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Estimaton of Rebar Diameter Using Ground Penetrating Radar

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ABSTRACT

Ground penetrating radar is a non-destructive method for detecting steel bars in reinforced concrete structures. The objective of this study is to locate the rebar and estimate its diameter in reinforced concrete (RC) structures. Radar-gram image is collected from two different slab specimens, with different diameter and cover depth, by using Ground penetrating radar (GPR) antenna (2.6 GHz), and converted into ASCII files which contain the amplitude values of reflected signals at every interface. The analog signals are converted into digital signals to get the amplitude values of reflected signals. The required values are obtained using MATLAB modules. Energy equation model reported in literature is being used in estimating the rebar diameter. The estimated diameter is close to the actual and is within ±3.6%.

Keywords: Non-Destructive Testing (NDT); Ground Penetrating Radar (GPR), Radar-Gram, Scan Length, Rebar Diameter.

INTRODUCTION

NDT has been defined as the methods used to examine objects, materials, or systems without impairing their future usefulness, that is inspect or measure the structure without harm.NDT methods depend on the fact that certain physical and chemical properties of concrete can be related to strength and durability of structures. In many field applications, it becomes essential to know the depth of cover, identify location of rebar's and their diameter. Ascertaining the cover depth is important to implement durability standards to the structure under construction. Knowing the diameter of the bar and their location is essential to understand the bar spacing and their placement, in existing structures where drawing may not be available. In some cases of old heritage buildings where the structural drawings might not be available, reinforcement bar parameters form to be an important aspect for structural rehabilitation and repair. Also, in cases where concrete core extracts are to be taken, the identification of the rebar locations becomes essential to avoid cutting of the reinforcement bars [1].Among various NDT methods a widely known non-destructive testing technique is ground penetrating radar (GPR), by which it is possible to acquire non visible information without causing damage to the structure[2].

GPR emits a short pulse of electromagnetic energy that will be radiated into the subsurface. When this pulse strikes an interface between layers of materials with different electrical properties, part of the wave reflects back, and the remaining energy continues to the next interface. GPR evaluates the reflection of electromagnetic waves at the interface between two different dielectric materials. The penetration of the waves into the subsurface is a function of the media relative dielectric constants (ε). If a material is dielectrically homogeneous, then the wave reflections will indicate a single thick layer [3].

Radar does not directly measure the diameter of a rebar, cable or conduit. Due to the signal wavelength, any object under 2" in diameter is a “dot” with no visible size. A larger target produces a stronger reflection. Under some special conditions, it is able to estimate the target diameter from the reflection strength (at least as small, medium or large) [4]. Many researchers reported about the applicability of GPR techniques for the thickness measurement, mapping of reinforcement, locating tendon ducts, moisture distributions, etc. [5 7].

In the present study, efforts have been made to locate the rebar and estimate the rebar diameter in the laboratory on reinforced concrete (RC) slab specimens with known parameters.

LITERATURE REVIEW

For studying the hyperbolic signatures different researchers adopted various methodologies for estimating the rebar radius / diameter.

Xianlei Xu .et al.[8] invented new air-coupled ultra wideband ground-penetrating radar (GPR) for highway pavement and bridge deck inspections that can achieve high spatial resolution and high inspection performance while operating on vehicles driving at regular highway speeds. The performance of this GPR design is greatly improved using new design techniques.

J.Hugenschmidt.[9] used mobile ground penetrating radar (GPR) systems are efficient tools for obtaining information such as depth of rebar, asphalt pavement thickness and concrete damage beneath the pavement. Radar inspections of bridges performed during contract work using a mobile GPR system.

Bello. Y. Idi.et al.[10] introduced a new approach for the fitting of hyperbolic signatures due to point or cylindrical reflector in GPR radar gram. The technique is based on the least square error minimization of hyperbolic function derived from the general equation of hyperbola leading to the determination of the optimal values of the fitting parameters at the minimal level of sum of squared error function. A unique hyperbolic signature obtained in the radar image was digitized and interpreted using the developed algorithm in MATLAB environment.

Chang et al.[11] proposed a methodology in which radii to be detected through GPR radar-gram, resulting in a more accurate estimation of depth and radius of rebar. Physical and theoretical modelling and experimental results of buried reinforcing steel bar were obtained and studied using measurements of radar gram data. It was concluded that the developed method allows reinforcing steel of radii to be quantitatively detected through GPR radar gram, resulting in a more accurate estimation of the power reflectivity of the surrounding concrete and of the depth of the bars, in addition to the radius estimation. The results indicate that, this method is capable of estimating the radius to within 7% of the actual size, which validates the method.

DESCRIPTION OF EQUIPMENT AND METHODOLOGY OF GPR

GPR Equipment. GSSI structure scan mini HR with 2.6 GHz was used. It consist of data acquisition system with processing software .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 is generally separate software for collection and processing of the data. Typical instrumentation for GPR includes the following main components: an antenna unit, a control unit, a display device, and a storage device [12].GPR can collect data up to 256 scans per second. The antenna used to determine data quality, range resolutions and maximum depth of penetrations. Antenna (transmitter and receiver) is most sensitive to metal targets that are parallel to scanning directions. The details are shown in Fig 1.

s 

Fig.1 Structure Scan TM Mini HR (2.6 GHz)

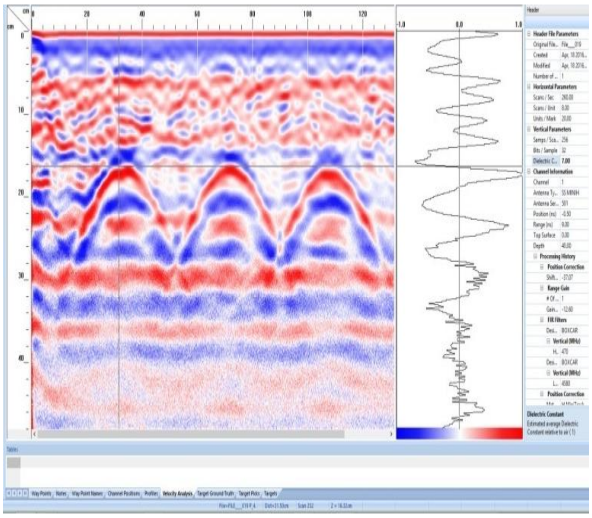
Methodology of GPR testing.

The GPR scanning technique has been proposed to predict the reinforcement details of slab specimens. Study is carried out by using Structure Scan TM Mini HR of 2.6 GHz antenna, which can collect both 2D and 3D scan data. Depth of scanning was given as 40cm, dielectric constant of material is given as 6.25 and scan density was given as 4 scans/unit (cm) to detect reinforcement in slab specimens.GPR data has been collected on specially cast concrete specimens using 2.6 GHz frequency antenna, the details is shown in Fig.2 (a) and (b).

(a) *(b)*

Fig.2 (a), and (b) shows slab specimens

Line scan data is collected on above concrete slab specimens. The collected data(raw radar gram) is opened in RADAN 7 software and is further processed by adjusting the gain values and color values for betterment of radar-gram shown in Fig.3 for slab specimen (a).



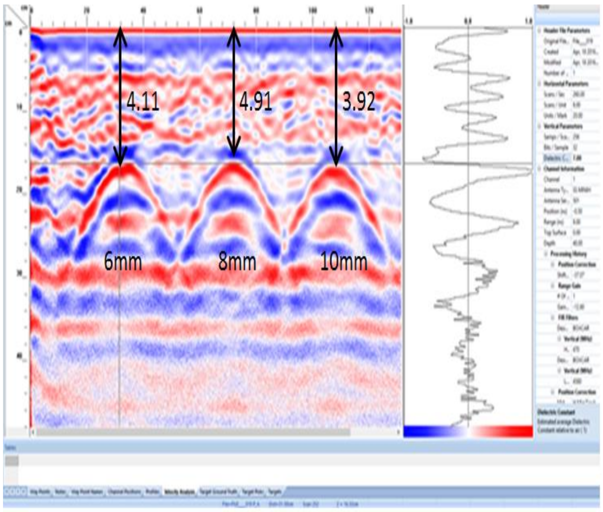


Fig.3 Radar-gram data of concrete slab specimen *Fig.4 Time zero correction*

From the radar-gram image the depth (H) value is estimated by using RADAN 7 software, which is done by applying time zero correction which is shown in Fig.4.Here the determined H value is nothing but the reinforcement clear cover or the exact depth at which the rebar is placed which is approximately 4.11cm and so on as shown in Fig.4.

Using migration tool available in RADAN 7 the velocity value and relative dielectric constant (ϵ) is obtained from specific hyperbola which is shown in Fig.5.The ghost hyperbola (black in color) is overlapped over the existing hyperbola in the radar-gram, the relative dielectric constant value and the velocity value is displayed on the screen. In a similar way for other specimens with varying diameter rods also the migration analysis is carried out.

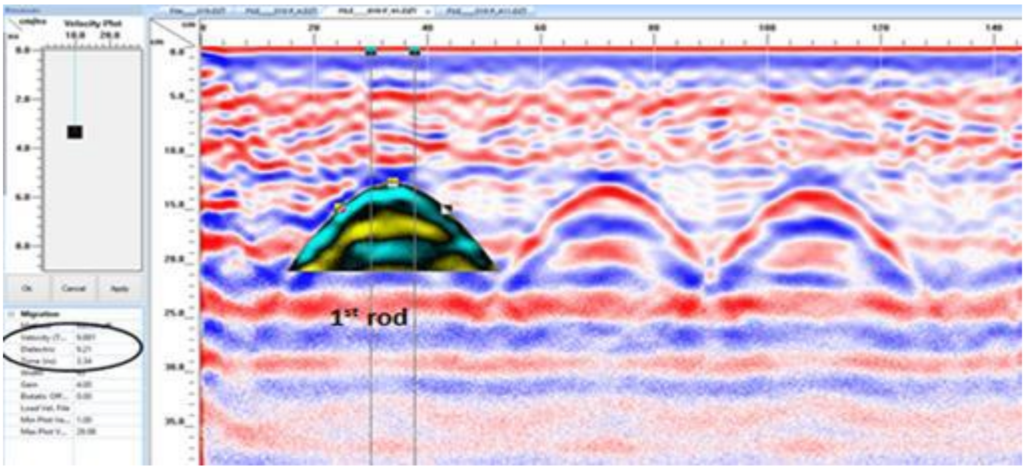


Fig.5 Migration analysis for 6mm diameter rod

After migration analysis, the obtained dielectric constant value is noted down which is used for further calculation. The processed RADAN file is converted into ASCII using the file converter RTOAW (RADAN to ASCII) provided by GSSI. RTOAW converts the radar-gram file into ASCII format which consists of the amplitude values of reflected signals. From the amplitude values the number of scans is obtained. The scan length is calculated by number of scans/scan density, which will be helpful in calculating the diameter by using the equations given below. To obtain the required values a MATLAB code is generated.

Following Eq.1 and 2 have been used in estimating the rebar diameter.

$$\frac{E}{2} = \frac{\lambda}{4} + \frac{H}{\sqrt{\epsilon+1}} \quad (1)$$

$$D = \frac{L-E}{\pi} \quad (2)$$

For estimating rebar diameter, the energy radius (E) and scan length (L) are needed. E depends on the wavelength of the penetrating radiation and the vertical position of the rebar (H) i.e. depth which is given in Eq.1.For calculating E value by using the Eq.1 & 2 the wavelength value is needed which can be calculated by using c = ϑλ where c is the speed of light in air whose value is c=30 cm/ns and the value of ϑ= 2.6 GHz so the λ value be 11.54 cm .Since the value of c and ϑ is constant in this case, while calculating energy radius the value λ is taken as 11.54 for all trials. For relative dielectric constant ∈=7.47 and H=4.11cm for 6mm diameter rod (Fig.5).

$$\frac{E}{2} = \frac{11.54}{4} + \frac{4.11}{\sqrt{7.47+1}}$$

E=8.59cm

The procedure to obtain scan length (in terms of scans) from hyperbola profile is rather difficult, since the starting and end points of hyperbola are not clearly seen in radar-gram. To calculate scan length, the radar-gram image (analog) is converted in to ASCII (digital/numeric) form to get the corresponding digital signal (numerical values) amplitudes. The variations of numerical encoded values have been traced by using suitable conditional format (highlighting the amplitudes of below average). From this, the start point and end point of hyperbola is fixed based on the shape of the numerical encoded values (hyperbola profile) and variations in the magnitudes of amplitudes. Extracting the required values is done by using the MATLAB code .

For 6mm diameter rod Number of scans=42

Scan length L=42/4=10.5cm

From the values of L and E using the equation (1) and (2), the value of diameter has been estimated as:

$$D = \frac{10.5-8.59}{\pi}$$

D = 0.61cm

RESULTS AND DISCUSSIONS

The diameter of the rebar estimated from the above procedure using generated MATLAB module for different diameter rods is presented in Table 1 and the difference in estimation of rebar diameter is ±3.6 %. Further studies have to be carried out to estimate the rebar diameter on concrete structural elements with multiple rebars by considering the effect of spacing of rebars, interference effect , etc.

Table 1.Results showing different parameters and diameter of rebar

Actual diameter (mm)	E (cm)	H (cm)	L (cm)	No of scans	Obtained diameter (mm)	% error
6mm	8.59	4.11	10.50	42	6.1	+1.4
8mm	8.83	4.91	11.25	45	7.7	-3.6
10mm	8.25	3.92	11.50	46	10.4	+3.5
32mm	8.53	3.75	18.75	75	32.5	+1.7
36mm	8.13	3.20	19.75	79	37.0	+2.8
46mm	8.13	3.20s	22.50	90	45.8	-0.4

CONCLUSION

Rebar location and diameter of rebar can be identified easily by using Ground penetrating radar (GPR) in addition to depth and spacing of rebar's in reinforced concrete structural elements. Estimation of rebar diameter is achieved by converting the raw GPR data into amplitude data and extracting the required values through MATLAB modules. Rebar diameter has been estimated in concrete using Ground penetrating radar (GPR) and the %error in estimation is within ±3.6%.This procedure in estimating the rebar diameter has to be validated for multiple rebar layers by taking noise and interference of signals from one bar into other.

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