# COVERING THICKNESS AND DIAMETER MEASUREMENT OF REINFORCING BARS BY EDDY CURRENT TESTING USING NEURAL NETWORK

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## INTRODUCTION

Techniques for determining the covering thickness and diameter of reinforcing bars are needed in the evaluation of the existing strength of reinforced concrete structures. When eddy current testing is used with a relatively high test frequency, the covering thickness and diameter of the rebar can be determined simultaneously using relations between amplitude versus covering thickness and phase versus diameter. Neural networks were employed to estimate covering and diameter of rebar in this study. The phase waveform of the eddy signal generated by scanning the test coil along the surface of concrete was used for input data for the neural network.

## EDDY CURRENT TEST SYSTEM

A self-induction type pancake coil, whose specifications are listed in Table 1, was used in this study. In conventional test equipment, such as covermeters, covering thickness or diameter of rebar can be determined only when the other feature is known in advance. A test frequency of 32 kHz was used in this study. When the test coil was placed just above the rebar, as shown in Figure 1, both good amplitude versus covering and phase versus diameter information was obtained. However, the phase of the eddy signal is changed by the rib angle. On the other hand, the waveform of phase, generated by scanning the test coil across the rebar, involves information of the rib angle of rebar. Therefore, the test coil

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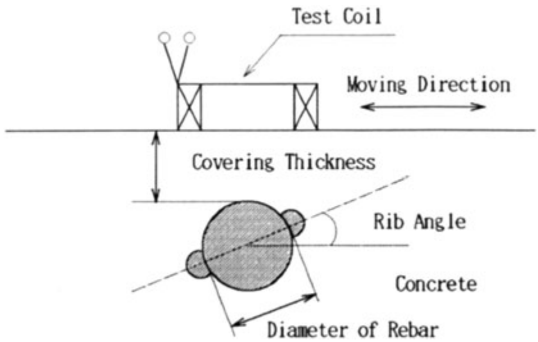


Figure 1 Arrangement of test coil and reinforcing bar.

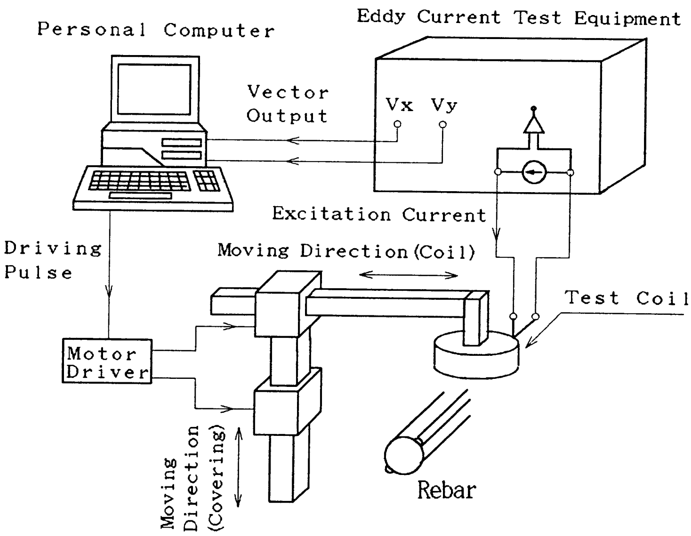


Figure 2 Schematic diagram of test equipment.

scanning system, shown in Figure 2, was used to get phase waveform corresponding to test coil scanning. A personal computer was used for controlling the scanner and acquisition of the data. Six deformed rebars, having nominal diameters of 10, 13, 16, 19, 22, and 25 mms were used in this experiment. The neural networks were constructed and trained on an engineering work station.

Table I. Specification of the test coil.

| Type | Diameter | Windings | Impedance |
|---|---|---|---|
| Self Induction | 100 mm | 36 turns | 50 Ω (at 32 kHz) |

## EDDY CURRENT SIGNAL WAVEFORMS

To investigate the basic characteristic of eddy current testing for reinforcing bar, data corresponding to the six rebars having different diameters were taken for various covering thicknesses at a test frequency of 32 kHz.

Figure 3 shows the relation between the covering thickness and amplitudes of eddy current signals. The peak amplitude is the peak value of amplitude waveform generated by the scanning of the test coil. The peak amplitude rapidly decreases when the covering thickness increases. The covering thickness can be determined from these relations, if the diameter of the rebar is known in advance.

Figure 4 shows the waveforms of the phase changes of eddy current signals generated by scanning for a rib angle of 0°. The phase waveform decreases when the diameter of the rebar increases. If the rib angle is set at different values (such as 45, 90, 135°), results illustrated on Figure 5 were obtained. The diameter of the rebar can be determined by these waveforms even if the rib angle is not 0°. Results illustrated in Figures 3 and 5 were fed to neural networks as input data.

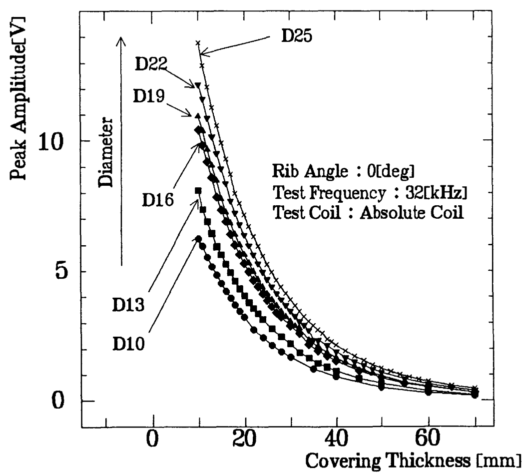


Figure 3 Plot of peak amplitude as function of covering thickness.

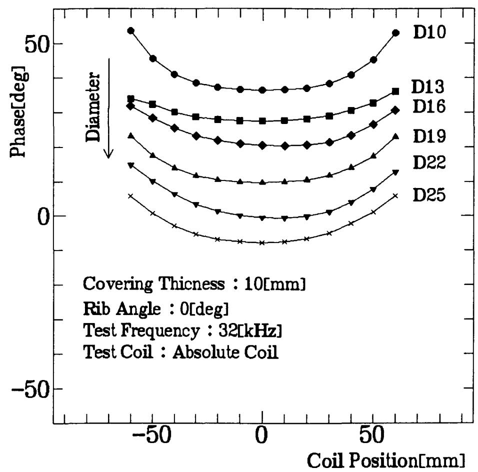


Figure 4 Plot of phase as function of coil position (rib angle 0°).

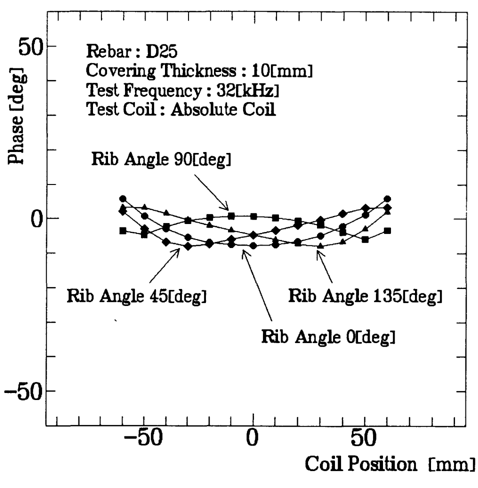


Figure 5 Plot of phase as function of coil position.

## NEURAL NETWORKS

### Construction of the Networks

Prior to the construction of the neural networks, several cases were examined to study the characteristics of neural networks. According to the results of such studies, the network was separated to two networks to estimate the covering thickness and the diameter of rebar, as shown in Figure 6. By this separation, the construction of each network was simple and the training time became short.

The networks studied here are multilayered feed-forward networks and back-propagation learning algorithm. Network 1, for diameter determination, has one hidden layer and consists of sixty cells. The input layer has fourteen input cells. The output layer has six cells corresponding to six nominal diameters handled in this study.

Network 2, for covering thickness determination, has also one hidden layer and its input layer uses six input cells being fed the resultant diameter determined by Network 1. One cell is fed the peak value of the amplitude waveform. The output layer has forty-five cells corresponding to covering thickness, previously defined by the relations between covering thickness versus amplitude.

### Training of the Networks

The data set for training the networks was taken from six kinds of rebars for a covering thickness range from 10 to 70 mm and for rib angles of 0, 45, 90, and 135°. Five

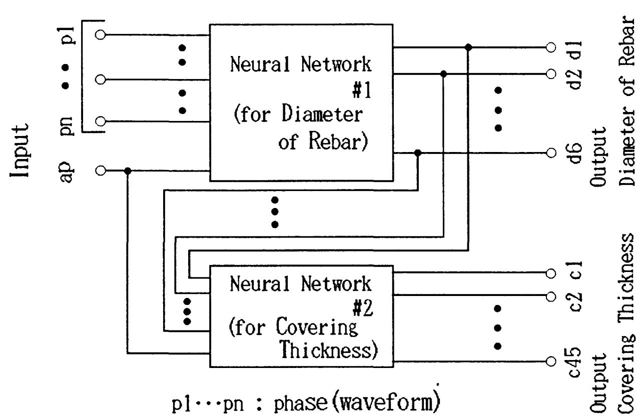


Figure 6 Structure of networks for covering thickness and diameter.

data sets were prepared. The scanning ranges of the data sets were 40, 60, 80, 100, and 120 mm, respectively. Then the network for diameter determination was trained. After the determination has been done by Network 1, the second network for covering thickness was trained.

RESULTS USING EXPERIMENTAL DATA

In the case of the 40 mm scanning range, the network did not converge because of insufficient information. 1,333 iterations were required for the 60 mm scanning range. As the scanning range increased, the iterations and error decreased. Five data sets for evaluation of the networks were prepared. Figure 7 shows the results of evaluation of 1 network for diameter determination. In this figure, the error rate, which was calculated as

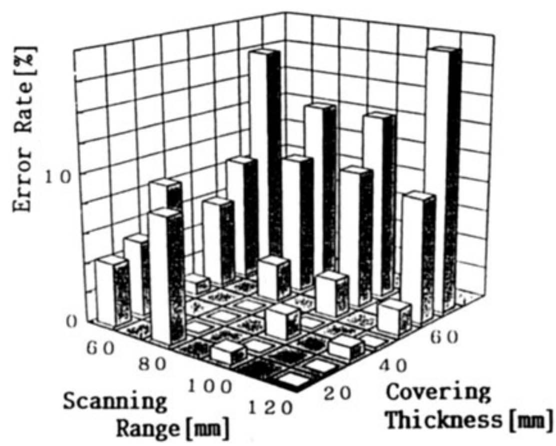


Figure 7 Error rate as a function of scanning range and covering thickness.

the ratio of miss-prediction time to 840 cases, is represented on the vertical axis of the 3-D diagram. It is clearly seen in this figure that the error rate increases when covering thickness increases. When the scanning range is small, the error rate becomes big even if covering thickness is relatively small. It can be said that 60 mm covering thickness is a limit of diameter determination, and at least 80 mm scanning range is required for reliable determination of diameter.

Table II. Error rate for covering thickness determination.

| Data Set | #1 | #2 | #3 | #4 | #5 |
|---|---|---|---|---|---|
| Error Rate (%) | 10.1 | 10.1 | 10.1 | 8.9 | 10.7 |

Table II shows the results of estimation of the 2 network for covering thickness determination. It can be seen from Table II that the error rate for predicting the covering thickness is under 10%. Most miss-predictions occurred in the small covering thickness, and in a neighboring output category for covering thickness, so that maximum error of covering thickness is approximately 2 mm.

## CONCLUSIONS

When eddy current testing is used to test rebar in concrete at a relatively high frequency, both the covering thickness and the diameter of the rebar can be determined simultaneously. Neural networks have been employed for the characterization of rebar using eddy current signals. The results of experiments show robust prediction of characteristics of the neural networks studied in this work. The effect of neighboring rebar should be studied in future works.