Experimental Study on Applicability of Measuring Method of Chloride Content using Electromagnetic Wave in Reinforced Concrete Structures

Toshiaki MIZOBUCHI, Dr.Eng
Professor
Department of Civil and Environmental Engineering
HOSEI University
3-7-2 Kajino-cho Koganei-city
Tokyo JAPAN
mizobuch@k.hosei.ac.jp

Kumiko SUDA, Dr.Eng
Supervisory Research Engineer
Kajima Corporation
2-19-1 Tobitakyu Chofu-city
Tokyo, JAPAN
suda@kajima.com

Daisuke HAYASHI
Research Engineer
Kajima Corporation
2-19-1 Tobitakyu Chofu-city
Tokyo, JAPAN
hayashda@kajima.com

Kosuke YOKOZEKI, Dr.Eng
Senior Research Engineer
Kajima Corporation
2-19-1 Tobitakyu Chofu-city
Tokyo, JAPAN
yokozeki@kajima.com

KEYWORDS: Electromagnetic Wave, Content of Chloride Ions, Dielectric Constant, Amplitude.

INTRODUCTION

A definite understanding about any corrosion of reinforcement is very difficult unless corrosion induced cracks appear on the surface. Thus, in order to detect chloride-induced corrosion at an early stage, chloride content within concrete needs to be investigated using cores drawn from the RC structure, and carrying out chemical analysis. Now, drawing cores could be structurally unacceptable, damage the reinforcement and the repair could be aesthetically unappealing, only very limited sampling can actually be carried out. In addition, drawing cores to estimate the chloride content in concrete could not make it possible to study the changes in chloride content over time (at exactly the same place). On the other hand, it has been obtained from laboratory tests under limited conditions that chloride content within concrete has could be almost estimated by using electromagnetic waves as one of the non-destructive tests. However, as all specimens have be added sodium chloride during the mixing of concrete in the laboratory tests, the experiments have been not carried out to estimate chloride content using specimens permeated chlorides from the concrete surface after placing. Since experiments to estimate the chloride content in concrete using electromagnetic waves have been carried out to apply existing concrete structures to be a premise, the convenient measuring instrument that the frequency was fixed was used. However, it should be considered that excellence frequency may be changed by water content and chloride content in concrete.

Thus, in order to confirm the possibility of the measurement of chloride content in reinforced concrete structures using the electromagnetic wave, experiments were carried out to estimate the chloride content in concrete specimens permeated chlorides from a surface using the electromagnetic wave. Further, the measurement was carried out to estimate the chloride content using the electromagnetic wave in the pier which was one of marine structures.

In this paper, the results obtained from a study carried out to evaluate the applicability of using electromagnetic waves as one of nondestructive tests to estimate the content of chloride ion in the concrete are reported.

OUTLINE ON MEASUREMENT OF CHLORIDE CONTENT IN CONCRETE USING ELECTROMAGNETIC WAVES

The dielectric constant of dry concrete varies in between 4 to 10, and that of wet concrete in the range of 10 to 20.

Thus, the dielectric constant of concrete varies depending on the moisture content of concrete. As mentioned above, the dielectric constant is the same for both fresh water and seawater.

In this study, as shown in Figure 1, when the distance to the reflecting surface, i.e. reinforcing bar, was known, it was detected that changes in the properties of the electromagnetic waves such as the dielectric constant are caused by differences in the properties of the intervening medium such as the moisture content, which in this case is concrete. Furthermore, it was also confirmed that changes of dielectric constant in the electromagnetic waves weren't caused by differences in the chloride content in concrete.

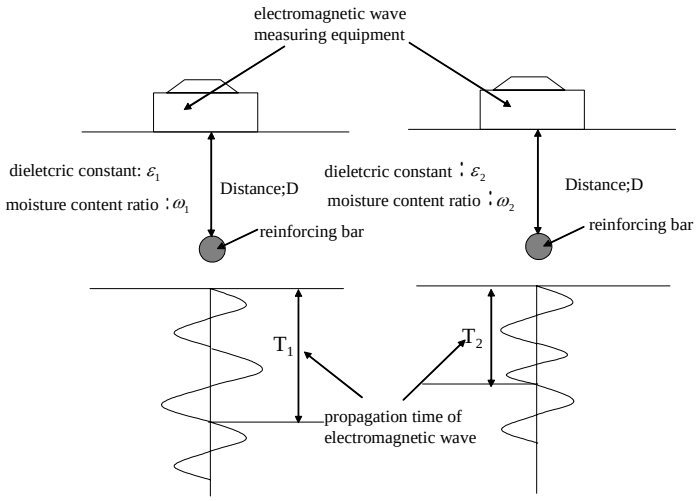

Figure 1. Concept of electromagnetic wave measurement

As mentioned above, the conductivity is likely to vary considerably with the amount of chloride ions in concrete. That is to say, when the electrolyte like sodium chloride exists in the concrete, it seems to be changed the electrical properties such as conductivity in comparison with the concrete without the chloride ions. Furthermore, because the amount of electrolyte varies with the difference of chloride ions concentration, the amount of electrolyte also changes depending on the moisture content in the concrete.

In this study, therefore, it was detected that changes in reflected waveform of electromagnetic waves were caused by differences in chloride ions concentration and moisture content in the concrete.

ESTIMATION OF CHLORIDE CONTENT IN CONCRETE SPECIMENS PERMEATED CHLORIDES FROM A SURFACE OF CONCRETE USING THE ELECTROMAGNETIC WAVE

In many concrete structures, chloride content caused reinforcement corrosion in the neighborhood of the reinforcing bars is not almost contained from the beginning. In many concrete structures damaged by reinforcement corrosion caused by the present of chloride ions, chloride content around the reinforcing bar has reached sufficient chloride ions caused reinforcement corrosion by gradual permeation and diffusion from a surface of concrete as in the case of marine structures or, cases where deicing salts are used to melt away snow on highways, etc.

Thus, the specimens permeated chloride ions from a surface of concrete were prepared. The measurement using the electromagnetic waves was carried out with these specimens.

Materials used and mix proportion

Table 1 and Table 2 show the materials used and the mix proportion of concrete used in casting the test specimens.

Table1. Details of materials used

Materials	Summary
Cement	Ordinary portland cement, density:3.16g/cm^3, fineness:3320cm^2/g
Fine aggregate	Hill sand, saturated surface-dry particle density: 2.62g/cm^3, fineness modulus:2.57
Coarse aggregate	Crushed stone, saturated surface-dry particle density: 2.65g/cm^3, solid content: 59.4%
Chemical admixture	Air-entraining and water reducing agent of Libin sulfonic acid compound, density: 1.25g/cm^3
	Air-entraining agent of denatuted rosinate-based anionic surface active agent

Table 2. Mix proportion of concrete

Maximum size of coase aggregate (mm)	Water to cement ratio (%)	Sand content (%)	Unit quantity (kg/m^3)				
			Water	Cement	Sand	Gravel	AEWRA
20	60.0	45.5	165	275	838	1015	0.96

NOTE; AEWRA: Air-entraining and water reducing agent

Specimens

Specimens, whose size were 100×100×400 mm were prepared. The test specimens were sealed all other planes of the specimen to permeate chloride ions from a plane of the specimen. The specimens with the seal were made to penetrate in water of chloride ion concentration whose was 3% and 10% for about 3 months.

Table 3. Specifications of electromagnetic wave measuring equipment

Item	Specifications
Rader frequencies	1.0 GHz
Measurement method	Impuls method
Transmission voltage	17Vp-p (at load 50Ω)
Horizontal resolution	80 mm

Test methods

For measurement of electromagnetic waves, an antenna of about 1.0 GHz with specifications as given in Table 3 was installed on the specimen. The specimens were placed on a steel plate to intensify the reflected electromagnetic waves. The scale of the monitor was fixed at the level of the gain of the machine when the measurement was started, and the amplitude of the reflected electromagnetic wave estimated using that scale (Full scale = 100%). Further, to study the change of the moisture content in concrete, the mass of the specimen, the temperature and humidity in the laboratory were measured during the electromagnetic wave measurement.

In our past study, from results of the experiments carried out in the laboratory, it was found that the content of chloride ions could be estimated with fairly good accuracy from the measurement of electromagnetic waves. When estimating the content of chloride ions, the dielectric constant, amplitude vales of reflected electromagnetic waves, amount of moisture in concrete and air temperature should be considered. Then, the content of chloride ions, C_c, as the criterion variable can be estimated by the multiple regressions analysis taking temperature in the laboratory T, amount of moisture in concrete μ, the dielectric constant ε and the amplitude value α as the predictor variables, using equation 1 below.

$$C_C = -0.374 \times T + 0.120 \times \mu - 0.114 \times \varepsilon - 0.123 \times \alpha + 18.9 \quad (\text{kg/m}^3) \qquad (1)$$

After the measurement of electromagnetic waves was finished, cores were drawn from the test specimens and it was carried to analyze distribution of chloride content for depth direction from the concrete surface.

Test results and discussions

Two cores were respectively drawn from one test specimen in order to analyze content of all chloride ions and content of soluble chloride ions within each specimen which respectively was penetrated in water of 3% and 10%chloride ion concentration. Figures 2 shows relationship between depth from the concrete surface and content of chloride ions.

In case when the content of chloride ions is estimated using electromagnetic waves, it is seemed that the content of

chloride ions estimates the average content to object (steel plate laid under the test specimen in this experiment) reflected the electromagnetic waves from concrete surface. Then, Figure 3 shows respectively the average of content of all chloride ions and soluble chloride ions shown in Figure 2 and the content of chloride ions estimated using equation (1). In case where the specimen penetrated in water of 3% chloride ion concentration, the average of content of all chloride ions was about half content estimated and the average of content of soluble chloride ions was about 1/3 content estimated. On the other hand, in case where the specimen penetrated in water of 10% chloride ion concentration, the average of content of all chloride ions and soluble chloride ions were respectively 2.3kg/m^3 and 1.9kg/m^3, while the content of chloride ions estimated using equation (1) was 2.6kg/m^3. The content of chloride ions estimated using equation (1) was comparatively approximate to that of all chloride ions.

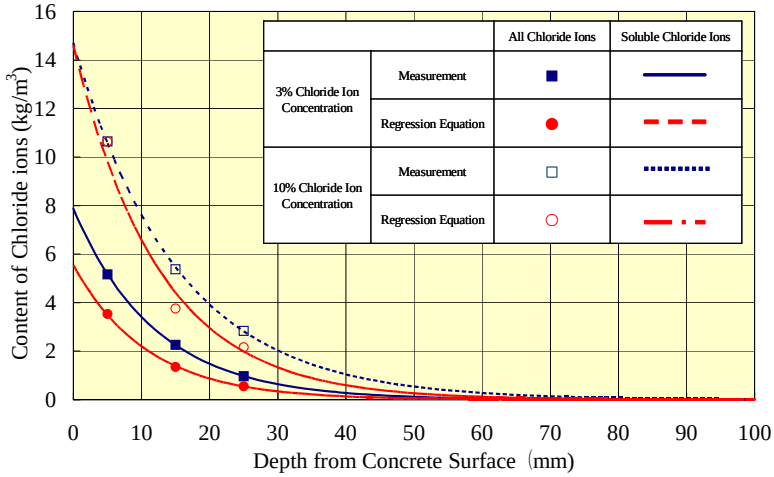

Figure 2. Distribution of Content of Chloride ions

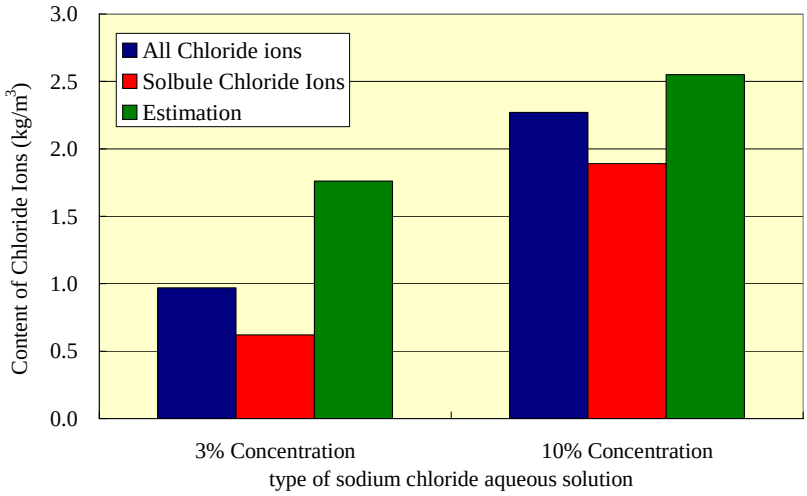

Figure 3. Comparison of Content of Chloride Ions

As mentioned above, in case where the specimen penetrated in water of 3% chloride ion concentration, the content of chloride ions estimated differed from the content of chloride ions measured. Because, though the chloride ions were permeated only to vicinity of 50mm depth from concrete surface, it was estimated that chloride ions permeated to 100mm depth from concrete surface. In case where the specimen penetrated in water of 10% chloride ion concentration, it seemed that the estimated content of chloride ions became comparatively similar for the average content of chloride ions measured, since the chloride ions permeated to vicinity of 80mm depth.

If it is assumed that the electromagnetic wave is not almost attenuated within not containing chloride ions, when the content of all chloride ions is averaged within permeating of chloride ions, the average content of chloride ions becomes 1.9kg/m^3 in case where the specimen penetrated in water of 3% chloride ion concentration and becomes 2.6 kg/m^3 in case where the specimen penetrated in water of 10% chloride ion concentration. Therefore, in both cases, the estimated content of chloride ions became similar for the average content of chloride ions measured. However, in actual structures, it is proven whether chloride ions have permeated in the neighborhood of the reinforcing bars. Therefore, the content of chloride ions estimated using electromagnetic waves may be estimated

larger than that permeated in concrete, when the chloride ions have not permeated to the neighborhood of the reinforcing bars yet. On this point, it is necessary to carry out experiments varied permeation depth of the chloride ions

ESTIMATION OF CHLORIDE CONTENT IN AN ACTUAL CONCTETE STRUCTURE USING THE ELECTROMAGNETIC WAVE

For the purpose of investigating the applicability of method of estimating content of chloride ions using electromagnetic wave in reinforced concrete structure, it was tried that the content of chloride ions was measured using electromagnetic waves for the pier. As shown in Figure 4, it was carried out to measure at three places of upper surface and joint division of floor slab and curbs. The content of chloride ions was calculated by substituting the dielectric constant and the amplitude value obtained from results measured using electromagnetic wave for multiple regressions equation (1). However, as it was not possible to measure the humidity of the concrete inside, the content of chloride ions was calculated as relative humidity being constant for 80% RH.

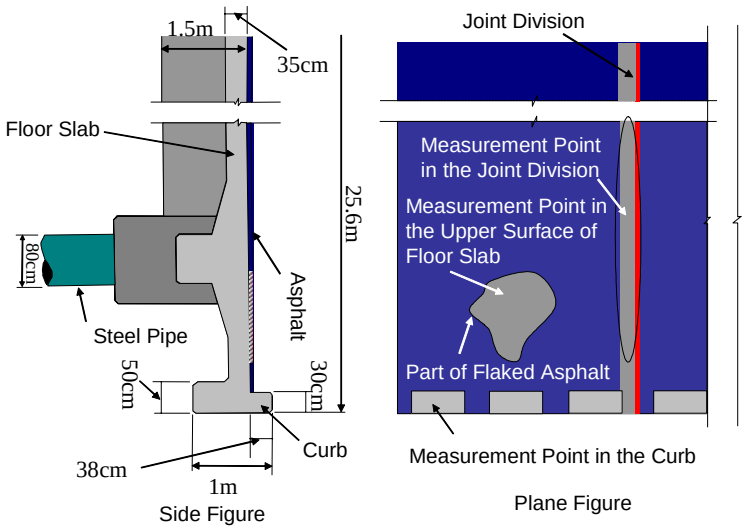

Figure 4. Outline of Measurement Place in Pier

Figure 5 shows the results of comparing the content of chloride ions estimated by electromagnetic wave with the content of chloride ions obtained by chemical analysis in each place. As shown in Figure 5, though the results estimated by electromagnetic wave became comparatively similar to results of chemical analysis obtained from cores drawn in curb and joint division of floor slab, the content of chloride ions obtained by chemical analysis of the cores drawn from upper surface of floor slab considerably became smaller than the content of chloride ions estimated by electromagnetic wave. By the condition of reinforcing bars arrangement and interval of reinforcing bars in the underside of floor slab, it may be seemed to affect that the estimated result was considerably smaller than result of analysis. However, the cause has not been clarified in present. Therefore, further work needs to be investigated to clarify the cause in the future.

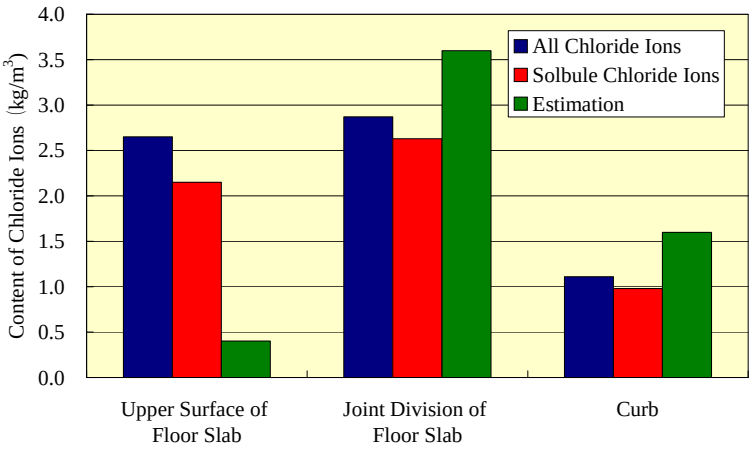

Figure 5. Comparison of Content of Chloride Ions (Pier)

CONCLUSIONS

The present research examined on applicability of the method of estimating the content of chloride ions in reinforced concrete using electromagnetic waves. The knowledge gained from this study can be outlined as follows.

(1) From results of estimating the content of chloride ions using electromagnetic wave in the test specimens permeated chloride ions from concrete surface, however it is necessary to carry out experiments varied permeation depth of the chloride ions in the future, it was found that it is possible to estimate the content of chloride ions from the measurement of electromagnetic waves.

(2) From the result of the measurement of the content of chloride ions in reinforce concrete structure, though it was limited condition, it was possible to estimate the content of chloride ions using electromagnetic waves by applying estimated equation of the content of chloride ions obtained from results of tests in the laboratory. However, as many problems have been held on application to reinforced concrete structures, further works need to be examined on influences of environmental condition, shape of the structure, moisture condition in concrete, etc..

REFERENCES

Japan Society of Civil Engineering of 2003. Enactment of Test Method for Diffusion Coefficient of Chloride Ion in Concrete and Trend of Test Method of normalization desired, Concrete Engineering Series 55, 2003 (in Japanese)

Toshiaki Mizobuchi et al 2002. Considerations on the measurement of chlorides in reinforced concrete by electromagnetic waves, Annual Proceedings of Concrete Engineering, Vol. 24, No. 1, Japan Concrete Institute, pp. 1509-1514, 2002. (in Japanese)

Kyouichi Fujimoto et al 2003. Influence Factors for Measurement of Content of Chloride Ions in Reinforced Concrete Using Electromagnetic Waves, Annual Proceedings of Concrete Engineering, Vol. 25, No. 1, Japan Concrete Institute, pp. 1667-1672, 2003. (in Japanese)

Taketomo Kamiya et al 2003. Experimental Study on Evaluation of Content of Chloride Ions in Reinforced Concrete Using Electromagnetic Waves, Annual Proceedings of Concrete Engineering, Vol. 25, No. 1, Japan Concrete Institute, pp. 1673-1678, 2003. (in Japanese)

Arthur v. H 1954: Dielectric Materials and Applications, Artech House Publishers, 1954.

Osamu Hashimoto 2003, Measurement Method on Material Properties, Morikita Publishers, pp30-44, 2003.