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Methodology of the Secondary Integrity Evaluation of Deteriorated Concrete Structures and the Study on its Application for Nuclear Power Plants

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Abstracts

The secondary evaluation of concrete structures is applied for the assessment of durability and integrity of the aged members or structures. In order to implement the secondary evaluation, it is required to study reasons or factors of deteriorations of the aged concrete, and to create effective model or diagram explaining these relations.

The previous research[1] conducted by Takesue and Kitsutaka proposed PDFt diagram which consists of 4 quadrants, time, deterioration factor, material deterioration, and performance of structure. In this diagram, relationship between 2 variables on each quadrant is obtained by extrapolation to the prediction formula, and the secondary integrity of reinforced concrete structures exceeding 30 years old is evaluated.

This paper focuses on neutralization of reinforced concrete, and applies the first and the second quadrant of PDFt diagram for the deterioration analysis. Also, this paper studies applicability of the formula for the existing concrete structures of the Japanese nuclear power plants. Using measurement data of the neutralization depth for various structures at each plant, coefficient of the neutralization prediction formula is obtained by extrapolation, and it is compared with the coefficient of Kishitani formula. The result shows that most of the reinforced concrete structures of the nuclear power plants have not been progressed in neutralization, whilst further data collection are required to study the deterioration in more detail.

Introduction

The secondary evaluation of reinforced concrete structures is necessary to evaluate aged and deteriorated ones which exceed 30 years old. In this evaluation, assessment of durability and integrity of the aged members or structures should be considered, and PDFt diagram with extrapolation is proposed as an effective model to study the relationship between time, deterioration factor, and etc. This paper states the methodology of the secondary evaluation of deteriorated concrete structures by using PDFt diagram, and the study on its application for the existing concrete structures of the nuclear power plants in Japan.

Deterioration Evaluation Diagram

Outline of the integrity evaluation method is shown in Fig.1. $V(t)$, expressing time-related changes in an evaluation value of V, is assumed as $V(t) = \alpha v(t)$, where α is coefficient, t is time, and $v(t)$ is an evaluation formula determined only by t. Evaluation values, V_{obs}, at certain points of time, t_{obs}, are determined by actual measurement and plotted. The coefficient, α, is then determined by extrapolating $v(t)$. When V_{eva} exceeds V_{rg}, the next step should be taken to proceed to the secondary evaluation.

In order to obtain a rational evaluation for concrete structures, the relationships of the deterioration factor and year (*F-t* diagram), the material deterioration and deterioration factor (*D-F* diagram) and the structural performance and material deterioration (*P-D* diagram) should be obtained as shown in Fig. 2.

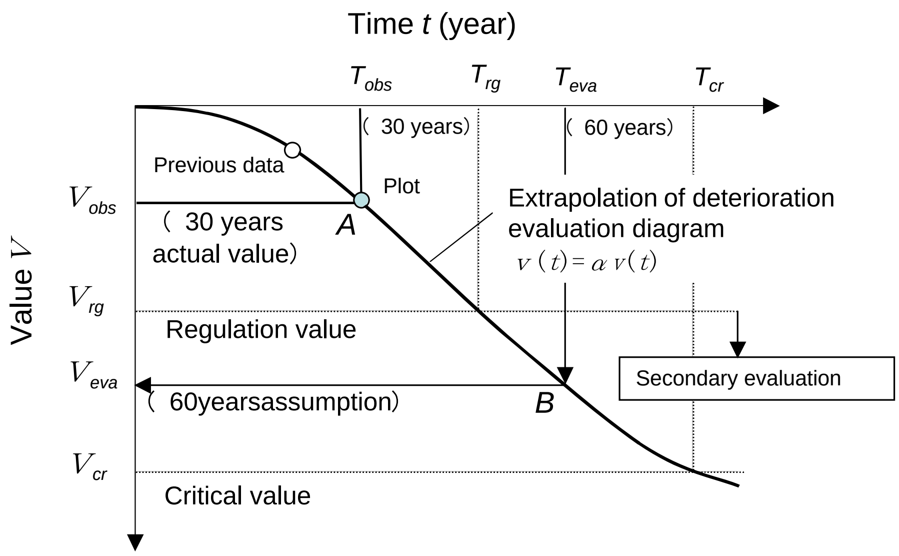


Fig.1: Outline of the integrity evaluation method by extrapolation

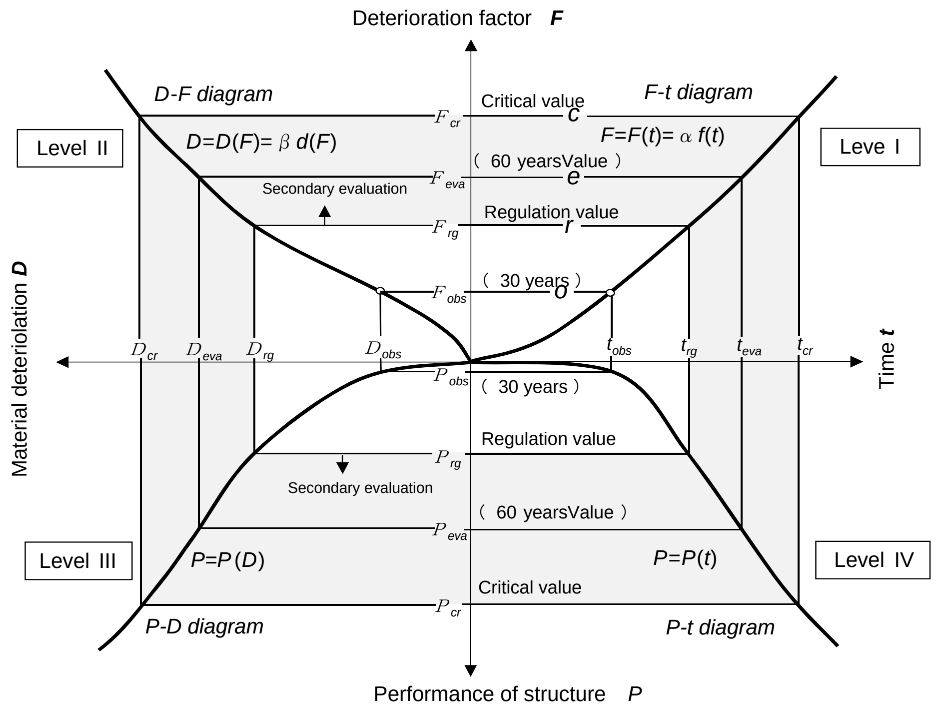


Fig.2: Integrity evaluation diagram of reinforced concrete structures (*PDFt diagram*)

PDFt Diagram for Neutralization

Deterioration mechanism of reinforced concrete caused by neutralization is quite complicated, and is difficult to be presented as a simple formula. Here, the neutralization depth is picked up as deterioration factor. The neutralization depth is formularized by $\sqrt{t}$ rule, and the formula is obtained by using coefficient a, which is determined by materials, construction method, and environmental factors as follows;

$$F = a\sqrt{t}$$

Here, F : Neutralization depth
a : Coefficient of neutralization velocity determined by characteristics of concrete (mixture, materials, construction condition, etc.) and environmental conditions (temperature, humidity, carbon-dioxide density)
t : Year

As for the evaluation of material deterioration, corrosion volume of reinforcement bar is used in accordance with the current technical evaluation manual for aging concrete. Partial loss ratio of re-bar sectional area, D, is used for material deterioration, and the relation formula with neutralization depth is obtained. The experimental result shows that corrosion volume is linear relation with $\sqrt{t}$, and thus, D is derived from the formula as follows;

$$D = b\ \sqrt{(F_1^2 - F_0^2)}$$

Here, D : Partial loss ratio of re-bar sectional area
b : Coefficient determined by environmental conditions (temperature, humidity, oxygen density) and material conditions (reinforced bar, concrete, etc.)

Relation between neutralization depth and corrosion volume of reinforced bar is described in Fig. 3.

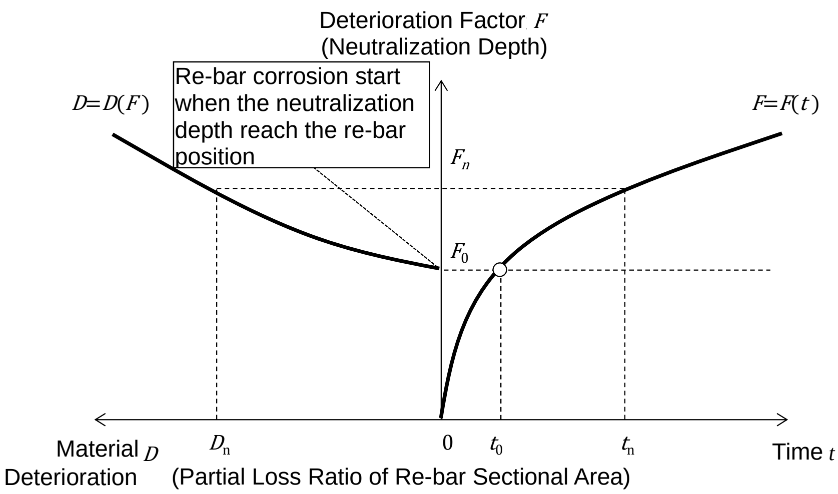


Fig.3: Relation between Material Deterioration and Deterioration Factor (Neutralization)

Application for the Existing Nuclear Power Plants in Japan

Currently, there are 17 nuclear power plants in Japan, most of which are located on the coastal area. Based on the actual measurement data of concrete deterioration for each power plant submitted to the former Nuclear and Industrial Safety Agency, we studied applicability of the neutralization formula. The measurement data for each plant is summarized in Table 1.

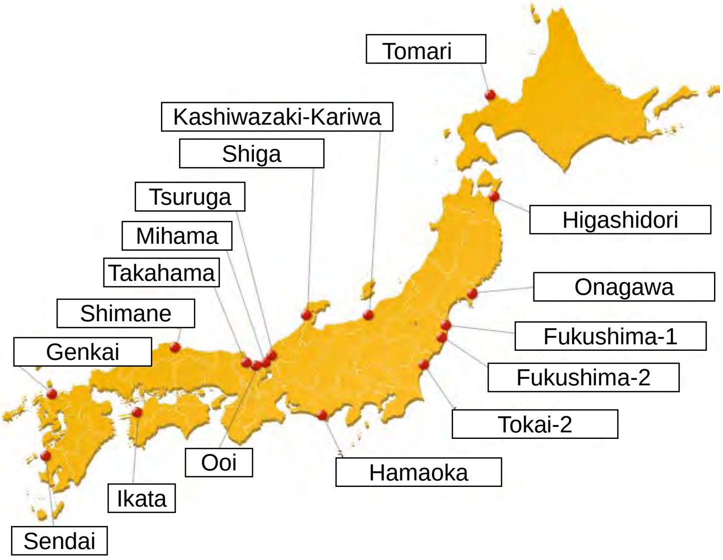


Fig.3: Location of the Japanese Nuclear Power Plants

Table 1: Summary of the measurement data

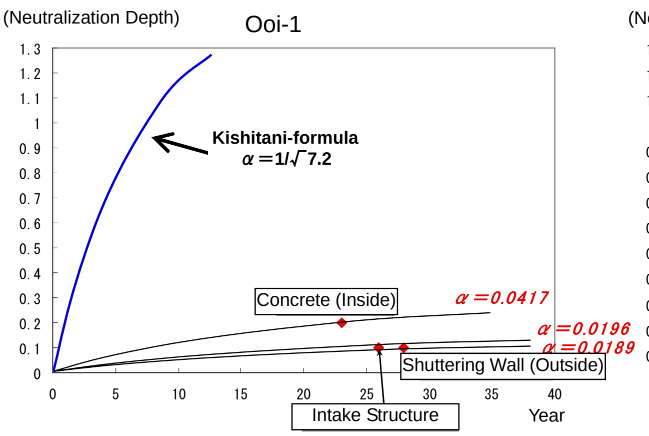
Name	Structures	Location	Neutralization Depth	Duration
Ooi-1	Shuttering Wall	Indoor	0.1	28
	Intake Structure	In the sea	0.1	26
	Intake Structure	Tidal Zone	0.1	26
	Intake Structure	In the air	0.1	26
	Concrete	Indoor	0.2	23
Ooi-2	Shuttering Wall	Indoor	0.1	26
	Intake Structure	In the sea	0.1	26
	Intake Structure	Tidal Zone	0.1	28
	Intake Structure	In the air	0.1	28
	Concrete	Inside	0.2	22
Genkai-1	Shuttering Wall	-	1.2	26
	Shuttering Wall	Inside	1.1	26
	Shuttering Wall	Outside	1.4	26
	Foundation of Nuclear Reactor	-	0.4	24
Genkai-2	Shuttering Wall	Indoor	1.2	24
	Nuclear Reactor Building	Indoor	1.5	24
	Intake Structure	In the sea	0.6	24
	Intake Structure	Tidal Zone	0.6	24
	Intake Structure	In the air	0.6	24
	Turbine Building	-	3.3	24
Shimane-1	Periphery Concrete	Indoor	1	26
	Periphery Concrete	Outdoor	1.3	26
Takahama-1	Shuttering Wall	Inside	0.7	22

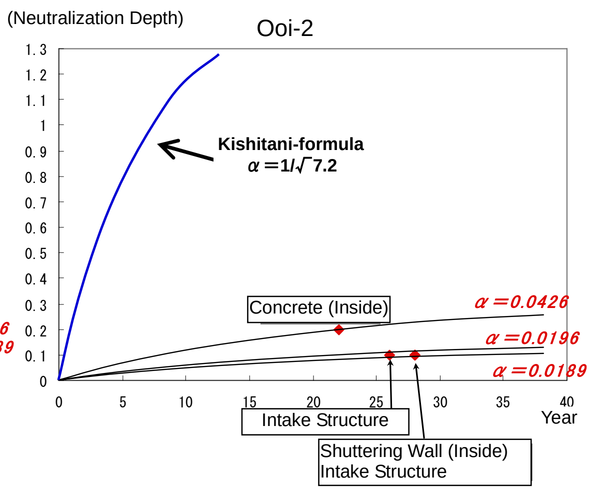
	Shuttering Wall	Outside	0.7	22
	Foundation of Nuclear Reactor	-	0.6	27
Takahama-2	Shuttering Wall	Inside	0.4	19
	Shuttering Wall	Outside	1.1	19
	Foundation of Nuclear Reactor	-	1	27
Hamaoka-1	Periphery Concrete of Nuclear Reactor Building	Indoor	0.53	26
	Periphery Concrete of Nuclear Reactor Building	Outdoor	0.03	26
Hamaoka-2	Turbine Building	Indoor	2.62	26
	Turbine Building	Outdoor	1.19	26
Mihama-1	Shuttering Wall	Inside	1.4	25
	Shuttering Wall	Outside	0.7	25
	Foundation of Nuclear Reactor	-	0.6	25
Mihama-1(40)	Shuttering Wall	Indoor	0.8	38
	Intake Structure	In the sea	0.6	38
	Intake Structure	Tidal Zone	0.6	38
	Intake Structure	In the air	0.6	38
	Concrete	Inside	1	38
Mihama-2	Shuttering Wall	Indoor	0.9	21
	Shuttering Wall	Outdoor	1.5	21
	Foundation of Nuclear Reactor	-	0.1	26
Mihama-3	Shuttering Wall	Outdoor	1.5	24
	Shuttering Wall	Indoor	0.9	24
	Foundation of Nuclear Reactor	Indoor	0.2	27

Relation between neutralization depth and duration is obtained by extrapolation using the measurement data taken at various concrete structures of the Japanese nuclear power plants. Comparing the data with the coefficient of Kishitani-formula, which is the representative formula of predicting neutralization depth, neutralization progress of a few structures is proved to be faster than that of Kishitani-formula; however most of the structures have yet been neutralized. Also, neutralization progress does not relate to the location; outside or inside of the structures, whereas outside was expected to be faster in the neutralization progress due to the severer climate conditions.

<u>Ooi</u>

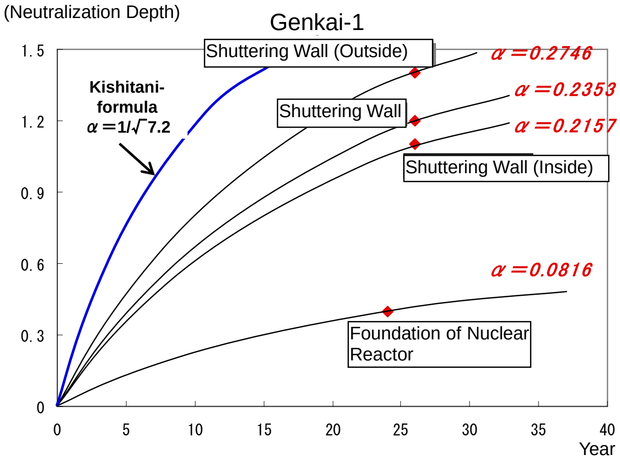
- Neutralization was not found, and the structures are proved to be safe.
- Neutralization progress is not different in inside and outside of structures.

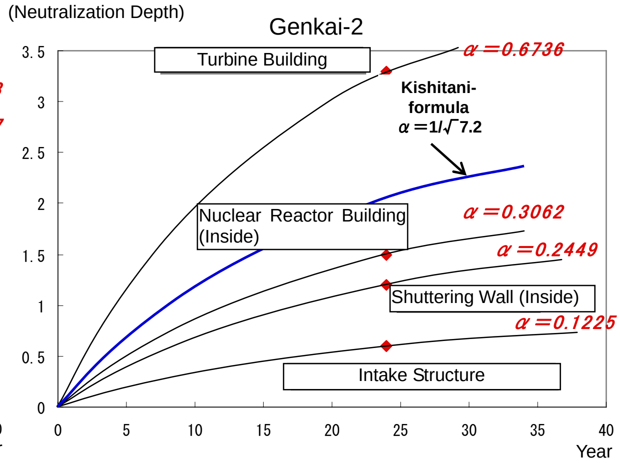




<u>Genkai</u>

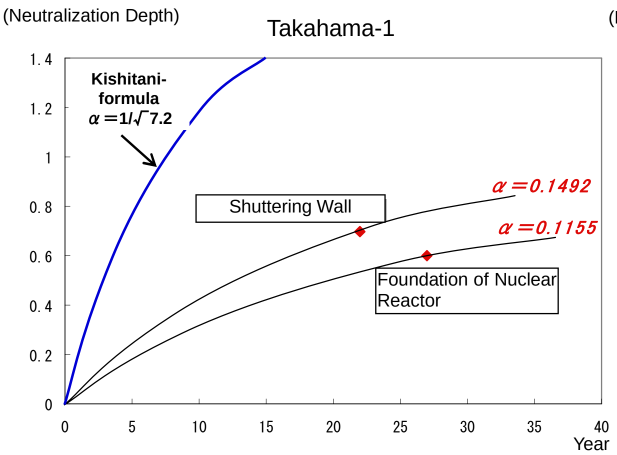
- Neutralization is progressed in some structures, but not yet in dangerous situation.
- Neutralization progress is not different in inside and outside of structures.

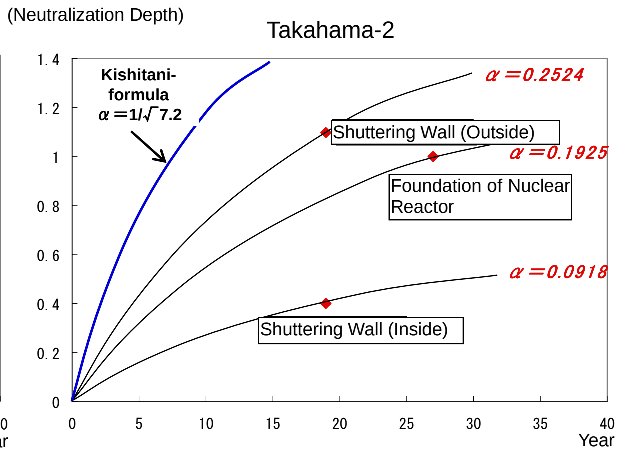




<u>Takahama</u>

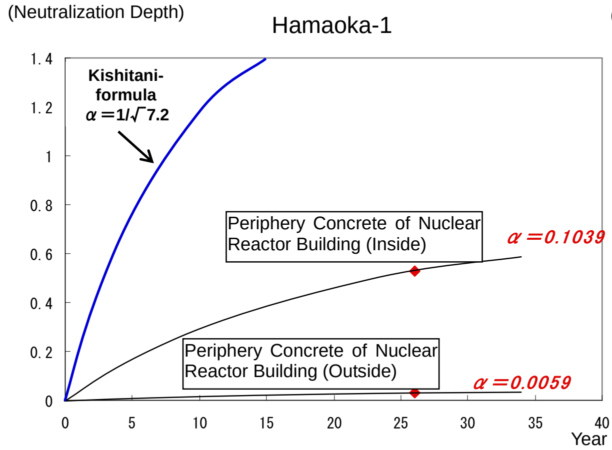
- Neutralization is not so progressed in both structures.
- The progress tends to be faster in outside structures than in inside ones.

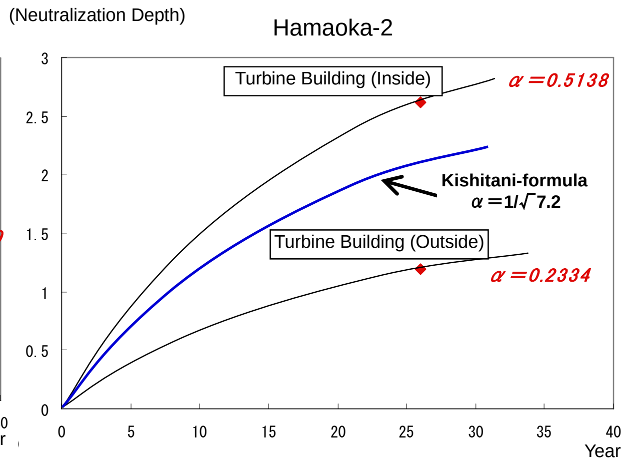




<u>Hamaoka</u>

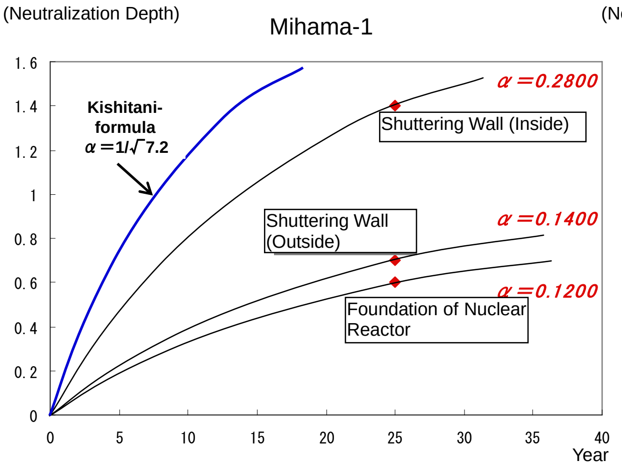
- Neutralization is progressed in some structures, but not yet in dangerous situation.
- The progress tends to be faster in inside structures than in outside ones.

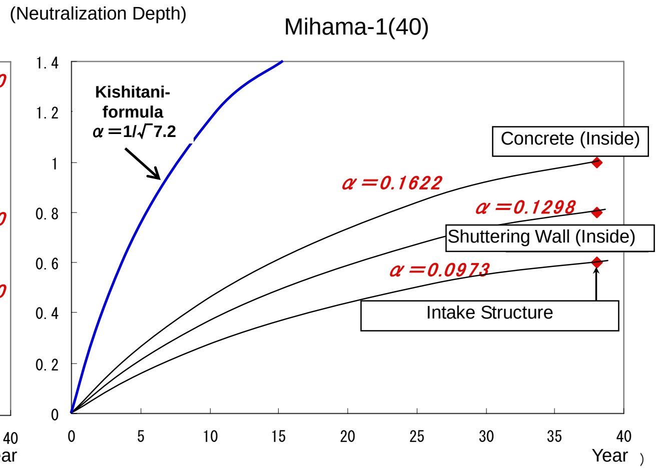


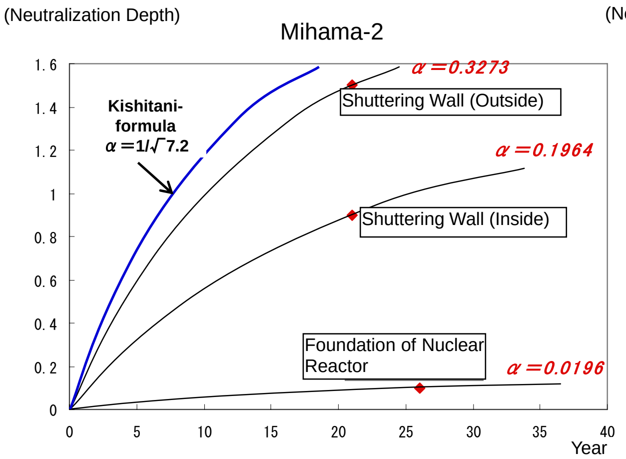


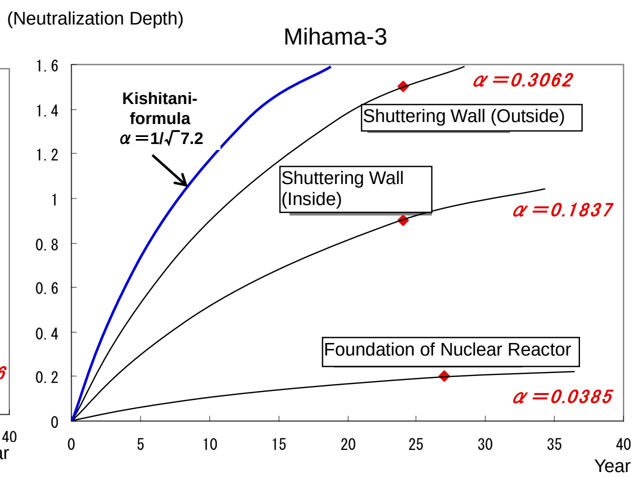
<u>Mihama</u>

- Neutralization is not progressed overall, and is not different in outside and inside.









CONCLUSIONS

Evaluation method by means of “extrapolation” is proposed to evaluate the integrity of deteriorated reinforced concrete structures, and PDFt diagram is proved to be an effective way to formulate relationships among the number of years elapsed, *t*, the amount of action of a deteriorative factor, *F*, the degree of material deterioration, *D*, and the performance of the structure, *P*, for both single and combined factors of deteriorations of concrete structures.

Also, the study was conducted to prove the effectiveness of the methodologies using the actual measurement data of neutralization of the concrete structures in the Japanese nuclear power plants. The evaluation result proved applicability of these methodologies; however, further data collection and more detailed study are required to evaluate the concrete structures, since the study was conducted under limited data and conditions.

References

[1] Takesue, N and Kitsutaka, Y, “Methodology and Framework of the Secondary Integrity Evaluation of Deteriorated Concrete Structures”, Smirt 21, 2011