AXIAL LOAD CARRYING CAPACITY OF R/C COLUMNS WITH SIDE-WALLS

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1 INTRODUCTION

Recent earthquake resistant design concept of structures places explicit emphases on limit state design. Regarding reinforced concrete members three limit states have been discussed, i.e. operation limit state, repair limit state and safety limit state. In the limit state design procedures a variety of evaluating methods of performances of members are expected to be proposed, i.e. initial stiffness, cracking strength, yield strength and deformation for operation limit state, reparability (crack width and concrete crush) for repair limit state and shear strength, deformation capacity, axial load carrying capacity for safety limit state.

On the other hand columns with side walls are widely used mainly in low rise R/C buildings. One of the benefit of side walls is that side walls are effective to enhance performance regarding operation limit state and repair limit state as well as safety limit state. In other words columns with side walls show higher elastic stiffness and higher reparability comparing to isolated columns for example.

However their behavior regarding three limit states mentioned above have not been clearly understood. The objectives of this study were to propose evaluating methods of a variety of performance listed above. In this paper axial load carrying capacity of side walls connecting with reinforced concrete columns subjected to high axial load was discussed.

2 OUTLINE OF TEST

2.1 Specimens

Table 1 shows main variations of specimens. Six column specimens were examined[1,2,3]. Main variables of those specimens were existence of side walls, direction of side walls to loading direction (parallel or crossing), location of side walls (centric or eccentric) and loading method of lateral force (two directional loading or one directional loading). Figure 1 shows sections and loading directions of six specimens. Table 2 shows properties of specimens. Figure 2 shows examples of reinforcement of specimen. Table 3 shows characteristics of materials.

Specimen C-5 with a square section representing a prototype column was subjected to one directional lateral load under constant high axial load. Specimens CSW-1and CSW-2 with side walls located at the center of the column were also subjected to one directional lateral load under constant high axial load. The lateral loading direction of these two specimens was parallel to the side walls, which meant those side walls were expected to be effective for axial load resistance, moment resistance and shear resistance. From this view point hoop type reinforcement was adopted for side walls of these specimens.

Specimen CSWTR-1 with side walls located at the center of the column was subjected to one directional lateral load under constant high axial load. The lateral loading direction of the specimen was crossing at right angles to the side walls, which meant the side walls were expected to be effective for axial load resistance only. Although hoop type reinforcement was known to be effective for axial load resistance, single reinforcing bar was arranged in the side wall of this specimen for practical use.

Effects of loading direction should be taken into account because crossing side walls to main loading direction are easily damaged by parallel loading direction to the side wall. From this view point specimen CSWTR-2 with the same section as specimen CSWTR-1 was scheduled to be subjected to two directional loading.

Expected damage under main loading of eccentrically located side walls used in specimen CSWTR-3 is more severe than that of centrally located side walls in specimen CSWTR-2. This is because the contribution for shear and moment resistance of eccentrically located side walls is larger than that of centrally located side walls. From this view point specimen CSWTR-3 was planed.

2.2 Loading method

All specimen were subjected to constant axial load and the antisymmetric moment reversals. The two directional loading system was composed by pre loading and main loading. At first the lateral load was reversed at the drift angle of 1/150 rad twice in the parallel direction to the side wall (this is called pre loading) and then the main load was applied in the crossing direction to the side wall (this is called main loading).

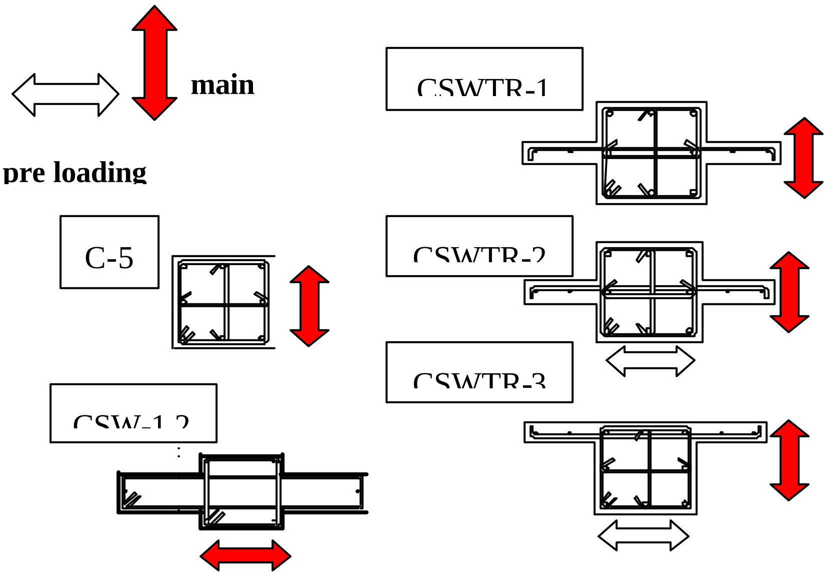


Fig. 1 Section and loading direction

Table 1 Main variation of specimen

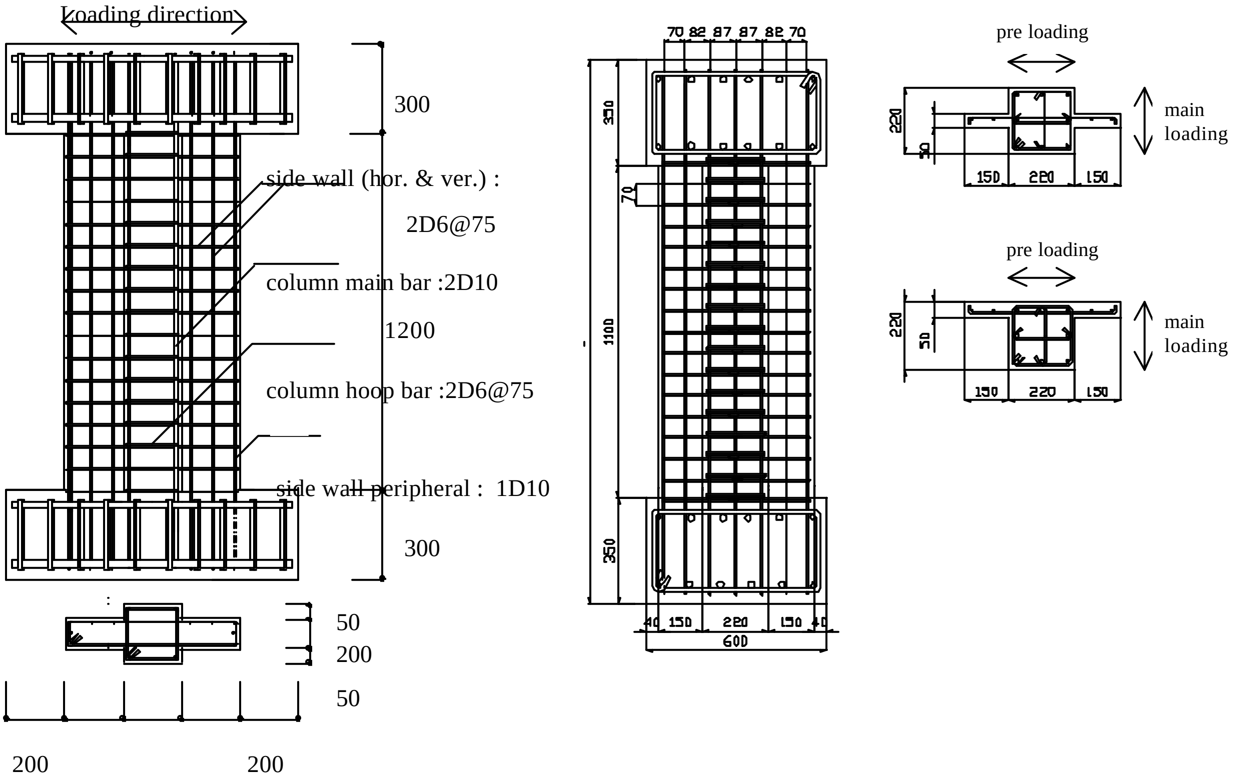
specimen	side wall	lateral force loading method
CSW-1	central	one directional (parallel to side wall)
CSW-2		
C-5	none	one directional
CSWTR-1	central	one directional (crossing side wall)
CSWTR-2		two directioanl
CSWTR-3	eccentrical	

Table 3 Characteristics of materials

	CSW-1,2		C-5、CSWTR-1		CSWTR-2、3	
	D6	D10	D6	D10	D6	D10
yield strength (MPa)	336	391	314	378	302	474
maximum strength (MPa)	512	541	483	517	389	543

Table 2 Properties of specimens

name	column section	side wall(one side)	height of column	total main bar of column	hoop (ratio)	peripheral reinforcement of side wall	reinforcement of side wall	concrete strength (MPa)	axial load (kN)
CSW−1	200×200mm	100×200mm	1200mm	4-D10	2-D6@75	1-D10	2-D6@75 (0.85%)	29.6	473
CSW−2									769
C−5	220×220mm	none	1100mm	8-D10	3-D6@70 (0.62%)	none	none	26.1	778
CSWTR−1		50×150mm				1-D6	1-D6@70 (0.91%)		
CSWTR−2									784
CSWTR−3									



(a)Specimen CSW-1,2 (b)Specimen CSWTR-1,2,3

Fig. 2 Example of reinforcement of specimen

3 EFFECTS OF PARALLEL SIDE WALLS TO LOADING DIRECTION

3.1 Test result of specimens CSW-1,2

Figure 3 shows relationship between lateral load and lateral deflection angle and relationship between axial strain and lateral deflection angle of specimens CSW-1 and CSW-2 with parallel side walls to loading direction. Lateral deflection angle was defined as lateral deformation divided by column height and axial strain was defined as axial deformation of the column divided by column height. These two specimens had same column sections and reinforcement. Only applied axial load was varied. The axial load ratios defined as axial load divided by axial compressive strength of column section only (side walls and reinforcement were ignored) were 0.4 for specimen CSW-1 and 0.65 for specimen CSW-2.

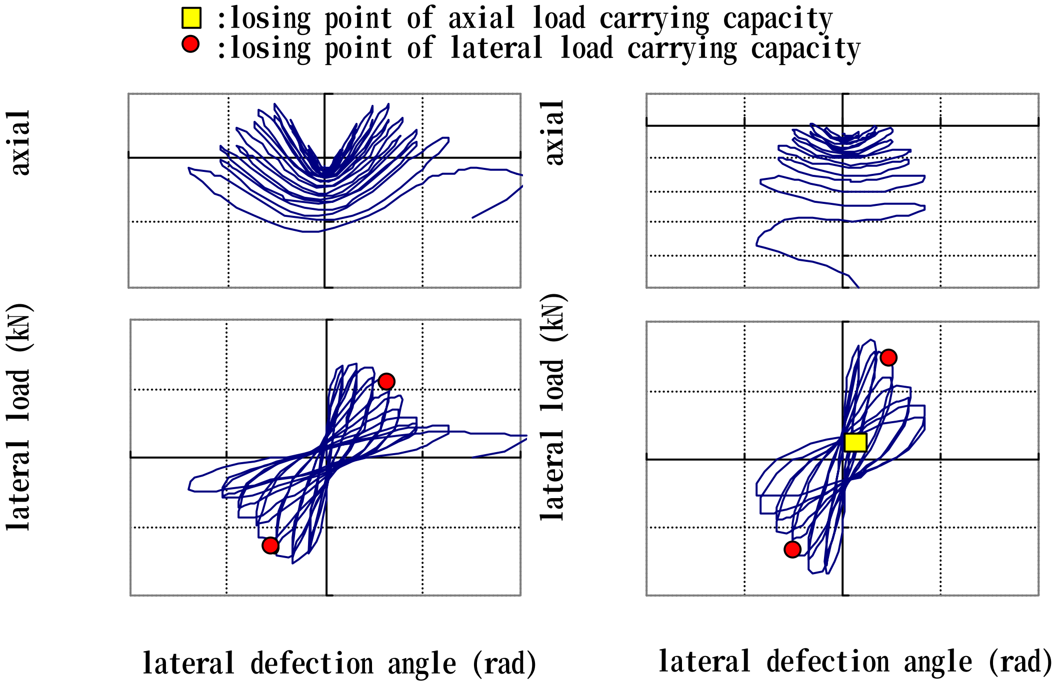
Circle marks in Fig. 3 represent losing points of lateral load carrying capacities defined as points where restoring force degraded to 80% of the maximum strength. Square mark in Fig 3 represents losing points of axial load carrying capacities defined as points where scheduled axial force could not be applied in the test. In specimen CSW-1 with smaller axial load ratio, losing point of axial load carrying capacity could not be observed. In other word the loading was terminated before the specimen lost it’s axial load carrying capacity in this specimen.

3.2 Axial load carrying capacity of parallel side wall

Figure 4 shows two square section analogy models which can be used to explain the behavior of columns with parallel side walls to loading direction. In the early loading stage with slight damage in side walls side wall model is appropriate to explain the behavior of column with side walls. However with increasing the damage of side wall the behavior tend to match with the column model ignoring side walls in compression. Consequently the behavior of columns with side walls in the parallel direction to loading direction can be obtained as envelope curve of two square section analogy models.

Figure 5 shows comparison between two square section analogy model and experiment. Evaluated flexural strength and axial load carrying capacity using each analogy model are shown in straight lines in this figure. The behavior of columns with side walls in the parallel direction was found to be expressed by envelope curve of two square section analogy models.

As mentioned before axial load carrying capacity of specimen CSW-1 was not observed. So the feasibility of the model can not be discussed in this specimen. However the axial load carrying capacity of specimen CSW-2, the loading of which was terminated by losing axial load carrying capacity, was roughly estimated by column model. In other words the effect of parallel side walls to loading direction on axial load carrying capacity was found to be small.



(a)Specimen CSW-1(η =0.4) (b)Specimen CSW2(η =0.65)

Fig. 3 Lateral load, axial strain – lateral deflection relations of specimens with parallel side walls to loading direction

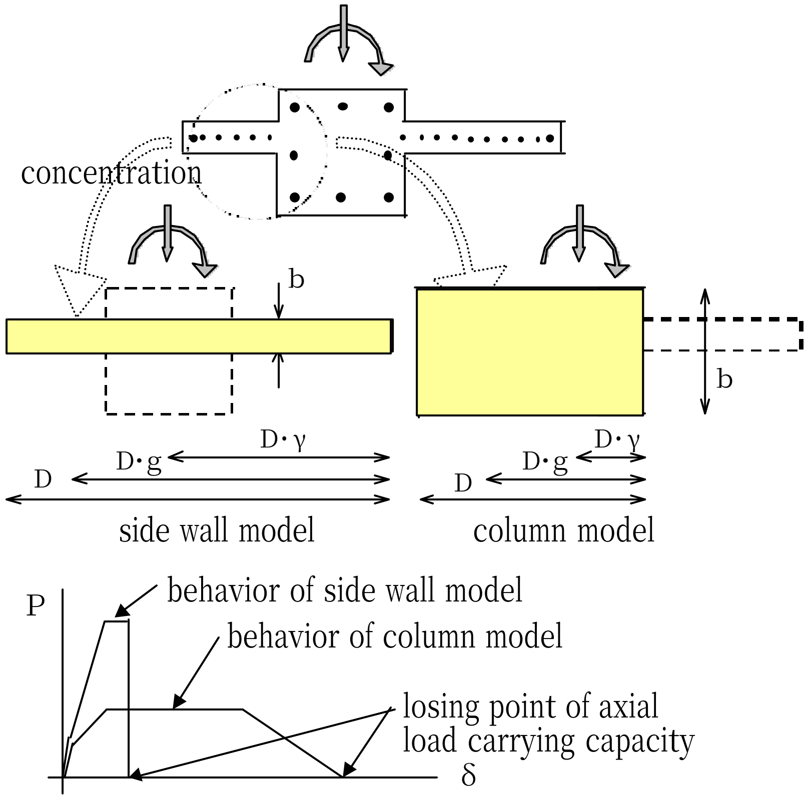
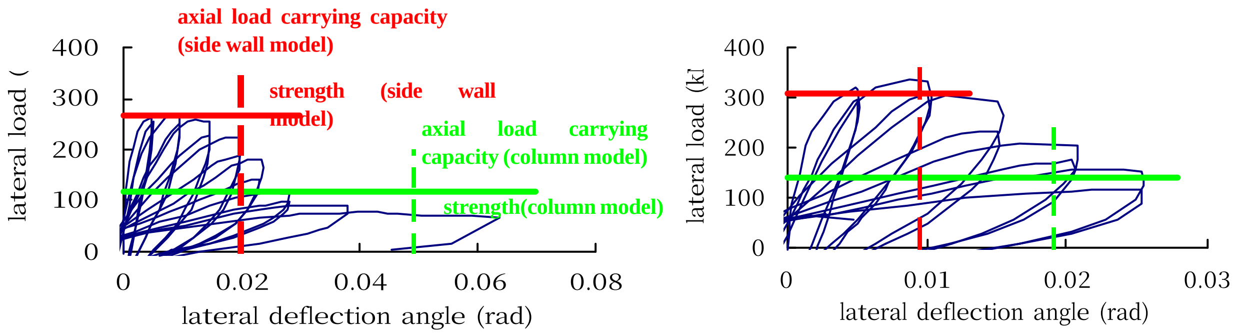
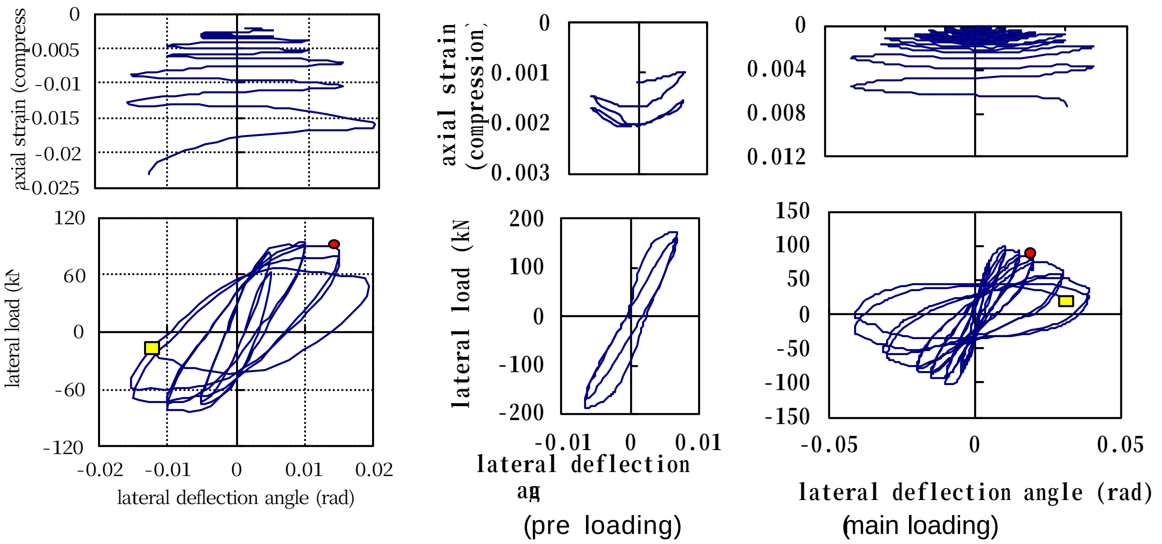


Fig. 4 Two square section analogy models of column with side wall

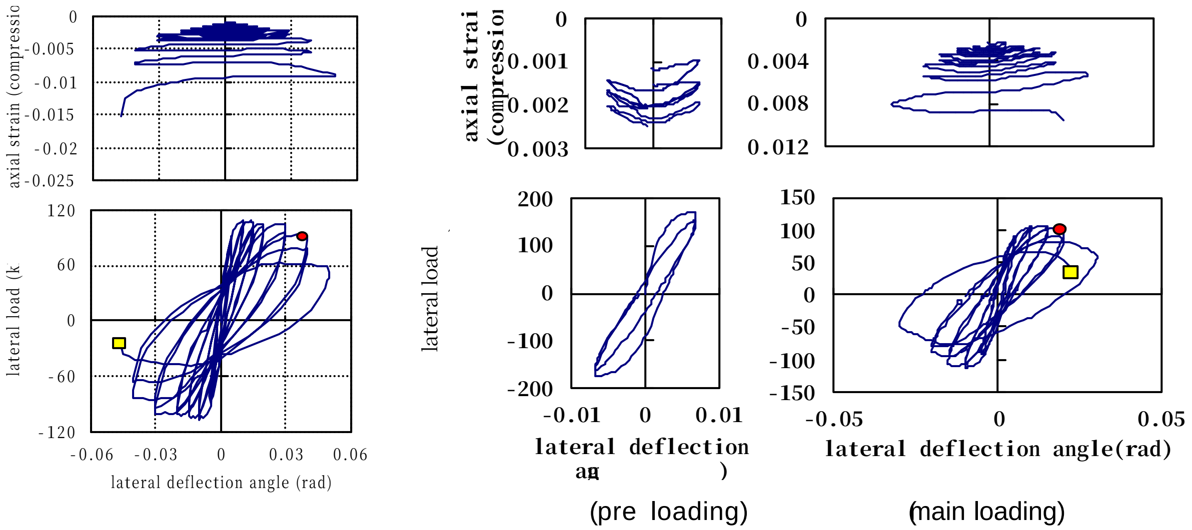


(a)Specimen CSW-1 (b)Specimen CSW2

Fig. 5 Comparison between analogy models and experiment



(a)Specimen C-5 (c)Specimen CSWTR-2



(b)Specimen CSWTR-1 (d)Specimen CSWTR-3

Fig. 6 Lateral load, axial strain – lateral deflection relation of specimens with crossing side walls to main loading direction

4 EFFECTS OF CROSSING SIDE WALLS TO LOADING DIRECTION

4.1 Test result of specimens C-5 and CSWTR-1,2,3

Figure 6 shows relationship between lateral load and lateral deflection angle and relationship between axial strain and lateral deflection angle of specimens C-5 and CSWTR-1,2,3 with crossing side walls to loading direction. Square marks in Fig. 6 represent losing points of axial load carrying capacities. As shown in this figure losing points of axial load carrying capacity were observed in all specimens.

Figure 7 compares envelope curves of specimens with crossing side walls to loading direction. Results of comparisons regarding axial load carrying capacities between each specimen are summarized as follows. Side walls located at the center of the column enhanced the axial load carrying capacity (comparison between specimen C-5 and specimen CSWTR-1). However the effect decreased by two directional loading (comparison between specimen CSWTR-1 and specimen CSWTR-2). In other words damage of side walls due to lateral loading parallel to side walls (pre loading) lead to loss of axial load carrying capacity. Furthermore the effect decreased in case of side walls located eccentrically (comparison between specimen CSWTR-2 and specimen CSWTR-3). This is because damage of eccentrically located side walls used in specimen CSWTR-3 was more severe than that of centrally located side walls in specimen CSWTR-2. This is because the contribution for shear and moment resistance of eccentrically located side walls was larger than that of centrally located side walls.

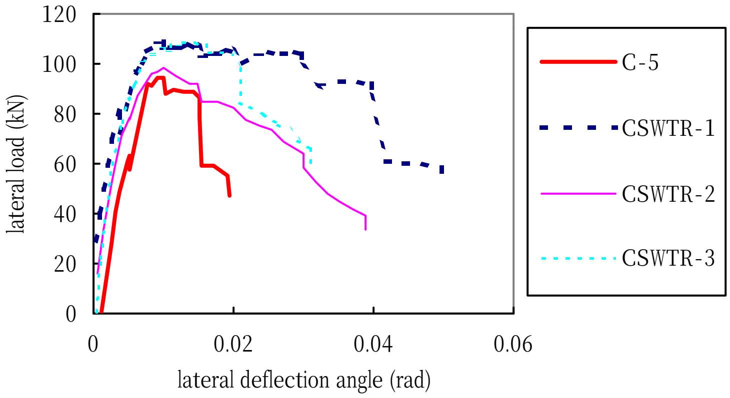


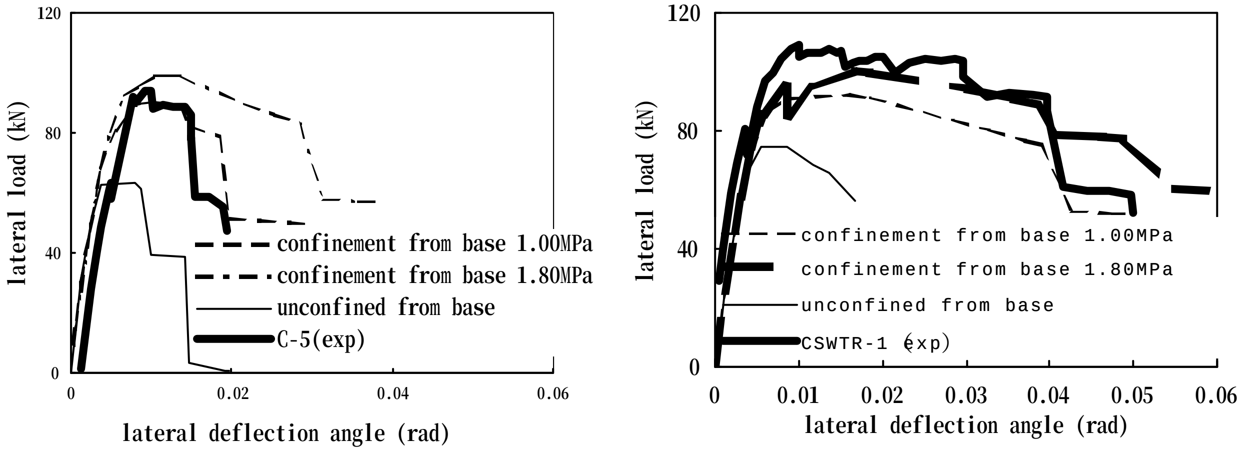
Fig. 7 Compariosn of envelope curve of column with crossing side walls

4.2 Comparison with flexural analysis

Effects of side walls on load deflection behavior are discussed through flexural analysis based on the theory assuming plane remains plane after bending[4] in this section. Figures 8(a)(b) show comparison between experiment and calculations of Specimen C-5, isolated column specimen (Fig.(a)) and Specimen CSWTR-1, column with non-damaged (i.e. without pre loading) side walls (Fig.(b)). One of the characteristics of the flexural analysis used in this paper was consideration of confinement from rigid base stub to column concrete of the hinge regions. In the previous paper[4] confinement stress of 1.80MPa was suggested. This confinement can be used adding it's stress to normal confinement stress from hoop reinforcement.

In Figures 8(a)(b) confinement from base stub was varied; i.e. 1.80 MPa as suggested in Ref[4], 1.00 MPa and 0.00 MPa which means no confinement from base. All cases were calculated until those columns lost their axial load carrying capacities; i.e. the last point of the curve denotes the specimen's axial load carrying capacity. Thin solid lines in Figures 8(a)(b) which denote no confinement from base underestimate the observation remarkably. On the other hand calculations using confinement stress of 1.00 MPa show good estimation for both Specimen C-5 and Specimen CSWTR-1.

Figure 9 shows trial to determine effective length of pre damaged side walls of specimen CSWTR-2 subjected to pre loading. Actual total length of both side walls was 30cm as shown in Fig. 2 but calculations were conducted varying length of side walls; i.e. 5cm, 15cm, and 25cm. Confinement stress of 1.00 MPa was used for all cases. These calculations can be compared with experimental data of Specimen CSWTR-2 and the figure indicates that the effective length of the side wall is roughly 5-15cm. Consequently the effective length of side walls is found to be roughly one third of total length of side walls in case that they have been damaged by parallel loading direction to the side walls.



(a)Specimen C-5 (b)Specimen CSWTR-1

Fig. 8 Comparison between experiment and calculation varying confinement from base stub

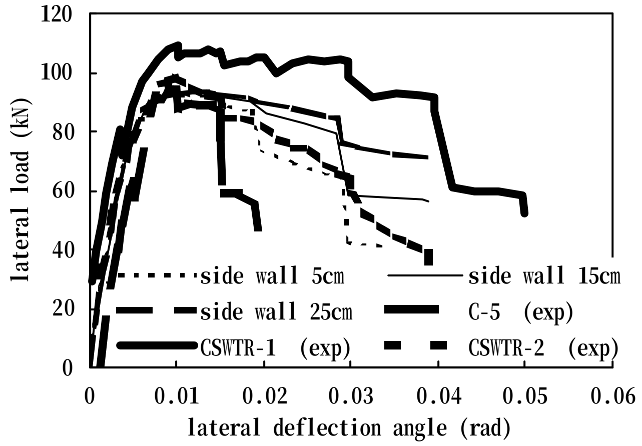


Fig. 9 Comparison between experiment and calculation of Specimen CSWTR-2 varying length of side wall

4.3 Axial load carrying capacity of crossing side walls

Figure 10 and Table 4 show trial to determine the axial load carried by crossing side walls of each specimen at the losing point of the axial load carrying capacity of specimens with crossing side walls. Figure 10 shows relations between axial load ratios of core section of columns and curvatures of the section at losing point of axial load carrying capacities. Solid curved line represents an average estimation for columns without side walls which was obtained using a number of experimental data[5]. Observed losing points of axial load carrying capacities of four specimens are also plotted in this figure using axial load ratios of core concrete of the column sections only. Dotted curved line represents an equation which matches the data of isolated column specimen C-5.

Using this dotted curved line axial load carried by crossing side walls can be estimated. Two broken arrow lines indicates this estimation in case of specimen CSWTR-1 showing the axial load ratio of core concrete of specimen CSWTR-1 was 0.43. In other words the curvature at losing point of axial load carrying capacity of specimen CSWTR-1 can be calculated using this dotted curved line and axial load ratio of 0.43. This axial load ratios to match with the estimation are listed in the second column of Table 4. Axial load carried by side walls can be estimated using the difference between the actual axial load ratio (listed in the first column of Table 4) and this axial load ratio to match with the estimation (listed in the second column of Table 4). These estimated axial load values carried by side walls are listed in the third column of Table 4. Consequently effective axial load ratios of side walls themselves are estimated as 0.81 for specimen CSWTR-1, 0.70 for specimen CSWTR-2 and 0.54 for CSWTR-3 as shown in the last column of table 4. Effective ratios to specimen CSWTR-1 are 86% for specimens CSWTR-2 and

67% for specimen CSWTR-3.

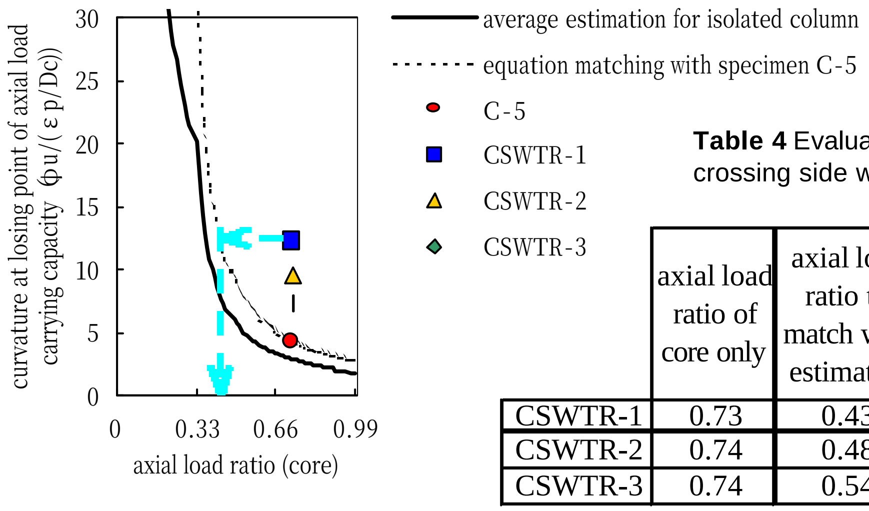


Table 4 Evaluation of axial load carried by crossing side walls

	axial load ratio of core only	axial load ratio to match with estimation	axial load carryed by side wall(kN)	effective axial load ratio of side wall (ratio to CSWTR-1)
CSWTR-1	0.73	0.43	317	0.81 (100%)
CSWTR-2	0.74	0.48	274	0.70 (86%)
CSWTR-3	0.74	0.54	211	0.54 (67%)

Fig. 10 Effect of crossing side walls on axial load carrying capacity (evaluation of axial load carried by crossing side walls)

5 CONCLUSIONS

(1)The effect of parallel side walls to loading direction on axial load carrying capacity is small. In other words axial load carrying capacity of columns with parallel side walls equals to that of isolated column.
(2)Crossing side walls to main loading direction located at the center of the column enhanced the axial load carrying capacity.
(3)The effect decreased by two directional loading. In other words damage of side walls due to lateral loading parallel to side walls lead to loss of axial load carrying capacity.
(4)The effect decreased in case of side walls located eccentrically. This is because damage of eccentrically located side walls was more severe than that of centrally located side walls. This is because the contribution for shear and moment resistance of eccentrically located side walls was larger than that of centrally located side walls.

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