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Study on Advanced Construction Method Application to NPPs Loading Tests of SC Shear Wall for Advanced Construction Methods PART 1 Comparison of faceplate connecting methods

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ABSTRACT

In order to apply the use of steel plate reinforced concrete (SC) structures in Japanese nuclear power plants, advanced construction methods are developed to minimize the construction term. In this study, horizontal loading tests are conducted to minimize the construction term, some types of advanced connecting methods of faceplates of SC blocks are proposed[1)-3)]. From the test results, the mechanical characteristics and the skeleton curve for each construction method will be confirmed, and the applicability of the conventional design equations written in Technical Code for Seismic Design of Steel Plate Reinforced Concrete Structures (JEAC4618)[4)] will be confirmed as well.
The test results indicate that the mechanical characteristics and the skeleton curve of each construction method are roughly the same as those of conventional construction methods. Furthermore, it is confirmed that the shear restoring force for each construction method is possible to be evaluated by the conventional design equations. Therefore, the applicability of each construction method for nuclear power plants is confirmed.

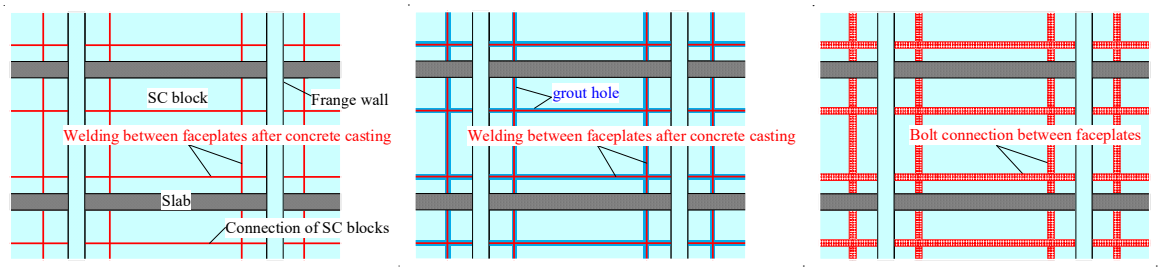
INTRODUCTION

In the construction of SC-type nuclear power plants, it is expected that the construction term will be expanded if faceplates of SC blocks are welded before concrete casting compared to reinforced concrete (RC) structures. The advanced construction methods are expected to minimize the construction term in which concrete casting is performed prior to welding. However, there are few reports on the construction records and mechanical characteristics of these methods, and therefore there are some challenges remaining for their practical implementation.
Therefore, horizontal loading tests are carried out on shear wall specimens modelling those construction methods to reduce construction term of SC structures so that the mechanical characteristics and the applicability of conventional design methods of each construction method are confirmed.
In Part 1, three connection methods of faceplates of SC blocks are examined: Method A, which involves direct conduction of welding heat to the concrete; Method B, which avoids direct conduction of welding heat to the concrete; and Method C, which adopts bolted connections without welding. Figure 1 shows overview of each construction methods.

Method A: Welding faceplates between SC blocks after concrete casting. Due to the heat conduction from welding to the concrete, there is a possibility of cracking and degradation of strength of the concrete.

Method B: Welding faceplates between SC blocks after concrete casting, like Method A. In this method a cavity (grout hole) is provided near the welding area in order to avoid heat conduction on the concrete. After welding, the grout hole is filled with grout.

Method C: Faceplates are connected by bolts instead of welding. In this method the ultimate strengths of the base steel plates are ensured by the friction generated by double shear using high tensile bolts for the connection between base steel plates and faceplates.



Method A Method B Method C

Figure 1. Overview of the advanced construction method

TEST CONDITION

Test Specimen

Table 1 shows an overview of the test specimens, while Table 2 shows the materials used. Additionally, Figure 2 shows the shapes of the test specimens.
Conventional method is applied to Specimen No. 1, in which the faceplates are welded prior to concrete casting. Method A is applied to Specimen No. 2, in which backing plates are sealed to prevent concrete from flowing to the welded joints. Method B is applied to Specimen No. 3, in which grout holes are set by using perforated metal plates on the backside of the welded joints. Method C is applied to Specimen No. 4, in which splice plates with a thickness of 2.3 mm are used at the bolted joint. High tensile bolts with a diameter of 12 mm are used to ensure the friction strength to exceed the ultimate strength of the faceplate by tightening.
As for the dimensions of the test specimen, the web wall thickness is set to be 230 mm, the web steel plate thickness is set to be 2.3 mm, and the studs with diameter of 4 mm with spacing of 70 mm in both vertical and horizontal directions are used. The scale of these components is approximately 1/5 of the dimensions of actual constructure members. In this case, the dominant mechanical characteristic of seismic walls is the shear characteristics. Therefore, the shear span-to-depth ratio is set at 0.7 for all the test specimens in order to induce a shear failure mode.

Table 1: Overview of the test specimens

No.	Target construction method	Concrete Fc	Web plate	Frange plate	Stud
No.1	Conventional construction method	33N/mm^2	PL2.3	PL6.0	Web φ4mm, @70×70 Frange φ6mm, @70×70
No.2	Welding between faceplates after concrete casting				
No.3	Welding between faceplates after concrete casting with grout hole				
No.4	Bolt connection between faceplates				

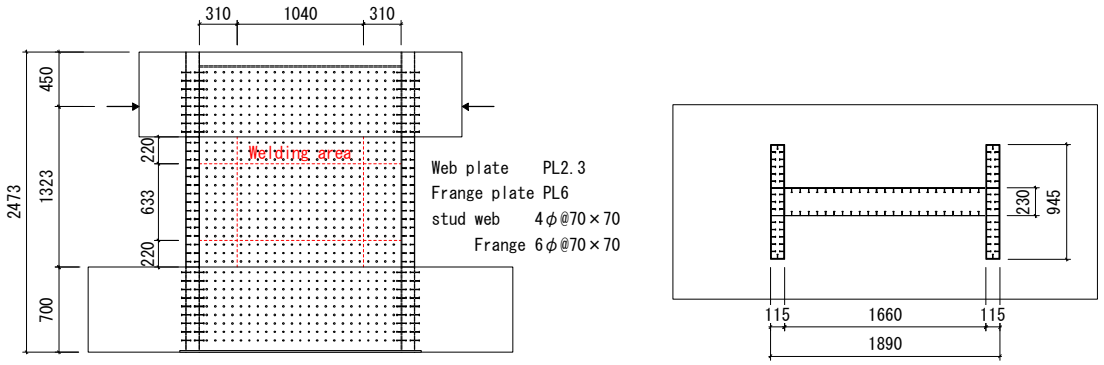
Table 2: Overview of the material used

(a) Concrete

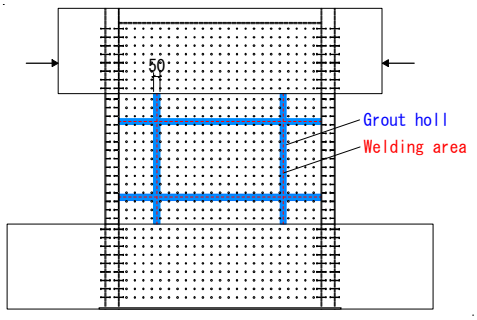
		Compessive strength N/mm^2	Splitting tensile strength N/mm^2	Young's modulus ×10^{4}N/mm^2	Poisson's ratio
Concrete (Wall)	No.1	38.1	3.00	2.69	0.195
	No.2	38.1	3.02	2.96	0.197
	No.3	40.5	2.87	2.84	0.196
	No.4	40.3	3.48	2.91	0.188
No.3 Grout		106	3.84	3.56	—

(b) Steel

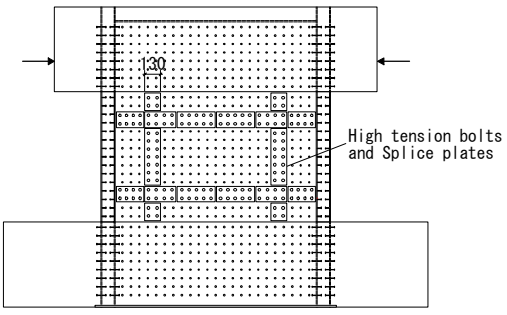
	Yield strength N/mm^2	Yield point strain	Young's modulus ×10^{5}N/mm^2	Tensile strength N/mm^2
PL2.3 (Web, Splice plate)	310	1549μ	2.09	449
PL6.0 (Frange)	333	1927μ	2.04	474
Stud 4φ (Web)	510	—	—	532
Stud 6φ (Frange)	539	—	—	568



(a) Specimen No.1 and No.2



(b) Specimen No.3



(c) Specimen No.4

Figure 2. The shapes of the test specimens

Test Equipment

The loading equipment is shown in Figure 3, and the measurement locations are indicated in Figure 4. The horizontal force is loaded by hydraulic jacks installed on the upper stub of specimen. In addition, no vertical axial force is loaded in this test. The horizontal force is measured using a load cell installed at the tip of the jack, and the horizontal displacement is measured using a contact-type displacement meter installed at the upper stub. The bending deformation is calculated from the rotation angle measured using vertical displacement meter installed at the flange wall.
Figure 5 shows horizontal load cycle. The horizontal loading is controlled through a cyclic incremental loading with positive and negative repetitions based on the wall deformation angle R. The horizontal loading is continued until the load is reduced to 80% of the maximum shear force after reaching the maximum shear force.

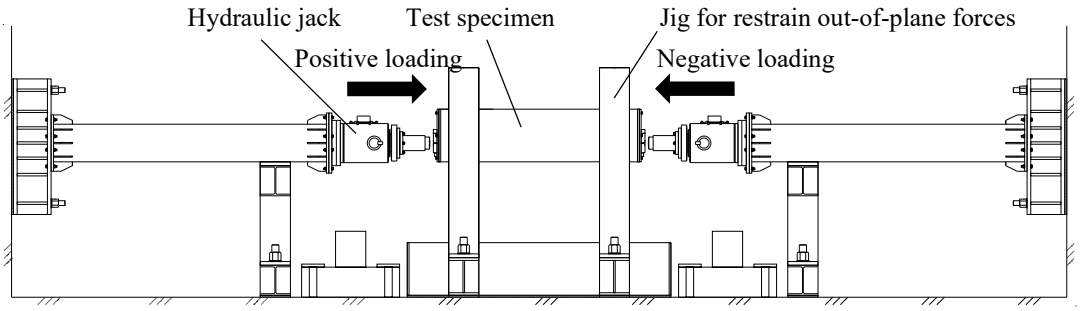
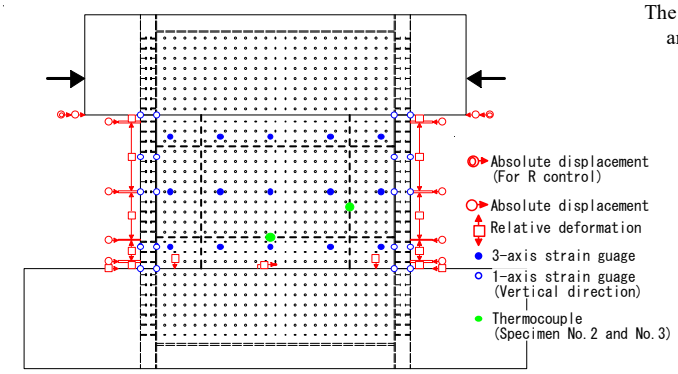
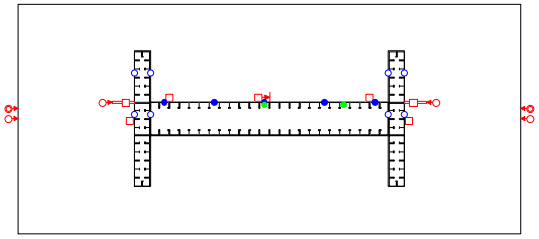


Figure 3. The loading equipment

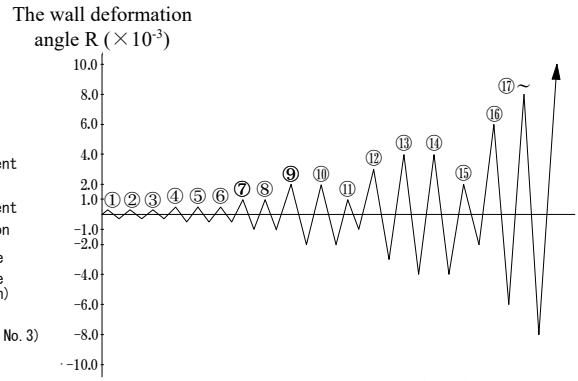


(a) Elevation view

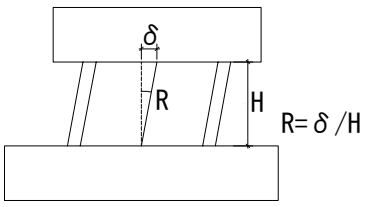


(b) Plan view

Figure 4. The measurement location



(a) Cyclic incremental loading



(b) Calculated equation to the wall deformation angle R

Figure 5. Horizontal load cycle

TRANSITION OF CONCRETE TEMPERTURE DUE TO WELDING

Heat conduction analysis

To predict the temperature of concrete due to welding, heat conduction analysis was conducted on the wall section models of both the actual constructure and the test specimens. Quick Welder[5)] is used for the heat conduction analysis tool. The rise of concrete temperature is calculated via heat conduction analysis, in which welding conditions such as current amount, voltage amount, number of welding passes, welding speed and inter-pass interval are set for each section model. Specimens No. 2 and No. 3 are constructed based on the welding conditions confirmed in heat conduction analysis.
From the analysis results, it is confirmed that the concrete temperature exceeding 200°C is limited only to the surface layer within stud depth for both the actual constructure and the test specimens. Therefore, it is considered that the effect on the mechanical characteristics of the seismic walls is minimal.

Temperature measurement result of test specimen

The internal temperature of the concrete around the connection between SC blocks is measured after concrete casting in specimens No.2 and No.3. Thermocouples are installed directly below the weld in specimen No.2 and the side of the grout hole in specimen No.3. The maximum temperature distribution obtained from measurements and analysis results is shown in Figures 6 and 7.
As shown in Figures 6 and 7, the analysis results of test specimens can reproduce the internal temperature distribution of wall specimens obtained from measurement results. Additionally, the effects of welding heat on the mechanical characteristics of the test specimen are more conservative than that of actual constructure because the maximum temperature distribution of the measurement results envelops the analysis results of the actual constructure.

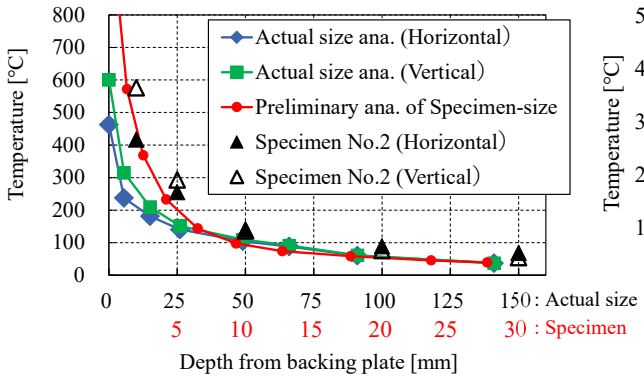


Figure 6. The analysis results of specimen No.2

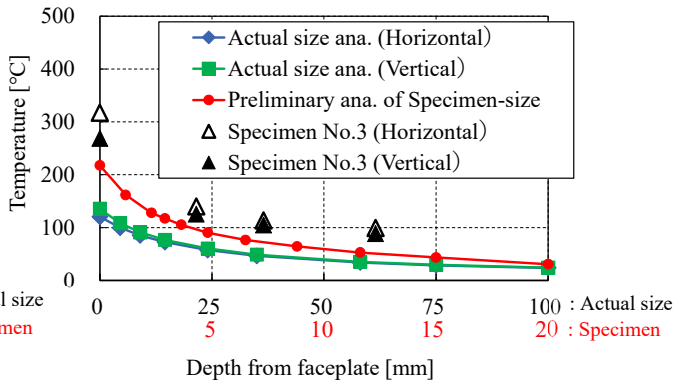


Figure 7. The analysis results of specimen No.3

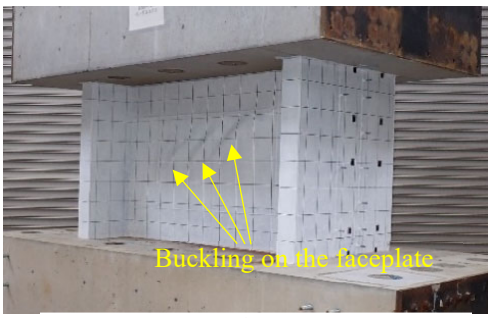
TEST RESULT OF THE HORIZONTAL LOADING

The results of the horizontal loading tests using SC-type seismic walls with different welding methods for the faceplates are summarized as follows.

Ultimate failure mode of test specimen

Figure 8 shows the condition of specimens No.2 and No.4 after horizontal loading test. The ultimate failure modes of all specimens were shear failure of the web walls. In all specimens, buckling had occurred on the faceplates of the web, however, no cracks were observed on the steel plates. No crack on splice plates or

bolts can be seen at bolted joints of specimen No.4. After horizontal loading test some parts of faceplates were removed to observe the inside. As a result of the observation, the compressive failure had occurred in the web concrete in all test specimens.

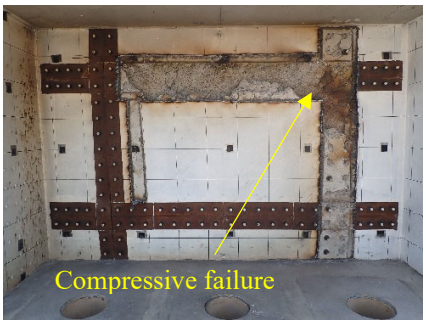


Appearance of the test specimen

Observe the inside

(a) Specimen No.2

Appearance of the test specimen



Observe the inside

(b) Specimen No.4

Figure 8. The condition of specimens after horizontal loading test

Mechanical characteristics of each construction method

Figure 9 shows the horizontal force-horizontal displacement relationship. The hysteretic characteristics of all test specimens showed relatively stable behavior. All test specimens reached the maximum force at the wall deformation angle of 8/1000 rad with positive or negative loading. For all test specimens, cracking had occurred in the web concrete at first, followed by the yielding of the web steel plate, then the yielding of the flange steel plate, ultimately reaching the maximum load, which is confirmed from the fracture progression until the end of the test as shown in the figure.

The mechanical characteristics of specimens No. 2 and No. 3 which were welded after concrete casting were generally the same as that of specimen No. 1 which was welded prior to concrete casting. Therefore, it was established that the welding heat had no effect on the decrease of mechanical characteristics.

On the other hand, specimen No.4 which used a bolted joint method, the reduction of horizontal force after the maximum force was slightly greater than the other test specimens. The difference in mechanical characteristics could be the difference in load burdens on the concrete. As for specimen No.4 the burden is relatively larger because studs were not installed on the splice plate. Furthermore, it was confirmed that a plastic deformation without sliding had occurred on the splice plate of No. 4 after reaching the maximum force.

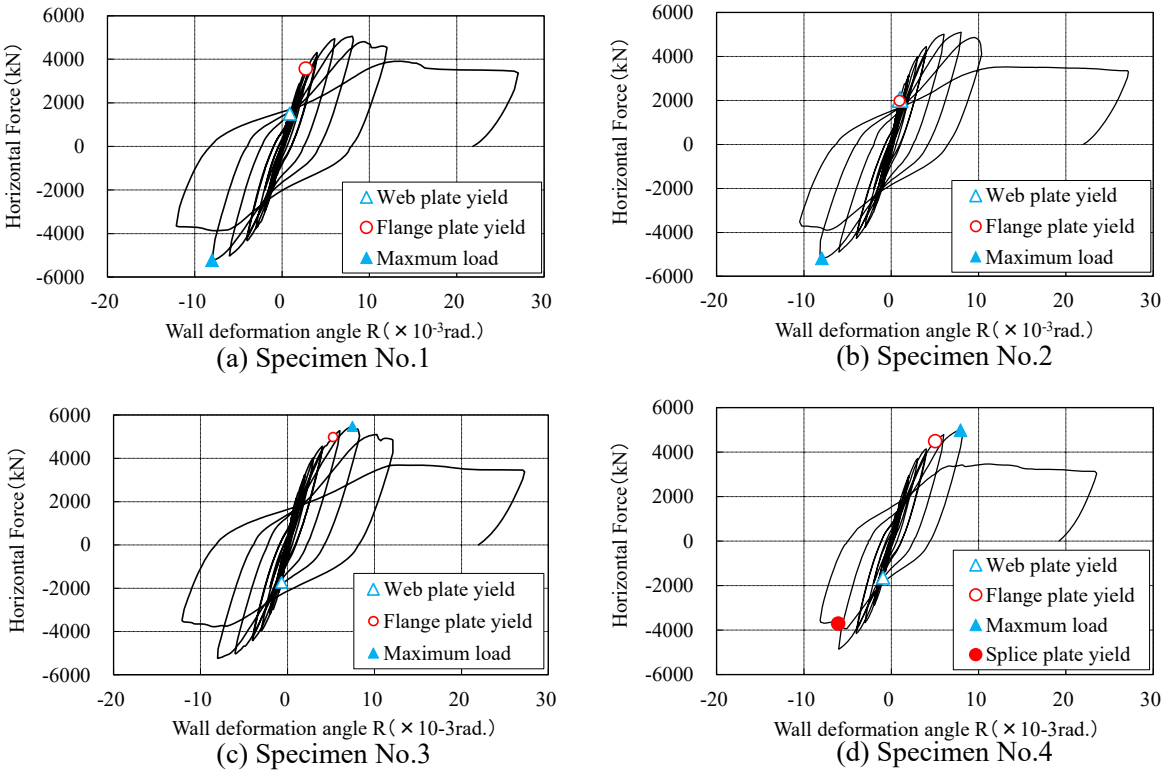


Figure 9. The relationship of horizontal force and horizontal displacement

Applicability study on design equation

In order to confirm the applicability of the conventional design equations skeleton curves of the shear force-shear strain relationship (Q-γ) described in JEAC4618 are compared to the test results. Ultimate values of the test results are compared to that of design equations in Table 3. Shear skeleton curves of positive loading test results are compared to that of design equations in Figure 10. In addition, the ultimate value of the test results is defined as the value at the point of maximum load occurrence.

Regarding the ratio of design values to the test results shown in Table 3, the ratio of shear force ranges from 1.04 to 1.14, and the ratio of shear strain ranges from 1.10 to 1.22. Furthermore, it is confirmed that the maximum shear strain of the test results exceeds ultimate shear strain of 6000μ as defined in JEAC4618. For all test specimens it was confirmed that the test force exceeds the design force at large deformation levels beyond the yield point in Figure 10. Additionally, there is no clear difference in the skeleton curves for each test specimen, therefore the mechanical characteristics of each construction method are similar.

From the above mentioned, the design equations conservatively evaluate the test results for all the test specimens. Therefore, it is acceptable to apply the conventional design equations to calculate the mechanical characteristics of the seismic walls constructed by each construction method.

Table 3: Comparison of the ultimate value of the test results to design equations

Specimen name	Test result		Design equation (JEAC4618)		Test/Design	
	Maximum load (kN)	Shear strain ($\times 10^{-3}$rad.)	Ultimate load (kN)	Ultimate shear strain($\times 10^{-3}$rad.)	Load	Shear strain
No.1	-5218	-7.32	4721	6.0	1.11	1.22
No.2	-5187	-7.11	4721		1.10	1.19
No.3	5475	6.61	4810		1.14	1.10
No.4	4978	7.14	4803		1.04	1.19

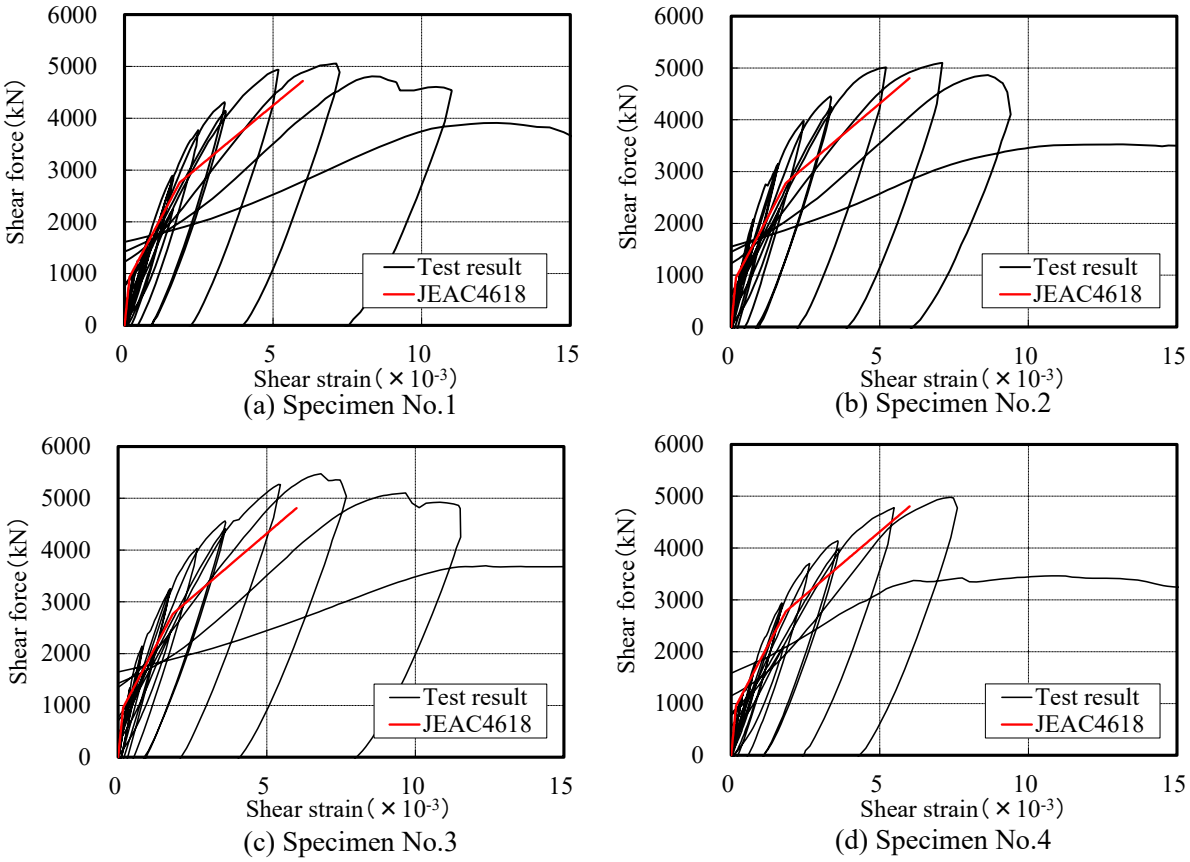


Figure 10. Comparison of shear skeleton curves of test results to design equations

CONCLUSION

Horizontal loading tests were performed for seismic wall specimens, whose failure mode is shear failure, constructed by construction methods A, B, and C which were employed to reduce construction term of SC shear wall. Based on the test results, these facts shown below were confirmed.

- No reduction of mechanical characteristics was confirmed as an effect of welding heat for both specimen No.2, by construction method B, and specimen No.3, by construction method C, with concrete casting prior to welding.

- The force after reaching the maximum force of specimen No.4, by construction method C, showed slightly larger decrease than other test specimens.
- The ultimate shear force and the ultimate shear strain were confirmed to exceed the design value, in all test specimens. Additionally, the ultimate shear strains of the test specimens were confirmed to exceed ultimate shear strain of 6000μ as defined in JEAC4618.
- The conventional design equations from JEAC4618 were applicable to calculate mechanical characteristics of seismic walls constructed by each construction method used in this study.

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