

A Compression and Shear Loading Test of Concrete Filled Steel Bearing Wall

Hiroshi AKIYAMA

University of Tokyo, Tokyo, Japan

Hisashi SEKIMOTO

Mitsubishi Heavy Industries, Ltd., Takasago, Japan

Masaaki FUKIHARA, Kazuo NAKANISHI

Mitsubishi Heavy Industries, Ltd., Kobe, Japan

Kiyoshi HARA

Kajima Corporation, Tokyo, Japan

1 INTRODUCTION

A concrete-filled steel bearing wall, called a SC structure, which is a composite structure of concrete and steel plate, has a larger load carrying capacity and a higher ductility compared to a conventional RC structure⁽¹⁾, and its construction method enables rationalization of construction procedures at site and shortening of the construction period. So, SC structures have begun to be applied to inner concrete structures of PWR nuclear power plants, and subsequently are planned to be applied widely to nuclear power plant auxiliary buildings.

The purpose of this study is to establish a rational design method for SC structures which can be applied to nuclear power plant auxiliary buildings.

In this study, we evaluate the buckling strength of surface plates and the ultimate strength of the SC structure from the results of compression and shear tests which have been conducted.

2 CONTENTS

2.1 Outline of the study

Since the rational design method of the SC structure is not yet established, a conservative design method has been adopted for application to the nuclear power plant buildings. Due to the fact that the superior characteristics of composite structures of concrete and steel are not fully taken into account in the conservative design method, the proposed surface plate of SC structures becomes relatively thick, so that a rational design method for SC structures is required for an extensive and effective application.

In order to establish a rational design method for SC structures, the following points should be taken into consideration.

- 1) In case of compression loading due to dead load, carrying load, and seismic overturning force, establishment of an evaluation method for compressive ultimate strength.
- 2) In case of shear loading due to seismic horizontal load, establishment of an evaluation method for shear ultimate strength.
- 3) In case of combined loading, establishment of an evaluation method for ultimate strength.
- 4) Establishment of a design method for joints.
- 5) Establishment of a reinforcing method for details such as openings.

In this study, to investigate subject 1) and 2) which are rather basic, we conducted a compression test and shear test.

2.2 Outline of tests

Table 1 shows the dimensions of test specimens. Each test specimen has stud bolts welded to the surface plate to prevent buckling of the surface plate and slipping between surface plate and concrete. Test specimens have a parameter of width-to-thickness ratio (B/t) where width (B) is spacing of stud bolts and thickness (t) is that of the surface plate.

Material properties of the test specimens are, concrete : $F_c = 240\text{kgf/cm}^2$, surface plate : SS41, thickness 3.2mm, and stud bolts : diameter 5mm, length 35mm.

Fig. 2 shows the method of testing. For the compression test, repeated compression loads are applied using 1000ton capacity apparatus, and for the shear test, the repetitive positive and negative loads are applied using four (4)-100ton hydraulic jacks.

3 COMPRESSIVE STRENGTH CHARACTERISTICS

3.1 Compression test results

Table 2 shows the results of the compression test. Fig. 3 shows the relationship between load and compressive displacement obtained in the test. Fig. 4 shows the relationship between measured buckling strain of the surface plate just before the occurrence of buckling and the width-to-thickness ratio (B/t). Fig. 5 shows a typical test specimen after compression tests.

The progress of the test is described as follows :

① Buckling of surface plates

Buckling of the surface plate occurs at a location between two adjacent lines of stud bolts in the upper part of the test specimen first, and then at the location in the lower part of the specimen. Load dropping and increasing of displacement after buckling is scarcely observed.

② Yielding of the side plate

Increasing of displacement and decreasing of stiffness are observed in the load-displacement relationship after yielding of the side plate.

③ Ultimate strength

The test specimen lost its load carrying capacity rapidly due to compressive collapse of the concrete after the maximum load was reached, because these test specimens have no shear bars to connect the surface plates.

3.2 Evaluation of the compression test results

Initial stiffness, buckling of surface plates, and ultimate strength are evaluated, which are important items for designing SC structure.

(1) Initial stiffness

The values of initial stiffness shown in Table 2 are calculated by a simplified cumulative formula for concrete and steel plate as follows :

$$K = (EA)_{eq}/H = (E_c \cdot A_c + E_s \cdot A_s)/H$$

(EA)_{eq} : Equivalent compressive stiffness
E_cA_c, E_sA_s : Compressive stiffness of concrete and steel plate
E_c, E_s : Young's modulus of concrete and steel plate
A_c, A_s : Section area of concrete and steel plate
H : Height of test specimen

As shown in Table 2, the ratios of test results to calculated values are about 0.8, almost the same as values obtained in past tests⁽²⁾.

(2) Buckling of surface plates

Buckling of surface plates occurs as follows :

① On the vertical line of welded stud bolts, buckling length almost corresponds to the spacing of stud bolts. On lines between the vertical line of stud bolts, buckling length is longer than the spacing of stud bolts.

② The calculation values are given by applying Euler's equation and a buckling

length equal to the spacing of stud bolts. So it is concluded that a column pin-supported at one end and fixed at the other end ($n=0.7$) would be adopted for estimation.

The range of the ratios of test results to calculated values based on $n=0.7$ becomes 1.02~1.44.

(3) Ultimate strength

The ultimate strengths shown in Table 2 are calculated by a simplified cumulative formula of concrete, side plate, and surface plate strength as follows :

$$N_{max} = N_C + N_W + N_F = A_C \cdot F_c + A_W \cdot \sigma_{WY} + A_F \cdot \sigma_{FCR}$$

N_C, N_W, N_F : Strength of concrete, side plate and surface plate
 A_C, A_W, A_F : Section area of concrete, side plate and surface plate
 F_c : Compressive strength of concrete
 σ_{WY} : Yield strength of side plate
 σ_{FCR} : Buckling strength of surface plate

As shown in Table 2, the ratios of test results to calculated values are 0.99~1.06. So it is found that the calculated value corresponds very well to the test results.

4 SHEAR STRENGTH CHARACTERISTICS

4.1 Shear test results

Table 3 shows the results of the shear test. Fig. 6 shows the load-displacement relationship in the test. Fig. 7 shows the relationship between measured buckling stress and the width-to-thickness ratio (B/t). Fig. 8 shows a typical test specimen after shear tests.

The progress of the test is described as follows :

① Shear cracking

Noise indicating the occurrence of shear cracking is heard at almost the same load for each test specimen.

② Buckling

Buckling occurs at the location of the stud bolt lines, on a line which has a 45° direction to the welded stud bolts line, in test specimen in SS150 and SS100. In test specimen SS50, following the yielding of the surface plate, no buckling occurs until the ultimate strength is reached.

③ Load-displacement relationship

Comparing load-displacement relationships of SS150 and SS100 test specimens in which buckling of the surface plate occurs, with that of the SS50 test specimen, in which no buckling of the surface plate occurs, it is realized that there is no load dropping and increasing of displacement due to buckling. About 70% of ultimate strength is kept after the maximum load is reached, and there is no breakage until the rotation angle of 1/50 rad. is reached.

4.2 Evaluation of shear test results

Initial shear stiffness, buckling of surface plate, and ultimate strength are evaluated, in the same manner as given in item 3.2.

(1) Initial shear stiffness

The initial shear stiffness values shown in Table 3 are calculated by a simplified cumulative formula for concrete and steel plate as follows.

$$K_s = (GA)_{eq} / h_o = (G_c \cdot A_c + G_s \cdot A_s) / h_o$$

$(GA)_{eq}$: Equivalent initial shear stiffness
 $G_c A_c, G_s A_s$: Shear stiffness of concrete and surface plate
 G_c, G_s : Shear modulus of concrete and surface plate
 A_c, A_s : Section area of concrete and surface plate
 h_o : Height of wall

As shown in Table 3, the ratios of test results to calculated values are 0.94~1.25, so it is concluded that the calculated value almost corresponds to the test

result, taking into account the scattering of concrete material properties.

(2) Buckling of surface plates

Buckling characteristics of surface plates are as follows :

① Buckling mode on the diagonal line of welded stud bolts shows that stud bolts are effective to prevent buckling of surface plates. Between the diagonal line of stud bolts, the buckling length is longer than the spacing between stud bolts.

② Buckling stress values are nearly equal to the theoretical values of a pin-supported plate of which the aspect ratio is infinitely large.

③ No buckling occurs in the test specimen SS50 for which B/t is 50.

The range of the ratio of test results to calculated values of a pin-supported plate are 0.99~1.10.

(3) Ultimate strength

The ultimate strengths as shown in Table 3 are calculated by the following equations.

$$Q_{max} = \sigma_{FY} / 2 \cdot A_F + 4.5 \sqrt{F_C} \cdot A_C$$

A_S , A_C : Section area of surface plate and concrete

σ_{FY} : Yield strength of surface plate

F_C : Compressive strength of concrete

In the equation above, $4.5 \sqrt{F_C} \cdot A_C$ ⁽³⁾ shows the average of the limit of shear strength for a general RC bearing wall.

As shown in Table 3, the ratios of test results to calculated values are 1.00~1.02, so it is found that calculated value corresponds very well to the test results.

5 CONCLUSION

As a result of the tests, the following characteristics of a SC structure were obtained.

(1) Stud bolts are effective to prevent buckling of the surface plate.

(2) Occurrence of buckling can be predicted by applying Euler's equation for a column pin-supported at one end and fixed at the other end for compression loads, and by the theoretical equation of a pin-supported plate of which the aspect ratio is infinitely large for shear loads.

(3) Occurrence of buckling has little effect upon the load-displacement behavior of the structure.

(4) Ultimate strength of the whole structure can be evaluated by the sum of the ultimate strength of concrete and steel plate.

REFERENCE

AKIYAMA, H., SEKIMOTO, H., TANAKA, M., INOUE, K., FUKIHARA, M., OKUDA, Y. (1989). 1/10th Scale Model Test of Inner Concrete Structure Composed of Concrete Filled Steel Bearing Wall. 10th Intl. Conf. on Structural Mechanics in Reactor Technology, pp. 73 ~78.

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Table 1 List of Specimen

(a) Compression Test			(b) Shear Test			(c) Materials		
Specimen	Stud spacing B (mm)	B/t	Specimen	Stud spacing B (mm)	B/t	Concrete	Surface Plate	Stud Bolt
NS50	160	50	SS50	160	50	$F_c = 240 \text{ kgf/cm}^2$	$\sigma_s = 3050 \text{ kgf/cm}^2$	$\phi = 5.0 \text{ mm}$
NS75	240	75	SS100	320	100	$t = 3.2 \text{ mm}$		$\ell = 35 \text{ mm}$
NS100	320	100	SS150	480	150			

(d) Arrangement of Stud Bolts

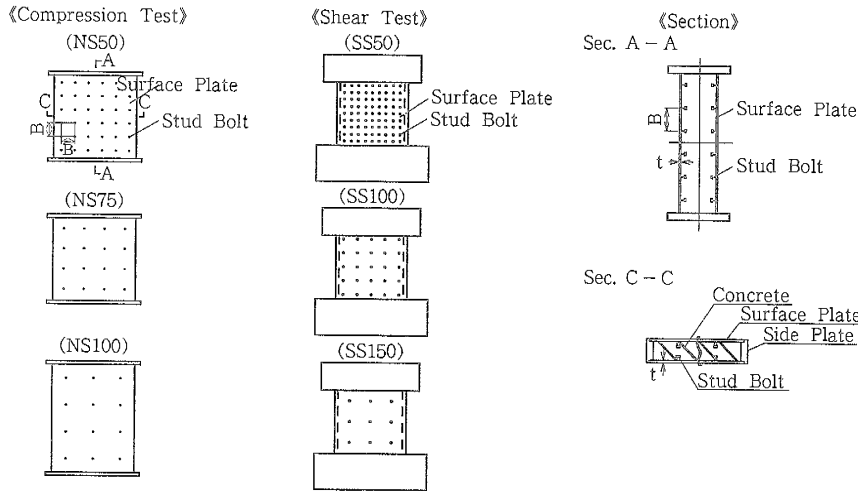


Table 2 Compression Test Results

Specimen	Measured			Calculated					
	initial stiffness $eK \text{ (tf/mm)}$	minimum buckling strain $\epsilon_{cr} (\times 10^{-3})$	ultimate strength $eN_{max} \text{ (tf)}$	initial stiffness		minimum buckling Strain		ultimate strength	
				$eK \text{ (tf/mm)}$	eK/cK	$\epsilon_{cr} (\times 10^{-3})$	$\epsilon_{cr}/\epsilon_{cr}$	$cN_{max} \text{ (tf)}$	eN_{max}/cN_{max}
NS50	515.0	723	740	669.7	0.77	671	1.08	748.4	0.99
NS75	515.0	303	715	664.9	0.77	298	1.02	687.2	1.04
NS100	412.4	240	751	505.9	0.82	167	1.44	707.4	1.06

Table 3 Shear Test Results

Specimen	Measured			Calculated					
	initial shear stiffness $eK_s \text{ (tf/mm)}$	minimum buckling stress $\sigma_{2cr} \text{ (kgf/cm}^2\text{)}$	ultimate strength $eQ_{max} \text{ (tf)}$	initial shear stiffness		minimum buckling Stress		ultimate strength	
				$eK_s \text{ (tf/mm)}$	eK_s/cK_s	$\sigma_{2cr} \text{ (kgf/cm}^2\text{)}$	$\sigma_{2cr}/\sigma_{2cr}$	$cQ_{max} \text{ (tf)}$	eQ_{max}/cQ_{max}
SS50	238	—	325.0	191	1.25	—	—	324.1	1.00
SS100	202	1005	322.4	190	1.06	1014	0.99	314.6	1.02
SS150	171	495	324.5	182	0.94	450	1.10	322.7	1.01

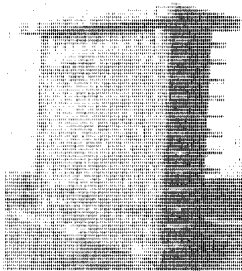


Fig. 5 Test Specimen (NS50) after Compression Test

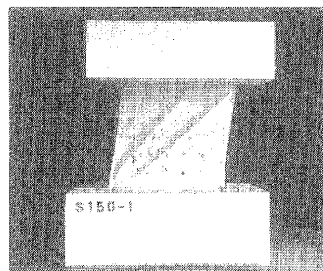


Fig. 8 Test Specimen (SS150) after Shear Test

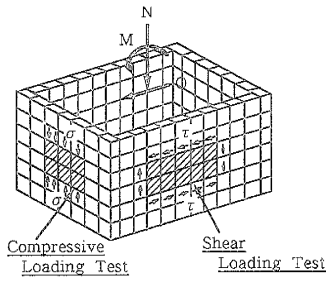


Fig.1 Items of Test

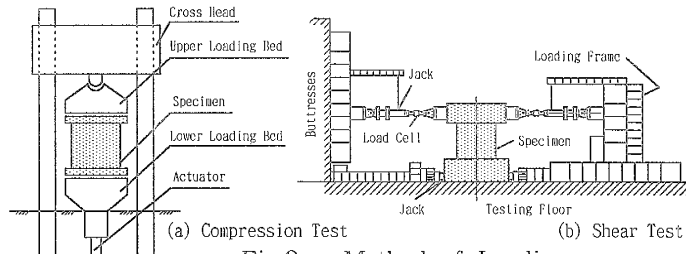


Fig.2 Method of Loading

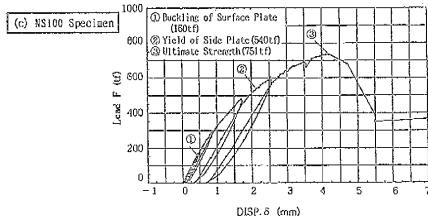
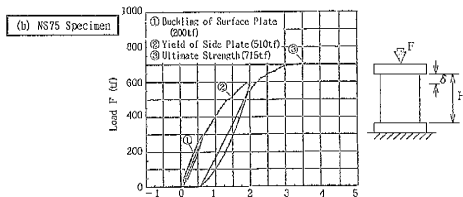
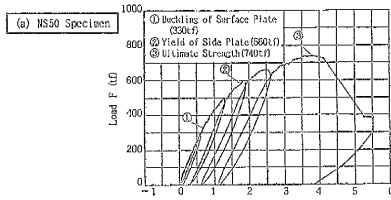


Fig.3 Load - Displacement Relationship in Compression Test

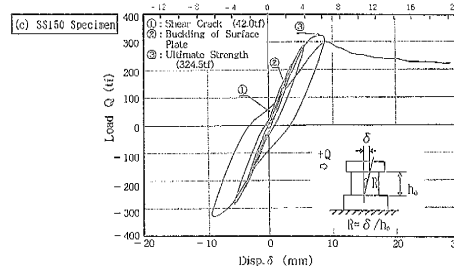
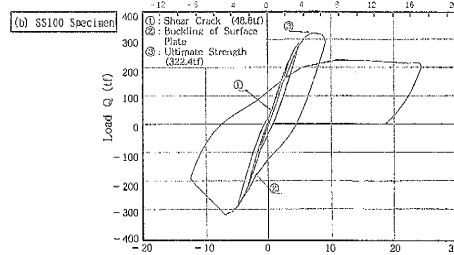
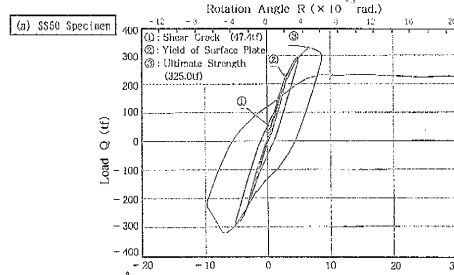


Fig.6 Load - Displacement Relationship in Shear Test

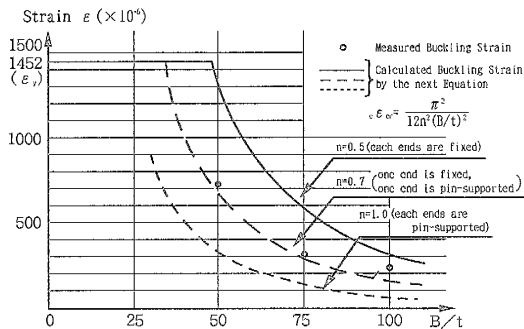


Fig.4 Buckling Strain of Surface Plate in Compression Test

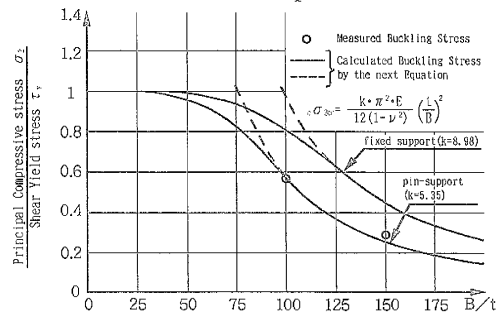


Fig.7 Buckling Stress of Surface Plate in Shear Test