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DAMAGE EVALUATION OF RC COLUMNS WITH WING WALLS FROM THE VIEWPOINT OF REPAIR TIME

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Abstract

For recent earthquake damage, cases have been reported where continued use of a building was not possible due to damage to non-structural walls, etc, hindering residence and economic activity even though the building itself was safe. Although a design system is required that both assures safety and maintains building functions, an index (a damage evaluation index) required for that purpose has not yet been established satisfactorily to evaluate post-seismic functional recovery.

The authors have proposed a method to evaluate the severity of damage to components from the viewpoint of repair time, based on “Time Damage”. Its characteristics and usefulness are as follows.

1) Time Damage is a kind of damage evaluation index. It grades the severity of damage incurred to components according to the repair time necessary for recovery. With Time Damage, even a person without special knowledge of a building's structure can relatively easily understand the degree of functional obstruction caused by damage.

2) The severity of different types of damage, such as cracks and spalling, can be evaluated uniformly by Time Damage. This makes it possible to compare levels of damage severity, from the viewpoint of functional recovery, to components that incur various kinds of damage simultaneously.

Generally, reinforced concrete (RC) columns with wing walls are excellent components with high rigidity and strength, while their wing wall part may easily be damaged, impeding the maintaining of the functions of a building. The purpose of this paper is to identify seismic performance of RC columns with wing walls from the viewpoint of functional recovery by comparing the Time Damage of RC columns with various kinds of wing walls and RC columns. The insights obtained from this study are as follows.

1) The Time Damage of RC columns with wing walls was about 2.5 times larger than that of RC columns, for drift angle of 1/100 rad, while the Time Damage of the column part of RC columns with wing walls was almost the same as the Time Damage of RC columns. This means that giving consideration to damage to RC columns with wing walls is important in maintaining functions of buildings.

2) The Time Damage of RC columns with wing walls on both sides and RC columns with wing wall on one side was almost the same, while the column part of each type of column showed different states of damage.

3) The Time Damage of RC columns with wing walls having double-layered reinforcement was kept at about two-thirds of that of RC columns with wing walls having single-layered reinforcement. It has been confirmed that increasing the shear reinforcement and thickness of wing walls is effective in suppressing Time Damage.

4) The Time Damage of RC columns with wing walls having spandrel and hanging walls was larger than that of RC columns with wing walls without such walls for drift angle of 1/200 rad, but was almost the same for drift angle of 1/100 rad.

Keywords: column with wing walls, evaluation of damage, time damage, repair time, functional recovery

1. Introduction

For recent earthquake damage, cases have been reported where the continued use of a building was not possible due to damage to non-structural walls, etc, hindering residence and economic activity even though the building itself was safe.[1) et al.] It is necessary to construct a design system that assures both the safety and maintenance of building functions. For that purpose, it is essential that a damage evaluation index is established to evaluate post-seismic functional recovery. However, no satisfactory index has yet been established.

The authors [2)3)] evaluate the severity of damage to rectangular columns, beams, and mullion walls in various failure modes in the context of functional recovery, based on "time damage". Time damage is a kind of damage evaluation index that uses repair time as a scale and permits a unified comparison of various types of damage that happen inside buildings, and of different severities. This index can clearly show the degree of functional loss caused by the damage, making it relatively easy for the general public to understand the severity. [2)]

In general, columns with wing walls are excellent earthquake-resistant elements, having higher rigidity and strength than general columns. However, their wing wall part is more likely to be damaged and it may eventually harm the functional recovery of a building. This study aims to evaluate damage to columns with wing walls based on time damage, and to clarify the impact of columns with wing walls on the functional recovery of a building through comparison with column components.

2. Evaluation of Damage-resistant Performance of Components from the Viewpoint of Functional Recovery

2.1 Relationships between quantity of damage, severity of damage, and loss

In this paper, the relationship between the severity of damage and the quantity of damage is defined by the following equations:

$$\text{Quantity of damage} = \text{severity of damage} \times \text{size of component} \quad (1)$$

$$\text{Loss} = \text{quantity of damage} \times \text{unit price} \quad (2)$$

where the loss means the financial loss (in yen) due to repairs or suspension of functions, and the unit price is the loss per unit quantity of damage. The "size of component" in Eq. (1) is an engineering quantity that indicates the size of a component, such as its surface area or volume. The crack length and the area of spalled concrete are engineering quantities which are related to the repair cost (i.e., the loss in yen) in Eqs. (3) and (5), respectively.

$$\text{Crack repair cost (yen)} = \text{crack length (m)} \times \text{unit repair cost (yen/m)} \quad (3)$$

$$\text{Crack length (m)} = \text{crack rate} \times (\text{surface area of component (m}^2))^{0.5} \quad (4)$$

$$\text{Spalling repair cost (yen)} = \text{area of spalled concrete (m}^2) \times \text{unit repair cost (yen/m}^2) \quad (5)$$

$$\text{Area of spalled concrete (m}^2) = \text{spalling rate} \times \text{surface area of component (m}^2) \quad (6)$$

Comparisons between Eqs. (1)(2) and, Eqs. (4)(3) and Eqs. (6)(5) indicate that both the crack rate and the spalling rate are the severity of damage which is defined above.

2.2 Severity of damage for evaluation of damage-resistant performance of components

Here, the quantity of damage (the "time damage quantity") is defined by the following equation.

$$\text{Time damage quantity} = \text{time required for repair} \times \text{floor space required for repair work.} \quad (7)$$

The time damage quantity is a quantity of damage caused by inhibition of functions, and is expressed in Eq. (7) as a product of the floor space where the function is suspended due to the damage and the duration of that suspension of function.

Considering the “floor space required for repair work” in Eq. (7) as an indicator of the size of a component, as it is greater when the component size is larger, it is recognized that Eq. (7) is in the same form as Eq. (1). Therefore, the “time required for repair” is deemed to be a kind of severity of damage. In this study, the repair time as calculated under the following typical repair conditions is called time damage ${}_td$. The time damage is a kind of damage evaluation index, which grades the relative severity of damage to a component, based on time.

The time damage ${}_td$ is defined by the following equation, based on the method[4)] generally used to calculate the construction period:

$$ {}_td = L / m \tag{8}$$

where L is the quantity of labor (in person-days) required to repair the target component, and m is the number of workers (persons) required to repair the target component.

The above m is the maximum number of workers as determined by the floor space a (m^2) to be used for repair (the “repair area a”). It is calculated by:

$$ m = a \times K \tag{9}$$

where K is a constant value that specifies the maximum number of workers per 1 m^2 of repair area. In this paper, K = 1 person/m^2 is applied throughout for convenience, based on the verification result from a repair time experiment[5)], where it is assumed that for wall repair, the maximum number of workers is one per 1 m^2 of floor space, which is obtained by multiplying 1 m (the distance between elbows of a worker with arms spread wide) by 1 m (the distance from walls).

The definition of the severity of damage varies by type of damage (such as cracks and spalling), as mentioned in 2.1. It is difficult to compare the severity of damage to components on which such different types of damage have occurred at the same time. The time damage, which allows a uniform evaluation of the severity of damage, enables comparison of the severity of damage to components which have suffered more than one type of damage.

By using the “floor unit price” (yen/m^2/day), which indicates the value of the unit floor space per unit time, the time damage quantity is related to the loss (opportunity loss) due to the suspension of function in Eq. (10):

$$ \text{Opportunity loss} = \text{time damage quantity} \times \text{floor unit price.} \tag{10}$$

Both the time damage and the time damage quantity have a definite relation with losses resulting from functional inhibition caused by damage, and are the basic information in the context of discussing the functional recovery of a building. They are also engineering quantities that are relatively easy for the general public to understand.

3. Repair Area and Required Labor Quantity

The repair time of components varies with the repair conditions (such as the peripheral environment, work efficiency, and the number of workers), even if the components are in a similar damage state. In this study, the index (the time damage) that makes a relative evaluation of only the damage state of a component is formulated by assuming standard repair conditions, to eliminate any influence from factors other than the damage state. For example, for the repair area, it is assumed that the space and floor area for repair work are located on the periphery of the component. The methods to calculate the repair area and the labor quantity required for repair, which are necessary to calculate the time damage by using Eq. (8), are described below.

3.1 Specification of repair area *a*

Before starting repair work, it is necessary to prepare the work area on the periphery of the component. An estimation manual[6)] for the repair of public buildings suggests that the work area should be prepared with temporary partitions positioned at a distance of 1 m from the repair target. In this study, it is assumed that the work direction is within the range of a 45-degree angle against the repair target point. The repair area (hatched) against the repair point is as shown in Fig. 1, and the repair area (gray) for a column with wing walls is determined as a set of these points.

3.2 Calculation of the required labor quantity L

The required labor quantity L_i for various types of damage is calculated by the following:

$$L_i = Repair\ work\ Quantity\ Q_i \times \beta_i \tag{11}$$

where β_i represents the repair time coefficient. Research projects[7),8)] of the Building Research Institute examined β_i in various repairs of damage to structures, non-structures and facilities, and compiled a repairability evaluation database. Based on the values of β_i (Table 1), the required labor quantity L in Eq. (8) is calculated by summing the labor quantity Li for various types of damage i as follows:

$$L = \sum L_i. \tag{12}$$

Note that the values of β in Table 1 differ for crack widths of "less than 0.2 mm" and "0.2 mm or wider" because different repair methods are adopted; a sealing method is used for the former and an epoxy resin injection method for the latter. Although the crack rate is defined in Eq. (4), a crack of width less than 0.2 mm is referred to hereafter as "crack rate 1" and a crack of width 0.2 mm or more as "crack rate 2".

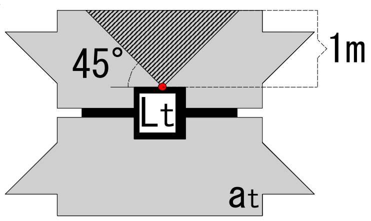


Fig. 1 – Repair area for a column with wing walls

Table 1 – Repair time coefficient β for various types of damage

various types of damage	Repair work Quantity Qi	Repair time cofficient β
crack widths of less than 0.2 mm	Crack length (m)	β_1=0.03 (person-days /m)
crack widths of 0.2 mm or wider	Crack length (m)	β_2=0.24 (person-days/m)
concrete spalling	Area of spalled concrete (m^2)	β_3=7.1 (person-days/m^2)

4. Evaluation of Severity of Damage to a Column with Wing Walls

4.1 Target component to be evaluated

The components evaluated in this study are listed in Table 2. Detailed measurement was conducted of the width and length of cracks and the amount of spalling. Columns with wing walls were divided into three principal categories (the wall categories A, B, and C shown in Fig. 2). Wall category A is a column with wing walls on both sides. Wall category B is a column with wing walls on both sides, having a spandrel and hanging walls, while wall category C is a column with a wing wall on one side having a spandrel and hanging walls.

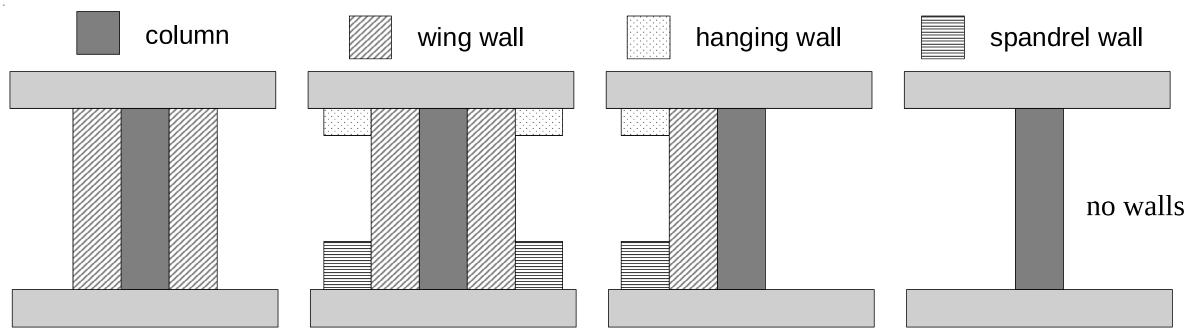
4.2 Method of comparison of damages

In this study, the time damage is used to compare the severity of damage, while the crack rate and spalling rate are used to compare damage states. The time damage used for the purpose of comparison in this study falls into three categories, which are defined below.

The "time damage for the entire column with wing walls" is calculated based on the required labor quantity and the repair area for the entire column with wing walls. The definitional equation and method of determining the repair area are as follows:

$${}_t d_t = \frac{L_t}{a_t \times K} \tag{13}$$

where $_{t}d_{t}$ is the time damage (day) of the entire column with wing walls, L_t is the required labor quantity (person-day) for the entire column with wing walls, a_t is the repair area (m^2) for the entire column with wing walls (see Fig. 1), and K is the maximum number of workers per 1 m^2 of repair area (person/m^2).



A: column with wing walls on both sides

B: column with wing walls on both sides (having spandrel and hanging walls)

C: column with wing wall on one side (having spandrel and hanging walls)

D: rectangular column

Fig. 2 – Wall categories of specimens

Table 2 – List of specimens

component number	component name	wall categories (Fig. 2)	width × length (mm×mm)	main reinforcement ratio Pg(%)	shear reinforcement ratio Pw(%)	wing wall thicknesses (mm)	wing wall length (mm)	height (mm)	inflection height ratio	wing walls	spandrel and hanging walls	reinforcement of wall	Psh※3(%)
①	CWW-D-N[9)]	A	700×700	1.65	0.72	200	700	2800	0.5	both sides	absence	double	0.71
②	CWW-D[10)]	B									presence		
③	CW-T-D[10)]	C								one side			
④	CW-C-D[10)]	C											
⑤	CWW-SL[11)]	B	675×675※1	2.26	1.06	120※1	675※1	2275※1	1	both sides		single	0.47
⑥	CWW-DL[11)]	B				210※1						double	0.53
⑦	rectangular column[12)]	D	700×700※2	1.99	1.42			2450※2	0.5				

※1 : multiplied by 3/2 to convert to full scale ※2 : multiplied by 7/4 to convert to full scale ※3 : shear reinforcement ratio of wall

The "time damage of the column section/wing wall sections" is calculated based on the required labor quantity and repair area for the respective sections. The definitional equations and method of determining the repair area are as follows:

$$_{t}d_{c} = \frac{L_c}{a_c \times \mathrm{K}} \tag{14}$$

$$_{t}d_{w} = \frac{L_w}{a_w \times \mathrm{K}} \tag{15}$$

where $_{t}d_{c}$ is the time damage (day) of the column section only, $_{t}d_{w}$ is the time damage (day) of the wing wall sections only, L_c is the required labor quantity for the column (person-day), L_w is the required labor quantity for the wing walls (person-day), a_c and a_w are the repair areas of the column and wing walls (m^2) (see Fig. 3), and K is the maximum number of workers per 1 m^2 of the repair area (person/m^2).

The "sharing of time damage severity of the column/wing walls" is calculated based on the required labor quantity of the respective part and the total repair area of the column with wing walls. The definitional equations and method of determining the repair area are as follows:

$$_{t}d_{c}' = \frac{L_c}{a_t \times \mathrm{K}} \tag{16}$$

$$_{t}d_{w}' = \frac{L_w}{a_t \times \mathrm{K}} \tag{17}$$

where ${}_td_c^{\prime}$ is the sharing of time damage of the column (day), ${}_td_w^{\prime}$ is the sharing of the time damage of the wing walls (day), L_c and L_w are the required labor quantity for the column/wing walls (person-day) (see Fig. 4), a_t is the repair area of the entire column with wing walls (m^2), and K is the maximum number of workers per 1 m^2 of the repair area (person/m^2).

It should be noted that although the value obtained as the sum of the respective sharing of time damage of a column and wing walls (${}_td_c^{\prime}$, ${}_td_w^{\prime}$) defined above corresponds to the time damage (${}_td_t$) of the entire column with wing walls (${}_td_c^{\prime} + {}_td_w^{\prime} = {}_td_t$), the value obtained as the sum of the time damage of the column section and the wing wall sections (${}_td_c + {}_td_w$) does not correspond to the time damage of the entire column with wing walls.

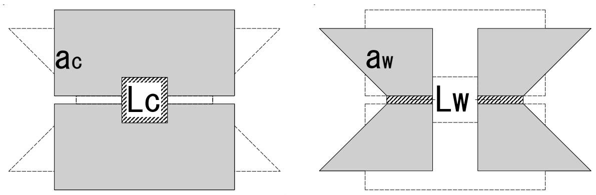


Fig. 3 – Repair area when determining the time damage of a column section (left) or wing wall sections (right)

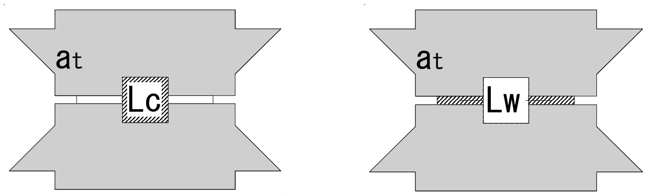


Fig. 4 – Repair area when determining the sharing of the time damage of a column (left) and the wing walls (right)

5. Comparison of Time Damage of Respective Specimens and Trend Analysis

The trend of the time damage of columns with wing walls are analyzed, based on the following four comparisons:

(1) rectangular columns and columns with wing walls;

(2) columns with wing walls on both sides and columns with a wing wall on one side;

(3) differences in wing wall thicknesses and the amount of shear reinforcement;

(4) the effect of a spandrel and hanging walls connected to wing walls.

When the damage to a component is severe, the damaged part is removed and replaced, but to consider time damage at this time makes the trend complicated. To avoid complexity, the comparison in this study is performed based on the time damage before removal and new construction.

5.1 Rectangular columns and columns with wing walls (CWW-D-N)

A rectangular column and a column with wing walls on both sides (CWW-D-N) are compared, to examine how the wing walls attached to the column affect the time damage and the damage state of the components.

The time damages of a column with wing walls on both sides and a rectangular column are shown in Fig. 5. At 1/400 rad, the time damage of a column with wing walls and that of a rectangular column are almost the same, although that of the column with wing walls slightly exceeds that of the rectangular column. At 1/100 rad, however, the time damage of the column with wing walls is about 2.5 times that of the rectangular column. The time damages for the column section (${}_td_c$) and the wing wall sections (${}_td_w$) are provided in the figure. It shows that the time damage of the wing wall sections is about 2.5 times as much as the time damage of the column section, suggesting that the wing walls are dominant in the time damage of the column with wing walls. Fig. 6, where the sharing of the time damage of the column and wing walls (${}_td^{\prime}_c$, ${}_td^{\prime}_w$) are compared, also indicates that the damage to the wing walls is dominant. Next, the time damage (${}_td_c$) of the column section shown in Fig. 5 and the time damage of the rectangular column (${}_td_t$) are compared. They have almost the same value, but the time damage of the column section of the column with wing walls is slightly smaller at a drift angle of 1/200 rad or smaller.

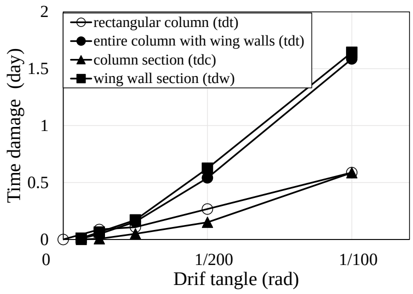


Fig. 5 – Comparison of the time damage of a column with wing walls and a rectangular column

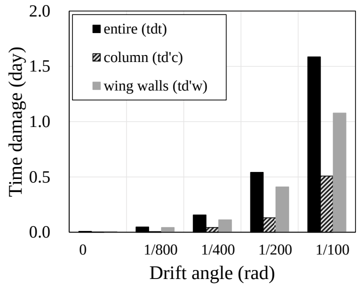
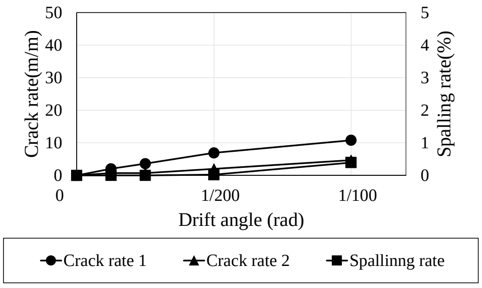


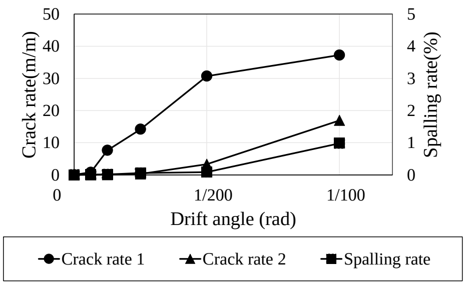
Fig. 6 – Sharing of time damage of a column with wing walls

The time damage of a column with wing walls and that of a rectangular column were compared, and a difference was observed between these two components. The cause of such difference is analyzed below, based on the damage state (crack rate and spalling rate).

First, the reason was examined for the time damages of the rectangular column and the column with wing walls being almost the same at a drift angle of 1/400 rad or smaller, while a difference of about 2.5 times was observed at 1/100 rad, as shown in Fig. 5. Fig. 7 compares the crack rates and spalling rates of these two components.



(a) Rectangular column

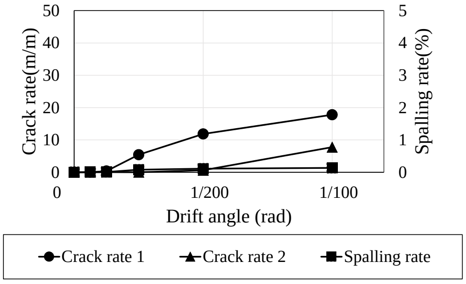


(b) Column with wing walls

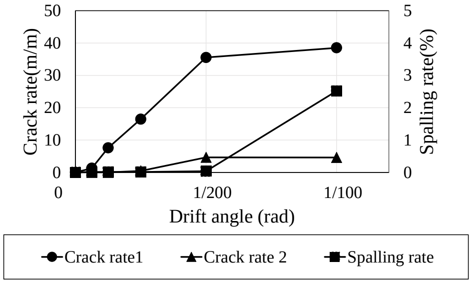
Fig. 7 – Crack rate and spalling rate of a column with wing walls and a rectangular column

Fig. 7 shows that crack rate 1 of a column with wing walls is about three times bigger than that of a rectangular column at a drift angle of 1/400 rad or smaller, while their crack rate 2 and spalling rates are almost the same. As shown in Table 1, the repair time coefficient β of crack rate 1 that is used to obtain the time damage is smaller than that of crack rate 2 or the spalling rate, and thus has less impact on the time damage. This means that even though there was a difference of about three times in crack rate 1 at 1/400 rad, it is a minor difference in the overall time damage. Accordingly, it is considered that the time damage of a rectangular column and that of a column with wing walls were almost the same at a drift angle of 1/400 rad or smaller. In addition, the figure shows that the time damage of a column with wing walls exceeds that of a rectangular column for any type of damage at a drift angle of 1/200 rad or more. It is considered that such difference is the reason why the time damage of a column with wing walls greatly exceeds that of a rectangular column.

Next, the reason why wing walls are dominant in the time damage of a column with wing walls is examined. In order to understand the damage state of a column with wing walls, the crack rate and spalling rate of the column and wing wall sections are shown in Fig. 8.



(a) Column section of a column with wing walls

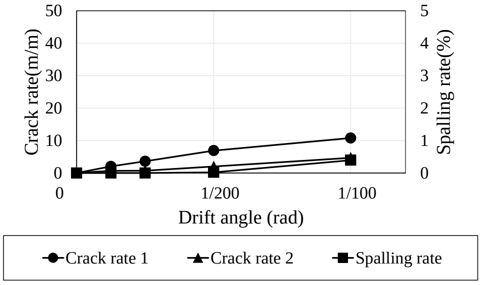


(b) Wing wall section of a column with wing walls

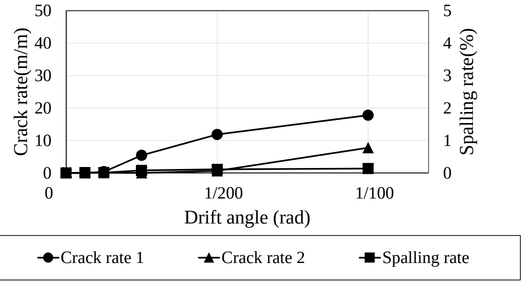
Fig. 8 – Crack rate and spalling rate of a column with wing walls

When the crack rates and spalling rates are compared, as shown in the above figure, it is seen that the wing walls have more damage in all cases except for crack rate 2 at 1/100 rad. It is considered that crack rate 2 of the wing walls was at a low level in the range from 1/200 rad to 1/100 rad because the damage was so severe, resulting in a transition from cracking to spalling. In the comparison between the two, the increase in spalling on the wing walls is particularly remarkable at a drift angle of 1/200 rad or more. This is considered to be the reason for the time damage ($_td_w$) of wing walls being dominant in the time damage ($_td_t$) of a column with wing walls.

Finally, the reason why the time damage of a rectangular column and that of the column section of a column with wing walls were almost the same is examined. The crack rate and the spalling rate of each are shown in Fig. 9.



(a) Rectangular column



(b) Column section of a column with wing walls

Fig. 9 – Comparison of crack rate and spalling rate of the column section of a column with wing walls and a rectangular column

As shown in Fig. 9, the column section of the column with wing walls exceeds the rectangular column in the cases of crack rates 1 and 2 at 1/100 rad, while the rectangular column has the larger spalling rate. It is considered that the magnitude relation of the crack rates and spalling rate are offset, resulting in the time damages of the rectangular column and the column section of the column with wing walls being almost the same.

5.2 A column with wing walls on both sides and a column with a wing wall on one side

Three components, CWW-D (a column with wing walls on both sides), CW-C-D (a column with a wing wall on one side), and CW-T-D (a column with a wing wall on one side), are compared to examine how the time damage and the damage state vary on a column with wing walls on both sides and a column with a wing wall on one side.

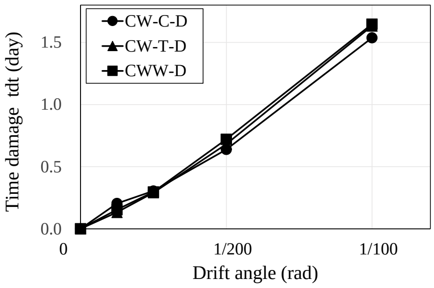
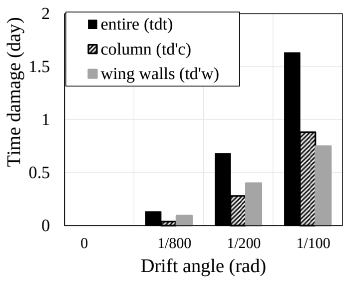
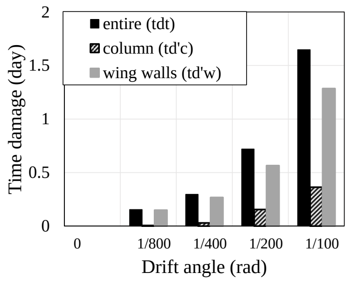


Fig. 10 – Comparison of the time damage (${}_td_t$) of three components



(a) Sharing of the time damage on CW-T-D



(b) Sharing of the time damage on CWW-D

Fig. 11 – Sharing of the time damage

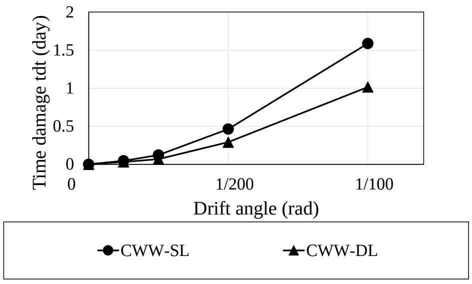
Fig. 10 shows the time damage (${}_td_t$) of the three components. Fig. 11 shows the sharing of the time damage of two of the components, CW-T-D (a column with a wing wall on one side) and CWW-D (a column with wing walls on both sides). As shown in Fig. 10, the time damages (${}_td_t$) of the column with wing walls on both sides and the column with a wing wall on one side are almost the same. However, while the sharing of the time damage of the column section and that of the wing walls are almost the same on a column with wing walls on one side, as shown in Fig. 11(a), the sharing of the time damage of the wing wall sections on a column with wing walls on both sides is about three times larger than that of the column section, as shown in Fig. 11(b).

Based on the above, it is found that although the time damage of the whole component is almost the same for a column with wing walls on both sides and a column with a wing wall on one side, the details of their damage states differ.

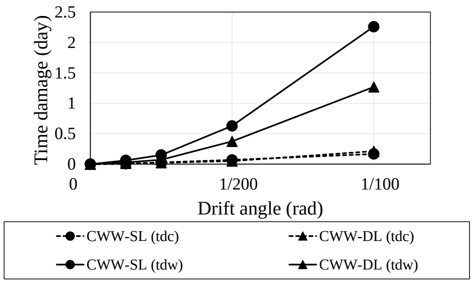
5.3 Differences in the wing wall thickness and the amount of shear reinforcement

Two components, CWW-SL (a single-layered reinforcement) and CWW-DL (a double-layered reinforcement), are compared to examine how a difference in wing wall thickness and the amount of shear reinforcement affect the time damage and the damage state.

The time damage (${}_td_t$, ${}_td_c$, ${}_td_w$) of two components are shown in Fig. 12. As shown in Fig. 12(a), CWW-SL exceeds CWW-DL for the time damage (${}_td_t$) of the entire component, and as shown in Fig. 12(b), CWW-SL is larger than CWW-DL for the time damage (${}_td_w$) of the wing wall sections. However, there is almost no difference between these two components for the time damage (${}_td_c$) of the column section. It is accordingly considered that the differences in thickness of the wing walls and amount of reinforcement do not influence the damage to a column. It means that the difference in the time damage (${}_td_t$) of the entire component shown in Fig. 12(a) was caused by damage to the wing wall sections.



(a) Entire component (${}_td_t$)



(b) Column section only (${}_td_c$)/wing walls section only (${}_td_w$)

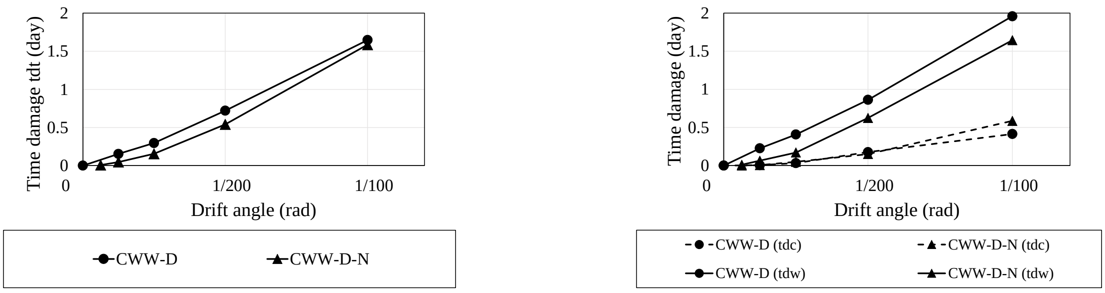
Fig. 12 – Comparison of the time damage of columns with wing walls having different wall thicknesses and amounts of shear reinforcement

From the finding described above, it is considered that the differences in wall thickness and the amount of shear reinforcement of wing walls substantially affect the damage to wing walls, causing the time damage to vary. Meanwhile, differences in the wing wall thickness and amount of shear reinforcement have almost no effect on damage to the columns.

5.4 Impact of spandrel and hanging walls connected to wing walls

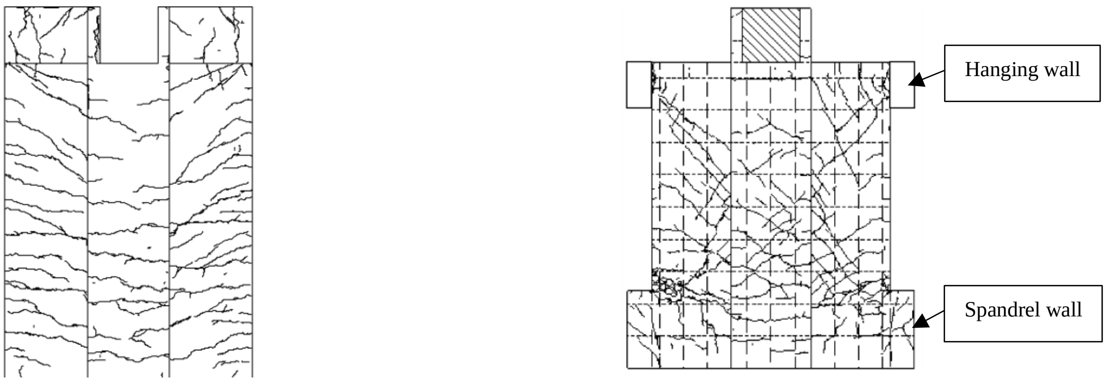
Two components, CWW-D-N (absent) and CWW-D (present), are compared to examine how the presence or absence of a spandrel and hanging walls affect the time damage and damage state.

Fig. 13 shows the time damage (${}_td_t$, ${}_td_c$, ${}_td_w$) of the two components. Fig. 13(a) shows a small difference between the time damages (${}_td_t$) of the entire components at drift angles of up to 1/200 rad, and a still smaller difference at 1/100 rad. In Fig. 13(b) there is almost no difference in the time damage (${}_td_c$) of the column section of these components at 1/200 rad, while there is a difference in the time damage (${}_td_w$) of the wing wall sections. It is accordingly considered that the difference in the time damage of the entire components is caused by the damage state of the wing walls.



(a) Entire component (${}_td_t$) (b) Column section (${}_td_c$)/wing wall section (${}_td_w$)

Fig. 13 – Comparison of time damage of column with wing walls having spandrel and hanging walls



(a) CWW-D-N (b) CWW-D

Fig. 14 – State of damage to the components at 1/200 rad

Fig. 14 shows the damage state of the respective components at 1/200 rad. As shown in the figure, the damage is comparatively uniformly dispersed over the entire component with no spandrel or hanging walls (CWW-D-N), while the damage is concentrated on the connecting parts between the wing walls and the spandrel and hanging walls in the case of the component with a spandrel and hanging walls (CWW-D). It is accordingly considered that when wing walls have a spandrel and hanging walls attached, damage to the connecting parts starts at an early stage, and the damage being concentrated on the connecting parts accelerates its progresssion.

6. Conclusion

In this study, the damage-resistant performance of columns with wing walls was evaluated based on the time damage. The following findings were obtained.

(1) Comparison of a rectangular column and a column with wing walls

· The time damage (${}_{t}d_{t}$) of a column with wing walls is about 2.5 times greater than the time damage of a rectangular column. It is important to consider damage to columns with wing walls when discussing the functional recovery of a building.

· On a column with wing walls, the time damage (${}_{t}d_{w}$) of the wing wall section is about 2.5 times greater than the time damage (${}_{t}d_{c}$) of the column section, and the difference between them is caused by spalling on the wing wall sections.

· The time damage (${}_{t}d_{c}$) of the column section of a column with wing walls is of about the same value as the time damage of a rectangular column.

(2) Comparison of a column with wing walls on both sides and a column with a wing wall on one side

· The time damage (${}_{t}d_{t}$) of a column with wing walls on both sides and that of a column with a wing wall on one side are of almost the same value.

(3) Difference in wall thicknesses and the amount of shear reinforcement of wing walls

· The time damage (${}_{t}d_{t}$) of a column with wing walls having a double-layered reinforcement is about two-thirds of that with a single-layered reinforcement, and thus it is confirmed that increases in wall thickness and the amount of shear reinforcement in wing walls reduce the time damage.

· The difference in time damages (${}_{t}d_{t}$) between columns with wing walls having either a double-layered reinforcement or a single-layered reinforcement is caused by damage to the wing wall section.

(4) Effect of a spandrel and hanging walls connected to wing walls

· At 1/200 rad, the time damage (${}_{t}d_{t}$) of a column with wing walls having a spandrel and hanging walls exceeds that of a column with wing walls having no spandrel or hanging walls, but the values are almost the same at 1/100 rad. It is considered that the difference observed at 1/200 rad is caused by damage to and around the connecting parts of the spandrel and hanging walls.

Acknowledgments

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