Index for Reparability Evaluations of Buildings Based on Engineering Factors in Repair Cost Increases

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SUMMARY
The purpose of this study is to propose an index to enable proper evaluations to be made of the severity of earthquake damage from the viewpoint of reparability, in which severity is defined to be caused by an increase in repair costs. The index was formulated taking into consideration the effects of engineering factors on an increase in repair costs, i.e. the amount of labor and the level of technology needed for repair work. The characteristics of the index are summarized as follows: (1) The index is clearly related to repair costs and repair time. (2) From the index, it is possible to gauge the amount of labor and the level of technology needed for repair work. (3) In the index, factors governing increases in repair costs are evaluated from the engineering viewpoint.

Keywords: Performance-based seismic design, Reparability evaluation, Repair cost, Repair time, Index

1. INTRODUCTION

The Great Hanshin-Awaji Earthquake in 1995 caused economic losses totaling 10 trillion yen. Recently, the Japanese government announced that if an earthquake were to hit Tokyo directly, the economic loss could be as high as 112 trillion yen, some 1.4 times the nation’s annual budget. In general, seismic-resistant designs primarily strive to protect life against large earthquakes, which are relatively rare. Designs rarely set design targets or damage limits explicitly to reduce economic losses. To limit damage to architectural structures during a severe earthquake and to reduce the amount of harm to society, it is desirable that a design method be developed with a view toward reparability after an earthquake. The purpose of this study is to propose an index (a reparability evaluation index) to properly evaluate the severity of damage from the viewpoint of reparability.

2. EVALUATION OF SEISMIC CAPACITY USING REPARABILITY EVALUATION INDEX

We consider the evaluation of the seismic performance for buildings in two stages: damage evaluation, and reparability evaluation, as shown in Fig. 2.1(1). In damage evaluation, we evaluate the levels of damage to each component that has responded to the design seismic motion. The results are expressed as damage levels, as shown in Fig. 2.1(2) A. A method for evaluating the level of damage is defined in five levels based on the extent of the cracks and other factors by the Japan Building Disaster Prevention Association. In the reparability evaluation, the levels of damage are evaluated from the viewpoint of reparability. The reparability evaluation index proposed in this study is for this second stage. As shown in Fig. 2.1(2) B, using the proposed index, the severity of damage is expressed for each part damaged from the viewpoint of reparability.

In this paper, the severity of damage is defined to be caused by an increase in repair costs. When considering whether to repair or rebuild, repair costs are an important factor. The following is a list of the factors influencing repair costs:

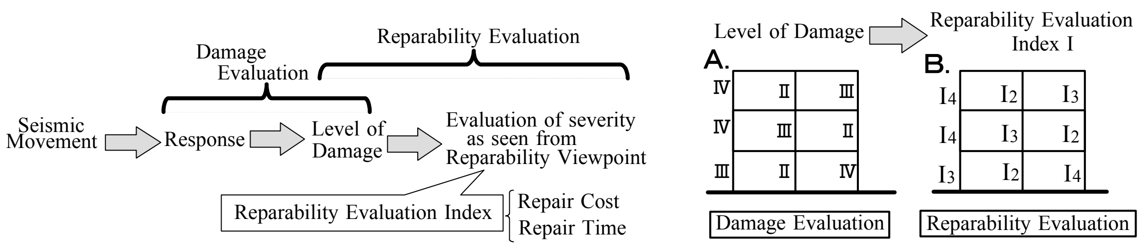
Engineering Factors
1. Places needing repair cover a large area.
2. Each repair needs a lot of work.
3. Highly specialized workers with a high level of technical ability required.
4. A lot of heavy machinery and expensive materials are required.
5. Construction environment: securing space for bringing in materials and work.

Economic Factors
6. Rise in unit price due to exceptional circumstances such as turmoil after an earthquake.
7. Regional disparities in material cost per units and labor.
8. Relationship of trust among parties involved.
9. Amount of transactions
10. Terms of payment
11. Supply and demand
12. Management strategy

Hereafter, these will be referred to as Factors 1 to 12.

It is necessary to clarify the position of the index by distinguishing between which factors need to be considered when evaluating repair costs and which do not. This is because there are many factors, both engineering and economic, that contribute to an increase in repair costs. The purpose of this study is to evaluate reparability from the viewpoint of the influence that engineering factors have on repair costs. For our index, we will look at Engineering Factors 1 to 4, but we will not be evaluating Engineering Factor 5 and Economic Factors 6 to 12. It is desirable to consider Factor 5, but an evaluation would be difficult or complicated, so at this time, the influence will not be considered.

Of the factors from 1 to 4, Factors 1 and 2 are evaluations of the 'time and effort' needed for repairs, while Factors 3 and 4 are evaluations of the 'technical level' needed for repairs. The index needs to be a relative comparison of the level of difficulty of repairs, and at the same time, a quantification of the 'time and effort' and the ' technical level.'



(1) Flowchart for Reparability Evaluation (2) Damage and Reparability Evaluation

Figure 2.1 Seismic Performance Evaluation using Reparability Evaluation Index

For the actual repairs, repair time is an important item to take in consideration in addition to repair costs. It is difficult to completely evaluate repair time and the resulting economic loss. However, depending on the building, the economic loss can easily exceed repair costs. It is desirable that the relation between the index and repair time is made clear.

In the next section, we will summarize the concept of the calculation of repair costs in making estimates. In Section 4, we will use that thinking to formulate a reparability evaluation index.

3. HOW TO CALCULATE REPAIR COSTS WHEN MAKING AN ESTIMATE

The make-up of repair costs may generally be expressed by the equation:

$$\text{Repair Costs} = \text{Labor Cost} + \text{Cost of Materials and Apparatus} + \text{Expenses} \tag{3.1}$$

Labor cost is the cost of the personnel needed for repairs. The cost of materials and apparatus is the cost of materials, machinery and implements that is necessary for the repairs. Expenses are the costs of small items and other expenses that cannot be included in the cost of materials and apparatus, as well as subcontracting costs. They are generally defined in a ratio to labor and materials/apparatus costs. The specific calculation of Eqn. 3.1 is made using the 'estimated unit price.'

$$\text{Repair Costs} = \text{Estimated Unit Price} \times \text{Amount of Damage} \qquad (3.2)$$

The estimated unit price is the repair costs per unit of amount of damage. This is calculated using Eqn. 3.3 based on the estimated labor, materials estimate and labor cost per unit and material cost per unit.

$$\text{Estimated Unit Price} = \Sigma\,({}_{R}Bi \times {}_{R}Ui) + \Sigma\,(zBi \times zUi) + \text{other} \qquad (3.3)$$

Here, ${}_{R}Bi$ is the estimated labor, ${}_{R}Ui$ is the labor cost per unit, zBi is the materials estimate, and zUi is the material cost per unit.

The first item is the labor costs required per unit of amount of damage. The second item is the cost of materials and apparatus. The third item is expenses. The calculation of the first two items is shown in Table 3.1 and Table 3.2.

The cost of labor required per unit of amount of damage that is calculated in the first item is the total of the labor estimates for each type of laborer multiplied by the labor cost per unit, as shown in Table 3.1. The labor estimate is the amount of labor required per unit of amount of damage shown in man-days (Unit: men × days). Therefore the more complicated and effort-requiring the damage, the higher the value becomes. The labor cost per unit is the amount per worker per day. This varies according to the type of worker, with work requiring special abilities set at a higher value. Every year, the Ministry of Land, Infrastructure and Transport publishes the standard values as the Design Labor Unit Price for Public Works.

The cost of materials and apparatus required per unit of amount of damage that is calculated in the second item is the total of the materials estimate multiplied by the material cost per unit, as shown in Table 3.2. The materials estimate is the amount of materials or tools and heavy machinery needed for repairs per unit of damage. The material cost per unit when using machinery or tools is calculated based on its rental or loss payments.

The labor estimate and estimated materials define the efficiency of the repair work, and are published as the standard value for regular construction and restoration work.

Table 3.1 Calculation of Labor Costs required per Unit of Amount of Damage

	Type of Work	Labor estimate	Labor cost per unit	Labor estimate × Labor cost per unit
	Regular Laborers	RB1	RU1	RB1×RU1
	Specialist Laborers	RB2	RU2	RB2×RU2
	Welders	RB3	RU3	RB3×RU3
Labor	Carpenters	RB4	RU4	RB4×RU4
	Rebar Workers	RB5	RU5	RB5×RU5
	▪	▪	▪	▪
	▪	▪	▪	▪
	▪	RBn	RUn	RBn×RUn
		ΣRBi		Σ(RBi×RUi)
		Unit Labor Amount		1st Item of Eqn.3.3

Table 3.2 Calculation of Cost of Materials and Apparatus per Unit of Amount of Damage

	Type of Materials & Apparatus	Materials estimate	Material cost per unit	Materials estimate × Material cost per unit
	Materials 1	$ZB1$	$ZU1$	$ZB1 \times ZU1$
	Materials 2	$ZB2$	$ZU2$	$ZB2 \times ZU2$
Materials	·	·	·	·
&	·	·	·	·
Apparatus	Apparatus 1	·	·	·
	Apparatus 2	·	·	·
	·	·	·	·
	·	ZBn	ZUn	$ZBn \times ZUn$
				$\Sigma(ZBi \times ZUi)$
				2nd Item of Eqn.3.3

4. REPARABILITY EVALUATION INDEX

4.1 Evaluation of Engineering Difficulty from the Estimating Viewpoint

In Section 2, we listed the factors influencing repair costs and said we would look at Engineering Factors 1 to 4. Here we will consider the evaluation index of the factors from the estimating viewpoint.

Factor 1, 'Places needing repair cover a large area,' means that the number of damaged columns and walls is large, and this results in the large 'Amount of Damage' in Eqn. 3.2. Factor 2, 'each damage needs a lot of work,' means that the amount of labor is large for each part damaged. The labor estimate mentioned in Section 3 means the amount of labor for each type of laborer per unit of amount of damage. Therefore, the total of labor estimates, i.e. Unit Labor Amount (Eqn. 4.1), represents the level of Factor 2. Specific examples of these calculations are shown in Table 3.1.

$$\text{Unit Labor Amount} = \Sigma\, {}_{R}Bi \tag{4.1}$$

'Amount of damage' and 'Unit Labor Amount,' are multiplied to obtain the amount of labor (Eqn. 4.2). The amount of labor is considered to be an index to show the 'time and effort' that is required for repair, i.e. Factors 1 and 2.

$$\text{Amount of Labor} = \text{Amount of Damage} \times \text{Unit Labor Amount} \tag{4.2}$$

The influence of Factor 3, 'highly specialized workers with a high level of technical ability required,' is seen in the increasing repair cost due to the rise in labor cost per unit. Here, when the repair work is assumed to be carried out by regular laborers, the cost of labor will be calculated by the following equation and called the basic labor cost.

$$\text{Basic Labor Cost} = \text{Amount of Labor} \times {}_{R}U_{F} \tag{4.3}$$

Here, ${}_{R}U_{F}$ is the labor cost per unit for regular laborers.
Actual labor costs divided by the basic labor costs are, as seen in the following equation, called the labor cost coefficient. The labor cost coefficient is considered to be an index to show the rise in labor cost per unit due to Factor 3.

$$\text{Labor Cost Coefficient} = \text{Labor Costs} / \text{Basic Labor Costs} \tag{4.4}$$

Repair work requiring Factor 4, 'a lot of heavy machinery and expensive materials required,' means that as a result of the increasing materials estimate and material cost per units, the ratio of cost of materials and apparatus to labor cost is great. To eliminate the influence of the rise in labor cost per unit due to Factor 3, the cost of materials and apparatus is divided by basic labor costs in the following equation. The cost of materials and apparatus coefficient can be considered to be an index of Factor 4.

$$\text{Cost of Materials and Apparatus Coefficient} = \text{Cost of Materials and Apparatus} / \text{Basic Labor Costs} \tag{4.5}$$

In summarizing the above, the level of difficulty of repair arising from Factors 1 and 2 can be evaluated by the 'amount of damage' and 'unit labor amount;' and the level of difficulty due to Factors 3 and 4 can be evaluated by the 'labor cost coefficient' and 'cost of materials and apparatus coefficient.'

4.2. Structure of Reparability Evaluation Index

The index for evaluating the level of severity of damage is defined by the following formula:

$$\text{Reparability Evaluation Index} = \text{Repair Cost Coefficient } \alpha \times \text{Repair Time Coefficient } \beta \times \text{Amount of Damage} \tag{4.6}$$

As mentioned above, 'Amount of Damage' is the index for evaluating Factor 1 (hereafter, 'Factor 1 Index'). The repair time coefficient β is the coefficient for evaluating the amount of labor needed per unit of amount of damage, and is defined by the unit labor amount mentioned in 4.1, as shown in Eqn. 4.7. From what was mentioned in 4.1, β means the index for evaluating Factor 2 (hereafter, 'Factor 2 Index').

$$\beta = \text{Unit Labor Amount} = \Sigma\, _{R}Bi \tag{4.7}$$

The part 'Repair Time Coefficient β × Amount of Damage' in Eqn. 4.6 is the size of the effort needed, i.e. the amount of labor needed (in man-days). The amount of labor is expressed as the number of days necessary for one worker to do the repair work. Therefore, the repair time coefficient β may be interpreted as a coefficient that converts the amount of damage into the total amount of repair hours.

The repair cost coefficient α is defined by the following equation using the 'labor cost coefficient' and 'cost of materials and apparatus coefficient'. These coefficients are indexes for measuring the intension of Factors 3 and 4. Therefore α evaluates Factors 3 and 4 (hereafter, 'Factors 3 and 4 Indexes').

$$\text{Repair Cost Coefficient } \alpha = \text{Labor Cost Coefficient} + \text{Cost of Materials and Apparatus Coefficient} \tag{4.8}$$

The reparability evaluation index defined by Eqn. 4.6 is also expressed as shown in Eqn. 4.9, using 'Factor 1 Index,' 'Factor 2 Index' and 'Factors 3 and 4 Indexes.' From that, we can see that they form the index for measuring the level of difficulty of repairs caused by Engineering Factors 1 to 4 that are to be evaluated as noted in Section 2.

$$\text{Reparability Evaluation Index} = \text{Factors 3 and 4 Indexes} \times \text{Factor 2 Index} \times \text{Factor 1 Index} \tag{4.9}$$

The part 'repair time coefficient β × amount of damage' in Eqn. 4.6 is the amount of labor and α is a dimensionless quantity, so the units for this index are man-days (men × days).

5. TRIAL CALCULATION FOR PROPOSED INDEX AND DATABASE

For the reparability evaluation using Eqn. 4.6, the repair cost coefficient α and the repair time coefficient β corresponding to the level of damage for each component (column, beam, wall, etc.) must be compiled into a database. The component to be evaluated should include nonstructural components and items of equipment as well as structural components. This database has been created and is maintained according to the research project 'Study on Continuity and/or Resiliency of Building Function after Disasters' of the Building Research Institute. In addition, data concerning the relation between the response value (drift angle and acceleration) and the level of damage were collected.

Here, the process of a trial calculation of an RC wall at Damage Level II will be shown, in which the repair cost coefficient α and the repair time coefficient β and the reparability evaluation index will be calculated. Taking into consideration 'Concrete Diagnostic Technology' published by the Japan Concrete Institute, we have assumed the method of repair as shown in Table 5.1 for five levels of damage. The table shows the amount of construction for each method postulated according to the damage of experimental results.

For the sake of convenience, the calculation of α is not performed using Eqn. 4.8, but performed using the following equation:

$$\text{Repair Cost Coefficient } \alpha = \text{Labor Cost Coefficient} + \text{Cost of Materials and Apparatus Coefficient} + \text{Expenses} / \text{Basic Labor Cost} \quad (5.1)$$

As mentioned before, the expenses include the cost of small items and other expenses that cannot be included in the cost of materials and apparatus, and generally defined to be the ratio of labor costs and cost of materials and apparatus (for example, 15% of labor costs). Therefore, the calculation method using Eqn. 5.1 does not cripple the operation of α as an index to measure Factors 3 and 4 (the index measuring the size of the labor costs and cost of materials and apparatus in relation to basic labor costs).

Equation 5.2 is the specific calculation of Eqn. 5.1. In Table 5.2, we show the calculation of each item based on the method of repair and the amount of construction postulated in Table 5.1. Keep in mind that the assumed wall has an area of 9.43 m^2 (width 4.6 m × height 2.05 m) with a thickness of 12 cm.

$$\alpha = \{\Sigma\,({}_{R}Bi \times \frac{{}_{R}Ui}{{}_{R}U_F}) + \Sigma\,({}_{Z}Bi \times \frac{{}_{Z}Ui}{{}_{R}U_F}) + \text{Others} / {}_{R}U_F\} \div \Sigma\,{}_{R}Bi \quad (5.2)$$

Table 5.1 Assumed Repair Method and Amount of Construction for Damage Level of an RC Wall

Level of Damage	Damaged Condition	Repair Method and Construction Amount
I	Cracks cannot be seen unless viewed close up (cracks up to 0.2-mm wide)	○Sealing Method (0.46 m/m^2)
II	Cracks can be clearly seen with the naked eye (cracks 0.2-mm to 1.0-mm wide)	○ Sealing Method (2.61 m/m^2) ○ Manual Injection of Epoxy Resin (1.02 m/m^2)
III	Comparatively large cracks (cracks 1.0-mm to 2.0-mm wide). Some spalling of concrete	○ Sealing Method (2.25 m/m^2) ○ Manual Injection of Epoxy Resin (1.43 m/m^2) ○ U-cut Flexible Epoxy Resin Filling + Automatic Low-pressure Resin Injection (0.29 m/m^2)
IV	Large cracks (cracks 2.0-mm to 5.0-mm wide). Pronounced spalling of concrete	○ Sealing Method (2.68 m/m^2) ○ Manual Injection of Epoxy Resin (2.08 m/m^2) ○ U-cut Flexible Epoxy Resin Filling + Automatic Low-pressure Resin Injection (0.97 m/m^2) ○ RC Patching (0.004 m^2/m^2)
V	Cracks wider than 5.0 mm. Internal concrete breaks and falls off	Complete Removal Re-casting of Concrete

The repair cost coefficient α and the repair time coefficient β and reparability evaluation index are obtained using the values calculated in Table 5.2, as follows:

$$\beta = \text{Eqn. 4.7} = 2.64 \text{ (men} \times \text{days)} \quad (5.3)$$

$$\alpha = \text{Eqn. 5.2} = (3.768 + 1.341 + 0.792) / 2.64 = 2.24 \quad (5.4)$$

Reparability Evaluation Index = Eqn. 4.6

$$= \alpha \times \beta \times \text{Amount of Damage} = 2.24 \times 2.64 \times 1.0 = 5.9 \quad (5.5)$$

Keep in mind that the amount of damage is one RC wall (wall panel area 9.43 m^2), and β is calculated as the amount of labor needed for the one RC wall.

The results of calculating the repair cost coefficients α and the repair time coefficients β are shown in Table 5.3 for Damage Levels I, II, III, IV and V. In the database mentioned above, we have stored information from such tables. By using this database, the reparability evaluation index for each component can easily be calculated and expressed as shown in Fig. 2.1(2) B. In Fig. 5.1, the changes in α and β and the index shown in Table 5.3 are plotted. As a result, the values of the reparability evaluation index that are calculated are small at Damage Level I, and from Damage Levels II to V, they are about 5.0, 10.0, 20.0, 40.0, showing a tendency to double with each rise in level.

Table 5.2 Calculating Process for Index (RC Wall (9.43 m^2), Damage Level II)

	Repair Method	Item	Unit	RBi	RUi/RUF	RBi×RUi/RUF
1st Item of Eqn.5.2	Sealing Method	Sealing Laborers	Men×days	0.714	1.429	1.020
	Injection of Epoxy Resin Method	Manual Injection Laborers	Men×days	1.924	1.429	2.748
				ΣRBi		ΣRBi×RUi/RUF
				=2.64		=3.768
	Repair Method	Item	Unit	ZBi	ZUi/RUF	ZBi×ZUi/RUF
2nd Item of Eqn.5.2	Sealing Method	Epoxy Resin Primer	kg	0.074	0.186	0.014
		Sealant	kg	0.984	0.171	0.169
		Expendables	-	1	0.026	0.026
		Tool Depreciation	-	1	0.040	0.040
	Injection of Epoxy Resin Method	Epoxy Resin	kg	1.924	0.214	0.412
		Epoxy Resin Primer	kg	1.443	0.171	0.247
		Aluminum Pipe 3 φ	pipes	57.7	0.0043	0.247
		Expendables	-	1	0.073	0.073
		Tool Depreciation	-	1	0.112	0.112
						ΣZBi×ZUi/RUF
						=1.341
3rd Item of Eqn.5.2						Others/RUF
		(Labor + Materials) × 15.5%				0.792

Table 5.3 Results of Trial Calculations for an RC Wall (9.43 m^2)

Level of Damage	Repair Cost Coefficient α	Repair Time Coefficient β	Reparability Evaluation Index
Ⅰ	2.07	0.13	**0.3**
Ⅱ	2.24	2.64	**5.9**
Ⅲ	2.38	4.14	**9.9**
Ⅳ	2.49	7.69	**19.1**
Ⅴ	1.63	23.76	**38.7**

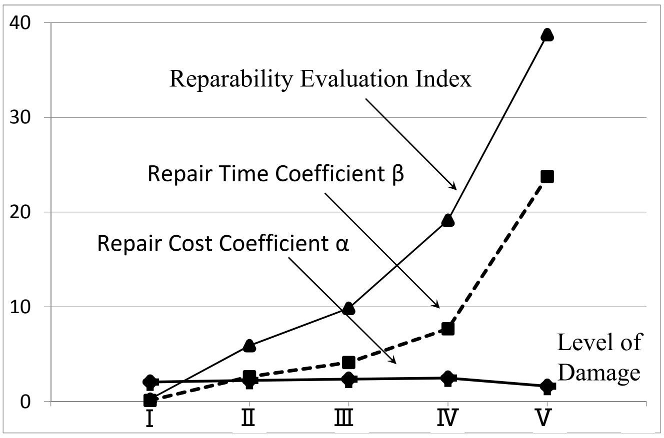


Figure 5.1 Damage Level and Index Values for an RC Wall (9.43 m^2)

6. CHARACTERISTICS OF REPARABILITY EVALUATION INDEX

The following is a summary of the characteristics of the proposed index.

(1) The relation between the index and 'repair cost and total repair time' is clear
To understand the proposed index, let us consider the meaning of the repair cost coefficient α. The repair cost coefficient α has the following relation with repair cost, from Eqn. 3.1 and Eqn. 4.4-5 and Eqn. 5.1:

$$\alpha \times \text{Basic Labor Cost} = \text{Repair Costs} \tag{6.1}$$

From Eqn. 6.1, it may be understood that α is the coefficient that converts basic labor costs into repair costs. However, it should be noted that, because the repair costs are calculated from Engineering Factors 1-4 mentioned in Section 2, and the other factors, Factors 5-12 have not been taken into account, thus the 'Repair costs' in Eqn. 6.1 are not the same as the repair costs on the market.

Since the part of Eqn. 4.6 'Repair Time Coefficient β × Amount of Damage' is the amount of labor, reparability evaluation index can be expressed in the following equations:

$$\text{Reparability Evaluation Index} = \alpha \times \text{amount of labor} \tag{6.2}$$

From Eqn. 4.3 and Eqn. 6.1, we can rewrite Eqn. 6.2 as the following:

$$\text{Reparability Evaluation Index} = \alpha \times \text{basic labor costs} / {}_{R}U_{F} = \text{repair costs} / {}_{R}U_{F} \tag{6.3}$$

In other words, when the proposed index is multiplied by the normal worker's labor cost per unit, it becomes the repair cost based on the engineering factors, meaning that the repair cost increases as the proposed index increases. For instance, in the trial calculation of the RC wall in the previous section, if the repair cost at Damage Level II is 1.0, from Table 5.3 we can see that the repair cost based on the engineering factors increases at a ratio of 0.05, 1.0, 1.7, 3.2 and 6.6 at Damage Levels I, II, III, IV and V. By using this index, it is possible to express more clearly the severity of the damage that is expected to occur.

When trying to convey an image of the severity of damage, repair time is an important index as well as repair costs. In the part of Eqn. 4.6, 'repair time coefficient β × amount of damage,' the size of the effort needed (amount of labor (men × days)) is calculated. The meaning of this amount is the number of days required for one worker to do the repair work. Here, it is called 'total repair time' and is to be distinguished from the actual repair time needed.

$$\text{Total Repair Time} = \text{Repair Time Coefficient } \beta \times \text{Amount of Damage} \quad (6.4)$$

The actual repair time is generally less than the total repair time, because of the numbers of repair workers that are working at the same time, and the number of operations going on at the same time. However, if the organizational structure and plan of execution for the repair work are assumed to be the same, it is possible to use 'total repair time' as an indication of the amount of repair time. Therefore, speaking in general terms, if the total repair time is doubled, it is possible to consider that the actual repair time has also doubled. For instance, in the trial calculation of the RC wall in the previous section, if the repair time at Damage Level II is 1.0, from Table 5.3 we can see that the repair time increases to a ratio of 0.05, 1.0, 1.5, 3.0 and 9.0 at Damage Levels I, II, III, IV and V.

(2) It is possible to understand the quality of the level of difficulty of repairs, i.e. the amount of effort and the level of technology needed

The reparability evaluation index can be, as shown in Eqn. 4.6, calculated as the multiplication of the repair cost coefficient α, the repair time coefficient β, and the amount of damage. The large repair time coefficient β means that damage that takes a great deal of effort has occurred. In addition, the large 'total repair time' obtained from multiplying β by the amount of damage means that a lot of time is needed for repairs. On the other hand, the repair cost coefficient α becomes small, especially when heavy equipment and materials are not used or when regular laborers can do the repair work. However, when expensive materials or heavy equipment with high rental rates are used, or when workers with high labor unit prices or construction that requires a high level of specialization are needed, the values become greater. The coefficient helps us to acquire an image of the need for heavy equipment or the technical level of materials needed for repairs.

In other words, as is shown in Figure 6.1, by looking at the 'Reparability Evaluation Index,' the 'Total Repair Time' and the 'Repair Cost Coefficient α' for each component, we may know the 'Repair Cost,' the 'Repair Time' and the 'Level of Technology' that are necessary for the repair of each component. Also, from Eqns. 6.5, 6.6 and 6.7, we can easily calculate the 'Reparability Evaluation Index,' the 'Total Repair Time' and the 'Repair Cost Coefficient α' for the whole building. From these, we can show the 'Repair Cost,' the 'Repair Time' and the ' Level of Technology' that are necessary for the repair of the whole building.

$$\begin{aligned}&\text{Reparability Evaluation Index for Whole Building}\\&\quad = \Sigma\,(\text{Reparability Evaluation Index for Each Component}) \quad (6.5)\end{aligned}$$

$$\text{Total Repair Time for Whole Building} = \Sigma\,(\text{Total Repair Time for Each Component}) \quad (6.6)$$

$$\begin{aligned}&\text{Repair Cost Coefficient } \alpha \text{ for Whole Building}\\&\quad = \text{Reparability Evaluation Index for Whole Building} / \text{Total Repair Time for Whole Building} \quad (6.7)\end{aligned}$$

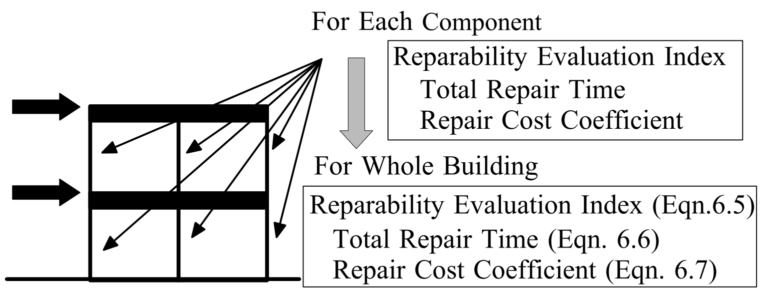


Figure 6.1 Display of Difficulty of Repair for Components and Whole Building

(3) Reparability evaluation that narrows down factors that increase repair costs to engineering factors
There are many factors that influence the level of difficulty of repair, from engineering factors to economic ones. When performing a reparability evaluation, it is important to be specific about which influencing factors are to be evaluated and to clarify them. In this paper, we have sought to indicate the concept of evaluating Engineering Factors 1-4 that influence repair costs from the viewpoint of estimate, and to bring them together to construct a reparability evaluation index. This index makes it possible to perform reparability evaluation that narrows down the factors that influence repair costs (Factors 1-12 listed in Section 2) to Engineering Factors 1-4.

Engineering Factors

1. Places needing repair cover a large area.
2. Each repair needs a lot of work.
3. Highly specialized workers with a high level of technical ability required.
4. A lot of heavy machinery and expensive materials required.

7. CONCLUSION

An index to properly evaluate the severity of earthquake damage from the viewpoint of reparability was proposed, in which severity is defined to be caused by an increase in repair costs. The index was formulated taking into consideration the effects of engineering factors on an increase in repair costs, i.e. the amount of labor and the level of technology needed for repair work. The characteristics of the index are summarized by the three items, which were dealt with in detail in Section 6.

(1) The relation between the index and ‘repair cost and repair time’ is clear.
(2) It is possible to understand the quality of the level of difficulty of repairs, i.e. the amount of effort and the level of technology needed.
(3) Reparability evaluation that narrows down factors that increase repair costs to engineering factors.

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