# CALCULATION METHOD FOR CHLORIDE CONCENTRATION IN ACTUAL CONCRETE STRUCTURES LOCATED IN LAND

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## 1. Introduction

Durability of reinforced concrete structures located near to sea shore is mostly governed by chloride concentration around reinforcing steel. Generally, the chloride concentration in concrete is calculated by adopting the analytical solution of Fick 2$^{nd}$ law under steady state in the following equation.

$$C(x,t) = C_0\left[1 - erf\left(x/2\cdot\sqrt{D.t}\right)\right] \qquad \textbf{Eq.1}$$

Following that, JSCE also published the calculation method for chloride concentration in concrete by specifying the chloride concentration at concrete surface according to the distance from sea shore [1]. However, the chloride concentration at concrete surface located in-land is actually not constant and gradually increases due to airborne chloride. Although the analytical solution of Fick 2$^{nd}$ under steady state was modified to depend on time, the incremental amount of chloride concentration was related to the square root of time [2]. Concerning on the mechanism of chloride transportation from sea shore, the new calculation method is proposed by inputting the flux of incoming chloride instead of chloride concentration at concrete surface.

## 2. Calculation Method

The calculation method is one dimensional analysis and based on Fick 2$^{nd}$ law of diffusion in following equation.

$$\frac{dC_{tot}}{dt} = \frac{dF}{dx} \qquad \textbf{Eq.2}$$

where, $C_{tot}$ is the concentration of total chloride [mg/cm$^3$ of concrete], $F$ is the flux of free chloride [mg/cm$^2$.year], $dt$ is the time step in calculation [year], and $dx$ is the element length [cm]. The incoming and outgoing flux of free chloride ions in the concrete matrix was calculated by Fick's law as shown in **Eq.3**. Different from the concrete matrix, the incoming flux of chloride ions at the concrete surface is related to the airborne chloride in this calculation method. Since the relationship between the flux of airborne chloride and incoming flux of chloride ions at concrete surface have not been clarified. Thus, the incoming flux of surface layer is firstly assumed to equal the flux of airborne chloride as shown in **Eq.4**.

$$F_{in}(i,t) = D_{i-1\rightarrow i}\left(\frac{C_{p,free}(i-1,t) - C_{p,free}(i,t)}{dx}\right) \qquad F_{out}(i,t) = D_{i\rightarrow i+1}\left(\frac{C_{p,free}(i,t) - C_{p,free}(i+1,t)}{dx}\right) \qquad \textbf{Eq.3}$$

$$F_{in}(0,t) = C_{airborne}\cdot dt \qquad \textbf{Eq.4}$$

where, $i$ is element number, $F_{in}$ is the incoming flux of free chloride at $i$ [mg/cm$^2$.year], $F_{out}$ is the incoming flux of free chloride at $i$ [mg/cm$^2$.year], $C_{p,free}$ is the concentration of free chloride [mol/cm$^3$ of concrete], $D$ is the diffusion coefficient of chloride in concrete [cm$^2$/year] and $C_{airborne}$ is the flux of airborne chloride [mg/cm$^2$.year].

In concrete only free chloride ions can diffuse into the concrete matrix [3]. Thus, in this calculation the free chloride was determined according to the total chloride [4]. The free chloride in concrete was previously proposed in the unit of percent weight cement; therefore, the amount of water in concrete is necessary to know in order to determine the concentration of free chloride as shown in **Eq.5**. The amount of water in concrete, gels and capillary pores, was determined from micro structures and mass transportation in concrete [5]. Based on the micro structures of concrete, the diffusion coefficient of free chloride ions can be determined [6]. In this calculation the advection mechanisms was not considered in determining diffusion coefficient because the data use in the following section was not subjected to the wetting and drying effect at concrete surface.

$$C_{p,free}(x,t) = \frac{C_{free}(x,t)\cdot W_{cement}}{100}\cdot\frac{1}{M_{Cl}}\cdot\frac{1}{\phi_{cg}S_{cg}} \qquad \textbf{Eq.5}$$

where, $W_{cement}$ is the cement content [mg/cm$^3$], $M_{Cl}$ is the molecular mass of chloride [mg/mol], $\phi_{cg}$ is the porosity of capillary and gel pores [1/cm$^3$], and $S_{cg}$ is the degree of saturation in capillary and gel pores.

## 3. Parameters in Calculation

From the data investigated by Public Work Research Institute [7], the water to cement ratio of specimens were not recorded and have to be conversed from the compressive strength of concrete [8]. Besides that, the amount of paste volume was already given. Incorporating these concrete properties with the temperature and relative humidity around the target structures, the water content insides the gel and capillary pores of concrete can be determined by adopting the micro structures and mass transportation in concrete [5]. Similarly, the diffusion coefficient of free chloride ions in concrete can be determined from the water to cement ratio and amount of paste volume. The incoming flux of chloride at concrete surface was assumed to equal the flux of airborne chloride which was determined from the total chloride content in the concrete specimens.

## 4. Calculation Results

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**Fig.1, Fig.2** and **Fig.3** are the comparsion between the calculation results of chloride concentration distributing in concrete and the investigated data from the real concrete structures. It is noted that the calculation results highly correspond with the investigated data. However, the calculation results are different from the investigated data at the concrete surface only. Since the investigated data did not subject to the wetting and drying, it is possible that the carbonation reduced the amount of fixed chloride near to concrete surface.

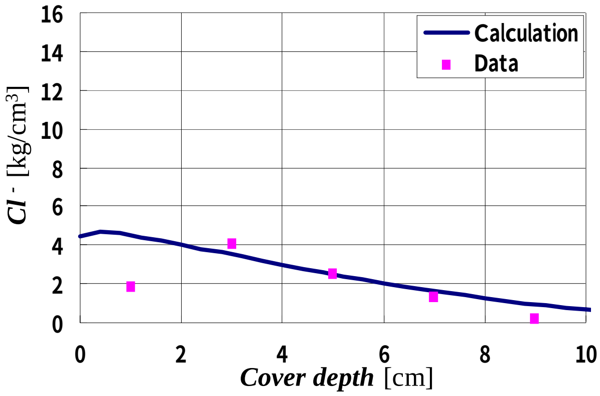


**Fig.1** Distribution of chloride concentration in specimen B1013.

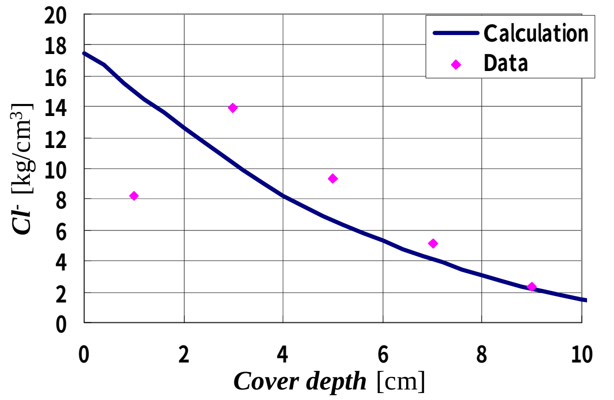


**Fig.2** Distribution of chloride concentration in specimen G3003.

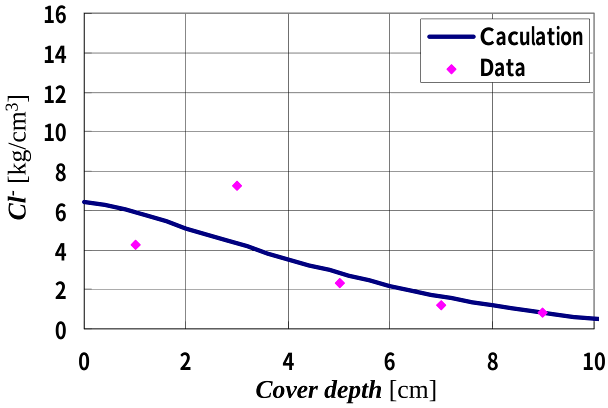


**Fig.3** Distribution of chloride concentration in specimen K3003.

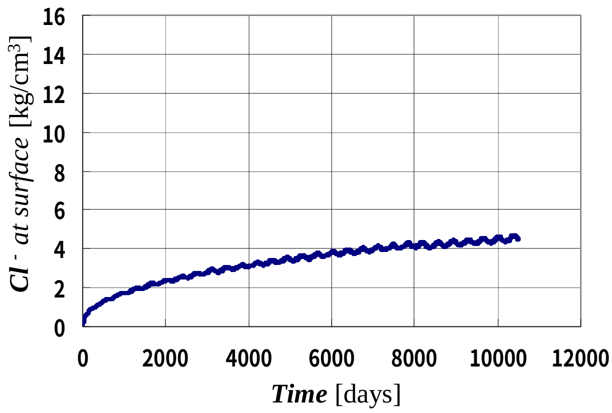


**Fig.4** Chloride concentration at surface element of B1013.

With this calculation method, it is noted that the chloride concentration at the surface element nonlinearly increased by time as shown in **Fig.4**. This is because at the surface element the first coming chloride, which did not diffuse into matrix element, was accumulated with the next coming chloride. Then, the different between the chloride concentration at surface element and matrix element became larger by time. Consequently, the nonlinearity increasing of chloride concentration at surface element was due to the increasing of the outgoing flux from surface element into matrix element.

## 5. Conclusion

The distribution of chloride concentration in the concrete located in-land was calculated by inputting the flux of chloride ions at concrete surface instead of the chloride concentration. The calculation was verified with the distribution of chloride concentration from the investigated data. Then, it was found that the calculation results agreed with the investigated data. Additionally, the chloride concentration at concrete surface, denoted by $C_0$, does not increase linearly though the accumulative chloride content in concrete increases linearly by time.

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