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Evaluation and Prediction Method on Neutralization of Supplied Long-term Hydraulic Concrete Structure

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ABSTRACT: Velocity of neutralization is occupied by three factors; W/C ratio in mixture proportion, type of cement and supplied environmental condition. Hydraulic concrete structures are objective in this study. Influences of supplement condition to neutralization characteristics were evaluated. As a result, coefficient of neutralization velocity of concrete exposed to air is larger than that of concrete exposed to water. However, as for hydraulic concrete structure, mortar is disappeared and coarse aggregate is exposed from concrete surface in water during long-term supplement. It means that coefficient of neutralization velocity of concrete in water could be an apparent coefficient and actual coefficient was almost same with that of concrete in air. On the other hand, coefficient of neutralization velocity of concrete canal was smaller than that of general engineering structures. Furthermore, neutralization depth and velocity of concrete canal was different even in same member. Therefore, it seems reasonable to conclude that evaluation of neutralization should be careful when concrete in water is measured.

Keywords: Neutralization, Phenolphthalein Method, Neutralization Depth, Prediction Method, Coefficient of Neutralization Velocity

1. INTRODUCTION

Neutralization of concrete generates at anywhere where carbon dioxide gas is supplied. This deterioration, commonly progresses from surface to inner part of concrete, gives serious damage to reinforced concrete. Investigation and diagnosis are necessary to carry out from the viewpoint on restriction of reinforcement corrosion in concrete.

Neutralization depth is the general expression for the evaluation of this deterioration. This depth is indicated with following Eq. (1);

$$y = at^{b} \tag{1}$$

where y is neutralization depth (mm), t is time (year), a and b are the constants; especially a is called as coefficient of neutralization velocity. In general, a constant b is stipulated as 0.5, which was confirmed from many previous studies.

Thus, the progress estimation of neutralization will also be achieved if there were plural measured data concerned to neutralization depth and supplied year [1].

On the other hand, following Eq. (2) is described for the estimation of neutralization depth when there were no measured data;

$$y = \left(-3.57 + 9.0W/B\right)\sqrt{t} \tag{2}$$

where W/B is the effective ratio of water per binder, W is the unit weight of water and B is the unit weight of effective binder [1]. However, it is difficult to identify W/B because the drawings and specifications of most existing old structures have disappeared during their long-term supplement. Moreover, progress velocity of neutralization is commonly occupied by two main factors; W/C ratio in mixture proportion of concrete (penetration velocity of carbon dioxide gas) and supplied environmental condition of concrete structures. It means that Eq. (2) is not always available for the prediction of neutralization if neither inspection data nor drawing and specifications were remained. Furthermore, Kawanishi et al. have reported that constant a was changed under some distinctive environmental conditions [2]. As the mix, proportion of hardened concrete is impossible to estimate accurately, it is necessary to clarify the influence of supplemental environment to neutralization of concrete in order to improve the precision on evaluation and prediction of neutralization.

Concrete canals for the agricultural use, one of the hydraulic concrete structures, are supplied long period under sever environmental condition. At the same time, concrete canals have one characteristic supplied environmental condition. The supplied condition of concrete canal is divided into two parts; the part that sunk into the water (call "water part") and the part exposed to the open air (call "air part") for comparatively long period. On the whole, it is considered that transfer velocity of carbon dioxide gas of concrete exposed to liquid phase is quite slower than that of concrete exposed to gaseous phase, and the progress of neutralization is possible to disregard. However, in case of concrete canal, water contacted to concrete surface is continually moving, there is a possibility that various ionic compounds become easy to dissolve and transfer due to water flow. Furthermore, exposure of coarse aggregate, one of the distinguishing trait deterioration of concrete canal, also can affect to the neutralization of concrete.

This research aimed to clarify the influence of different environmental conditions to the neutralization depth of concrete experimentally. Objective structures were actual concrete canals for the agricultural use that were supplied for long terms. To be specific, the surfaces in water and in air of concrete canal were shaved by the rock drill. Phenolphthalein method was applied and measured the neutralization depth. Relationship between supplied year and neutralization depth, as well as the influence of different supplied conditions, in air and in water, to the progress of neutralization, were investigated in this study. Finally, applicable prediction method for the evaluation of neutralization against concrete canal was examined.

2. RESEARCH SIGNIFICANCE

Neutralization of normal civil engineering structure has been studied and their tendency about this deterioration has clarified sufficiently. In spite, huge number of hydraulic concrete structures has been constructing in this world, their specific supplied condition and effect against neutralization has not focused enough yet. Hydraulic concrete structures are considered to face the multiple deterioration; not only the neutralization but also the abrasion. It will be necessary to evaluate both deterioration for accurate evaluation and prediction of them. The authors believe that this study will work for the review on the effect of supplied environment to the neutralization of concrete.

3. EXPERIMENTAL PROCEDURE

The subject of this study is accumulating the neutralization data of hydraulic concrete structures in order to grasp the tendency and clarify the influence on supplied environment to the neutralization. An object of this study was the large concrete open channel supplied for long periods. Especially a side wall of concrete canal was focused member for the investigation because the side wall has both water part and air part in same member.

3.1 Objective Concrete Canals

Open canal network focused in this study was located in the center of Kochi prefecture, Japan. This canal network was developed from 1968 to 1985 consecutively under prefectural management for improving the water utilization of paddy field. In Japan, even though these projects had public infrastructural aspect, but the part of construction cost should be paid by the beneficiaries (the beneficiary pays principle). The size of beneficial area was 1,860 hectares paddy fields, and the length of this main canal network was 36kilometers. Designed service life of mainstay concrete open channel for the agricultural use is established for 40 years, and design criteria strength of concrete was estimated to 21MPa (approximately 200kgf/cm^2). Supplied periods of investigated concrete canal were between 23 to 39 years. Moreover, additional two concrete canals supplied longer periods, 42 and 47 years, were examined in order to analysis the relationship between service periods and neutralization depth in detail.

3.2 Field Investigation Method

Concrete surface was shaved as one of the partial destructive method for the diagnosis of concrete. Phenolphthalein method was applied against these shaved phases of concrete. 1.0% concentration of phenolphthalein ethanol solution was used in this study. Measurement procedure was described as follows; this solution was sprayed after opening at least 50mm depth of hole at the side wall of concrete canal and blowing off the fine powders of concrete completely. Waiting for a couple minutes, then, measured the depth of discoloration boundary from the surface. Phenolphthalein ethanol solution is one of a coloring reagent and applies for the evaluation of neutralization depth of concrete as this solution change the color from clear into deep red-violet when the concrete has enough alkalinity. In general, discoloration generates when the potential of hydrogen (pH) of concrete is higher 8.2 to 10. Authors have also confirmed the discoloration boundary of this solution and clarified the threshold value on potential of hydrogen was 10 experimentally [3]. The state of discolored condition by the phenolphthalein solution is shown in Fig.1, and an overview on evaluation of neutralization depth is shown in Fig.2. The neutralization depth, distance from surface of concrete to discoloration boundary is measured using depth gage. Three holes were drilled at air part and water part in each one member, and calculated the average depth.

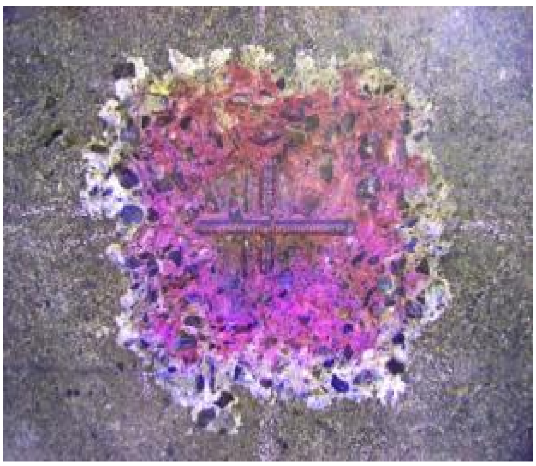

Fig.1 State of Discolored Condition by Phenolphthalein Solution

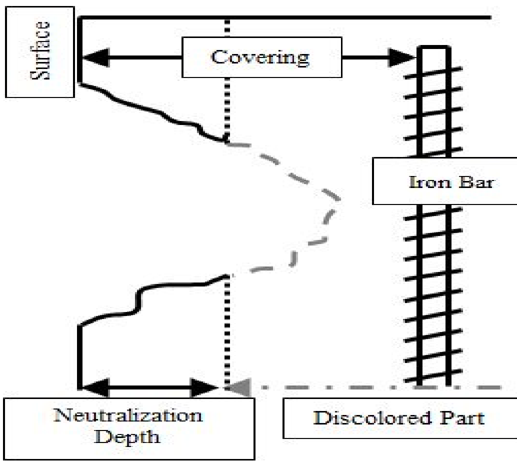

Fig.2 An Overview on Evaluation of Neutralization Depth

4. RESULTS AND DISCUSSION

4.1 Neutralization Depth and Supplied Periods

Relationship between neutralization depth and supplied periods are shown in Fig.3. As a whole, neutralization depths are less than 30mm in spite of their different service periods.

In addition, we cannot see the correlation between them. Basically the neutralization depth would be larger as the supplied periods were longer. It is considered that the progress velocity of neutralization had a great influence to the neutralization depth. Say in other words, it is necessary to pay attention not only to the service periods but also to the coefficient of neutralization velocity (call CNV here after) for the evaluation of neutralization.

Comparing the neutralization depth of air part and water part, we can confirm big difference between them. There is a tendency that the neutralization depth of water part is smaller than that of air part. Phenomenologically, it would be resulted that external factors such as the difference on concentration of carbon dioxide gas and humidity affect to the neutralization velocity. However, coarse aggregates were exposed at most of all water part on the side-wall of concrete canal shown in Fig.4, and this phenomenon is omnipresent as the deterioration of hydraulic concrete structures. Neutralization depth of water part should be evaluated if the equivalence of evaluation with that of air part was necessary to secure. Therefore, it is revealed that measured neutralization depth could not be the enough data for the accurate evaluation of hydraulic concrete structures if the coarse aggregates were exposed on their surface.

4.2 Substantial Neutralization Depth of Hydraulic Concrete Structures

Described as foregoing paragraph, neutralization depth of water part has possibility that its evaluation result was the apparent neutralization depth. According to author's previous study concerning to the explosion of coarse aggregate, this phenomenon would be actualized when 6mm thickness of mortar was disappeared from the surface of concrete despite of water cement ratio [4]. It was considered that at least 6mm thickness of mortar has already abraded if the coarse aggregate were exposed at the side wall of concrete canal. Relationship between estimated neutralization depth taking into account the 6mm thickness of disappeared mortar and supplied periods are shown in Fig.5. Without this consideration, 96% of neutralization depth of air part was higher than that of water part. However, thus, in addition to this consideration, only 48% of neutralization depth of water part could show the same result. As a result, the assumption concern to the general theory that the neutralization velocity of water part is smaller than that of air part cannot be comprised all the time against hydraulic concrete structures. Significant abrasion of concrete canal is observed frequently at the draft level; the highest frequency water level. Therefore, evaluation of neutralization at this water level will be also more important for securing the accuracy on this deterioration.

4.3 Comparison on Coefficient of Neutralization

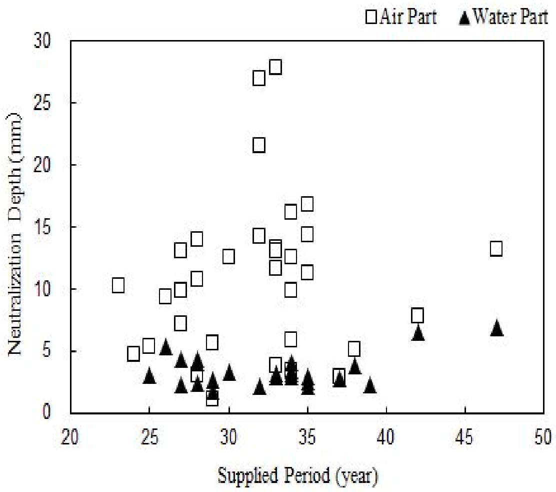

Fig.3 Relationship between Neutralization Depth and Supplied Periods

Fig.4 An Overview of Abraded Surface of Concrete Canal

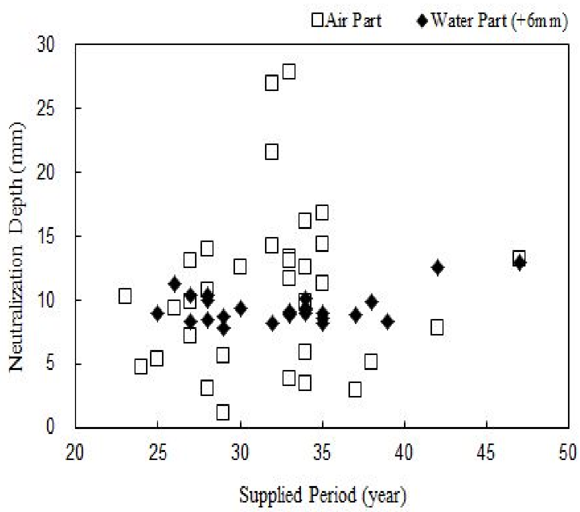

Fig.5 Relationship between Neutralization Depth Considering 6mm Thickness of Disappeared Mortar and Supplied Periods

Velocity (CNV)

A fundamental equation on the neutralization depth was shown as Eq. (1). Now CNV was calculated on assumption that the neutralization advances in proportion to a square root of time. In short, CNV was calculated from the measured data and supplied years. A histogram of CNV was shown in Fig.6, and their average and standard deviation were shown in Table I. Around 55% of CNV of air part was less than 2.0 in the whole. However, around 90% of CNV of water part was less than 1.0. In addition, if considering the disappeared mortar thickness in water part was 6mm as an assumption, around 95% of CNV in water part was less than 2.0. Previous study has reported that the highest frequency range on CNV of general civil structures (nominal strength: 16 to 21MPa) were 0.0 to less than 2.0. All the results from air part, water part, and water part of additional condition, showed the same tendency with the past study [5]. In the same literature, percentages of CNV under the range distribution of $0 < CNV < 2$, $2 < CNV < 4$, $4 < CNV < 6$ were around 50%, 35% and 15%, respectively. Comparing the same range distribution between it and our results, CNV of air part of concrete canal was approximately same or smaller than the result of civil engineering structures; $0 < CNV < 2$, $2 < CNV < 4$, $4 < CNV < 6$ were around 55%, 40% and 5%, respectively.

As for the average and standard deviation results of CNV shown in Table I, average on CNV of air part was three times larger than that of water part. As well, the standard deviation on CNV of air part was five times larger than that of water part. In particular, the difference of standard deviation between air part and water part was generated from the supplied environmental conditions. It was considered to be the difference of humidity; the air part was faced to various conditions of dryness and moisture due to the rainfall and solar radiation, on the contrary, water part was more stable condition rather than air part. These environmental conditions affected to the difference of standard deviation of them.

4.4 Prediction of Neutralization Considering the Disappeared Mortar

It was considered that the mechanism on progress of neutralization was different between air part and water part of concrete canal. To be more precise, neutralization at the air part of hydraulic concrete structures advanced with the same way with general civil engineering structures, however, at the water part, the exposure of coarse aggregate due to abrasion is going on at the same time with the progress of neutralization. Therefore, it would be impossible to express the equation for prediction of neutralization such as Eq. (1) when the partial loss of surface is going on such as water part of hydraulic concrete structures.

For example, as for the predictive equation against sulfate acid attack, one kind of serious deterioration of concrete, different equations are applied due to their deteriorative conditions; while the original shape of structure is keeping or not. In specific terms, deterioration velocity increased in proportion to the square root of time if the shape of original structure was remaining as it was. On the contrary, deterioration velocity increased in proportion to the time if the shape was partially loss [6]. Then predictive equation was assumed to follow to the latter theory, and expressed the equation for the water part could be as follows:

$$y = at \tag{3}$$

Average and standard deviation of CNV were calculated with this Eq. (3) and gained 0.29 and 0.05, respectively. Comparing this result with the result from Eq. (1), CNV was extremely small. In other words, progress velocity of neutralization in water part should be smaller than the air part because the mortar area is becoming smaller due to the exposure of coarse aggregate, and as a result, penetration amount of carbonate ion into mortar was decreased relatively.

On the other hand, neutralization depth drawn in Fig.3, the approximation line should be sloped from right to left. However, the neutralization depths were constant nevertheless the progressing of time. It was considered that the reason was the assumed thickness of disappeared mortar; constant 6mm thickness of mortar. It meant that the exposure of coarse aggregate was actualized when the 6mm thickness of mortar was disappeared, but it would be difficult to evaluate the actual disappearance accurately at the presence in case if more than 6mm thickness of mortar had lost. Thus, it will be possible to evaluate the actual neutralization depth if the actual disappearance thickness of mortar could be obtained in detail in the future.

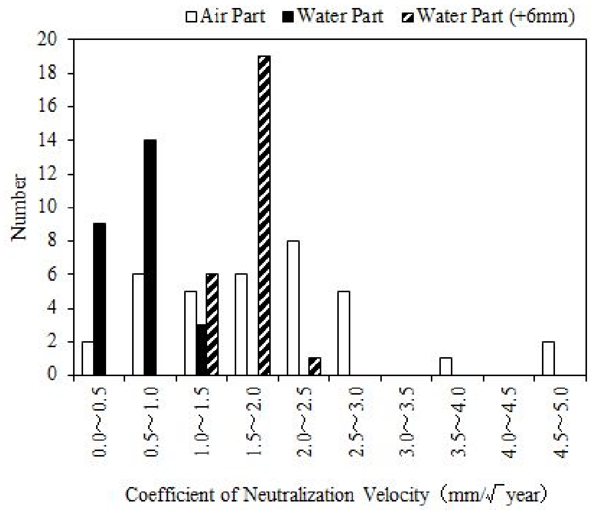

Fig.6 Histogram on Coefficient of Neutralization Velocity of Hydraulic Concrete Structures

Table I Average and Standard Deviation of Coefficient of Neutralization Velocity

	Average (mm)	Standard deviation (mm)
Air part	1.92	1.08
Water part	0.60	0.20
Water part (+6mm)	1.65	0.21

5 CONCLUSIONS

Based on the results of this experimental investigation concerns to neutralization of actual hydraulic concrete structures, the following conclusions are drawn:

1) Comparing the air part and water part of neutralization depth and coefficient of neutralization velocity, both values of water part were smaller than those of air part. Moreover, standard deviation also showed the same tendency with above result.
2) Those differences between air part and water part were not confirmed when considering the estimated thickness 6mm of disappeared mortar.
3) Coefficient of neutralization velocity of hydraulic concrete structures was smaller than that of general civil engineering structures even though the nominal strength was equivalent each other.

6 FURTHER RESEARCH

It has not clarified the exact progressive process of neutralization in water part. For establishing the progressive prediction method, further studies concerns to the deterioration mechanism on water part of concrete should be examined, including the relationship between neutralization and abrasion of hydraulic concrete structures.

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