DAMAGE EVALUATION OF RC BUILDINGS FROM THE VIEWPOINT OF FUNCTIONAL RECOVERY USING IDEAL REPAIR TIME

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Abstract

In recent earthquake damage, cases have been reported where buildings, including non-structural components, were damaged so heavily that it affected economic activity and/or people's daily living, even though the damage to structures was small and the buildings themselves were safe. This has inspired strong interest in the examination of the post-seismic functionality of buildings at seismic design.

On the other hand, when designing a high-rise building, it is recommended that the entire collapse mechanism (i.e. strong column-weak beam mechanism) be planned and sufficient safety of the building be ensured by allowing earthquake damage to spread throughout the building and by ensuring that the energy generated by the earthquake is absorbed evenly by the entire building. However, there are concerns that such a design principle, that permits a large "quantity of damage" and "spread of damage" to all floors, may result in excessive repair time and cost, thereby making it difficult to recover the building functions. Therefore, a seismic design method is required that takes into account post-seismic functional recovery in addition to safety, to protect building functions against large earthquakes.

This paper discusses the usefulness and appropriateness of an index called Ideal Repair Time (IRT) necessary for the design method. IRT is used to evaluate the relative severity of damage from the viewpoint of functional recovery. Its characteristics, usefulness, and appropriateness are as follows.

1) IRT is a kind of damage evaluation index, which grades the severity of the damage according to the repair time necessary for recovery. With this index, the owner of a building can easily understand the severity of the damage from the viewpoint of functional recovery. An index that can show an assured performance level to a building's owner is important in implementing an seismic design method targeting the recovery of building functions.

2) IRT is defined by formula (1), which clearly shows the relationship between the extent and/or quantity of damage and its repair time. Using IRT, the appropriateness of the planned collapse mechanism (i.e., the appropriateness of the area and quantity of damage that will be incurred) can be examined from the viewpoint of functional recovery.

$$\text{IRT} = \text{quantity of damage} / \sqrt{(\text{extent of damage})} \times \text{constant} \tag{1}$$

where, "quantity of damage": amount of labor necessary for repair, "extent of damage": floor area that must be repaired.

3) The period of construction work or repair work generally becomes n^{η} times longer when the amount of work becomes n times larger. IRT has similar characteristics when the amount of work increases due to the quantity and extent of damage, and the relative increase of IRT with quantity and area of damage agrees well with the relative increase of repair time observed for Kobe Earthquake (1995). This means that IRT is a proper index for the evaluation of the relative increase of repair time as the quantity and extent of damage increases.

4) A comparison of IRT calculated by seismic response analysis and actual repair time in Kobe Earthquake (1995) also shows the validity of IRT quantitatively.

Keywords: damage evaluation, functional recovery, repair time, RC building, ideal repair time

1. Introduction

In recent earthquake damage, cases have been reported where buildings, including non-structural components, were damaged so heavily that it affected economic activity and/or people's daily living, even though the damage to structures was small and the buildings themselves were safe [1]. On the other hand, for high-rise buildings in particular, a design method that spreads the damage throughout the building and absorbs seismic energy, by planning the entire collapse mechanism, is recommended so as to assure sufficient safety. However, there are concerns that such a design principle, that permits a large "quantity of damage" and "spread of damage" to all floors, may result in excessive repair time, thereby making it difficult to recover the building functions. Therefore, a seismic design method is required that takes into account post-seismic functional recovery in addition to safety, to protect building functions against large earthquakes and reduce the effect of the damage on society.

Under these circumstances, in recent years, methods of evaluating functional recovery have been actively studied [2–8]. Functional recovery is evaluated based on repair cost and repair time, and evaluating the repair time resulting from damage is extremely important in order to examine functional recovery. Currently, however, most studies attempt to evaluate damage in terms of repair cost, rather than repair time.

This paper proposes an index to evaluate the severity of damage from the viewpoint of functional recovery, instead of safety, by defining the severity of damage as the relative increase of repair time. In other words, the index is used to evaluate the severity of damage from the viewpoint of repair time, which is an important factor in evaluating functional recovery, instead of the severity of physical damage which reduces safety levels. The proposed index is expected to be used in setting target performance levels for seismic design aiming to assure damage-resistant performance, and in evaluating the assured performance levels. In this paper, "damage-resistant performance" means an ability to reduce both the functional damage to buildings and the time taken to recover from the functional damage, by preventing damage from occurring at the time of an earthquake.

2. Evaluation of the severity of damage from the viewpoint of functional recovery

When developing a damage index, it is important to clarify the index by distinguishing the factors to be evaluated from others. As explained above, this paper defines the severity of damage as a relative increase of repair time. As shown in Table 1, repair time can be affected by eight factors. Factors I and II ("quantity of damage" and "extent of damage") are related to the damage state, while Factors III to VIII (III: efficiency of repair work, IV: process design, V: contractual repair time, VI: non-working days, VII; surrounding environment, and VIII: social environment) are factors unrelated to the damage state. The purpose of this study is to establish an index to evaluate the severity of the damage state (Factors I and II) based on the repair time required to recover from the damage.

Table 1 – Factors affecting repair time and hypothesis to eliminate their impact

	Factor	Hypothesis to eliminate impact
Ⅰ	Quantity of damage	-
Ⅱ	Extent of damage	-
Ⅲ	Repair method and skillfullness of workers	Standard method and work efficiency
Ⅳ	Process design	Standard number of workers m_s (Eqs. (9) and (10))
Ⅴ	Repair time required by building owner	No requirement
Ⅵ	Non-working days due to holidays and weather	No non-working days
Ⅶ	Restrictions due to surrounding environment	No restriction
Ⅷ	Restrictions due to social environment	No restriction

Actual repair times at the time of an earthquake (actual repair time) can differ, even with the same damage state (the same severity in I and II), depending on Factors III to VIII. Thus, it cannot be used as a damage evaluation index. It is necessary to set an index that produces one evaluation value for the damage state (Factors I and II), excluding the effects of Factors III to VIII by some means. In the following chapters, an attempt is made to establish an index for relative evaluations of the severity of damage, based on the repair time defined by the factors related to the damage state: Factors I and II only. The impact of the differences in Factors III to VIII, which are unrelated to the damage state, are excluded by setting the hypotheses shown in Table 1.

Chapter 3 below describes the damage evaluation of components, and Chapter 4 describes the damage evaluation of an entire building.

3. Damage evaluation of components

3.1 Time damage

The repair times of identical components may differ, even with the same damage state, depending on repair conditions (e.g., repair method, number of workers, work efficiency, etc.) In this study, the repair time for component *i* as calculated under the following typical repair conditions is called time damage, or tdi . The time damage, tdi is a kind of damage evaluation index, which grades the relative severity of damage to a component, based on time. Repair conditions usually differ between individual sites and so tdi may not be consistent with the actual repair time, but tdi provides a good estimate of repair time, according to the damage state. The time damage for component *i* is calculated as follows:

$$tdi = Li/m_i \tag{1}$$

where Li is the amount of labor necessary to repair component *i* (person-day) and m_i is the number of workers (persons). The value of m_i is calculated as follows, based on the floor area a_i ("repair work area") necessary to repair component *i*:

$$m_i = a_i \times k_1 \tag{2}$$

The k_1 is a constant used to determine the maximum number of workers that can work in the repair work area a_i. This paper uses k_1 = 1.0 person/m^2, based on Ref.[9], which means that each worker is assumed to occupy a floor area of 1.0 m^2, which is calculated by multiplying 1.0 m (the width a worker needs when spreading out both arms) by 1.0 m (the distance from the face of a repair target) (Fig. 1).

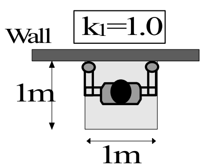


Fig. 1 – Coefficient k_1 and work area

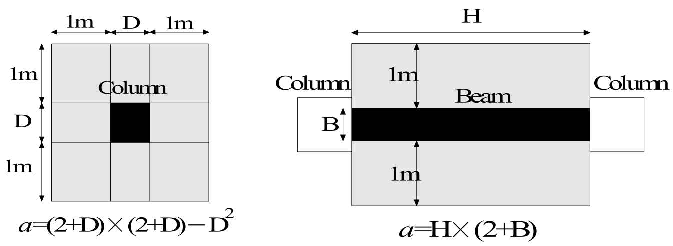


Fig. 2 – Repair work areas of column and beam

Further, parallel lines are drawn 1.0 m from the repair target faces. The area taken by the repair target is subtracted from the area surrounded by the lines, and the remaining area is defined as the repair work area a_i. Fig. 2 shows a sample calculation of a repair work area, for a column and a beam. The difference between the beam and the columns is that, because both ends of the beam contact a column, the beam is not surrounded by work area, and the area directly below the beam is included in the repair work area.

Li, the amount of labor required for component *i*, is calculated by totaling the labor amounts required to repair various types of damage:

$$Li = \Sigma(Q_j \times \beta_j) \tag{3}$$

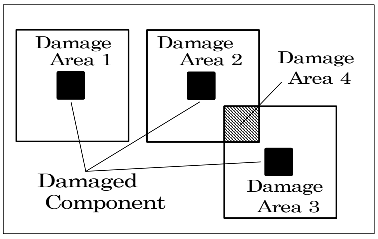
where β is a repair time coefficient. Values of β for various repair works carried out on damaged structural components, non-structural components, and facilities and equipment were surveyed in a research project undertaken by the Building Research Institute [5]. The data were compiled in its recovery evaluation database.

3.2 Area time damage

For a component with time damage tdi , the repair work area a_i cannot be used, due to repair work, for a period of tdi . In cases of multiple components, the area that cannot be used increases, while an area with multiple a_i requires a longer repair time. The area time damage td_A distribution is this repair time represented in a plan view. The td_A for each point on a plan view is calculated as follows:

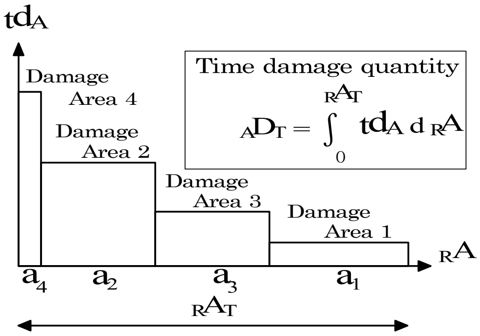
$$td_A = \sum_{i=1}^{n} tdi \tag{4}$$

where n is the number of components whose repair work area includes the point. Fig. 3(1) shows a model of td_A distribution in a case where three components in a building have time damage td_1 , td_2 , and td_3 . Because they overlap, there are four areas with the same td_A ("damage areas"), and the time damage and area ("$_RA$") of these areas are expressed as shown in the table in the figure.



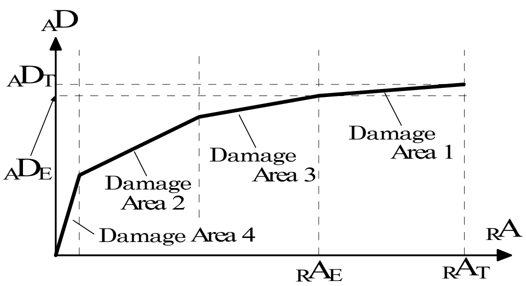
	td_A	$_RA$
Damage Area 1	td_1	a_1
Damage Area 2	td_2	a_2
Damage Area 3	td_3	a_3
Damage Area 4	$td_2 + td_3$	a_4

(1) Damage area $_RA$ and area time damage td_A

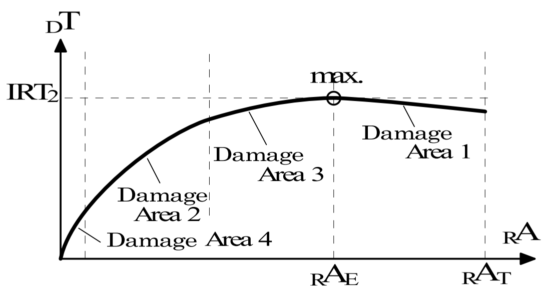


(2) Relation of td_A and $_RA$

Fig. 3 – Area time damage td_A



(1) Relation of $_AD$ and $_RA$



(2) Relation of $_DT$ and $_RA$

Fig. 4 – Calculation procedures of IRT_2

Fig. 3(2) shows td_A for each damage area, arranged in descending order, with $_RA$ on the horizontal axis. The time damage quantity $_AD$ is calculated by integrating the relation td_A - $_RA$ with respect to $_RA$. Based on Eqs. (1), (2), and (4), $_AD$ is calculated as follows.

$$_AD = \int_0^{_RA} (td_A) d_RA = L / k_1 \tag{5}$$

Where L is the amount of labor needed to repair the damage within $_RA$ (person-day). The relation shown in Fig. 4(1) is obtained by showing $_RA$ on the horizontal axis and $_AD$ on the vertical axis. The total of damaged areas $_RA$ is called the "total damage area $_RA_T$." Further, the total time damage quantity $_AD_T$ is calculated by integrating the relation $_AD$ - $_RA$, which is shown in Fig. 4(1), from zero to $_RA_T$, as follows:

$$ {}_{A}D_T = \int_0^{{}_{R}A_T} (t d_A) d_R A = L_T / k_1 \quad (6) $$

where L_T is the amount of labor needed to repair damage within ${}_{R}A_T$ (total labor amount) (person-day).

4. Ideal Repair Time (IRT)

IRT is a repair time calculated without considering any relative differences caused by Factors III to VIII, which are factors other than the damage state that affect repair time, as shown in Table 1. The differences are excluded by setting the hypotheses stated in the table. In this paper, the word "ideal" means the satisfaction of certain conditions (the hypotheses), not the best state.

IRT is determined by the value IRT_1 or IRT_2, whichever is larger. IRT_1 is a repair time determined by damage quantity and IRT_2 is a repair time determined by the extent of damage. IRT_1 and IRT_2 are repair times that correspond to the aforementioned Factors I and II.

4.1 Formulation of repair time

The number of workers on a construction site is decided upon from the requirements of construction and economic efficiency. The number of workers that seems to be the average for the actual condition of construction is determined as the standard number of workers, m_s. On the assumption that m_s is constantly used throughout the entire construction period (i.e., an assumption that the order of construction can be freely changed and multiple construction phases can be implemented simultaneously), the construction period T can be calculated as follows, using m_s and the total labor amount L_T.

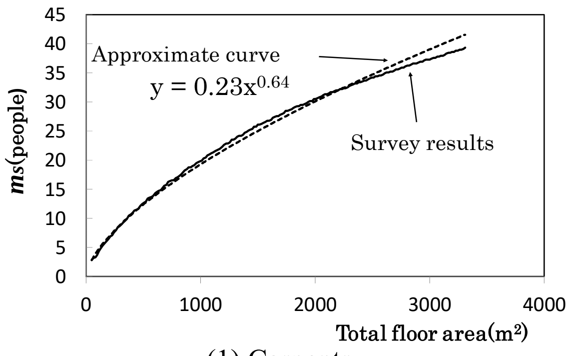
$$ T = \frac{L_T}{m_s} \quad (7) $$

The larger the standard number of workers m_s is, the shorter the construction period T. Although the construction period can be less than a day if a large value is assigned to m_s, hiring many workers to shorten the construction period to less than a day (e.g., a half-day) is not reasonable, in terms of workers' schedule. Therefore, this paper assumes the minimum construction period to be one day in order to derive a formula.

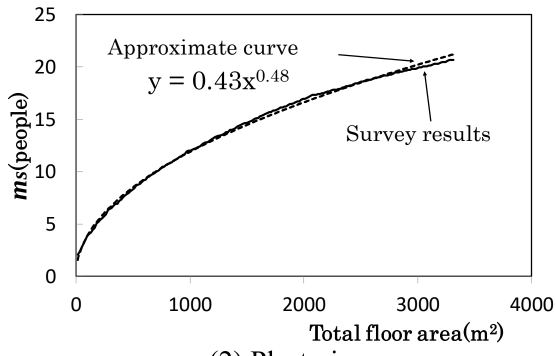
Sasama [10] conducted a questionnaire survey of 10 experts in carpentry and 10 experts in plastering on the standard number of carpenters and plasterers allocated for the construction of one to two story wooden buildings, and derived the relation between the total floor area A of a building and m_s, as shown in Fig. 5. Approximate curves obtained from the assumed Eq. (8) are shown in the figures. In Eq. (8), λ_1 and γ are constants.

$$ m_s = \lambda_1 \times A^{\gamma} \quad (8) $$

Fig. 5 clearly shows that Eq. (8) expresses well the relation between total floor area A and m_s. The values of γ for these approximate curves are 0.64 for carpentry and 0.48 for plastering.



(1) Carpentry



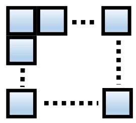
(2) Plastering

Fig. 5 – Standard number of workers m_s and total floor area [10]

In this study, in reference to these values, the value of γ is set to 0.5 in order to devise a formula. When the total floor area A is regarded as the amount of work, Eq.(8) shows that if the amount of work increases by n times, the standard number of workers m_s increases by n^{γ} times.

Here, repair work with the minimum m_s value of 1 is called a unit repair work. There are two cases of unit repair work. Case A is where m_s becomes 1 because the repair work amount (labor amount) is small, and Case B is where m_s becomes 1 because the damaged area is small. Case A occurs when the labor amount is 1. This is because the value of m_s cannot be more than 1 when the labor amount is 1, on the aforementioned assumption that the minimum work period is one day. In contrast, Case B occurs when the damaged area is $1/k_1$. This is because the value of m_s cannot be more than 1 when the damaged area is $1/k_1$. These facts are organized in the fields of "Unit repair work" in Table 2.

Table 2 – Unit repair work and m_s with n times unit repair work

		Unit repair work	Repair work with n times unit repair work
			
Case A	Amount of labor	1	n
	m_s	1	n^{γ}
Case B	Damaged area	$1/k_1$	n/k_1
	m_s	1	n^{γ}

As explained above, when the amount of repair work increases by n times, the standard number of workers m_s increases by n^{γ} times, accordingly. On the other hand, since m_s for the unit repair work is 1, m_s for repair work that is n times the unit repair work is n^{γ}, as shown in Eqs. (9) and (10), in both cases (see Table 2). In Case A, when the amount of labor for repair work that is n times the unit repair work is represented as L_T, then $n = L_T$, because the labor amount of the unit repair work in Case A is 1, as explained earlier. Therefore, m_s for repair work that is n times the unit repair work in Case A is expressed as follows:

$$m_s = n^{\gamma} = L_T^{\gamma} \tag{9}$$

On the other hand, in Case B, when the damaged area of repair work that is n times the unit repair work is represented as ${}_RA$, then ${}_RA = n/k_1$ because the damaged area of the unit repair work in Case B is $1/k_1$. Therefore, m_s for repair work that is n times the unit repair work in Case B is expressed as follows:

$$m_s = n^{\gamma} = ({}_RA \times k_1)^{\gamma} \tag{10}$$

The values of m_s that are calculated in Eqs. (9) and (10) are standard numbers of workers that are determined by the "quantity of damage" and "extent of damage," respectively.

4.2 Repair times IRT_1 and IRT_2 as determined by the quantity and extent of damage

IRT_1, the repair time that is determined by the quantity of damage, is calculated as follows, by substituting Eq. (9) (the standard number of workers determined by the quantity of damage), into Eq. (7) and using the relation of Eq. (6) and $\gamma = 0.5$:

$$IRT_1 = ({}_AD_T \times k_1)^{1-\gamma} = \sqrt{{}_AD_T \times k_1} \tag{11}$$

IRT_2, the repair time determined by the extent of damage, is now examined. ${}_DT$, the repair time for cases where the labor amount L exists within the damaged area, is calculated as follows, using Eq. (7), Eq. (10) (the standard number of workers determined by the extent of damage), and the relation of Eq. (5) and $\gamma = 0.5$:

$${}_DT = \frac{L}{(k_1 \times {}_RA)^{\gamma}} = {}_AD\frac{k_1^{(1-\gamma)}}{{}_RA^{\gamma}} = {}_AD\sqrt{\frac{k_1}{{}_RA}} \tag{12}$$

The relation ${}_DT - {}_RA$, which is obtained by converting the vertical axis ${}_AD$ of the relation ${}_AD - {}_RA$ shown in Fig. 4(1) into ${}_DT$, using Eq. (12), is schematically shown in Fig. 4(2). As shown in the figure, ${}_DT$ does not necessarily increase monotonically, but it can decrease while ${}_RA$ increases. In the example in Fig. 4(2), ${}_DT$ increases in the damaged areas 4, 2, and 3, but it starts decreasing as the damaged area 1 is added. This is because the increase in m_s resulting from an increase in ${}_RA$ is larger than the increase in L due to the addition of the damaged area 1. In a real repair, however, the repair time for the damaged areas 1, 2, 3, and 4 can never be shorter than that for the danaged areas 2, 3, and 4. In reality, repair work for damaged area 1 will be conducted and completed separately while damaged areas 2, 3, and 4 are being repaired, and ${}_AD$ and ${}_RA$ for the damaged area 1 will thus not affect the increase in repair time.

Therefore, Eq. (12) is altered using the effective damaged area ${}_RAe$, which is calculated by subtracting ${}_RA$ for damaged area 1 from ${}_RA_T$, and its time damage quantity ${}_ADe$ ("effective time damage quantity"). IRT_2 is then calculated as shown below. IRT_2, the repair time determined by the extent of damage, is obtained as the maximum value of ${}_DT$ for the relation ${}_DT - {}_RA$.

$$IRT_2 = {}_AD_E\sqrt{\frac{k_1}{{}_RA_e}} \tag{13}$$

5. Damage analysis of buildings with an entire collapse mechanism

5.1 Target building and analysis method

The target building is a five-story RC frame structure with an entire collapse mechanism, as shown in Fig. 6. The clear spans of columns and beams on each floor are 2.8m and 3.8m, respectively. The number of spans in direction X (the direction to be analyzed) is four, with three in direction Y.

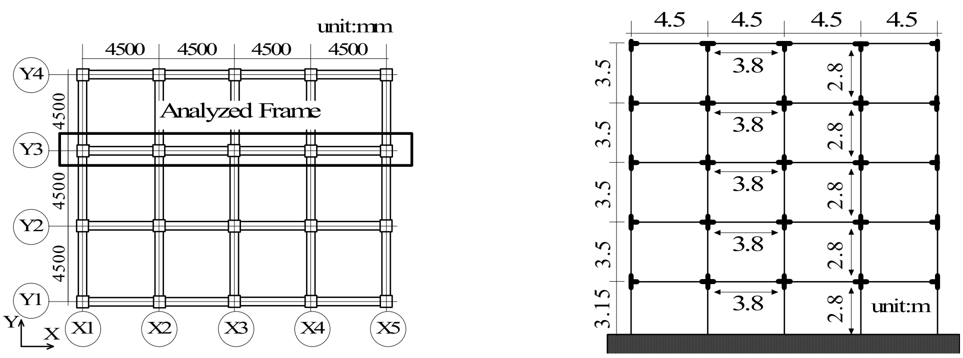


Fig. 6 – Analyzed Building

Table 3 – Analysis cases with different numbers of spans

Analysis case	S3	S7	S15	S31
Number of spans in Y direction	3	7	15	31
Total Floor Area(m^2)	1215	2835	6075	12555

Table 4 – Analysis cases with different quantities of non-structural components

Analysis case	Exterior wall	Door and window on exterior wall	Interior wall	Interior door
N1	0.817	0.09	0.55	0.07
N2	0.727	0.09 × 2	0.55 × 2	0.07 × 2
N3	0.637	0.09 × 3	0.55 × 3	0.07 × 3
		Unit: Quantity of components m^2/floor area m^2		

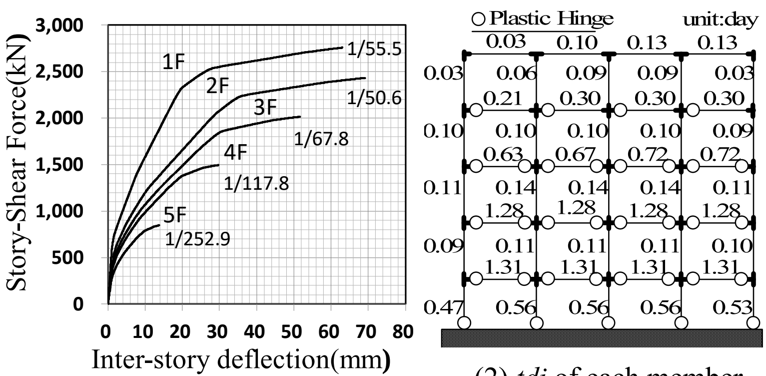
With this as a basic model, analysis was performed on the four cases where the number of spans in the Y direction are changed to 3, 7, 15, and 31 (S3, S7, S15, S31 in Table 3). Further, with reference to Ref.[11], non-structural components (non-structural RC exterior wall, exterior wall door, exterior wall window, partition wall, interior door) were taken into account, with quantities of the three levels (N1, N2, and N3) shown in Table 4. Analysis was conducted on the combinations of these cases; a total of 12 cases (S3N1 to S31N3).

The analysis performed was a push-over analysis that uses *Ai* distribution as external force distribution. Analysis was discontinued as soon as the story drift angle of any story reached approximately 1/50 rad., and damage severity at that time was analyzed. SNAP, a structure calculation program, was used for the analysis. The columns and beams were modeled by line elements with nonlinear springs. The columns have bend springs, shear springs, and axis springs. The beams have bend springs and shear springs. The rigid region of column–beam joints was assumed to be at the face position.

5.2 Damage state and time damage

Fig. 7(1) shows the relation between each story's shear force and inter-story deflection as obtained from the analysis. It shows that the deformation at stories 1, 2, and 3 is larger. Fig. 7(2) shows locations where plastic hinges occurred, and the values of *tdi* , the time damage of columns and beams. It indicates that *tdi* becomes larger for the beams on stories 1 and 2, requiring a repair time of approximately 1.3 days for each component. On the other hand, the colums on story 1 require 0.5 days and the beams on the story 4 require 0.3 days. Representing the severity of damage with a time danage value enables even people without special knowledge to understand the degree of severity of damage at various places within a building.

The damage evaluations of columns, beams, and non-structural components were conducted based on the relation between the time damage *tdi* of each component and the deflection angle, created from the aforementioned database resulting from the research project of the Building Research Institute [5]. Fig. 8 is an example of the relation between the *tdi* of the columns and beams and the deflection angle, used for the damage evaluations.



(1) Inter-story deflection of each story

(2) *tdi* of each member

Fig. 7 – Damage state and time damage *tdi*

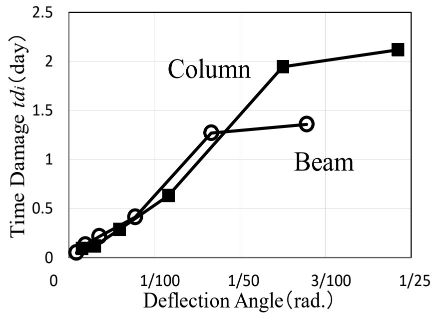


Fig. 8 – Evaluation of time damage for beam and column

6. Examination of appropriateness and usefulness of Ideal Repair Time (IRT)

6.1 Qualitative evaluation for the quantity and extent of damage

Although the entire collapse mechanism delivers greater safety, it allows a large "quantity" and "extent" of damage because it distributes damage throughout the building structure. The index to be proposed should be one that can appropriately evaluate the relative increase in severity (an increase in repair time) that is caused by those factors.

It is shown in Ref.[12] that the relation between the construction period *T* under typical conditions (the standard construction period) and total floor area *A* is expressed as follows:

$$T = \lambda_2 \times A^{\eta} \tag{14}$$

In Eq. (14), λ_2 and η are constants. From Eq. (14), the ratio between the construction period T_0 of a building with total floor area A_0 and construction period T of a building with total floor area A is calculated as follows. Fig. 9 shows Eq. (15) with the parameter η in the form of a graph.

$$\frac{T}{T_0}=\left(\frac{A}{A_0}\right)^{\eta} \tag{15}$$

Usually, η takes values that are greater than zero but less than 1. As seen from Fig. 9, construction with smaller values of η covers cases where an increase in the construction period can be reduced by employing an efficient process design, etc.

It is shown in Ref.[12] that η takes values between 0.09 and 0.4 in construction work, depending on the type of each building. An increase in the total floor area A in the construction of a building is an increase in the quantity and extent of construction work. Therefore, Eq. (14) can be regarded as a relation between the quantity and extent of work and the work period.

An increase in the quantity and extent of damage can be regarded as an increase in the quantity and extent of repair work. Assuming that when the degree of damage is the same, the larger the total floor area of a building, the greater the quantity and extent of damage (i.e. the greater the quantity and extent of repair work), the relation between total floor area of a damaged building and its repair time can also be the same as that of Eqs. (14) and (15). In fact, Suwa [13] analyzed actual repair time in the case of the Kobe earthquake (1995) and derived a relational formula similar to Eq. (14). In this reference paper, the values of η are 0.49 for severe damage and 0.38 for moderate damage (severe/moderate: damage levels as used in Ref.[14]) .

For the reasons above, this paper examines the appropriateness of IRT evaluation for the quantity and extent of damage, using Eqs. (14) and (15), which are applicable to typical construction work and actual repair work. Specifically, IRTs for multiple buildings with varying total floor areas are calculated, and it is studied whether the relation between total floor area and IRT can represent the trends shown by Eq. (14), and

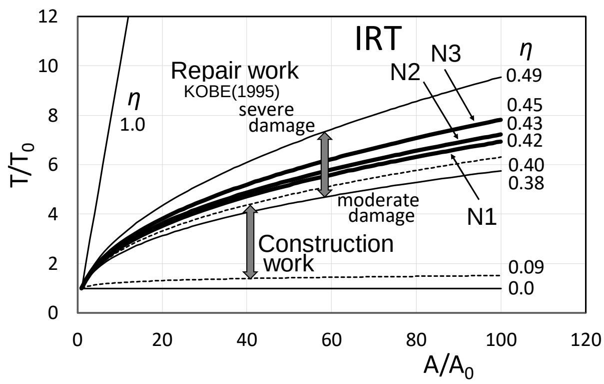


Fig. 9 – Relative increase in repair time with total floor area

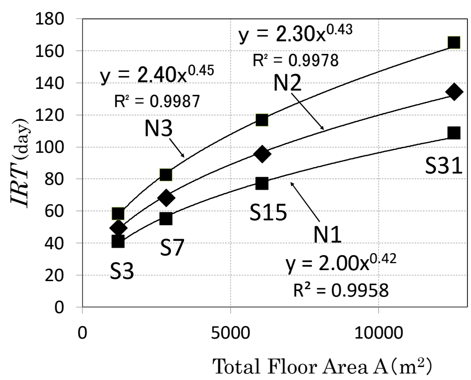


Fig. 10 – Increase in IRT with total floor area

whether η at that time will take an appropriate value. Eq. (15) indicates that η is an important coefficient in relative comparison of repair times, which are the target of evaluation in this study.

Fig. 10 shows IRT as the number of spans in the Y direction increases, changing the total floor area (S3 to S31) for each of the buildings with non-structural components with quantities N1, N2, and N3, with the total floor area on the horizontal axis. In the figure, approximate curves of Eq. (14) are shown, which indicate that the approximate curves with η values of 0.42, 0.43, and 0.45 are sufficiently precise, capturing the tendency to increase.

The aforementioned curves for the typical construction work and actual repair work are shown in Fig. 9: η for moderate damage is about the same as the upper limit for the typical construction work, and η for severe damage is above the upper limit for the construction work. It can be considered that η takes larger values in cases of severe damage because making an efficient repair schedule for severe damage is more difficult than for moderate damage.

The thick solid line in Fig. 9 represents a relative increase in the IRT calculated from Eq. (15) with η values of 0.42, 0.43, and 0.45, compared to those for the aforementioned construction work and actual repair work. The thick solid line is located between the curves for moderate damage and severe damage, which Suwa derived using actual repair times. The deflection angle of beams on stories 1 and 2 of the target building, where damage is severe, is about 1/50 rad.. The damage state of each analysis case can be considered to be between moderate and severe, and 0.42, 0.43, and 0.45 seem appropriate as values of η for the state.

6.2 Quantitative comparison with actual repair time

IRT is a repair time that is determined only by the state of damage (Factors I and II), without considering the effect of Factors III to VIII. The state of Factors III to VIII at each actual site of repair usually differ, and thus repair times vary. Therefore, it is considered that IRT does not match actual repair times. However, IRT is expected to be suitable for use as an estimate of repair time according to the state of possible damage in evaluating the seismic performance of buildings. If IRT differs completely from the actual repair time in quantitative terms, that will be a problem in terms of the usefulness of the index. For this reason, the quantitative relation between IRT and actual repair time is examined below.

Fig. 11 shows the actual repair time [13] of the moderately and severely damaged buildings surveyed by Suwa, with IRT as the total floor area changes (S3 to S31) according to an increase in the number of spans in the Y direction, for each of the buildings with non-structural component quantities N1, N2, and N3, and approximate curves for those IRTs. Since the actual repair time is given in calendar days, the IRT in the figure was converted to the number of calendar days by multiplying it by a correction factor (= 360/(360–77)) in which a total of 77 days per year of Sundays and holidays are assumed to be non-working days.

The plots of actual repair times in Fig. 11 are widely dispersed. This can be because the aforementioned quantity and extent of damage (Factors I and II) can differ even for the same moderately or severely damaged buildings, and because the repair time increases or decreases due to Factors III to VIII, which are unrelated to the damage state. As shown in Fig. 11, the IRT is located almost in the center of the plots for the actual repair time. IRT can thus be considered as capable of producing appropriate results in quantitative evaluation as well.

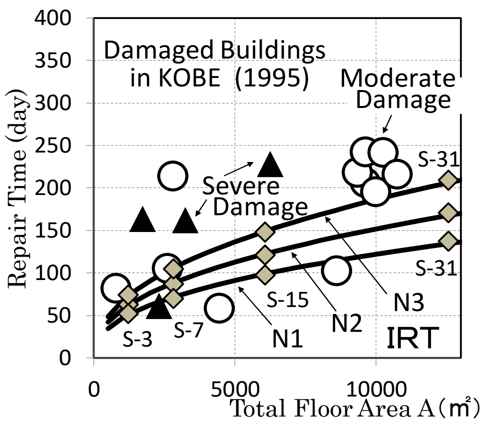


Fig. 11 – Repair time in KOBE earthquake (1995) and IRT

7. Conclusion

In this paper, an index, "Ideal Repair Time (IRT)", was proposed to relatively evaluate the severity of damage to buildings in terms of function recovery after an earthquake, in which the severity of damage was defined as the relative increase of repair time. IRT is expected to be used in setting target performance levels for seismic design aiming to assure damage-resistant performance, and in evaluating the performance levels. The following are considerations on the appropriateness and usefulness of IRT.

1. IRT is not used to evaluate repair time spent at the time of an earthquake (actual repair time). It is a kind of structural performance evaluation index, which evaluates the degree of severity (i.e., repair time)

resulting from the state of damage (Factors I and II: the quantity and extent of damage) in a relative manner. For this reason, the impact of Factors III to VIII shown in Table 1, which are not the state of damage (i.e., factors unrelated to the structural performance of a building, such as the surrounding environment or construction period requested by the owner), were excluded by setting hypotheses for calculation. Actual repair time cannot be used as a structural performance evaluation index, since it varies even for the same state of damage, depending on Factors III to VIII, which are not associated with the structural performance of a building. In contrast, IRT, which is determined only by the state of damage, excluding the effects of Factors III to VIII, is considered useful as an index to evaluate structural performance.

2. On the basis of the relative increase of construction periods as the quantity and extent of building construction work increases, as shown in existing studies, and the relative increase of actual repair time observed for the Kobe earthquake, the paper demonstrated that IRT appropriately evaluates the relative increase of repair time as the quantity and extent of damage increases.

3. IRT, which is determined by Factors I and II, was not significantly different from the actual repair time in the case of the Kobe earthquake and was capable of approximately representing the quantitative increase of actual repair time as the quantity and extent of damage increases. This indicates that Factors I and II (the state of damage) are the main contributing factors to the increase in repair time, and that a design that is based on IRT, which is determined by Factors I and II, is effective in reducing the actual repair time.

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