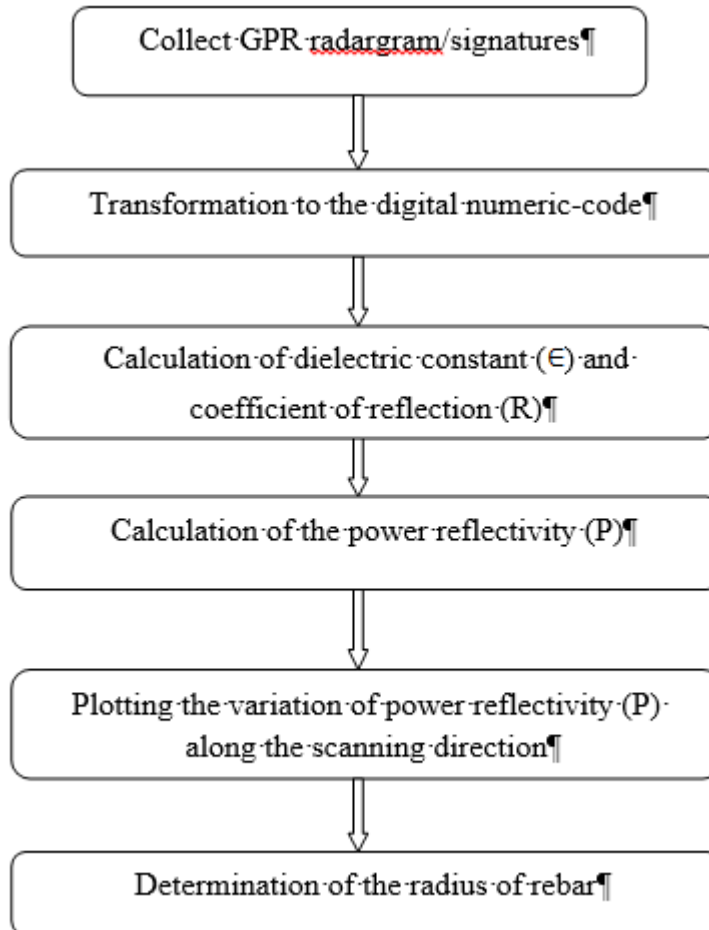
**Photos/Figures**



.....Fig. 1(a) GPR with antenna .....| Fig. 1(b) Compact GPR (Structure Scan Mini-HR)¶

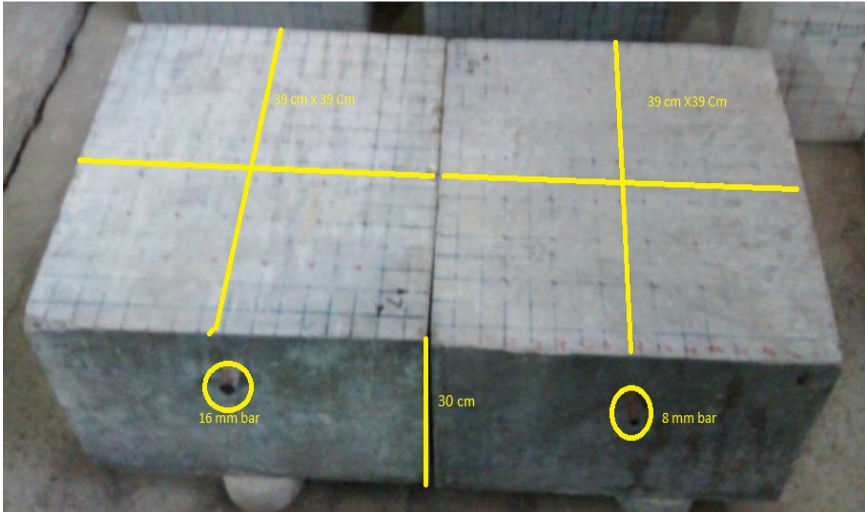


**Fig. 2 Radargram with hyperbolas showing rebar locations**



**Fig. 3 Flow chart showing sequence of steps**





**Fig. 4 Concrete blocks of 8mm and 16mm diameter rebars**



**Fig. 5 Data collection on a typical concrete block specimen with 8mm diameter rebar**



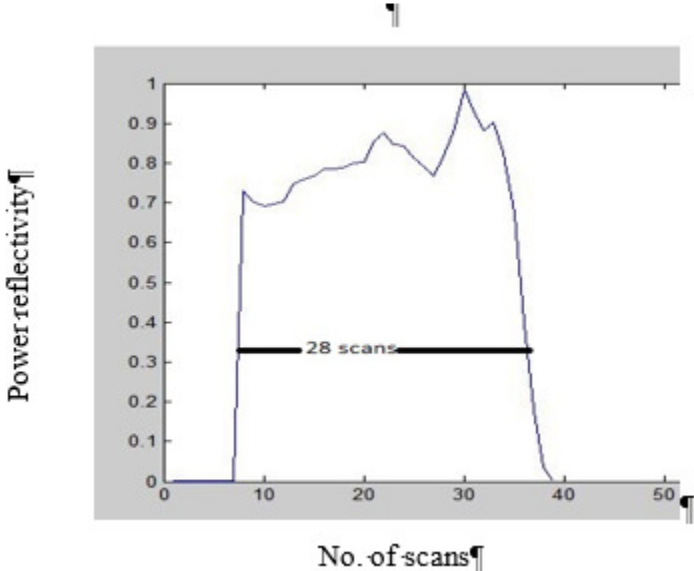


Fig. 6 Power reflectivity plot of specimen with 8 mm diameter rebar

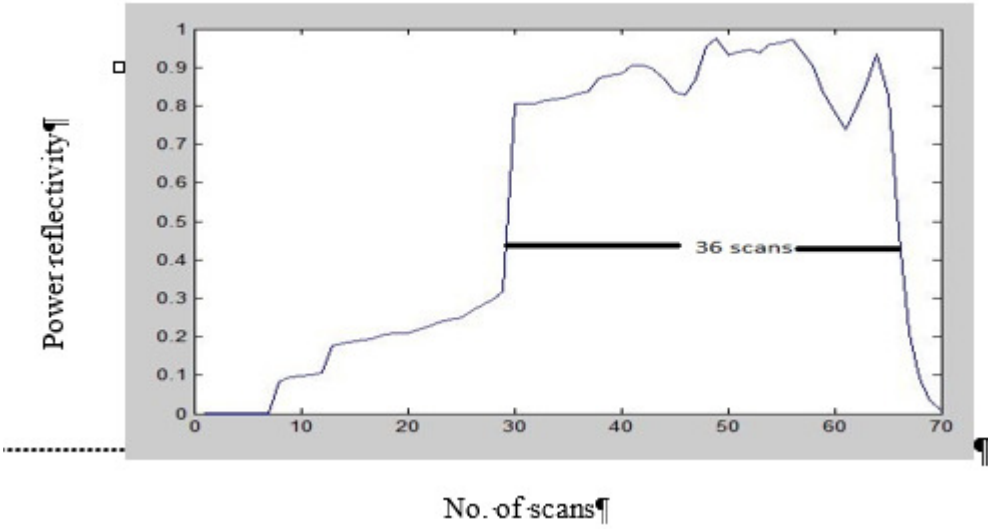


Fig. 7 Power reflectivity plot of specimen with 16 mm diameter rebar

Tables

Table 1 Antennas with different frequency - penetration depth

Primary antenna choice	Secondary antenna choice	Depth range (approx.)	Appropriate application
2600MHz	1600MHz	0-0.3m(0-1.0ft)	Structural concrete, Roadways, Bridge decks

1600MHz	1000MHz	0-0.45 m (0-1.5ft)	Structural concrete, Roadways, Bridge decks
1000MHz	900MHz	0-0.6 m (0-2.0 ft)	Structural concrete, Roadways, Bridge decks
900MHz	400MHz	0-1 m (0-3 ft)	Concrete, Shallow Soils, Archaeology
400MHz	270MHz	0-4 m (0-12 ft)	Shallow Geology, Utilities, Archaeology
200MHz	100MHz	0-9 m (0-39 ft)	Geology, Environmental, Utility, Archaeology
100MHz	16 - 80MHz	0-30 m (0-90 ft)	Geology Profiling

**Table 2 Results showing different parameters and radius of rebar**

Rebar diameter	E(cm)	H(cm)	L(cm)	Radius (mm)	Diameter (mm)	%error
16	13.05	5	18	7.87	15.75	1.56
8	13.18	5	15.55	3.77	7.54	5.75