# Detection of Steel Bars and Internal Defects Inside Concrete using Non-Destructive Test Equipment

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## ABSTRACT

In this study, detection of steel bars embedded in concrete has been performed by using commercial non-destructive test equipment for the purpose of identifying performance of each equipment to detect steel bars embedded in concrete, and characteristics and detective limitation of each equipment were derived therefrom. Two types of radar detection systems and one electromagnetic detection system using the electromagnetic detection method were used in conducting the non-destructive test. Steel bars having various diameters of 13, 16, 19, 25 and 55 mm were embedded in concrete specimens for detection of them with their respective covering thickness being different, while a PVC pipe ( 30 mm), a sheath ( 50 mm), a wood piece (20×100 mm), a Styrofoam piece (20×100 mm) and a water container (150×300 mm) were embedded in concrete specimens for detection of them as internal defects with their respective covering thickness being different. Meanwhile, spacing lengths in the horizontal arrangement of steel bars were measured with such spacing lengths being made to range from 50 to 350 mm for detection of such spacing lengths. As a result of detecting so, it has been demonstrated that the radar detection method is effective in detecting locations of steel bars embedded in concrete and spacing lengths in the arrangement thereof, while the electromagnetic detection method is effective in detecting locations of steel bars embedded in concrete.

## INTRODUCTION

In order to maintain any structure in a safe condition, it is required to identify whether the structure is normal or abnormal by inspecting the structure precisely. Further, the structure shall be preserved in a safe condition by taking any appropriate action before any structural problem takes place therewith. For this reason, it is necessary to diagnose the structure in respect of its endurance. As a method for diagnosing so, the non-destructive test is getting to be more available and important. However, studies on more accurate and systematic utilization of the non-destructive test method have still remained in a rudimentary stage at home and abroad.

Therefore, this study is to identify performance of respective non-destructive test equipment, which are prevalently used in Korea. As such equipment, two types of radar detection systems and one electromagnetic detection system were used in the experiment for this study. Since this study is to identify performance and characteristics of respective non-destructive test equipment by types, neither manufacturer's names of the used systems nor names of them are referred to in this paper. However, photographs of the actual systems used in this study are inserted in this paper for easy understanding. Average measurement values, which were obtained by using respective systems, were used as results of measurement.

## OPERATION PRINCIPLE AND CHARACTERISTICS OF MEASUREMENT EQUIPMENT

### Radar Detection System

The measurement principle of the radar using the electromagnetic wave is based on the fact that when the electromagnetic wave belonging to the microwave band penetrates any object or medium, penetration and reflection of the electromagnetic wave gets to be affected by electromagnetic characteristics and shape of the object or medium. When the electromagnetic wave is radiated from the transmitting antenna to the concrete test specimen where steel bars to be detected are embedded in the actual measuring process, this electromagnetic wave gets to be reflected from the boundary surface of any matter having any different electromagnetic nature, such as a steel bar, a cavity or an internal defect, and further to reach the receiving antenna. The shape and material of the embedded object can be discriminated by the reflected waveform of the electromagnetic wave. Fig. 1 depicts briefly the measuring process using the radar detection system.

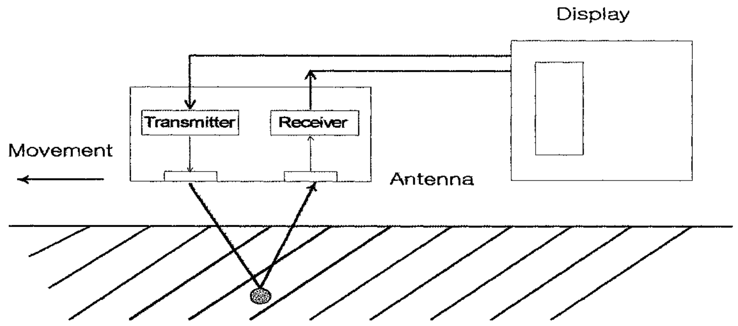



**Fig. 1 Measuring Process by Radar Detection System**

Wherein, the velocity of the electromagnetic wave in the concrete specimen varies according to the dielectric constant, $\varepsilon_r$ that is the electromagnetic material characteristic of the concrete.

$$v = \frac{C}{\sqrt{\varepsilon r}} \qquad (1) \qquad\qquad D(m) = \frac{C}{\sqrt{\varepsilon r}} \times \frac{T}{2} \qquad (2)$$

Wherein, C is the velocity of the electromagnetic wave ($3\times 10^8$ m/s) in a vacuum condition, and $\varepsilon_r$ is the dielectric constant of the concrete. The distance (D) from the transmitting antenna to the embedded object can be obtained by using Eq. 2 on the basis of the transmitting time (T) while the incident wave goes from the transmitting antenna to the object and further the reflected wave returns from the object to the receiving antenna.

The non-destructive test equipment using the radar detection method is mainly used in detecting any steel bar, any cavity, any piping, a back face of any tunnel lining and any metal pipe, and its measurable depth is several meters. Photo 1 and 2 represent respective actual configurations of the two radar detection systems used in this study.

**Electromagnetic Detection System**

The measurement principle of the electromagnetic detection method is to identify whether there is any steel bar embedded in the concrete specimen by generating a magnetic field between both poles of a probe and further measuring the quantity of the returned magnetic flux. In case there is any steel embedded in the concrete specimen, the intensity of the magnetic field gets to vary, and the varying quantity thereof gets to be different according to the diameter of the steel bar and the distance from the probe to the steel bar. The quantity of the magnetic flux penetrating the steel bar is affected by the covering thickness and the diameter of the steel bar. The smaller the covering thickness is and the greater the diameter of the steel bar is, the more the magnetic flux penetrates the steel bar and thereby the possibility to detect it gets to be higher.

Generally, the electromagnetic detection method is available for detecting any steel bar with its covering thickness being within 0～120 mm. This method is effective in detecting steel bars which are arranged at wide intervals, but it is difficult to get reliable results of detecting steel bars which are arranged densely or steel bars around a large steel material through this electromagnetic detection method.

The electromagnetic detection system as used in Korea is mainly used in detecting any steel bar, any steel bar's diameter and any concrete covering thickness. Its measurable depth is several tens centimeters. Photo 3 represents the actual configuration of the electromagnetic detection system used in this study.

Photo 1. Radar Detection System I

Photo 2. Radar Detection System II

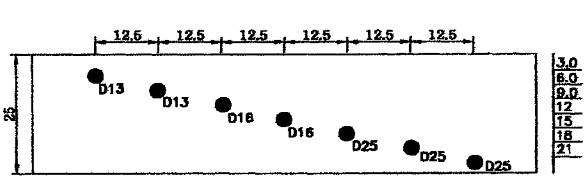

Photo 3. Electromagnetic Detection System

## MANUFACTURING TEST SPECIMENS

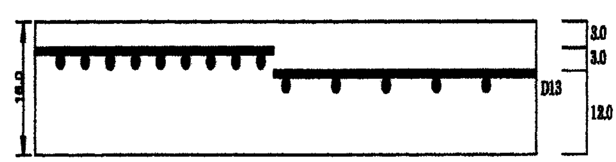
Respective experiments on detection of locations of steel bars (measurement of concrete covering thickness), spacing lengths of steel bars arranged horizontally and internal defects were conducted by using 4 types of basic specimens and one applied specimen as manufactured for this study. Among such basic specimens, one basic specimen for detection of locations of steel bars was manufactured so that its size might be 1,000 mm (length) × 300 mm (width) × 250 mm (thickness) with various covering thickness ranging from 30 to 210 mm, where the embedded steel bars had various diameters ranging from 13 to 25 mm.

And two basic specimens for detection of spacing lengths of steel bars arranged horizontally were manufactured so that their size might be 1,000 mm (length) × 300 mm (width) × 180 mm (thickness) with various spacing lengths ranging from 50 to 150 mm being between steel bars, where the embedded steel bars had various diameters ranging from 13 to 25 mm.

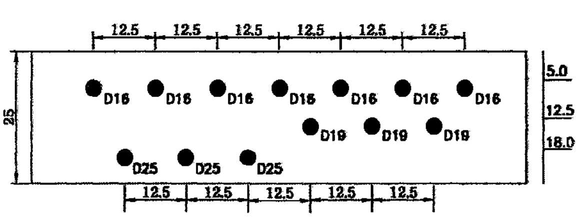
Further, one basic specimen for detection of internal defects was manufactured so that its size might be 1,000 mm (length) × 300 mm (width) × 180 mm (thickness), where a wood piece and a Styrofoam piece having the size of 20 mm (thickness) × 100 mm (length) respectively, a 30 mm PVC pipe and a 50 mm sheath, were embedded as internal defects. Respective sections of the basic specimens are illustrated in Fig. 2.



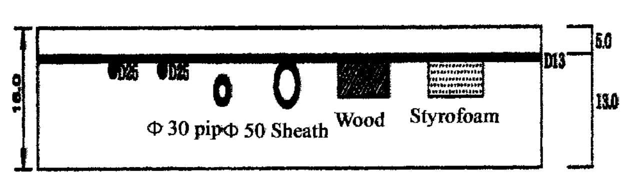

(a) Specimen #1
(Covering : 30～210 mm, Spacing : 125 mm)




(b) Specimen #2
(Covering : 30～60 mm, Spacing : 50～100 mm)



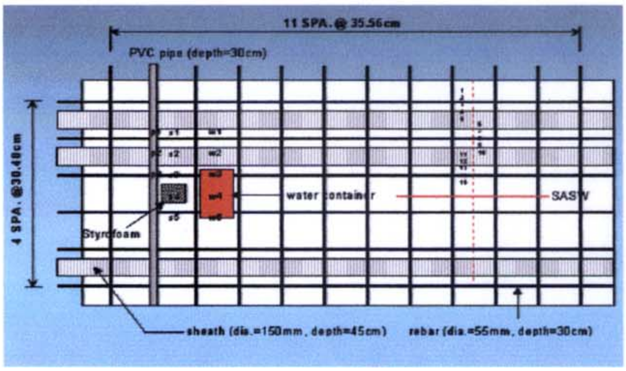

(c) Specimen #3
(Covering : 50～180 mm, Spacing : 125 mm)



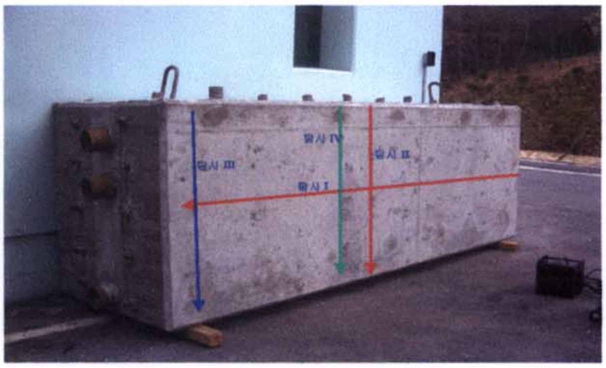

(d) Specimen #4
(Wood Piece, Styrofoam, PVC Pipe, Sheath)

**Fig. 2 Sections of Basic Specimens**

The applied specimen was manufactured as a mock-up of a selected typical section of the containment building in the actual nuclear power plant, and its manufacturing drawing and the mock-up are illustrated in Fig. 3.




(a) Section of Wall of Containment Building in Nuclear Power Plant



(b) Mock-up of Wall of Containment Building in Nuclear Power Plant

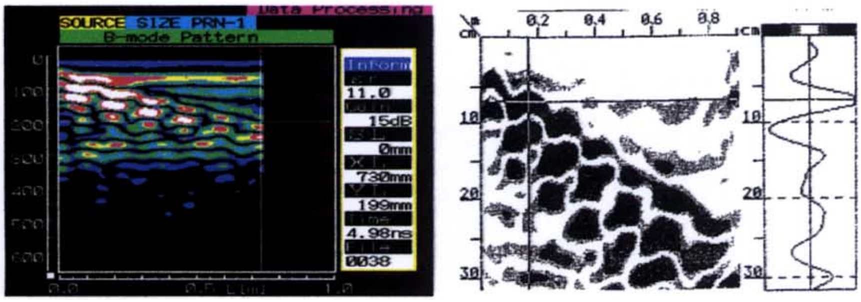
**Fig. 3 Section of Applied Specimen**

## EXPERIMENT RESULTS AND INTERPRETATION

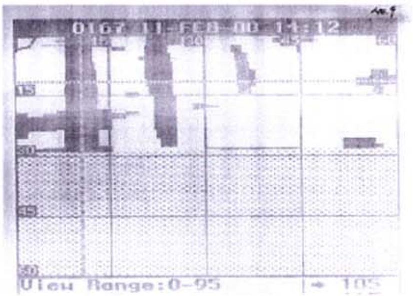
### Basic Specimens

### Measurement of Locations of Steel Bars

Fig. 4 shows the results of detecting locations of steel bars in the basic specimens by using the radar detection systems and the electromagnetic detection system. As a result of detecting locations of steel bars in basic specimens, in case the radar detection method was used, locations of steel bars could be detected relatively exactly even though some error existed in such results yielded by both radar detection systems. As a result of interpreting the measurement data, the measurement data yielded by System I was found to be more reliable than the measurement data yielded by System II. However, in case the electromagnetic detection method was used, steel bars embedded in the concrete specimens with their covering thickness being over 150 mm could not be detected, and reliability of the measurement data yielded by the electromagnetic detection system was found to be poor.




(a) Radar Detection Systems

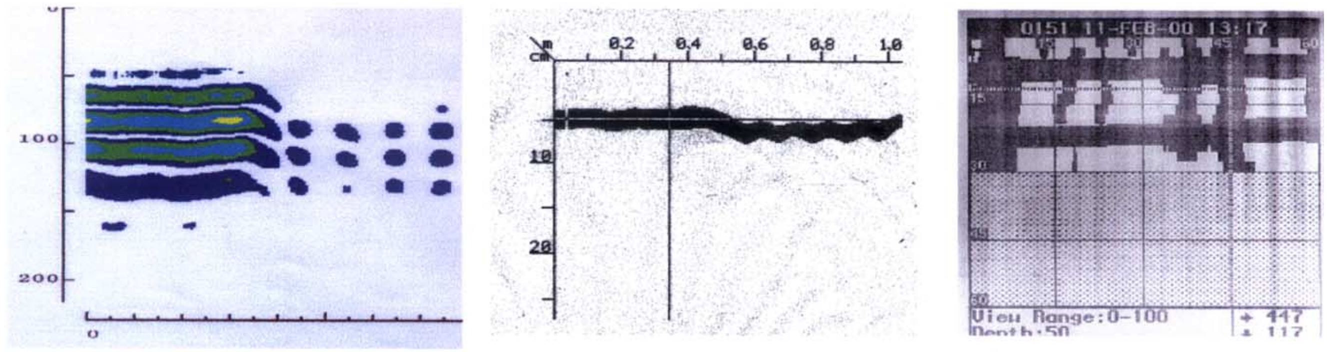


(b) Electromagnetic Detection System

**Fig. 4 Results of detecting Locations of Steel Bars (Specimen #1)**

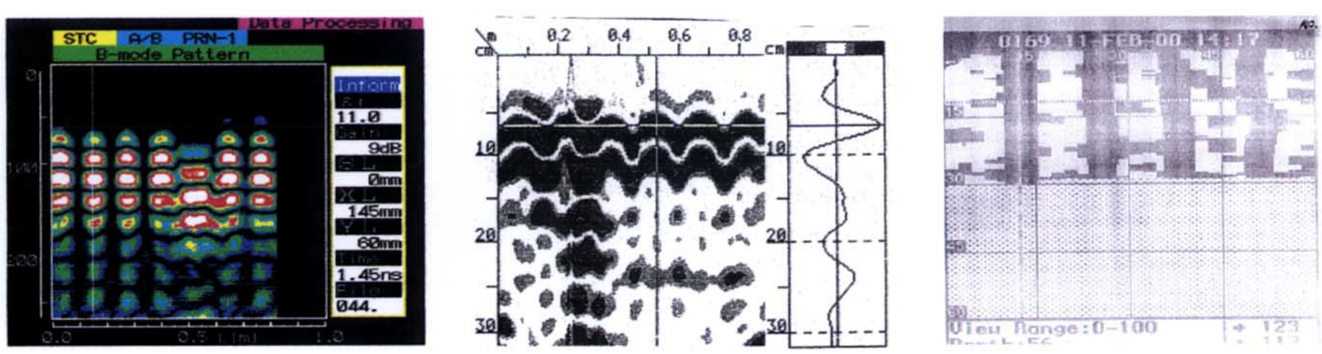
**Measurement of Spacing Lengths in Arrangement of Steel Bars**

Fig. 5 and 6 show the results of detecting spacing lengths in arrangement of steel bars and double reinforcements by using the radar detection systems and the electromagnetic detection system.




(a) Radar Detection Systems (b) Electromagnetic Detection System

**Fig. 5 Results of detecting Spacing Lengths in Arrangement of Steel Bars (Specimen #2)**



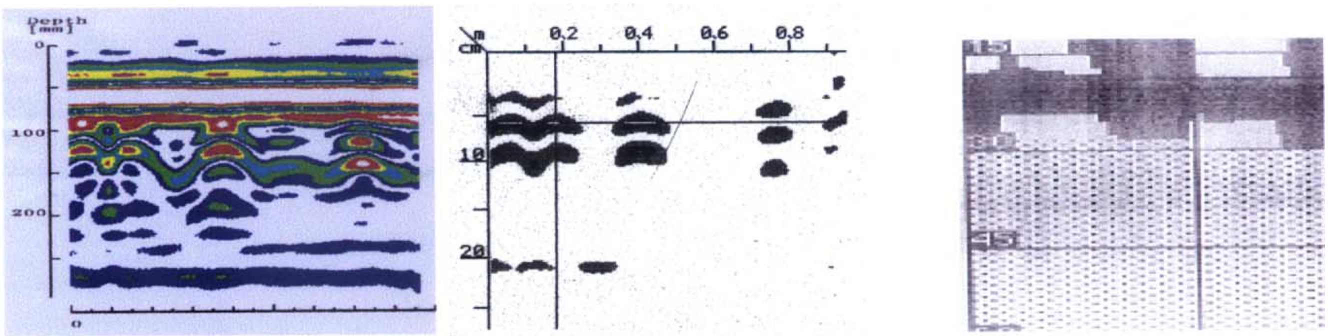

(a) Radar Detection Systems (b) Electromagnetic Detection System

**Fig. 6 Results of detecting Double Reinforcements (Specimen #3)**

As a result of detecting spacing lengths in arrangement of steel bars in basic specimens, in case the radar detection method was used, steel bars arranged with their spacing length being below 50 mm were shown in the form of one band so that their spacing length could not be detected, while the spacing length of steel bars arranged with their spacing length over 50 mm could be detected. In case the electromagnetic detection method was used, the spacing length of steel bars arranged with their spacing length being below 50 mm could be just detected but its measurement data reliability was found to be poor, while the spacing length of steel bars arranged with their spacing length being over 50 mm could be detected exactly. However, double reinforcements could not be detected by the radar detection method and the electromagnetic detection method alike.

**Detection of Internal Defects**

Fig. 7 shows the results of detecting internal defects in the concrete specimen by using the radar detection systems and the electromagnetic detection system.




(a) Radar Detection Systems (b) Electromagnetic Detection System

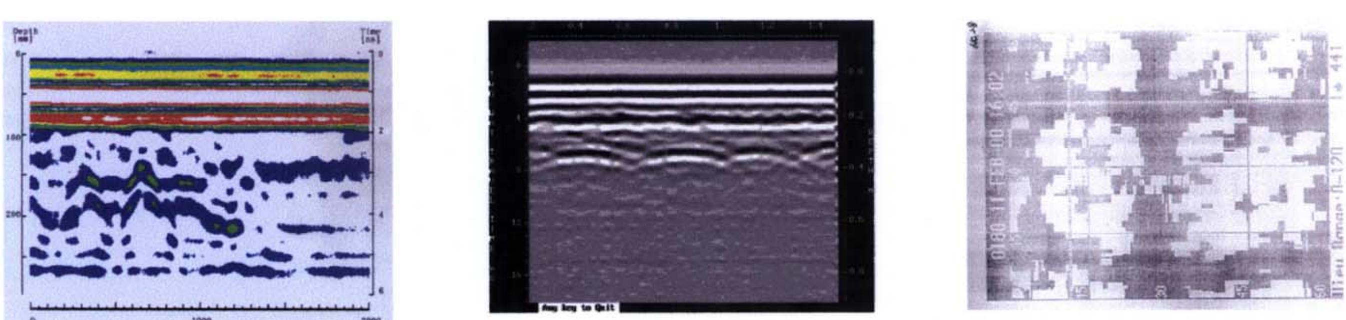
**Fig. 7 Results of detecting Internal Defects (Specimen #4)**

As a result of detecting internal defects in the basic concrete specimen # 4, in case the radar detection method was used, the PVC pipe, the wood piece and the Styrofoam piece could not be detected by the two radar detection systems alike, while the sheath was shown in a form similar to the form in which a steel bar was shown. Therefore, it has been found out that in case any internal defect exists in concrete, it is difficult to discriminate its material from a steel bar by using the radar detection method. Also, in case the electromagnetic detection method was used, the results of detecting internal defects in the basic concrete specimen # 4 are similar to them with the case where the radar detection method was used, except for the sheath. Therefore, it has been found out that it is impossible to discriminate internal defects excluding the sheath from a steel bar by using the electromagnetic detection method.

**Applied Specimen**

**Measurement of Locations of Steel Bars and Spacing Lengths**

Fig. 8 shows the results of detecting locations of steel bars in the applied specimen by using the radar detection systems and the electromagnetic detection system. As a result of detecting steel bars in the applied specimen, in case the radar detection method was used, both the radar detection systems could detect locations of steel bars relatively exactly. However, in case the covering thickness of steel bars was over 200 mm, the reliability of the measurement data got to be poor, and further in case it was over 250 mm, locations of the steel bars could not be detected. Meanwhile, in case the electromagnetic detection method was used, locations of steel bars with their covering thickness being over 150 mm could not be detected, and the reliability of the measurement data also got to be poor.



(a) Radar Detection Systems (b) Electromagnetic Detection System

**Fig. 8 Results of detecting Locations of Steel Bars and Spacing Lengths (Applied Specimen)**

**Detection of Internal Defects**

For the applied specimen, the lower frequency antenna has been used. Since the signal from the higher frequency antenna of 900 MHz, 1 GHz, and 1.5 GHz was not able to penetrate into the thick specimen due to attenuation of the wave at higher frequency range. The 400 MHz antenna signal was able to detect the presence of internal defect inside the concrete specimen as shown in Fig. 9.

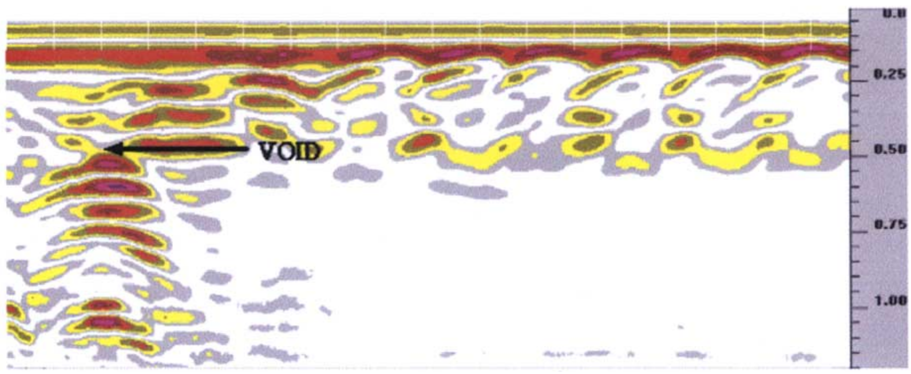



**Fig. 9 Radar Measurement Result at 400 MHz(Applied Specimen)**

## CONCLUSIONS

This study has yielded the following conclusions;

1) As a result of detecting locations of steel bars, locations of steel bars in basic specimens could be detected relatively exactly by the radar detection method and the electromagnetic detection method alike. In case the electromagnetic detection method was used, it was impossible to detect locations of steel bars embedded in concrete with their covering thickness being over 150 mm, and further the reliability of their measurement data got to be poor. In case locations of steel bars in the applied specimen were detected by the radar detection method, they were detected in a good condition. However, in case the covering thickness of steel bars was over 200 mm, the reliability of the yielded measurement data got to be poor, and further in case the covering thickness was over 250 mm, it was impossible to detect locations of steel bars in the applied specimen.
2) As a result of detecting spacing lengths in arrangement of steel bars in basic specimens, in case the radar detection method was used, the spacing length of the steel bars arranged with their spacing length being below 50 mm could not be detected because they were shown in the form of one band, while the spacing length of the steel bars arranged with their spacing length being over 50 mm could be detected exactly. In case the electromagnetic detection method was used, the spacing length of the steel bars arranged with their spacing length being below 50 mm could be just detected but the reliability of the measurement data got to be poor, while the spacing length of the steel bars arranged with their spacing length being over 50 mm could be detected exactly. However, it has been found out that double reinforcements could not be detected by the radar detection method and the electromagnetic method alike. The spacing length in arrangement of steel bars in the applied specimen could be detected in a good condition by the radar detection method and the electromagnetic detection method alike.
3) As a result of detecting internal defects in concrete, in case the radar detection method was used, the PVC pipe, the wood piece and the Styrofoam piece could not be detected by the two radar detection systems alike, and the sheath was shown in a form similar to the form in which a steel bar was shown. Therefore, it has been found out that in case any internal defect exists in concrete, it is difficult to discriminate its material from a steel bar by using the radar detection method. Also, in case the electromagnetic detection method was used, the results of detecting internal defects in the basic concrete specimen # 4 are similar to them with the case where the radar detection method was used, except for the sheath. Therefore, it has been found out that it is impossible to discriminate the

other materials excluding the sheath from the steel bar by using the electromagnetic detection method. But, in case the applied specimen, the 400 MHz antenna signal was able to detect the presence of internal defect inside the concrete specimen.

4) Through this study, it has been demonstrated that the radar detection method was effective in detecting locations of steel bars and spacing lengths in arrangement of steel bars in concrete, while the electromagnetic detection method was effective in detecting locations of steel bars.

## ACKNOWLEDGEMENTS

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