Abstract—Ground penetrating radar (GPR) 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 radius in reinforced concrete (RC) structures. Studies have been carried out on concrete slab specimen, which was casted with three different rebar of diameter and cover depth. Radar-gram image has been collected by using 2.6 GHz antenna and converted into ASCII file which contain the amplitude values of reflected signals. Energy equation model reported in literature is being used in estimating the rebar radius. From the limited study, it is observed that the estimated radius is close to the actual and is within ±2.5%.

Keywords— non-destructive testing (NDT); ground penetrating radar (GPR), radar-gram, scan length, rebar radius;

I 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. In recent history NDT methods are considered as modern tools for evaluating existing concrete structures with regard to their strength and durability. NDT methods have been drawing more attention, in the sense of reliability and effectiveness. The importance of being able to test in situ has been recognized, and this trend is increasing as compared to traditional random sampling of concrete for material analysis [1].

In recent years, various techniques such as impact echo, pulse echo, thermography, ground penetrating radar (GPR), etc., are gaining importance in the field of structural engineering for determining the thickness and identification of defects. 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 is used for,

i. Estimation of the thickness elements from one surface;
ii. Location of reinforcing bars and metallic ducts and estimation of concrete depth;
iii. Determination of most important feature construction;
iv. Localization of moisture variations;
v. Localization and the dimension of voids;
vi. Localization of cracks;
vii. Estimation of bar size[3]

GPR is a non-destructive method that 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 ($\varepsilon$). If a material is dielectrically homogeneous, then the wave reflections will indicate a single thick layer [4].

In concrete structures steel reinforcing bars are the most common targets. Transverse rebar (i.e., rebar oriented perpendicular to the survey line) produce clean and strong hyperbolas. The reflection strength (amplitude) of a rebar increases with rebar size, and it decreases with depth and/or presence of corrosion. Rebar size can be estimated from reflection strength on a comparative basis, but cannot be accurately measured. 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. A steel pipe (conduit, for instance) looks exactly the same as a steel rebar of the same diameter [5].

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) [5]. Many researchers reported about the applicability of GPR techniques for the thickness measurement, mapping of reinforcement, locating tendon ducts, moisture distributions, etc. [6-8].

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

II LITERATURE REVIEW

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

Vincent Utset et al.[9] suggested that GPR can also be used to estimate rebar diameters. The results of GPRmax3D simulations for two center frequencies of GPRs applied to a range of rebar sizes at different depths. But a number of practical problems were encountered during the processing of the data. One of these occurs when the rebar spacing is closer than 200mm. Another problem was the influence of adjacent rebar in the direction of travel interfering with the cross polarization measurement.

G. Windsor et al. [10] applied generalized Hough transform method to measure the diameters of buried cylindrical pipes by Ground Penetration Radar (GPR).

M.R. Shaw et al. [11] used a neural network approach to automate and facilitate the post-processing of ground penetrating radar results. The radar data is reduced to a simplified data set by using an edge detection routine. Signal reflections from reinforcing bars displaying a hyperbolic image format are detected using a multi-layer perception (MLP) network with a single hidden layer containing 8 nodes to recognize a simplified hyperbolic shape.

Runtao Zhan et al. [12] compared the difference of discrete wavelet Transform (DWT) and stationary wavelet transform (SWT) and prepared the contour map of SWT detail coefficients, then found out SWT is an effective method to measure the diameter of steel bar.

Xian-Qi He et al. [13] developed direct least-square method and was specially adopted for a hyperbolic conic section, it can adequately deal with noisy data having missing points and is completely efficient. M. B. Alhasanet al. [14] presented a new algorithm to extract the diameter of a buried utility from a GPR image depending on its hyperbolic shape. It was concluded that the values of ‘D’ and ‘T’ can be determined from the GPR software or through a simple program using Excel software, whereby interpreters then by using the values of ‘X’ and ‘T’ as inputs to obtain the required information on the diameter of the buried object.

Chang et al. [15] 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.

III DESCRIPTION OF EQUIPMENT AND METHODOLOGY OF GPR

A. GPR Equipment

GSSI structure scan mini HR with 2.6 GHz was used. Here GPR 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 [16].

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 Figure 1.1.
B. Methodology of GPR testing

The GPR scanning technique has been proposed to predict the reinforcement details of slab specimen. Study is carried out by using Structure Scan™ 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 8 scans/unit (cm) for detecting reinforcements in slab specimen.

To demonstrate the methodology (Figure 1.2), GPR data has been collected on specially cast concrete specimens using 2.6 GHz frequency antenna. The specimen is a slab of dimension 1.5m×1.5m×0.5m the details is shown in Figure 1.3.
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 Figure 1.5. 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 16cm as shown in Figure 1.5.

Using migration tool available in RADAN 7 the velocity value and relative dielectric constant (ε) is obtained from specific hyperbola which is shown in figure 1.6. 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 [5]. In a similar way for other diameter rods also the migration analysis is carried out.

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 radius by using the equations given below.

Following equations (1) and (2) have been used in estimating the rebar radius.

\[
\frac{E}{2} = \frac{\lambda}{4} + \frac{H}{\sqrt{\varepsilon + 1}} \quad (1)
\]

\[
R = \frac{L - E}{2\pi} \quad (2)
\]

For estimating rebar radius, 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 Equation (1). For calculating E value by using the Equation (1) & (2) the wavelength value is needed which can be calculated by using \( c = \lambda \) where \( c \) is the speed of light in air whose value is \( c = 30 \) cm/ns and the value of \( \theta = 2.6 \) GHz so the \( \lambda \) value be 11.54 cm. Since the value of \( c \) and \( \theta \) is constant in this case, while calculating energy radius the value \( \lambda \) is taken as 11.54 for all trials.

For relative dielectric constant \( \varepsilon = 8.4 \) and \( H = 15.9 \) cm for 25mm diameter rod (figure 1.7)
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 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. It is observed that there is a significant variation at the metal-concrete interface. By dividing the scan length (in terms of number of scans) with scan density (in this case, it is 8 scans/unit), one can get the scan length, L.

For 25mm diameter rod

Number of scans = 193
Scan length, L = 193/8 = 24.125 cm

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

\[ r = \frac{L - E}{2\pi} \]

For 25mm diameter rod

\[ r = \frac{24.125 - 16.14}{2\pi} \]
\[ r = 1.27 \text{ cm} \]

**IV RESULTS AND DISCUSSIONS**

The radius of the rebar estimated using the above procedure for different diameter rods is presented in Table 1 and the difference in estimation of rebar radius is ±2.5%. Further studies have to be carried out to estimate the rebar radius on concrete structural elements with multiple rebars by considering the effect of spacing of rebars, interference effect, etc.

<table>
<thead>
<tr>
<th>Rebar Diameter</th>
<th>E(cm)</th>
<th>H(cm)</th>
<th>L(cm)</th>
<th>Rebar Radius</th>
<th>% error</th>
</tr>
</thead>
<tbody>
<tr>
<td>16mm</td>
<td>16.01</td>
<td>15.98</td>
<td>21.0</td>
<td>7.90mm</td>
<td>-1.25</td>
</tr>
<tr>
<td>20mm</td>
<td>16.07</td>
<td>15.98</td>
<td>22.5</td>
<td>10.25mm</td>
<td>2.3</td>
</tr>
<tr>
<td>25mm</td>
<td>16.02</td>
<td>15.90</td>
<td>24.0</td>
<td>12.70mm</td>
<td>1.6</td>
</tr>
</tbody>
</table>

**V CONCLUSION**

- Ground penetrating radar (GPR) can be used to identify the location of rebar, spacing between rebar in reinforced concrete structural elements.
- Rebar radius has been estimated in the laboratory cast specimens and the % error in estimation is within ±2.5%.
- Further studies are needed to estimate the rebar radius in closely spaced and multi-layer specimens/concrete structures.
- One can also adopt different procedure to estimate the radius by fitting a curve equation to the hyperbolic data set which can be related to the geometric and parametric properties of hyperbola.

**NOTATIONS**

- \( E \): long dimension radius of the energy footprint
- \( \lambda \): wavelength of the radar energy
- \( H \): depth from the surface to the reflection surface
- \( \epsilon \): average relative dielectric permittivity of the material for the depth (H)
- \( r \): radius of rebar
- \( L \): length of scan

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**REFERENCES**


