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Proposal of Soundness Index for Existing RC Apartment Building for Proper Management Through Visual Monitoring

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Abstract. *A numerical index for housing complexes of reinforced concrete maintained properly was proposed. First, based on the literature review, deterioration grade and a method for evaluating soundness for RC housing complexes, which determined by visual inspection, was proposed. And then, accelerated deterioration experiments of small RC wall and investigation of existing buildings were conducted. From the study, a correlation between the deterioration grade determined visually and rebar corrosion grade was confirmed. By using building health H(t), that is proposed as index of soundness for existing RC housing complexes, RC housing complexes whose age were 46 to 69 years were evaluated. From the study, it was confirmed how much deterioration the evaluation value indicates.*

Keywords: *Numerical index for soundness; On-site investigation; Visually inspection; Rebar corrosion; Existing building; Maintained properly*

1 Introduction

Towards the formation of a sustainable society, there is a need to effectively utilize existing housing complexes of reinforced concrete (RC) that are aged but still have no problem with structural strength. In order to effectively utilize existing housing, it is necessary to understand the current status of existing housing, estimate its remaining useful life, and implement measures to extend its service life. As a method to determine the condition of the existing buildings, there are preliminary assessment and detailed assessment to judge sufficient reliability (ISO16311-2 2014). For example, there is visual inspection to detect deteriorating events for the entire exterior as preliminary assessment, and then, coring a sample and measuring the carbonation depth of the concrete as detailed assessment to estimate the remaining useful life. However, there are two issues with the current assessment methods: First, visual inspection of the overall exterior is used to detect deterioration events and to plan repairs for individual parts, but it does not assess as the building soundness whole. Second, estimation of the remaining useful life by carbonation depth ignored the partial deterioration such as cracks, which possibly occur throughout the building. Therefore, the objective of this study is to propose a method for evaluating the soundness of the RC housing complexes, which is not a local assessment such as measuring crack width but a whole one taking into account partial deterioration.

2 Evaluation Method

2.1 Literature Review Research

2.1.1 Building standards in Japan

Specific deterioration events are described for each section, component, and material, however either limit state is not indicated.

2.1.2 Finishing materials

The criteria for repair are presented by each materials and methods. There are criterias of partial deteriaration like as 0.2mm-wide- crack (Government building repair department, Japan 2022), criteria by sum of partial deterioration amount (Government building repair department, Japan 2006). Except the inspection for avoiding falling tiles and mortar, either case, finishing materials are maintained for preservation of the body parts materials.

2.1.3 Body parts material (Reinforced concrete)

In the evaluation for main structual members, the rebar corrosion and the concrete deterioration are indicators, since focused on structual safety and use safety. To put it plainly, rebar corrosion cause cover concrete spalling and reduce structual safety. (AIJ 1997) (Government building repair department, Japan 2007) (AIJ 2016). While, the deteriorated area and the amount of deterioration are concerned to seismic capasity, and used as deterioration indicators (JBDPA 2017). In addition, there are deteriaration grade from the start that surface deformaton, and then partialy spalling, finally these spread entirely (AIJ 2016).

2.1.4 Summary of review

From the above, it was confirmed that if deterioration is evaluated for each section and material, it is also possible to evaluate the entire building based on this evaluation.
In addition, if deterioration due to corrosion of steel bars in concrete is used as an indicator, the finish materials can be positioned as a function to protect the body parts materials. Therefore, the deterioration of the finish materials and of the body parts materials can be evaluated by using a sequence of deterioration, i.e. indicators due to corrosion of steel bars in concrete.

2.2 Deterioration Grade Setting

Based on the literature research, the deterioration grade of reinforced concrete was set as shown in Table 1 and Figure 1, focusing on deterioration due to corrosion of steel bars. Beside, deterioration grades could be determined by visual inspection.

2.3 Section for Evaluation

For evaluation, the building parts was divided into section like as south wall, west wall, balcony and etc. Add to that, the section divited into section element J_{ei} as shown on blue lines in Figure 2. The deterioration grade was evaluated for each section element J_{ei}.

Table 1. Index of the condition of concrete surface and Degradation Grade.

Degradation grade	Descript-ion	Index No.	Condition/ Deterioration event
D0	Healthy	1	Nothing
D1	Early deteriora-tion	2	Detachment of exterior package, degradation of exterior finish (without coating degradation)
		3	Cracks on concrete surface
		4	Efflorescence
D2	Middle deteriora-tion	5	Rust elution print
		6	Crack caused by rebar corrosion (ex. cracks along the rebar, cracks with rust elution)
D3	Limit of safety in use	7	Concrete detachment from rebar caused by rebar corrosion within 20cm along the rebar
		8	Concrete detachment from rebar caused by rebar corrosion over 20cm along the rebar
		9	Exposure of the rebar
D4	Concern-ed to structual safety	10	Flexural deformation, Slopng of slab, Inclination of column or vertical member
-	-	recital	Make a note if detected as followings: Repair patch, peanuts brittle, cracks caused by structural work, flexure, gradient and so on

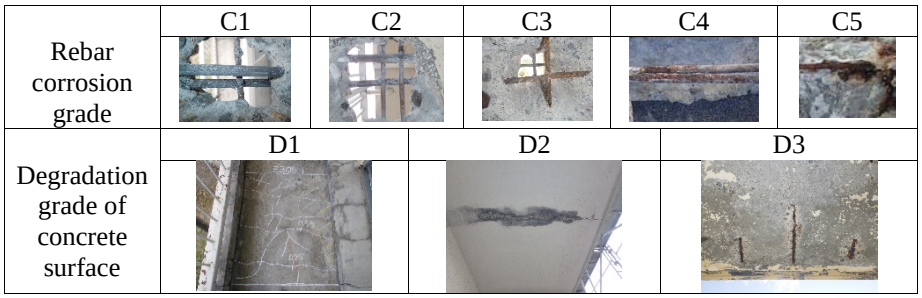


Figure 1. Example of the Grade in this study.

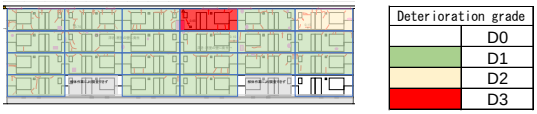


Figure 2. Section element J_{ei} (blue line area) and evaluation of deterioration grade.

2.4 Evaluation Method of Building Health

2.4.1 Deterioration grade $D_J(t)$

The deterioration grade $D_J(t)$ of the section J is shown in Equation 1.

$$D_J(t) = \frac{\sum \alpha_{Je}(t)}{N} \quad (1)$$

Where,

$D_J(t)$: Deterioration grade of the section J at age t

$\alpha_{Je}(t)$: Grade of deterioration as determined by the section element J_{ei} at age t
J: Specific section areas to be evaluated
J_{ei}: Section element (an element that divides the section J into multiple grids) (i : 1，2，3･･n)
N: Total number of section elements J_{ei}
t: age of the building

2.4.2 Health of section $H_J(t)$

Evaluation of the health of section H_J at age t is according to equation 2

$$H_J(t) = 1 - \frac{D_J(t)}{(\text{Deterioration Grade 3 Score})} \quad (2)$$

Where,
$H_J(t)$: Health of the section at age t
The score for each Deterioration Grade adopts grade number
A soundness score of 1 indicates the as-built condition, while a soundness score of 0 indicates a deteriorated grade 3 condition, i.e., delamination and exposed rebar due to rebar corrosion.

2.4.3 Building Health H(t)

Deterioration progresses differently depending on the environment in which the area is located, etc. (ISO22965-1. 2007). Therefore, Smallest of the health of section $H_J(t)$ is evaluated as the health of the building.
The building health H at age t is given by Equation 3

$$H(t)=\text{Min}\{ H_J(t) \} \quad (3)$$

Where,
H(t): Building health at age t

3 Building Investigation and Experimental Verification

3.1 Accelerated Deterioration Tests of Simulated RC Wall

3.1.1 Experimental methods

Accelerated deterioration experiments were conducted. Small RC wall like size as 1m ×1m× 0.18m were prepared, and a constant current had been applied to steel bars, then corrosion was accelerated (K. Nakada et al. 2021) (N. Tsuchiya et al. 2022).

3.1.2 Results

Figure 3 shows some example results of accelerated deterioration test, in the case that the cover thickness is small. With the progression of rebar corrosion, the following occurred that concrete surface cracked along the rebar first, then covering concrete were lifted and spalled, and finally, rebar become exposure. The results show that with the progression of rebar corrosion, deterioration events appear as shown in the stages of deterioration grade in Figure 1.

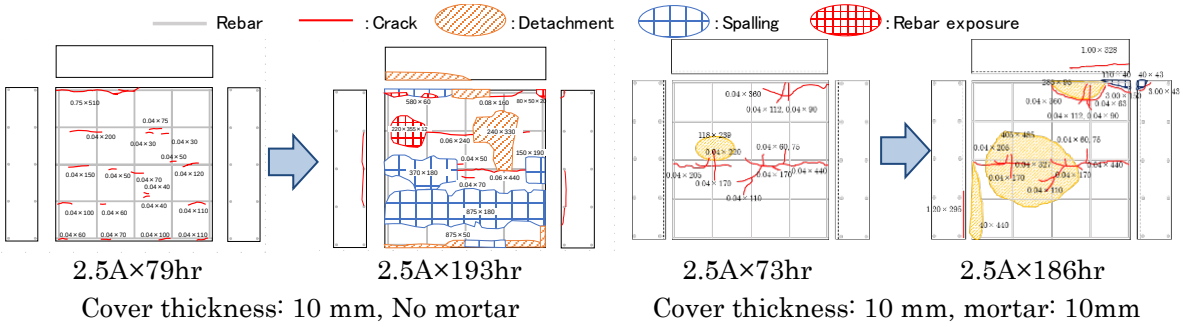


Figure 3. Example of experimental results of accelerated deterioration of simulated wall members.

3.2 Study on Deterioration Grade for Existing Buildings

3.2.1 Investigation methods

9 RC housing complexes in ranging in age from 46 to 69 years were investigated (Naoko Tsuchiya et.al. 2022). Table 2 shows a summary of the investigated buildings. After visual inspection for 1m × 1m area and evaluated the deterioration grade, the rebar inside the concrete was ground out to measure the rebar corrosion grade. Table 3 shows the rebar corrosion grade in accordance with the gideline (AIJ. 1997).

Table 2. Investigated buildings

Building code name (location)	Structure type and scale	Completion date	Investigation date	Concrete strength (N/mm^2)
A (Toyama)	RC, 4-story	1962	2020	38.5
B-1 (Kagoshima)	RC, 5-story	1972	2020	19.1
B-2 (Kagoshima)	RC, 5-story	1974	2020	35.1
C-1 (Fukuoka)	RC, 5-story	1971	2020	34.7
C-2 (Fukuoka)	RC, 5-story	1971	2020	38.4
D (Gifu)	RC, 4-story	1951	2020	10.9
E (Tokyo)	RC, 7-story	1971	2020	24.6
F-1 (Miyagi)	RC, 4-story	1970	2020	28.3
F-2 (Miyagi)	RC, 4-story	1972	2020	24.4

Table 3. Index of the rebar corrosion grade

Grade of the rebar corrosion	Condition
C1	Free from corrosion, negligible rust spot on the surface
C2	Rust spots spread on the surface
C3	Whole rust and partial avulsion of the rebar after spot rust
C4	Spread of the avulsion rust, the rust adheres to the concrete, and partial cross-section lack, of less than 20%
C5	Spread of the heavy layered rust and the marked cross-section lack is over 20%

3.2.2 Results

Figure 4, which has been mentioned in Authers paper (Naoko Tsuchiya et.al. 2022), shows the percentage of deterioration grades measured at each rebar corrosion grade. It shows that the percentage of higher deteriolation grades increases with the rebar corrosion grade increases.

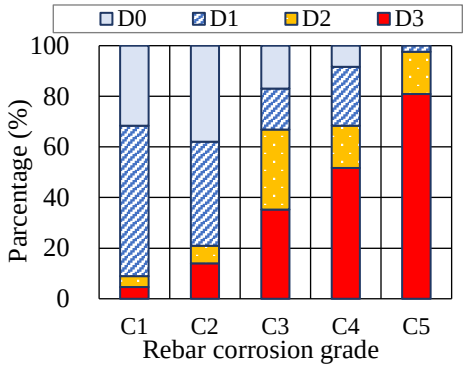


Figure 4. Proportion of the degradation grade on each rebar corrosion grade（903 data, 9 building）.

From the above 3.1 and 3.2, it was confirmed that the deterioration grade determined visually has a correlation with steel bar corrosion.

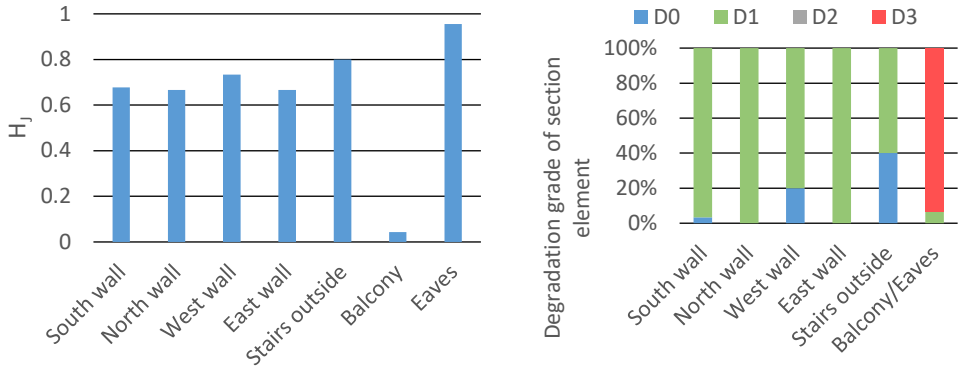
3.3 Evaluation of the Building Health H(t) for the Existing Buildings

3.3.1 Object buildings

RC housing complexes whose age were from 46 to 69 years, as shown in Table 2, were evaluated.

3.3.2 Results

Figure 5 shows the health of section H_J of building B-2 for instance. Also, a breakdown of the results of the deterioration grade of the section elements J_{ei} is also shown. In this case, since the balcony/eaves section have the smallest value of the health of section $H_J(t)$, the value is taken used as the building health H(t) at the present.
Figure 6 shows the relationship between the building health H(t) and rebar corrosion grade of the section. The results shows that the building health H(t) decrease with the rebar corrosion grade increse. Especially, when the rebar corrosion grade are from 3 to 5, the building health H(t) show less than 0.3.
Figure 7 shows the proportion of degradation grade at each health of section $H_J(t)$. It shows that he deterioration grade gradually increases with decrease of health of section H_J basically. Also, it shows that in the case less than 0.5 of health of section $H_J(t)$, deterioration grade D3 becomes more than 20%. From the study, it was confirmed how much deterioration the evaluation value indicates.



（a）Health of section $H_J(t)$ （b）Proportion of deterioration grade of section element J_{ei}

Figure 5. Evaluation results of the health of section $H_J(t)$（Building B-2）.

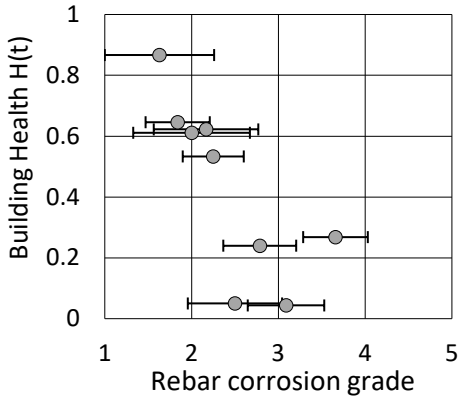


Figure 6. The relationship between the building health H(t) and rebar corrosion of the section.

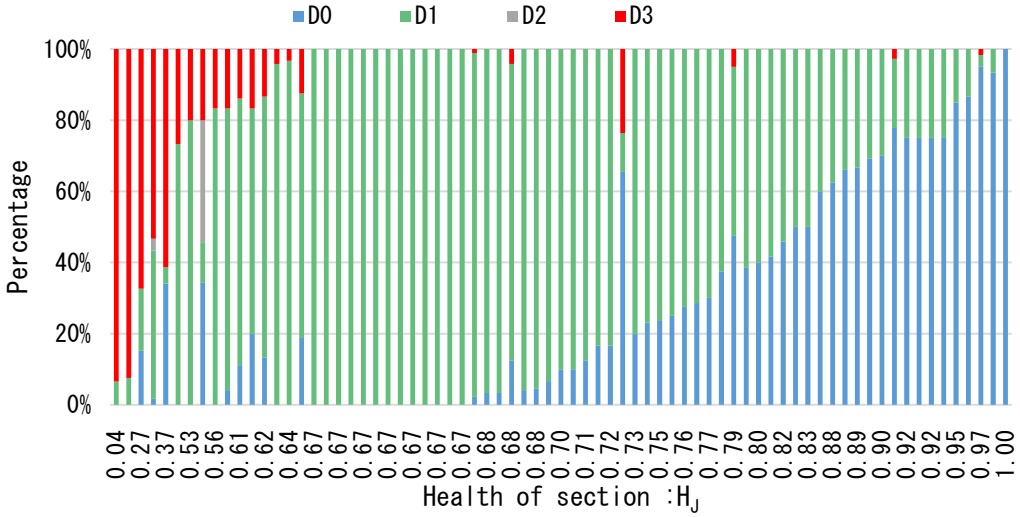


Figure 7. Proportion of deterioration grade at each health of section $H_J(t)$.

4 Summery

In this study, to propose a neumerical index evaluating the health of the building which is not a local assessment like as measuring crack width but a whole one taking into account partial deterioration, for RC housing complexes, the followings were studied.

- Based on the literature review, deterioration grade and a method for evaluating soundness for RC housing complexes, which determined by visual inspection, was proposed.
- The results of the accelerated deterioration experiments of simulated wall members shows that with the progression of rebar corrosion, deterioration events appear as proposed deterioration grade.
- In the result of the relationship between rebar corrosion grade and deterioration grade for existing buildings, the percentage of higher degradation grades increases with the rebar corrosion grade increases.
- From the above 2) and 3), a correlation between the deterioration grade determined visually and rebar corrosion grade was confirmed.
- Building health H(t), that was proposed as index of soundness for existing RC housing complexes, were appied to evaluating RC housing complexes whose age were from 46 to 69 years. From the study, it was confirmed how much deterioration the evaluation value indicates.

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