



# Damage Assessment Method of Reinforcement Concrete Building By Fuzzy Theory

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**Abstract.** As reinforcement concrete building is composition material which reinforcement bar and concrete work together, effect factors concerned with its damage are countless much and interrelationship between them is also very complex and indefiniteness. Until now many researches about the damage assessment of a building has been performed but the problem accounting correctly damage of the reinforcement concrete building by connecting several of damage factors has not yet been solved. In research a method accounting damage of reinforcement concrete building in the fuzzy integral way in consideration of fuzzy property existing in the damage assessment system of it has been newly suggested.

**Keywords:** building, damage, fuzzy, reinforcement concrete

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## 1 Introduction

In this thesis [1] [2], according to earlier research for the damage assessment of a reinforcement concrete building, the problem accounting in consideration of complicated damage factors concerned each other generally has not been showed. With only probability in an area in which judgement of people holds in the design of structure and structural part [3], probability in assessment of the strength of construction materials and the statistical analysis and assessment of the load making its fixed quantity is impossible [4]. In this thesis [5] damage assessment has been performed indicating on fuzzy graph the relation between many factors affect to the damage of the structure. Also in this thesis [6] using speech variable of fuzzy set theory in the reliability interpretation of structure research about damage cause of individual factor and assessment method has been performed. Next in this thesis [7] indeterminacy factor has been divided into objective factor and subjective factor, objective factor has been discussed through the probability [8], subjective factor has been suggested methods to deal with fuzzy set theory, each part of parts which borders aren't clear applying theory making fuzzy quantity and a

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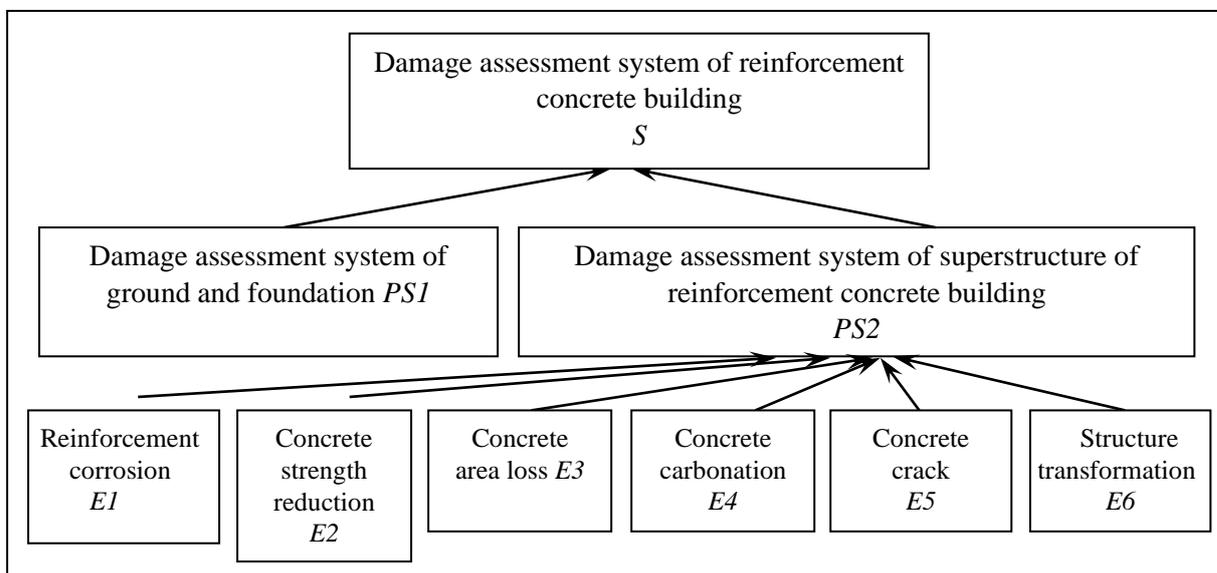
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method to classify it has been pointed out using fuzzy theory. In this thesis [6] [7], as a result of this in research a method to perform a damage assessment of a building according to it from the test result get probability statistically based in survey data of a skyscraper and considering several damage factors generally.

## 2 Measurement and processing for damage assessment of reinforcement concrete building

Damage assessment system of a reinforcement concrete building can be divided into two parts of system that is “damage assessment of ground and foundation and damage assessment of superstructure” [9]. And subelement system of superstructure is dealt as consisting of reinforcement corrosion, concrete strength deterioration, concrete area loss, carbonation, concrete crack, structure transformation etc [10]. Subelement systems determined here could be seen as elements because they are in the lowest level of the mainsystem [11]. It is considered that “damage assessment system of ground and foundation” may be part system and also subelement [12].

As a result of this, system is composed from up to down and result is composed from down to up. “Damage assessment system of a reinforcement concrete building” composed like this has been shown on the following figure 1.



**Figure 1** Composition of damage assessment system of a reinforcement concrete building

### 1) Measurement and conduct result for damage assessment of ground and foundation

Possibility density function of damage degree for settlement of ground and foundation is as follows.

$$P(k_{PS1}) = \frac{1}{0.0051 \cdot \sqrt{2\pi}} \cdot \exp\left[-\frac{(k_{PS1} - 0.0074)^2}{5.15 \times 10^{-5}}\right] \quad (1)$$

That  $K_E$  is 0.0158 in final result about its damage about being measured that settlement of ground and foundation does not exist means that it could be damaged f-or 1.58%, about 1.6% by unconsidered several factors.

Measurement and its disposal result of check points for the damage assessment of superstructure of building

### Damage from reinforcement decay

Relation between check result  $x_{E1}$  and characteristic value  $y_{E1}$  that can be instituted as follows. (It is the standard that the corrosion depth of reinforcement is less 8% than initial reinforcement diameter.)

$$y_{E1} = \begin{cases} 1 - x_{E1} / 0.08d & , x_{E1} \leq 0.08d \\ 0 & , x_{E1} > 0.08d \end{cases} \quad (2)$$

Where  $y_{E1}$  -safety rate for reinforcement corrosion

$d$  -a initial diameter of reinforcement, mm

$x_{E1}$  -a corrosion depth of reinforcement, mm

Otherwise in case of that check result is a left diameter of reinforcement can be instituted as follows.

$$y_{E1} = \begin{cases} 1 - (d - x_{E1}) / 0.08d & , x_{E1} \geq 0.92d \\ 0 & , x_{E1} < 0.92d \end{cases} \quad (3)$$

Where  $x_{E1}$  - the left diameter of reinforcement removing rust layer, mm

Relation of characteristic value  $y_{E1}$  and damage degree  $k_{E1}$  has been instituted as follows seeing this element as very important element.

$$k_{E1} = 1 - y_{E1}^2 \quad (4)$$

Where  $k_{E1}$  - Damage degree for reinforcement corrosion

Determination values about fuzzy parameters ( $\alpha$ ,  $\beta$ ,  $a$ ,  $b$ ,  $g(y)$ ,  $c$ ) have been given in table 1, in result of that normality about possibility distribution of damage degree was inspected in MATLAB is Gaussian distribution and analysis result values have been given in table 2.

Probability density function of damage degree about reinforcement corrosion of beam is as follows.

$$P(k'_{E1}) = \frac{1}{0.0153 \cdot \sqrt{2\pi}} \cdot \exp\left[-\frac{(k'_{E1} - 0.0238)^2}{4.69 \times 10^{-4}}\right] \quad (5)$$

Probability density function of damage degree about reinforcement corrosion of floor is as follows.

$$P(k''_{E1}) = \frac{1}{0.0171 \cdot \sqrt{2\pi}} \cdot \exp\left[-\frac{(k''_{E1} - 0.0286)^2}{5.87 \times 10^{-4}}\right] \quad (6)$$

Probability density function of damage degree about reinforcement corrosion of wall is as follows.

$$P(k'''_{E1}) = \frac{1}{0.0138 \cdot \sqrt{2\pi}} \cdot \exp\left[-\frac{(k'''_{E1} - 0.0207)^2}{3.82 \times 10^{-4}}\right] \quad (7)$$

### Strength reduction of concrete

Relation of characteristic value  $y_{E2}$  and damage degree  $k_{E2}$  has been instituted as follows seeing this element as very important element.

$$k_{E2} = 1 - y_{E2}^2 \quad (8)$$

where  $k_{E2}$  -Damage degree about the strength reduction of concrete

In result of analysis, strength fall of concrete didn't exist in lower part and upper part of building neither through check using law of elasticity nor through check didn't using blanking lead and this ever have distribution type.

### Area loss of concrete

Measurement about area loss factor of concrete element was performed in about 80 places.

Area loss factor of concrete follows to Gaussian distribution with  $N(0.0015, 1.24 \times 10^{-7})$  and its probability density function is

$$P_A(x_{E3}) = \frac{1}{3.52 \times 10^{-4} \cdot \sqrt{2\pi}} \cdot \exp\left[-\frac{(x_{E3} - 0.0015)^2}{2.48 \times 10^{-7}}\right] \quad (9)$$

Probability density function of damage degree about area loss of concrete is as follow.

$$P(k_{E3}) = \frac{1}{0.0053 \cdot \sqrt{2\pi}} \cdot \exp\left[-\frac{(k_{E3} - 0.0078)^2}{5.64 \times 10^{-5}}\right] \quad (10)$$

### Carbonization of concrete

In perimeter wall carbonization depth of concrete follows to Gaussian distribution is  $N(1.2520, 0.1319)$  and its probability density function is

$$P_A(x'_{E4}) = \frac{1}{0.3632 \cdot \sqrt{2\pi}} \cdot \exp\left[-\frac{(x'_{E4} - 1.2520)^2}{0.2639}\right] \quad (11)$$

In other words, in interior wall carbonization depth of concrete follows to Gaussian distribution is  $N(0.3617, 0.0197)$  and its probability density function is

$$P_A(x''_{E4}) = \frac{1}{0.1403 \cdot \sqrt{2\pi}} \cdot \exp\left[-\frac{(x''_{E4} - 0.3671)^2}{0.0394}\right] \quad (12)$$

Relation of check result  $x_{E4}$  and characteristic value  $y_{E4}$  is instituted in the below condition.

Concrete carbonization is regarded as dangerous damage when evidence of corrosion was beginning to appear in main reinforcement when average carbonization depth of concrete is same as or thicker than depth of average protective layer of main reinforcement and it is placed in wet environment or can be affected from aggressive medium [13] [14].

As a result of this, relation of check result and characteristic value can be described as ratio of carbonization depth of concrete and average protective layer of main reinforcement.

$$y_{E4} = \begin{cases} 1 - x_{E4} / a & , x_{E4} \leq a \\ 1 & , x_{E4} > a \end{cases} \quad (13)$$

where  $y_{E4}$  - safety factor about carbonization of concrete

$a$  - Depth of average protective layer of main reinforcement, mm

$x_{E4}$  - carbonization depth of concrete, mm

Relation of characteristic value  $y_{E4}$  and damage degree  $k_{E4}$  has been instituted as follows seeing this element as very important element.

$$k_{E4} = 1 - y_{E4} \quad (14)$$

where  $k_{E4}$  - Damage degree about carbonization of concrete

Determination values about fuzzy parameters ( $\alpha$ ,  $\beta$ ,  $a$ ,  $b$ ,  $g(y)$ ,  $c$ ) have been given in table 1. As a result of inspecting the damage degree possibility distribution about concrete carbonization in exterior and interior wall its distribution is Gaussian distribution analysis results value following to this are shown in table 2.

Probability density function of damage degree about concrete carbonization of perimeter wall is as follows.

$$P(k'_{E4}) = \frac{1}{0.0104 \cdot \sqrt{2\pi}} \cdot \exp\left[-\frac{(k'_{E4} - 0.0188)^2}{2.18 \times 10^{-4}}\right] \quad (15)$$

Probability density function of damage degree about concrete carbonization of interior wall is as follows.

$$P(k''_{E4}) = \frac{1}{0.0077 \cdot \sqrt{2\pi}} \cdot \exp\left[-\frac{(k''_{E4} - 0.0118)^2}{1.19 \times 10^{-4}}\right] \quad (16)$$

### Crack of concrete

Crack width of concrete follows to Gaussian distribution is  $N(0.0690, 1.42 \times 10^{-4})$  and its probability density function is

$$P_A(x_{E5}) = \frac{1}{0.0119 \cdot \sqrt{2\pi}} \cdot \exp\left[-\frac{(x_{E5} - 0.0690)^2}{2.83 \times 10^{-4}}\right] \quad (17)$$

Relation of check result  $x_{E5}$  and characteristic value  $y_{E5}$  instituted that crack width of concrete is 0.4mm~1mm as transient area and was considered that it was on very dangerous stage when it is over 1 mm.

$$y_{E5} = \begin{cases} 1 & , x_{E5} < 0.4 \\ 1 - (x_{E5} - 0.4) / 0.6 & , 0.4 \leq x_{E5} < 1 \\ 0 & , 1 \leq x_{E5} \end{cases} \quad (18)$$

where  $y_{E5}$  - Safety factor for crack of element

$x_{E5}$  - Crack width of element, mm

Relation of characteristic value  $y_{E5}$  and damage degree  $k_{E5}$  has been instituted as follows seeing this element as very important element.

$$k_{E5} = 1 - y_{E5} \quad (19)$$

where  $k_{E5}$  - Damage degree to crack of concrete

As a result of analysis of damage degree to concrete crack performed in base of determination value about fuzzy parameters ( $\alpha$ ,  $\beta$ ,  $a$ ,  $b$ ,  $g(y)$ ,  $c$ ), crack of concrete didn't have any type of distribution.

### Structure deformation

Deflection coefficient of concrete element follows to Gaussian distribution is  $N(9.69 \times 10^{-5}, 2.89 \times 10^{-10})$  and its probability density function is

$$P_A(x_{E6}) = \frac{1}{1.70 \times 10^{-5} \cdot \sqrt{2\pi}} \cdot \exp\left[-\frac{(x_{E6} - 9.69 \times 10^{-5})^2}{5.77 \times 10^{-10}}\right] \quad (20)$$

Relation of check result  $x_{E6}$ , characteristic value  $y_{E6}$  and damage degree  $k_{E6}$  can be instituted as follows being based upon allowable deflection value of concrete element.

$$y_{E6} = \begin{cases} 1 - x_{E6} / (L_0 / c_o) & , x_{E6} \leq L_0 / c_o \\ 0 & , x_{E6} > L_0 / c_o \end{cases} \quad (21)$$

where  $y_{E6}$  — Damage degree to the deflection of element

$x_{E6}$  — Deflection value of concrete element, mm

$L_0$  — Calculated bay length of concrete element, mm

$c_o$  — Constant being changed with type of element

(beam and floor 150, truss 200)

Otherwise using check result of deflection coefficient of concrete element, the relation as follows can be instituted.

$$y_{E6} = \begin{cases} 1 - c_o \cdot x_{E6} & , x_{E6} \leq 1 / c_o \\ 0 & , x_{E6} > 1 / c_o \end{cases} \quad (22)$$

Relation of characteristic value  $y_{E6}$  and damage degree  $k_{E6}$  has been instituted as follows seeing this element as very important element.

$$k_{E6} = 1 - y_{E6} \quad (23)$$

where  $k_{E6}$  - Damage degree to deflection of concrete element

Probability density function of damage degree about deflection of concrete element is as follows (Table 1-2).

$$P(k_{E6}) = \frac{1}{0.0058 \cdot \sqrt{2\pi}} \cdot \exp\left[-\frac{(k_{E6} - 0.0146)^2}{6.69 \times 10^{-5}}\right] \quad (24)$$

**Table 1** Decision of fuzzy parameter of individual test item (member)

Parameter decision factor	Fuzzy relation $R_1$				Fuzzy relation $R_2$			
	$y = f(x)$	$\alpha$	$\beta$	$a$	$b$	$k = f(y)$	$\sigma = g(y)$	$c$
XPS1	$y_{PS1} = 1 - (x_{PS1} / T) / 2$	0.95	0.0	0.01	0.01	$k_{PS1} = 1 - y_{PS1}^2$	$\sigma = c$	0.005
XE1	$y_{E1} = 1 - x_{E1} / 0.08 \cdot d$	0.95	0.0	0.025	0.025	$k_{E1} = 1 - y_{E1}^2$	$\sigma = c$	0.010
XE2	$y_{E2} = 1 - \frac{F + \sigma - x_{E2}}{2\sigma}$	1.0	0.0	0.25	0.25	$k_{E2} = 1 - y_{E2}^2$	$\sigma = c$	0.010
XE3	$y_{E3} = 1 - x_{E3} / (1/3)$	0.95	0.0	0.02	0.03	$k_{E3} = 1 - \sqrt{y_{E3}}$	$\sigma = C \cdot \sin\left(\frac{\pi}{2} \cdot \frac{y}{y_{\max}}\right)$	0.015
XE4	$y_{E4} = 1 - x_{E4} / a$	1.0	0.0	0.03	0.02	$k_{E4} = 1 - y_{E4}$	$\sigma = c$	0.010
XE5	$y_{E5} = \frac{1 - (x_{E5} - 0.4)}{0.6}$	0.95	0.0	0.025	0.025	$k_{E5} = 1 - y_{E5}$	$\sigma = C \cdot \sin\left(\frac{\pi}{2} \cdot \frac{y}{y_{\max}}\right)$	0.010
XE6	$y_{E6} = 1 - c_o \cdot x_{E6}$	0.95	0.0	0.01	0.01	$k_{E6} = 1 - y_{E6}$	$\sigma = c$	0.005

**Table 2** Assessment of damage degree of reinforcement concrete building according to individual test item

Result value Test item	Average value of test result $\bar{X}$	Standard deviation of test result $\sigma$	Distributed form of test result	average value of damage degree $m_K$	Standard deviation of damage degree $\sigma_K$	Distributed form of test result	Final damage degree $K_E$
$X_{PS1}$	0.001	0.0005	$N(0.001, 2.5 \times 10^{-7})$	0.0074	0.0051	$N(0.0074, 2.57 \times 10^{-5})$	0.0158
$X_{E1}$	$X'_{E1}$	0.0098	$N(0.0098, 3.17 \times 10^{-7})$	0.0238	0.0153	$N(0.0238, 2.34 \times 10^{-4})$	0.0490
	$X''_{E1}$	0.0151	$N(0.0151, 1.17 \times 10^{-6})$	0.0286	0.0171	$N(0.0286, 2.93 \times 10^{-4})$	0.0568
	$X'''_{E1}$	0.0075	$N(0.0075, 2.84 \times 10^{-7})$	0.0207	0.0138	$N(0.0207, 1.91 \times 10^{-4})$	0.0434
$X_{E2}$ elasticity method	$X'_{E2}$	42.1841	$N(42.1841, 19.3623)$	0.00	0.00	—	0.00
	$X''_{E2}$	39.7726	$N(39.7726, 16.8200)$	0.00	0.00	—	0.00
$X_{E2}$ sampling	$X'_{E2}$	38.4656	$N(38.4656, 11.7401)$	0.00	0.00	—	0.00
	$X''_{E2}$	36.5192	$N(36.5192, 16.7672)$	0.00	0.00	—	0.00
$X_{E3}$	0.0015	0.000352	$N(0.015, 1.24 \times 10^{-7})$	0.0078	0.0053	$N(0.0078, 2.82 \times 10^{-5})$	0.0165
$X_{E4}$	$X'_{E4}$	1.2520	$N(1.2520, 0.1319)$	0.0188	0.0104	$N(0.0188, 1.09 \times 10^{-4})$	0.0360
	$X''_{E4}$	0.3617	$N(0.3617, 0.0197)$	0.0118	0.0077	$N(0.0118, 5.96 \times 10^{-5})$	0.0245
$X_{E5}$	0.0690	0.0119	$N(0.0690, 0.000142)$	0.00	0.00	—	0.00
$X_{E6}$	$9.69 \times 10^{-5}$	$7.70 \times 10^{-5}$	$N(9.69 \times 10^{-5}, 2.88 \times 10^{-10})$	0.0146	0.0058	$N(0.0146, 3.34 \times 10^{-5})$	0.0241

**3 The assessment method of the damage assessment system of reinforcement concrete building by fuzzy integral**

First subsystem  $PS_2$  must be assessed, and then mainsystem based on it be consider.

Subsystem  $PS_2$  is consists of six members ( $E_i, i = \overline{1, 6}$ ), these members have not only individual damage degree ( $K_{Ei}, i = \overline{1, 6}$ ) but also weight, which is dependent on the importance of effect affecting on subsystem.

The sub of weight of every member is 1, and it should be satisfied next condition expression.

$$\sum_{i=1}^6 M_{Ei} = 1 \tag{25}$$

where  $M_{Ei}$  – Weight of  $i$  th member

Thus it has determined the weight of every member. Then it can be simply assessed subsystem  $PS_2$  as follows.

$$K_{PS_2} = \sum_{i=1}^6 K_{Ei} \cdot M_{Ei} \quad (26)$$

where  $K_{Ei}$  – Damage degree of  $i$  th member

$M_{Ei}$  – Weight of  $i$  th member

$i$  – Indexed number of members

Assessed value, damage degree ( $K_{PS_2}$ ) of subsystem  $PS_2$  is written following expression.

$$K_{PS_2} = \sum_{i=1}^6 K_i \quad (27)$$

where  $K_{PS_2}$  - Damage degree of subsystem  $PS_2$

$K_i$  – Result value of  $i$  th combined item

Considering weight above expression can be written as follows.

$$K_{PS_2} = \sum_{j=1}^6 (K_{Ej} - K_{Ej+1}) \cdot M_j \quad (28)$$

where  $K_{PS_2}$  – Damage degree of subsystem  $PS_2$

$K_{Ej}$  – Damage degree of  $j$  th member,  $K_{E7} = 0$

$M_j$  – Weight of  $j$  th combined item (member), fuzzy measure

$j$  – Indexed number of newly marked member

From the foregoing discussion the overall assessment with considering subsystem  $PS_1$  and  $PS_2$  can be written as following expression.

$$\begin{aligned} K_s &= (K' - K'') \cdot M' + K'' \cdot m(PS_1 + PS_2) \\ &= (K' - K'') \cdot M' + K'' \end{aligned} \quad (25)$$

where  $K_s$  – Damage degree of building with considering some influence factor

$K'$  – Biggest value of damage degree between the two subsystems

$K''$  – Less value of damage degree between the two subsystems

$$K' \geq K'' \quad (26)$$

$M'$  - Weight factor of subsystem with large damage degree

The calculation method as like this is becomes fuzzy integral by fuzzy measure  $m$ .

### - Ranking arrangement of damage degree

In order to assessment of superstructure damage of building, ranking arrangement of damage degree based on table. 1 are to be considered (Table 3-5).

$$K_1 = K_{E1} = 0.0568, K_2 = K_{E4} = 0.0360, K_3 = K_{E6} = 0.0241, K_4 = K_{E3} = 0.0165,$$

$$K_5 = K_6 = K_{E2} = K_{E5} = 0.0000$$

### -Weight coefficient of factor combined with ranking of damage degree

**Table 3** Mark standard

mark	mean
9	One is the most important than other when compare two factor
8	One is very important than other when compare two factor
7	One is clearly important than other when compare two factor
6	One is rather important than other when compare two factor
5	Two factor has same important when compare two factor

**Table 4** Decision table of weight coefficient

Assessment mark \ Compared mark	Corrosion	Strength reduction	Area loss	Carbonation	crack	Deformation	$h_i$	weight $m_i = \frac{h_i}{\sum_{i=1}^6 h_i}$
Reinforcement corrosion	×	8	9	8	8	9	42	0.28
Concrete strength	2	×	6	5	5	6	24	0.16
Concrete area loss	1	4	×	5	4	4	18	0.12
Concrete carbonation	2	5	5	×	5	5	22	0.1467
Concrete crack	2	5	6	5	×	5	23	0.1533
Structure deformation	1	4	6	5	5	×	21	0.14
$\Sigma$							150	1

**Table 5** Frequency distribution of weight ratio with considering corrosion of reinforcement

№ (i)	1	2	3	4	5	$\Sigma$
Interval of grade	0.2267 ~ 0.2603	0.2603 ~ 0.2939	0.2939 ~ 0.3276	0.3276 ~ 0.3612	0.3612 ~ 0.3948	
frequency	7	12	12	6	3	40
Central value	0.2435	0.2771	0.3107	0.3444	0.3780	
$n \cdot P_i$	5.5211	11.2085	12.1169	6.9765	2.1366	37.9597
$\frac{(n_i - n \cdot P_i)^2}{n \cdot P_i}$	0.3962	0.0559	0.0011	0.1367	0.3489	0.9387

The result being performed average value and  $\chi^2$  test of weight of individual element is as follows and follows to Gaussian distribution.

(1) Weight for reinforcement corrosion

$$\bar{x} = 0.2981, \sigma = 0.0412$$

$$q = 5\%, f = 5 - 2 - 1 = 2$$

$$\chi_{0.05, 2}^2 = 5.991$$

$$\chi_{E1}^2 = 0.9387 < \chi_{0.05, 2}^2 = 5.991$$

As a calculated result, it is judged that weight for reinforcement corrosion follows to Gaussian distribution.

(2) Weight for concrete strength reduction

$$\bar{x} = 0.1531, \quad \sigma = 0.0158$$

$$\chi_{E2}^2 = 4.2463 < \chi_{0.05, 2}^2 = 5.991$$

(3) Weight for concrete area loss

$$\bar{x} = 0.1202, \quad \sigma = 0.0155$$

$$\chi_{E3}^2 = 1.2384 < \chi_{0.05, 2}^2 = 5.991$$

(4) Weight for concrete carbonization

$$\bar{x} = 0.1495, \quad \sigma = 0.0134$$

$$\chi_{E4}^2 = 0.7813 < \chi_{0.05, 2}^2 = 5.991$$

(5) Weight for crack of concrete

$$\chi_{E5}^2 = 4.5506 < \chi_{0.05, 2}^2 = 5.991$$

(6) Weight for deformation of structure

$$\bar{x} = 0.1348, \quad \sigma = 0.0134$$

$$\chi_{E6}^2 = 2.7813 < \chi_{0.05, 2}^2 = 5.991$$

Like this weights of elements gained individually should be satisfied expression (25) from the satisfied condition of weight. For this, weights of individual elements are instituted as follows again.

$$m_{E1} = m(E_1) / \sum_{i=1}^6 m(E_i) = 0.2981 / 0.9934 = 0.3001 \approx 0.30$$

$$m_{E2} = m(E_2) / \sum_{i=1}^6 m(E_i) = 0.1531 / 0.9934 = 0.1541 \approx 0.15$$

$$m_{E_3} = m(E_3) / \sum_{i=1}^6 m(E_i) = 0.1202 / 0.9934 = 0.1210 \approx 0.12$$

$$m_{E_4} = m(E_4) / \sum_{i=1}^6 m(E_i) = 0.1495 / 0.9934 = 0.1505 \approx 0.15$$

$$m_{E_5} = m(E_5) / \sum_{i=1}^6 m(E_i) = 0.1377 / 0.9934 = 0.1386 \approx 0.14$$

$$m_{E_6} = m(E_6) / \sum_{i=1}^6 m(E_i) = 0.1348 / 0.9934 = 0.1357 \approx 0.14$$

As a result of this, weight of elements combined with ranking of damage degree can be in the range of following value.

$$\left. \begin{aligned} M_1 &= m(E_1) = 0.30 \\ M_2 &= m(E_1 + E_4) = [0.45, 1] \\ M_3 &= m(E_1 + E_4 + E_6) = [0.59, 1] \\ M_4 &= m(E_1 + E_4 + E_6 + E_3) = [0.71, 1] \\ M_5 &= m(E_1 + E_4 + E_6 + E_3 + E_2) = [0.86, 1] \\ M_6 &= m(E_1 + E_4 + E_6 + E_3 + E_2 + E_5) = 1 \end{aligned} \right\}$$

To determine weights of combined elements with ranking of damage degree  $\chi^2$  test was performed (Table 6-7).

**Table 6** values of weights when reinforcement corrosion and concrete carbonization are considered together

No	1	2	3	4	5	6	7	8	9	10
1	0.60	0.6~0.65	0.6~0.65	0.55	0.60	0.60	0.55	0.55	0.55~0.7	0.70
2	0.60	0.65	0.55~0.6	0.5~0.6	0.55~0.7	0.5~0.6	0.7~0.75	0.65~0.7	0.55	0.6~0.7
3	0.50	0.45	0.55~0.7	0.5~0.55	0.60	0.5~0.7	0.60	0.55~0.7	0.50	0.55
4	0.45~0.6	0.55~0.6	0.65~0.7	0.60	0.6~0.75	0.6~0.65	0.50	0.65~0.7	0.60	0.70

**Table 7** Frequency distribution of weight ratio with considering corrosion of reinforcement and carbonization of concrete

No (i)	1	2	3	4	5	$\Sigma$	
Interval of grade	0.4500 ~ 0.5050	0.5050 ~ 0.5600	0.5600 ~ 0.6150	0.6150 ~ 0.6700	0.6700 ~ 0.7250		
frequency	4	9	11	9	7	40	
Central value	0.4775	0.5325	0.5875	0.6425	0.6975		
$n \cdot P_i$	2.3672	8.1914	13.5394	10.7097	4.0504	38.8581	
$\frac{(n_i - n \cdot P_i)^2}{n \cdot P_i}$	1.1263	0.0798	0.4763	0.2729	2.1479	4.1032	

Next the result being performed average value and  $\chi^2$  test of weight of each combined element is as follows and follows to Gaussian distribution.

(1) Weight for reinforcement corrosion and concrete carbonization

$$\bar{x} = 0.5975, \quad \sigma = 0.0620$$

$$\chi_{M_2}^2 = 4.1032 < \chi_{0.05, 2}^2 = 5.991$$

As a calculated result, it is judged that it follows to Gaussian distribution

As  $\bar{x} = 0.5975$ , when it is half-carried below 3 digit in significant digit average value of weight is that  $m = 0.60$ .

At this moment test value,  $Z$  is get as follows. (Level of  $q = 5\%$ )

$$Z = \frac{\bar{x} - m}{\frac{\sigma}{\sqrt{n}}} \quad (31)$$

Because in case of weight considering reinforcement corrosion and concrete carbonization together, test value,  $Z$  is

$$Z_{M_2} = \left| \frac{0.5975 - 0.60}{\frac{0.0620}{\sqrt{40}}} \right| = 0.2555 < Z_5 = 1.96$$

It is judged that  $M_2 = m(E_1 + E_4) = 0.60$  is significant in the level of  $q = 5\%$ , i.e. combined weight of reinforcement corrosion and concrete carbonization can be seen as follows.

$$M_2 = m(E_1 + E_4) = 0.60$$

In the same way, weights follow to combined elements can be extracted.

- (2) When weight  $M_3$  considering reinforcement corrosion, concrete carbonization and deformation of structure is extracted, it is as follows.

$$M_3 = m(E_1 + E_4 + E_6) = 0.75$$

- (3) Weight considering area loss more than upper 3 elements  $M_4$

$$M_4 = m(E_1 + E_4 + E_6 + E_3) = 0.90$$

$$M_5 = m(E_1 + E_4 + E_6 + E_3 + E_2) = 0.95 (\text{※ addition of weight for hair crack})$$

$$M_6 = m(E_1 + E_4 + E_6 + E_3 + E_2 + E_5) = 1 (\text{※ general weight})$$

-Assessment of subsystem and mainsystem

The value of  $K_{PS2}$  is obtained by using expression (28)

$$K_{PS2} = \sum_{i=1}^6 (K_{E_j} - K_{E_{j+1}}) \cdot M_j = 0.03393$$

It is mean that the damage of the superstructure of building is average 3.4 percent. The damage degree on the base and foundation or superstructure of building is arranged in order as follows.

$$K' = 0.03393 \quad K'' = 0.0158$$

$$M' = 0.4 \quad M'' = 0.6$$

By using expression (29) is obtained general assessment result.

$$K_s = (K' - K'') \cdot M' + K'' = 0.023052$$

From above result general damage degree of analyzed reinforcement tall building is 2.3 percent, generally it is good state.

#### - Analysis result

Example of reinforcement concrete tall building is shown analysis assessment as below. General damage degree of analyzed reinforcement tall building is 2.3 percent, therefore as a whole it safe and good state. The damage degree by corrosion of reinforcement is the tallest than other one. The building is safe as a whole, but need local repair.

#### 4. Conclusion

The research is solved problems as follows in suggesting the application method of system engineering and fuzzy theory. First, determine the attribute function for process the test result and suggest the member assessment method of damage assessment system by fuzzy probability theory. Finally suggest the assessment method of subsystem and mainsystem of damage assessment system and made progress general damage assessment of reinforcement concrete building.

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