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A Conception of the Construction of a System to Estimate and Evaluate the Service Life of Reinforced Concrete Structures*

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Abstract

In order to assess the durability of design, maintenance and management of a reinforced concrete structure, it is necessary to estimate and evaluate the service life of that structure. To do this objectively and quickly, a suitable system must be established.

This study investigates the estimation and evaluation flow, structure of the data base and the composition of the system required to be studied.

As for the results of the basic investigation, the following points were noted:

1) To show the estimation and evaluation process of the service life and the progress of deterioration clearly and objectively.

2) It is possible to reduce the number of cases where estimation is impossible by utilizing the data base, making use of artificial intelligence, etc., and by Presuming and recognizing the errors even when some data are lacking regarding the conditions at the time of estimation and evaluation.

3) To achieve accuracy in estimation and to further improve it, accumulation of secular change (progress of deterioration) data and classification of data according to environmental conditions and type of structure is carried out and then applied according to the conditions.

1. Introduction

In order to assess the durability of design, maintenance and management of a reinforced concrete structure, it is necessary to estimate and evaluate the service life of that structure. To do this objectively and quickly, a suitable system must be established.

This study investigates the estimation and evaluation flow, structure of the data base and the composition of the system required to study these basic points. To estimate and evaluate the service life, data on both external and internal factors and an equation for estimating the progress of deterioration are needed. To be more precise, the data on external/internal factors comprise data related to design conditions, etc., and these include environmental conditions and con-

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struction data, such as the target data of concrete and air volume, etc. In addition, there are the inspection data required for the daily maintenance and management of reinforced concrete structures. These items are also subject to investigation.

2. Inspection Method

First of all the investigation items required to evaluate the service life of the structure are summarized. The procedure is then investigated and an overall flow is prepared, as shown in Fig. 1 which represents an investigation flow for the system of estimating and evaluating such structures. The procedure involves investigating and summarizing the secular change data of the structure as well as investigating its standards and specifications.

Based on these results, data analysis, investigation of the grading of deterioration and the evaluation flow, etc., are carried out. After these have been examined, construction of an evaluation system is performed compensating for the results of these investigations. When the system satisfies the required degree of reliability, it is used as the estimation and evaluation system.

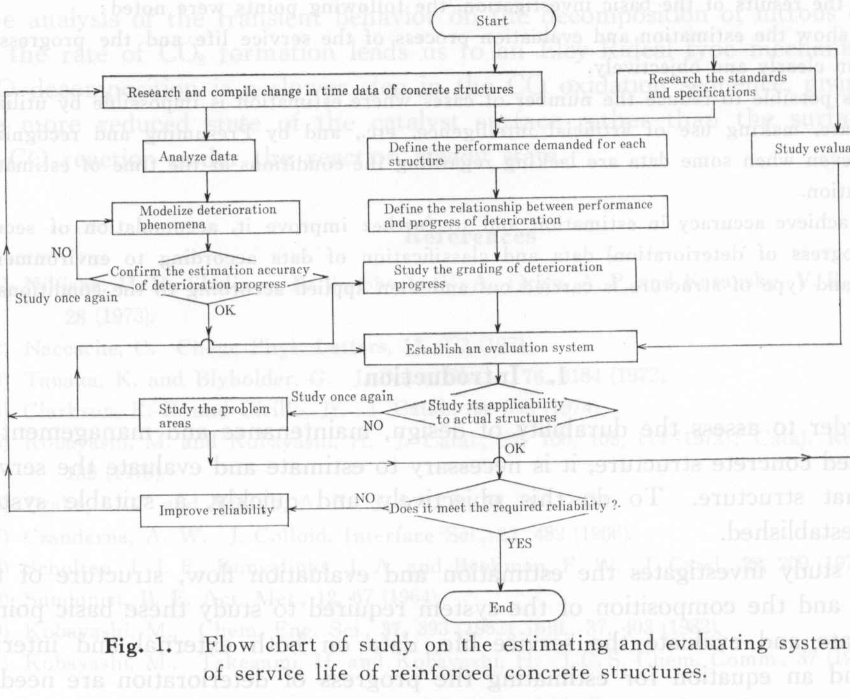

Fig. 1. Flow chart of study on the estimating and evaluating system of service life of reinforced concrete structures.

3. Investigation

3.1 Investigation of the service life of a reinforced concrete structure, estimation and evaluation of the progress of deterioration (soundness) and durability control flow

Fig. 2 shows the service life of a reinforced concrete structure, the estimation and evaluation of the progress of deterioration (soundness), and the durability control flow. The type of newly constructed or existing structure subject to investigation, its required performance, conditions of external causes of deterioration, design value and number of years of evaluation, is inputted. The deterioration index is calculated using an equation that estimates deterioration based on these conditions, and by means of a grading process, the deterioration of each item is evaluated. The decision is then made as to whether these values are within the predetermined allowable limits of deterioration (allowable progress of deterioration) for each item. If such conditions are not satisfied, the design values (in the case of repair and reinforcement for example, that design value) are rest and the judgement is made once again. If the results are within the allowable progress of deterioration, the number of years until the progress of

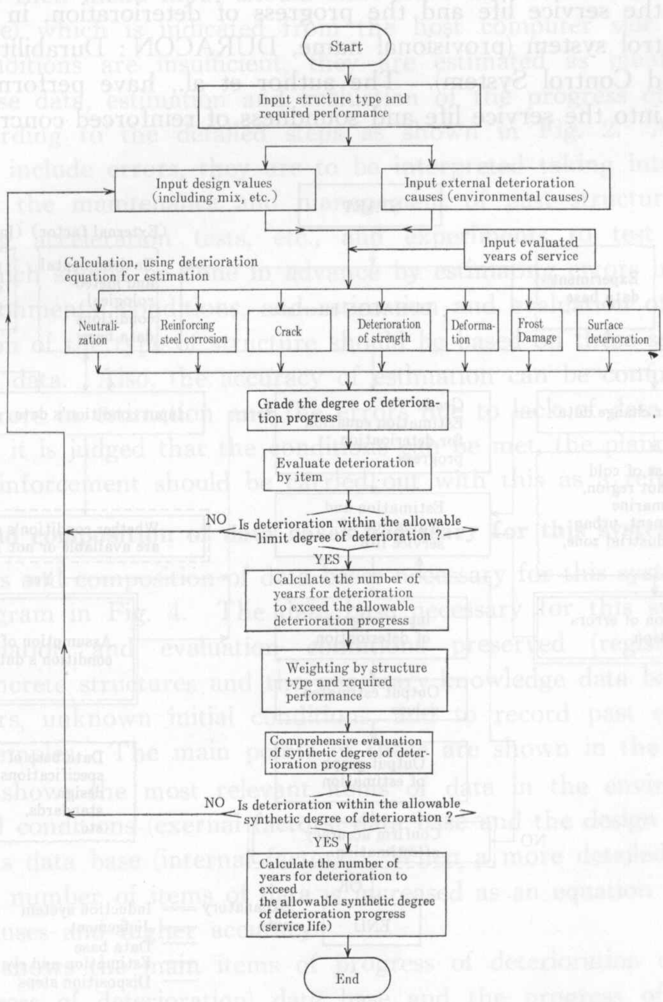

Fig. 2. Flowchart for estimating and evaluating the service life and deterioration progress (soundness) and durability control of reinforced concrete structures.

deterioration exceeds the limit is calculated and an estimate is made. As for the next step, evaluation of the comprehensive progress of deterioration is performed by weighting each item according to its type of structure and required performance. Unless the results are within the allowable comprehensive progress of deterioration (allowable synthetic degree of deterioration), judgement will be made once again after resetting the design values. If the comprehensive progress of deterioration stays within the allowable limits, the number of years (service life) until it exceeds the comprehensive progress of deterioration is calculated.

3.2 The service life of a reinforced concrete with regard to the creation of a system to estimate the progress of deterioration and the durability control system

Fig. 3 shows a conceptual block diagram representing a system to estimate and evaluate the service life and the progress of deterioration, in addition to a durability control system (provisional name, DURACON: Durability of Concrete Evaluation and Control System). The author et al., have performed numerous investigations into the service life and soundness of reinforced concrete structures.

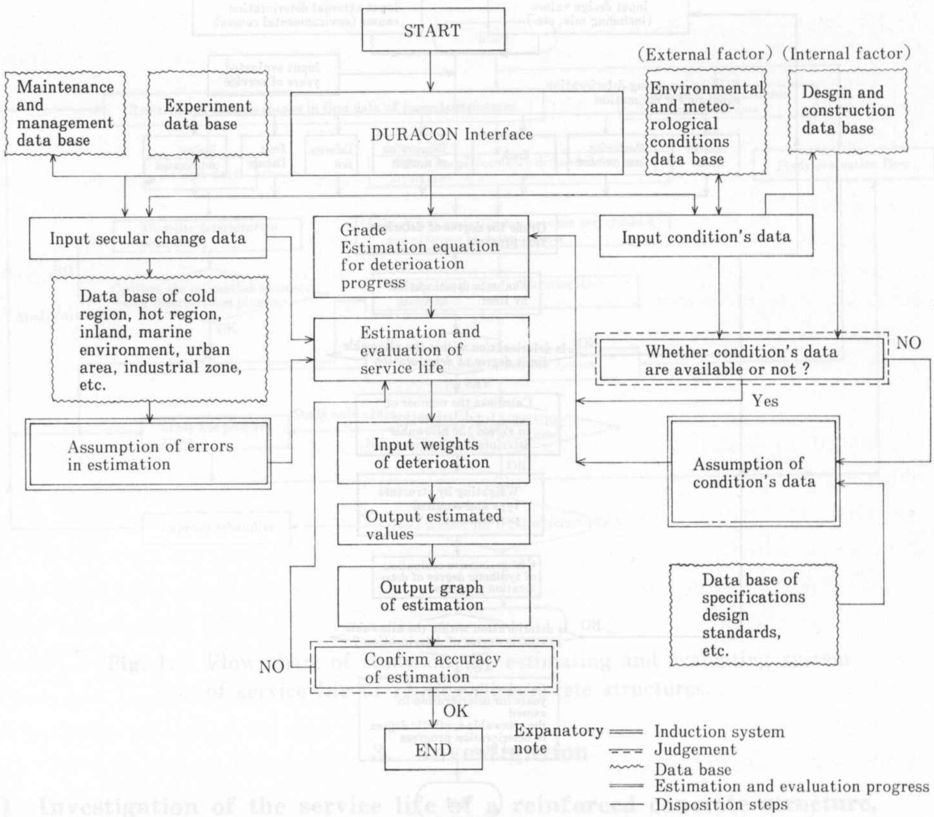

Fig. 3. Conceptual block diagram of estimation of service life and progress of deterioration (soundness) and durability control system.

however in many cases the design and construction data of the actual structures were not available. Therefore, it was considered necessary to develop a system of estimation and evaluation combined with the data base, etc., for estimating design and construction conditions. Furthermore a system whereby estimation of the service life and the progress of deterioration is possible by estimating the initial values from the design and construction data base in cases where data on past specifications, standards, design and construction of the existing structure are unavailable, is also under investigation.

When using the system, first of all, it must be determined whether the objective of the evaluation is to estimate the life and the progress of deterioration for the designated number of years of evaluation of the new or existing structure, or the service life of the repair and reinforcement of the existing structure, and then menu input should start from the interface portion (DURA-CON interface) which is indicated from the host computer side. If the data regarding conditions are insufficient, they are estimated as mentioned before. Based on these data, estimation and evaluation of the progress of deterioration is made according to the detailed steps as shown in Fig. 2. Also, as these estimates will include errors, they are to be interpreted taking into account the data base for the maintenance and management of past structures, laboratory data including acceleration tests, etc., and experiments to test for exposure etc., all of which should be done in advance by estimating errors using the most realistic environmental conditions, and estimation and evaluation of the progress of deterioration of the type of structure should be based on these secular changes (deterioration) data. Also, the accuracy of estimation can be confirmed by combining the errors in estimation and the errors due to lack of data as mentioned before, and if it is judged that the conditions can be met, the planning of design, repair and reinforcement should be carried out with this as a reference.

3.3 Types and composition of data bases necessary for this system

The types and composition of data bases necessary for this system are shown in a tree diagram in Fig. 4. The data base necessary for this system consists of the estimation and evaluation conditions preserved (registered) of the reinforced concrete structures and the necessary knowledge data base in order to estimate errors, unknown initial conditions, and to record past estimation and evaluation examples. The main points of these are shown in the diagram.

Table 1 shows the most relevant items of data in the environmental and meteorological conditions (exernal factors) data base and the design and construction conditions data base (internal factors). When a more detailed estimation is necessary the number of items of data is increased as an equation for estimation with more causes and higher accuracy.

Table 2 shows the main items of progress of deterioration of the secular change (progress of deterioration) data base and the progress of deterioration index which records them. There are differences in items to be inspected and measured depending upon the type of structure, its required performance and

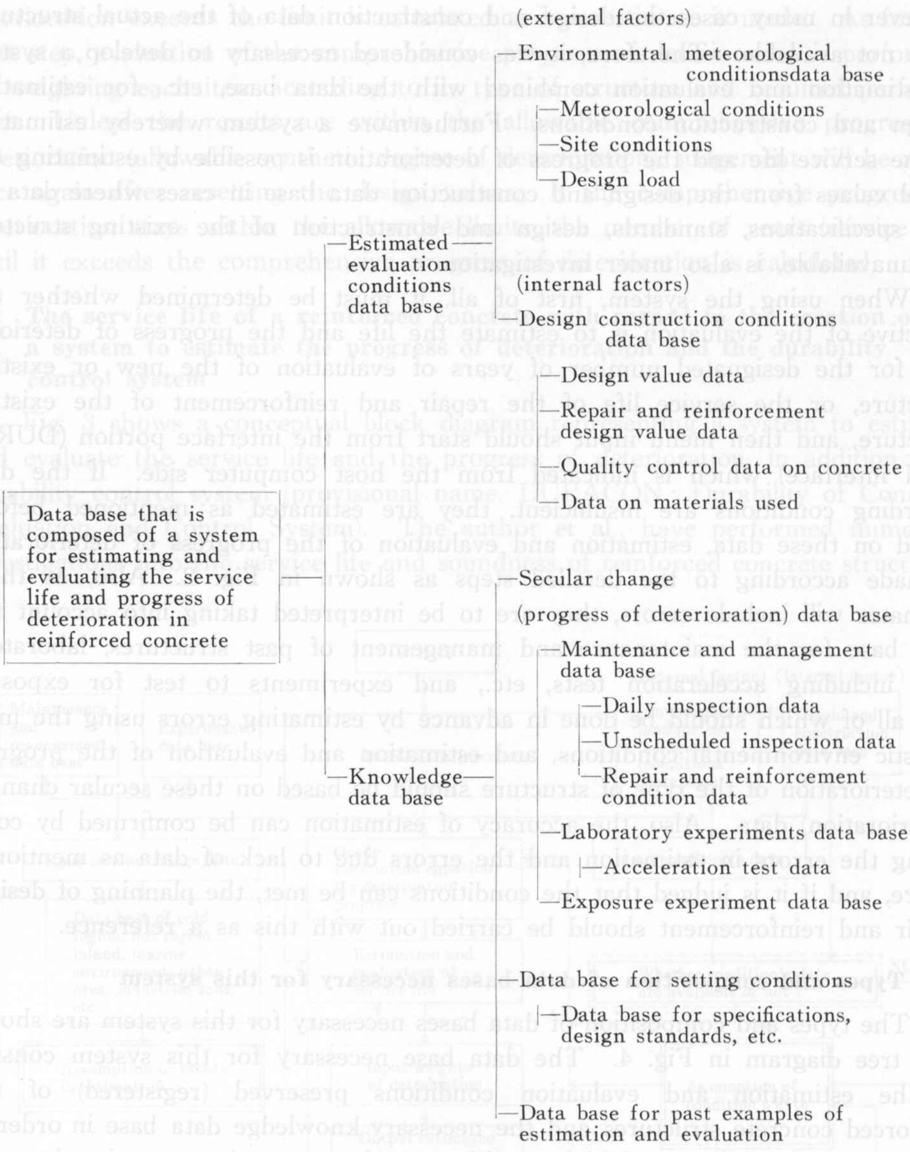

Fig. 4. Tree diagram of types and composition of data bases necessary for this system.

management. There are differences in the deterioration indicator, etc., used for measurement due to the remarkable advancements in measurement equipment in recent years. The investigative method and a program to calculate for conversion and interpolation between the differences in the deterioration indicator becomes necessary. It is necessary for the interface to possess these function.

Table 1. The relevant items of data in the enviromental and meteorological conditions (external factor) data base and the design and construction conditions data base (internal factors)

Factor		Mark: Parameter (unit)	Factor		Mark: Parameter (unit)
External factors	External factor of deterioration	t: Service life (year)	Internal factors	Material	fb: Average bond strength of concrete and steel (kgf/cm^2)
		L: Distance from sea (m)			Ec: Youngs modulus (kgf/cm^2)
		Co: Amount of chloride from sea (Wt %)			ϕ: Coefficient of creep
		Tc: Change of temperature (°C)			W/C: Water cement ratio (%)
		S: Concentration of sulfate of water contacted surface (Wt %)			Uc: Unit weight of cement (kg/m^2)
		M: Cycles of feezethaw per year			Uw: Unit weight of water (kg/m^2)
		W: Coefficient of supplying seawater			R: Type of cement Type of AE agent Type of aggregate
Internal factors	Design	D: Depth of cover (mm)			Ru: Amount of Na_2O in aggregate by cement (%)
		fs: Stress of reinforcing steel (kgf/cm^2)			RG: Content of reactionable aggregate (%)
		α: Stress of concrete (kgf/cm^2)			AE or Non AE: Whether there is AE agent
		β: Note 1			Dc: Diffusivities of concrete (cm^2)
		A: Note 2 (cm)		Construction	α: Coefficient of type of cement and curing condition
		b: Width of the section (m)			K: Ratio of decreasing surface strength
		h: Depth of the member (m)			γ: Index of workability: $\gamma=1$
		NH: Number of steel members	Result of investigation		x: Depth of neutralization (mm)
		ϕ: Diameter of the steel (m)			p: Corrosion surface
	Material	fc: Compressive strength of concrete (kgf/cm^2)			Crack etc.
		fct: Tensile strength of concrete (kgf/cm^2)			

Note (1) β: The ratio of distance from axial of neuturality to center of reintorcing steel to distance from axial of neuturality to tensile side in the case of beam 1.2.

Note (2) A: The area of tensile side concrete to symmetry with a number of reinforcing steel bars.

3.4 Software and equipment for the construction of this estimation and evaluation system

As a primary condition, SAS (Statistical Analysis System) is used in this system as the software for data accumulation and analysis to enable preparation of a data base of investigative data on past reinforced concrete structures and to make available data for the future. To make the estimation and evaluation objective and to enable estimation from change in time data of similar types of

Table 2. The main items of progress of deterioration of the secular change (progress of deterioration) and the progress of deterioration indicator

Quantifying Item	Selected Indicator: Indicator	Selected Indicator: Phenomenon	Quantifying Item	Selected Indicator: Indicator	Selected Indicator: Phenomenon
a. Neutralization	Depth of neutralization x (mm)	① Neutralization	d. Deterioration of strength	Notes 2) Ratio of compressive strength SN (%)	① Deterioration of penetrating sulfate
b. Reinforcing steel corrosion	Ratio of corrosion surface P (%)	① Corrosion of penetrating chloride			② Deterioration of frost damage
		② Corrosion of neutralization			③ Deterioration of alkali-silica reaction aggregate
		③ Corrosion of crack	e. Deformation	Strain ε (%)	① Deformation of creep strain
c. Crack	Maximum witdth of crack (mm)	① Crack of steel stress			② Deformation of dry and temperature
		② Crack of dry and temperature shrinkage	f. Frost damage	Change rate in relative dynamic modulus of elasticity DN (%)	① Frost damage
		③ Crack of alkali-silica reaction	g. Surface deterioration	Average depth of damage H (mm)	① Surface deterioration of frost damage

structure to be taken into account, and the closest environmental condition in the accumulated data, the artificial intelligence system is used. The language used in the artificial intelligence system is the Prolog, which is able to rink easily with the Fortran in the program that calculates the progress of deterioration. Therefore, as the system incorporates these in one unit, a large computer system (HITAC M680 or M682) is used. In addition, to permit the system to accumulate input data and to give it higher accuracy in estimation, both of which are important as users will be applying it in their evaluations of the soundness of reinforced concrete structures, an on-line system is used with personal computer access by means of modem with NTT circuits, thereby permitting users to apply this system wherever they may be.

4. Conclusions

As for the results of the basic investigation into the construction of a system to estimate the service life and evaluate the progress of deterioration of reinforced concrete structures, the importance of the following points was noted :

1) To show the estimation and evaluation process of the service life and the

progress of deterioration clearly and objectively.

2) It is possible to reduce the number of cases where estimation is impossible by utilizing the data base, making use of artificial intelligence, etc., and by presuming and recognizing the errors even when some data are lacking regarding the conditions at the time of estimation and evaluation.

3) To achieve accuracy in estimation and to further improve it, accumulation of secular change (progress of deterioration) data and classification of data according to environmental conditions and type of structure is carried out and then applied according to the conditions.

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Reference

1) H. Sakurai, T. Aoki, K. Momosaki and A. Suzuki: The examination and consideration on analysis of data for estimation of secular change of concrete structure, Annual Lecture Meeting Papers of JCI, pp. 221–224, 1988.

2) H. Sakurai, K. Ayuta, A. Suzuki, K. Momosaki, N. Saeki and Y. Fujta: Analysis and examination on secular change for durability design and estimation of service life of a reinforced concrete structure, "Symposium of predicting the service life of a reinforced concrete structure" pp. 28–30, 1988.

3) H. Sakurai, K. Ayuta, A. Suzuki and N. Okada: Examination on evaluation techniques for evaluating the service life of a concrete structure, JSCE Preceeding of Annual Scientific Lecture 5, pp. 724–726, 1989.