Structural characteristics of column with precast wing walls as energy absorption elements

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SUMMARY:
An idea of hybrid column system which consists of strong column and week wing walls as energy absorption elements was proposed at 13th WCEE meeting. The idea is as follow; the column with wing walls is so rigid to the horizontal drift, and the week wing walls generate multiple clacks earlier at small deformation and absorb much energy. Eventually the column with wing walls does not response so much in horizontal displacement, and it survives damage. This system is supposedly more applicable to the too much flexible steel frame structure. This paper shows the test results of hybrid steel columns with wing walls made of week precast mortal panel and the earthquake response analyses to verify the idea of the hybrid steel column system. It was confirmed that the earthquake displacement response could be much reduced by the wing walls that work as a response control device.

Keywords: Column, Wing wall, Precast, Energy absorption, Earthquake response

1. INTRODUCTION

An idea of hybrid column system was proposed at 13th WCEE meeting (ISO et al. 2004). When the bare frame structure is too flexible to keep elastic during earthquake; its response would be much controlled if some response control device would be combined. ISO et al. (2004) combined RC column with wing walls that generate multiple cracks at small deformation and dissipate a lot of energy owing to low strength steel bars embedded inside. Eventually the columns would stay within small displacement and survive damage. In order to generate the multiple cracks, FRC was used for the wing walls.

This idea could be more suitably applicable to the flexible steel frame structure. In this paper, the restoring force characteristics of flexible steel column with wing walls was experimentally discussed. The wing walls were precast with low strength mortal, and low strength steel bars and grid type FRP reinforcement were embedded to generate the multiple cracks instead of the use of FRC. Those wing walls were installed to the flexible steel column using the post-installed shear keys to the column and boundary beams. This installation method of shear keys is also aimed to be applied to seismic retrofit of existing steel structures for the seismic rehabilitation. The reduction of earthquake response displacement by this system was verified by the earthquake response analyses using the restoring force model that was postulated based on the test results of the steel column with wing walls.

2. EXPERIMENTAL PROGRAM

2.1. Introduction

2.1.1.Specimens
Parameter of specimens shows in Table 2.1. Four specimens are tested to verify the idea of hybrid

column with precast wing walls proposed in this study. S-C is bare column. Steel square pipes are used as columns. The cross section size of columns is 50×50×4.5. The shear span to depth ratio of the bare column is 4.0. The other three specimens have the same column to S-C, but installed the precast wing walls to the columns. The parameters of these specimens are amount of the PVA fibers grids to reinforcement and the steel bars in precast wing wall panel.
Fig.2.1 shows example of test specimens. Steel bars placed in the center of cross section of the wing wall panel, and PVA fiber grids placed in the near of the both sides of the panel.
Fig 2.2 shows joints between column, stub and precast panel of wing wall. Fig 2.3 shows cotters using joints between columns and panels. These cotters are made beforehand by steel pieces and aramid fiber sheet. These aramid fiber sheets with steel pieces are bonded to column and beam stubs. And at the side of wing walls to joint to column and beams shear keys are made. Ready mixed non-shrinkage mortar is casted in the space between precast panel and column or beam stub.
This joint method is considered to be simple and easy to construct and have good deformation capacity.

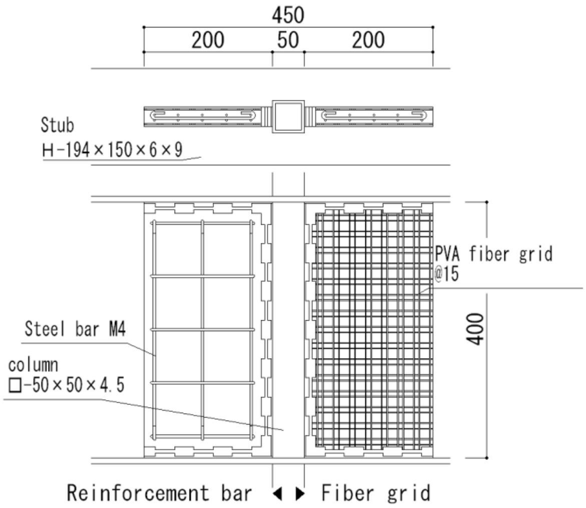


Figure 2.1 Example of test specimens

Tabel 2.1 Parameter of specimens

Specimens	Column		Wing wall		
	Section (mm)	Yield strength (N/mm^2)	Reinforce-ment ratio (%)	Amount of fiber (g/m^2)	Strength of mortar (N/mm^2)
S-C	□-50×50×4.5	441.00	-	-	-
S-0.67			0.67	260	10.48
S-0.67H			0.67	130	
S-0.33			0.33	260	

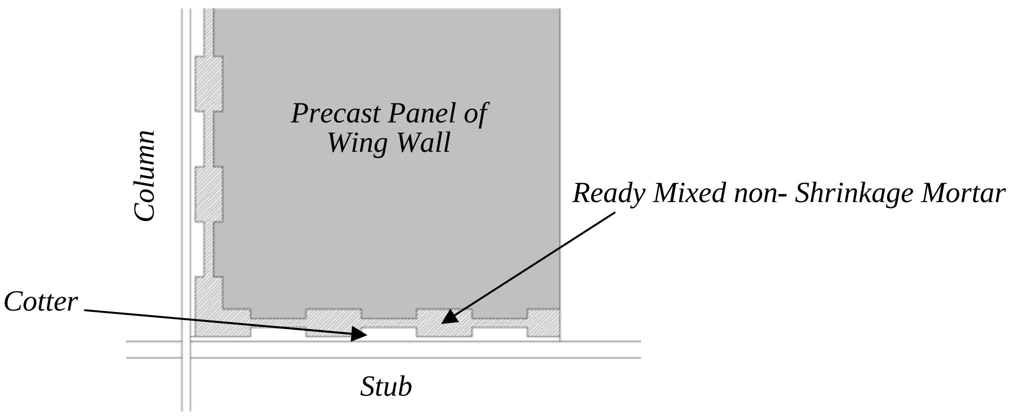


Figure 2.2 The joint between wing walls and columns

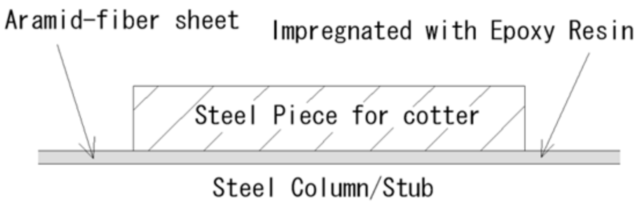


Figure 2.3 Cotter of the joint between columns and stubs and precast wing walls

2.1.2 Loadings

The loading apparatus is illustrated in Fig.2.4.

The reversed cyclic loads were given gradually increasing the drift angle so that the clear span has a reversed symmetrical moment distribution.

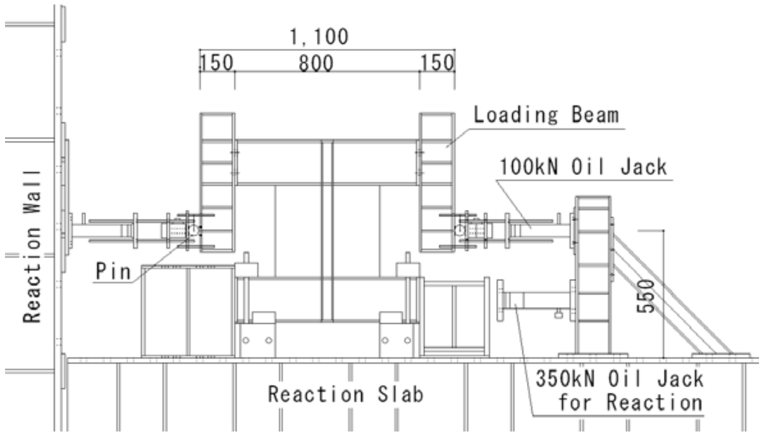


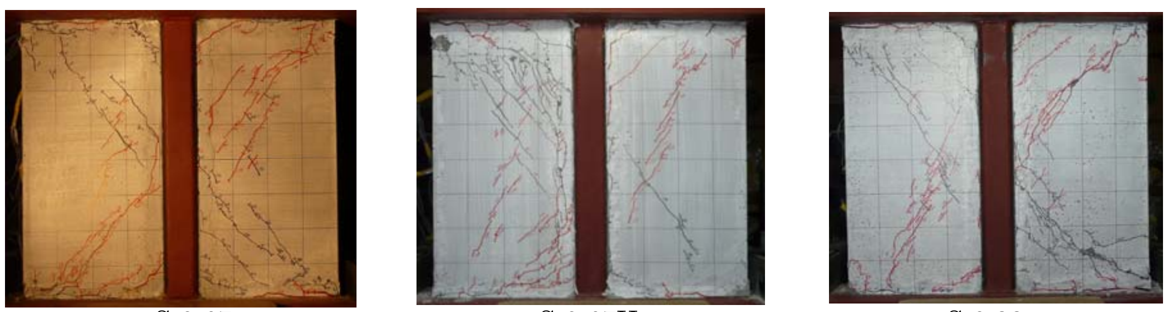
Figure 2.4 Loading apparatus

2.2. EXPERIMENTAL RESULTS

2.2.1 Crack condition

Photo. 1 shows cracks in the wing wall panels at the drift angle of 1.0/100 radian.

Some cracks occurred in the part of joint between wing wall panels and steel structure at very small drift angle. However, shear cracks on the wing walls initiated at very small drift angle and a large number of cracks were generated before the drift angle reached 1.0/100 radian. As a result of shear cracks occurred in the wing wall panels, low strength steel bars yield and absorb hysteresis energy. Compered the crack conditions of each specimen, the effects of amount of steel bars and fiber grids on the crack conditions are not clear in these experiments.



S-0.67 S-0.67H S-0.33

Photo. 1 Cracks at the drift angle of 1.0/100 radian

2.2.2 Shear Force vs. Displacement Relationships

Fig. 2.5 shows relationships between shear force and horizontal displacement of the results of the tests of four specimens. The relationship of shear force and displacement of steel bare column (S-C) shows almost elastic behaviour, the amount of energy absorption is less because of the behaviour before yielding.

On the other hand, stiffness and shear strength of the specimens with precast panel wing walls (S-0.67, S-0.67H, S-0.33) increase. And then, hysteresis energy is absorbed because of damage in wing walls, and residual displacements are very small because of elasticity of steel columns.

As the results of these tests, the effects of amount of fiber grids and reinforcing bars on the relationships between shear force and horizontal displacement are not large.

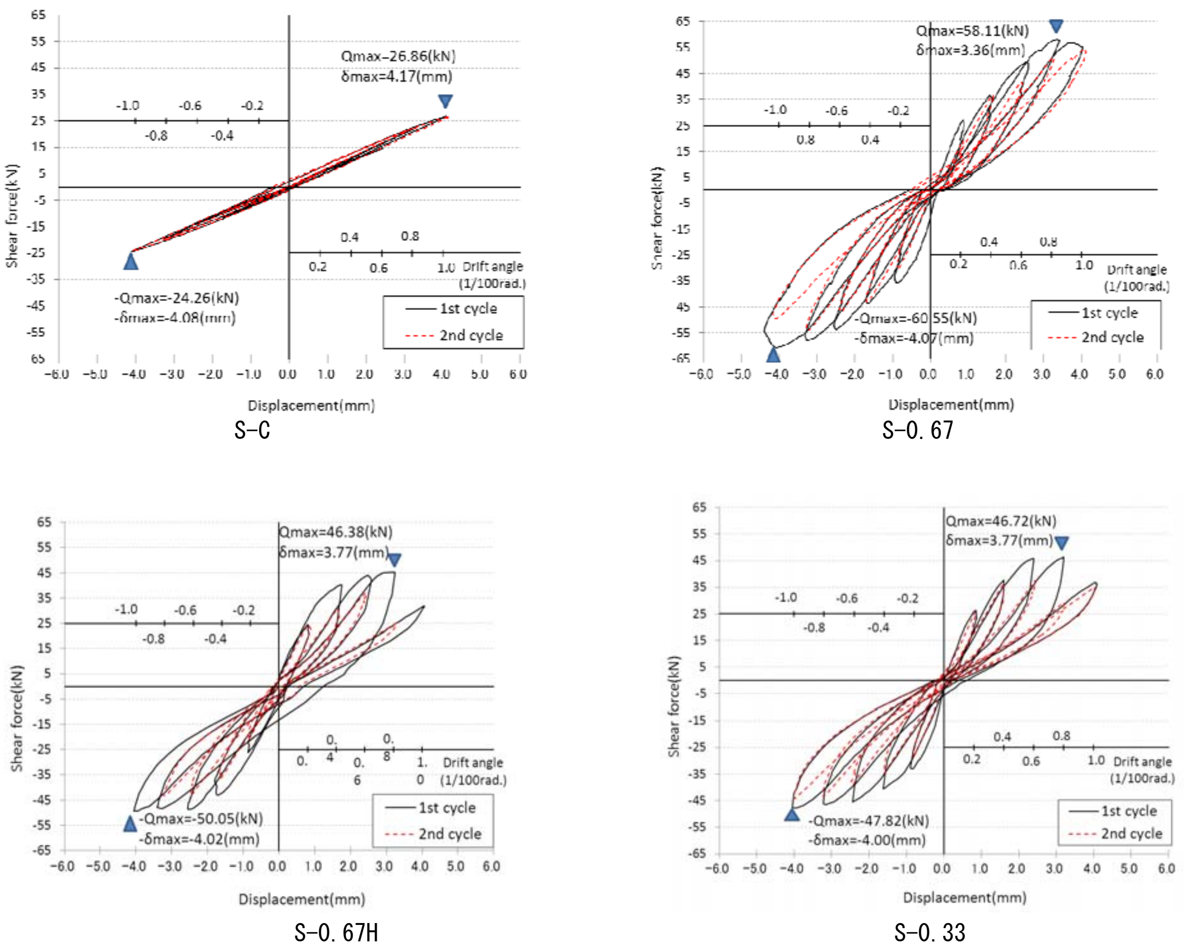


Figure 2.5 Relationships between shear force and horizontal displacement

2.2.3 Equivalent viscous damping ratio

Fig 2.6 shows equivalent viscous damping ratio of four specimens. Figure at left side shows the result of 1st cycle of loading and Figure at right side shows the result of 2nd cycle.

The equivalent viscous damping ratios of S-C, specimen without wing walls, are very small because the behaviour of S-C is in elastic region. Fig. 2.5 also shows that behaviour of S-C is in elastic region. .

The equivalent viscous damping ratios of S-0.67,S-0.67H,S-0.33 are larger than those of S-C. This results shows absorptions of energy are caused by installed low strength and high ductility precast panels as wing walls.

From these results of tests, it is clear that the amount of steel bar in the wing wall panels and the amount of fiber grid do not effect on energy absorption in the region of these specimens.

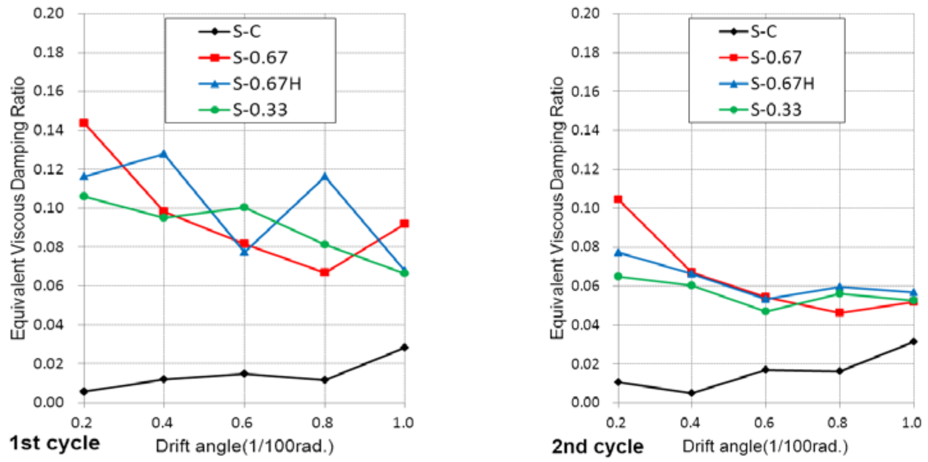


Figure 2.6 Equivalent Viscous Damping Ratio

3. EARTHQUAKE RESPONSE ANALYSIS

3.1.Introduction

3.1.1 Analytical model

The analytical model is used mass system model for earthquake response analyses. The model has two parallel springs for each mass, which means structural characteristic of column and wing walls.

Fig. 3.1 shows the assumed building structure for analyses. This model is 3 stories and 10 spans. Span is assumed 7m and mass is assumed 1.0 ton/m^2.The natural period of the model without wing walls is assumed 0.324(s). It is assumed that the distribution of stiffness in the vertical direction is proportional to distribution of shear force distribution based on the *Ai* distribution in Japanese seismic code. It is assumed that damping is tangent stiffness-proportional damping and viscous damping ratio is 5% for column and is ignored for wing walls.

Elevation

Plan

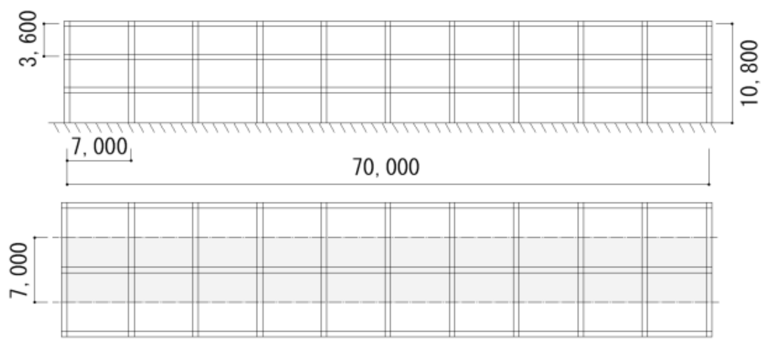


Figure 3.1 Model Frame of building

3.1.2 Hysteresis model of restoring force characteristics of frame

Bi-liner model is used for hysteresis model of restoring force characteristics of frame without wing walls. Stiffness ratio after yield shear strength is 0.01.

Yield base shear coefficient is assumed 0.25.

3.1.3 Hysteresis model of restoring force characteristics of wing walls

Fig 3.2 shows the shear force vs. displacement relationships of wing walls of S-0.33 specimen. This result is got by the difference between the results of tests of models with wing walls and those of model without wing walls. With the result as a reference, hysteresis model of restoring force characteristics of wing walls is assumed as Fig.3.3

Fig.3.3 shows hysteresis model of restoring force characteristics of wing walls. This model is considered clack, decreasing stiffness, maximum point-oriented and slip. Stiffness ratio after maximum of shear strength of pair of wing walls are assumed $\gamma = 0$ and $\gamma = -0.428$.
In the analyses, it is assumed the maximum shear strength of a pair of wing walls panel is 900kN, clack strength is 300kN, story drift at maximum strength is 0.6/100 and story drift at clack strength is 0.06/100.

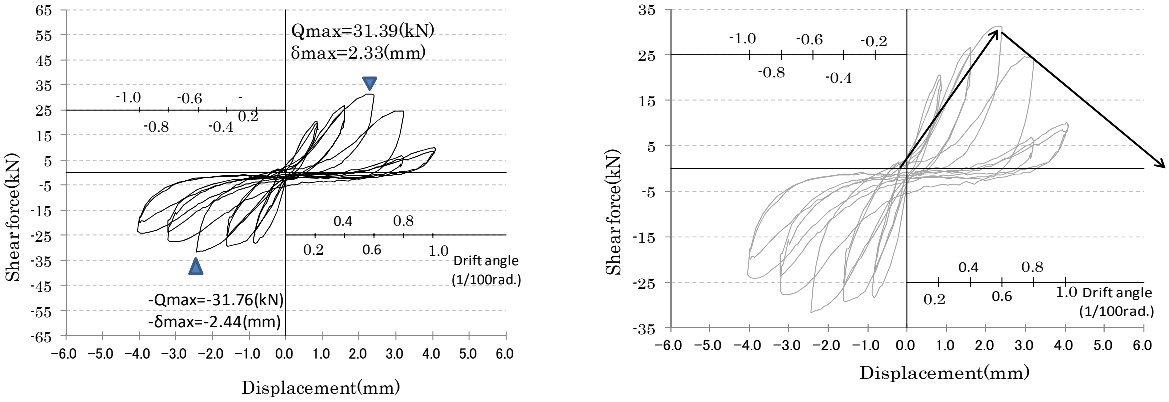


Figure 3.2 Shear force vs. displacement relationships of wing walls of S-0.33

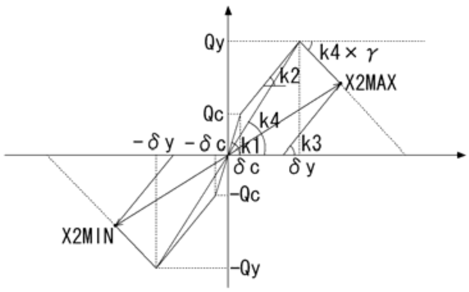


Figure 3.3 Hysteresis model of restoring force characteristics of wing walls

3.1.5 Input Earthquake motion
In this study, simulated earthquake motions of the building center of JAPAN of BCJ-L1(Maximum of ground velocity 25cm/s)、BCJ-L2(50cm/s)、BCJ-2×1.5(75cm/s)、BCJ-2×2.0(100cm/s) are used as input earthquake motion.

3.1.6 Analytical Parameters
Four analytical models are assumed in the analyses. As below, the numbers of wing walls in the model are different.

Model 0 : Frame model without wing wall
Model-1 : Frame model with one pair of wing walls in the 3rd story, two pair in the 2nd story and three pair in the lst story
Model-2 : Frame model with two pair of wing walls in the 3rd story, four pair in the 2nd story and six pair in the lst story
Model-3 : Frame model with three pair of wing walls in the 3rd story, six pair in the 2nd story and nine pair in the lst story

For each models, stiffness ratio after maximum of shear strength γ of pair of wing walls are assumed

$\gamma = 0$ and $\gamma = -0.428$.

Four models with different number of wing walls (Model-0, Model-1, Model-2, Model-3), two types of stiffness ratio of wing walls($\gamma = 0$ and $\gamma = -0.428$), four levels for input earthquake motion, total number of analyses is 28 cases.

3.2 ANALYTICAL RESULTS

3.2.1 Maximum of story drifts

Fig. 3.3 shows the max. of response displacement of each story. The horizontal axis shows maximum displacement and the vertical axis shows position of story. Upper four figures show the analytical results of Model-1 on 25cm/s, 50cm/s, 75cm/s and 100cm/s respectively, middle four figures show those of Model-2 and lower four figures of Model-3. Three lines are drawn in the all figures, the results of Model-0 and the results of the models which have different stiffness ratio after maximum shear strength of pair of wing walls, $\gamma = 0$ and $\gamma = -0.428$.

From these figures, stiffness ratio after maximum of shear strength of pair of wing walls is not important for earthquake response displacement, for 25cm/s and 50cm/s. The earthquake response displacements are decreased by installed wing walls. The results of $\gamma = 0$ and $\gamma = -0.428$ are different in case of 75cm/s and 100cm/s. The concentrate of response is increasing in case of $\gamma = -0.428$.

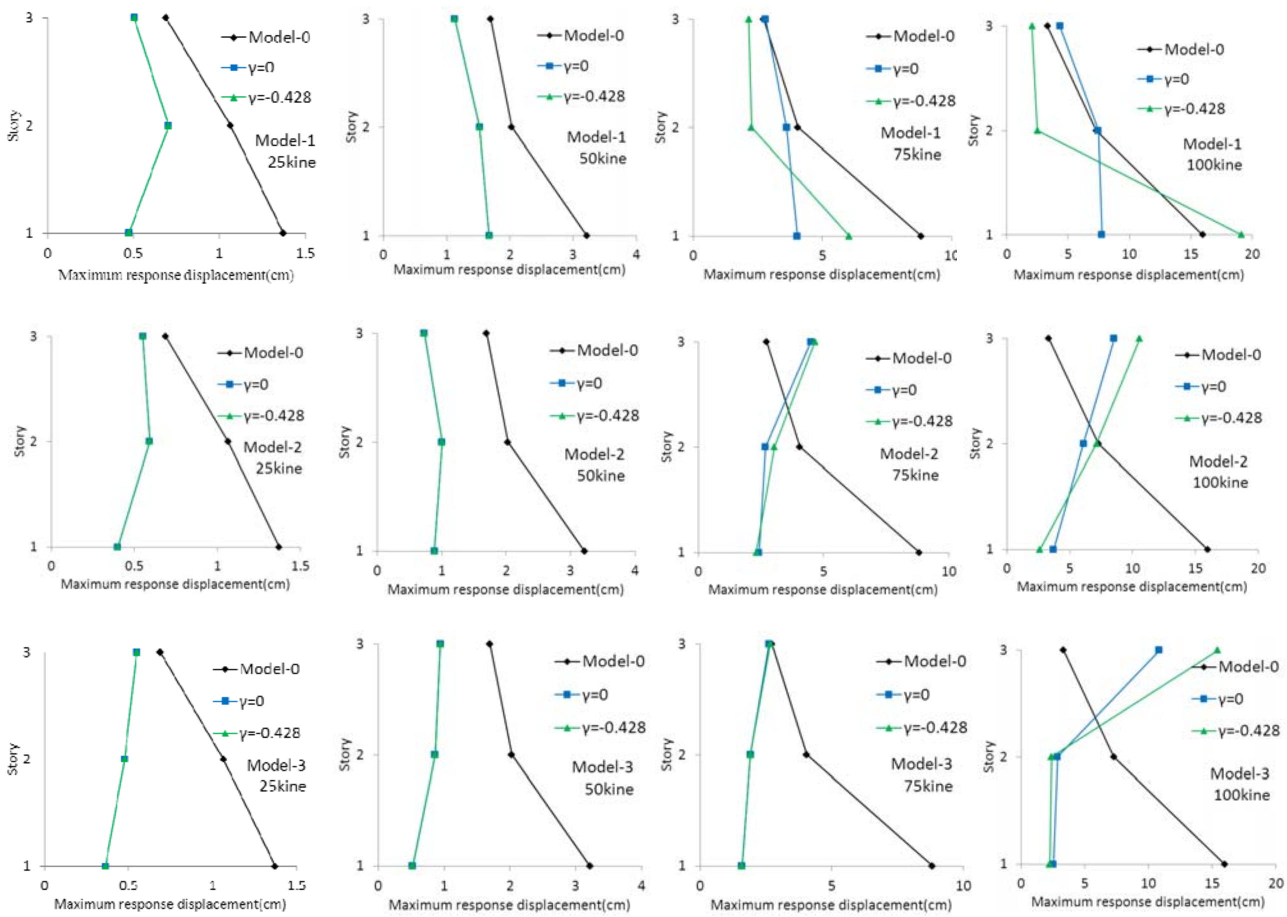


Figure 3.3 Maximum response displacement of each story compered about stiffness ratio after maximum of shear strength

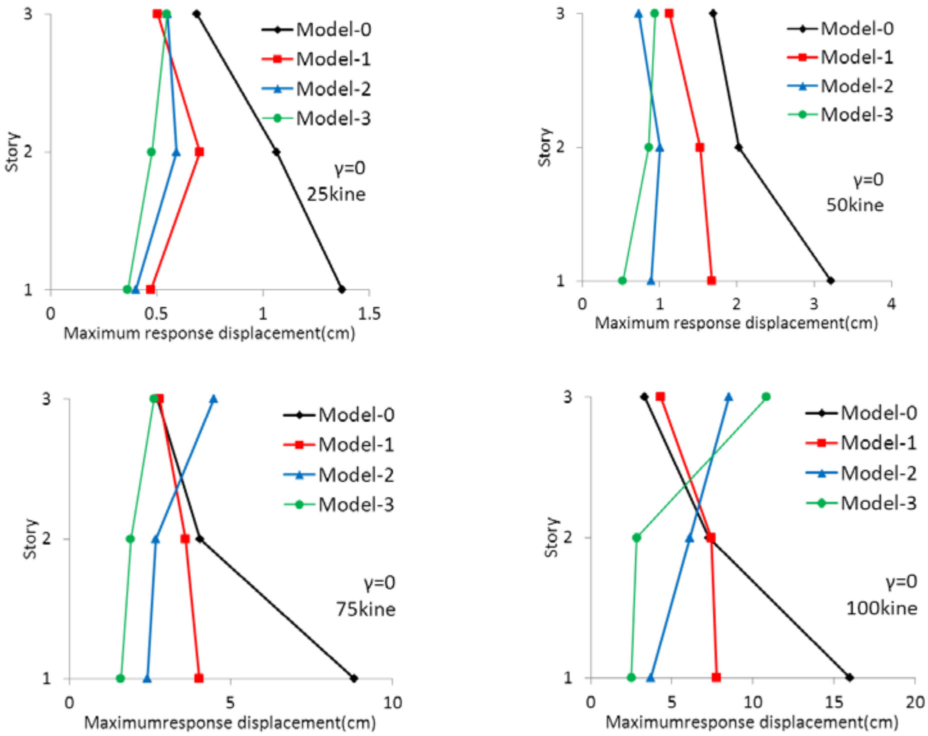


Figure 3.4 Maximum response displacement of each story compered about different models.

Fig. 3.4 shows max. of response displacement of each story compered about different models in case of $\gamma = 0$. It is shown that the responses tend to be decreased by installed wing walls, but distribution of displacement along the height of building models are different. It is not always that maximum responses are small for the models have many wing walls.

3.2.2 Input energy and historical energy

Fig. 3.5 shows earthquake input energy (left: normal graph, right: semilog graph) for model of $\gamma = 0$. Horizontal axis shows level of input earthquake. There is the tendency that the earthquake input energy is larger, in case that analytical model has more wing walls, however, it is found that the effect of number of wing walls on earthquake input energy is not so much.

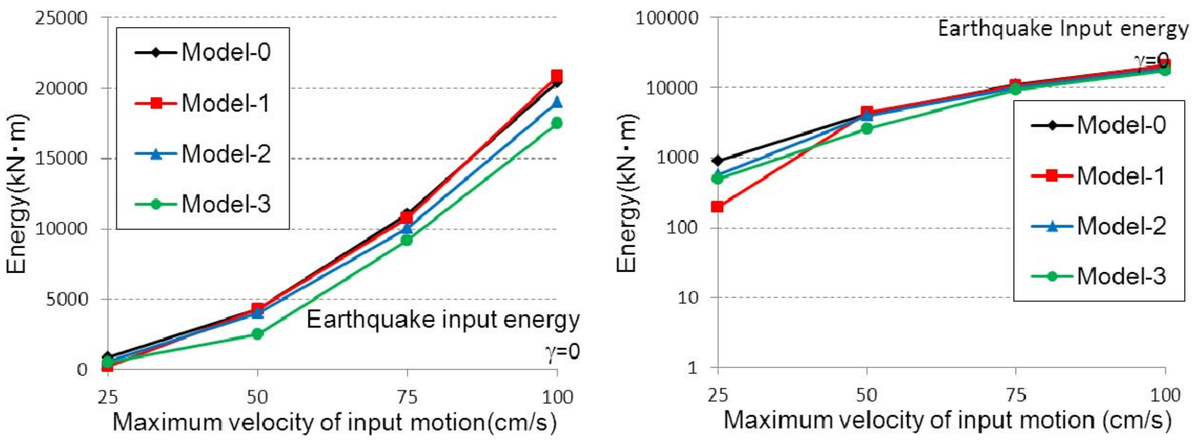


Figure 3.5 Earthquake input energy (left : normal graph , right : semilog graph)

Fig. 3.6 shows hysteresis energy of columns (left : normal graph , right : semilog graph). Hysteresis energy of columns is similar to earthquake input energy in Fig. 3.5. Therefore, most of input energy is absorbed as hysteresis energy of columns.

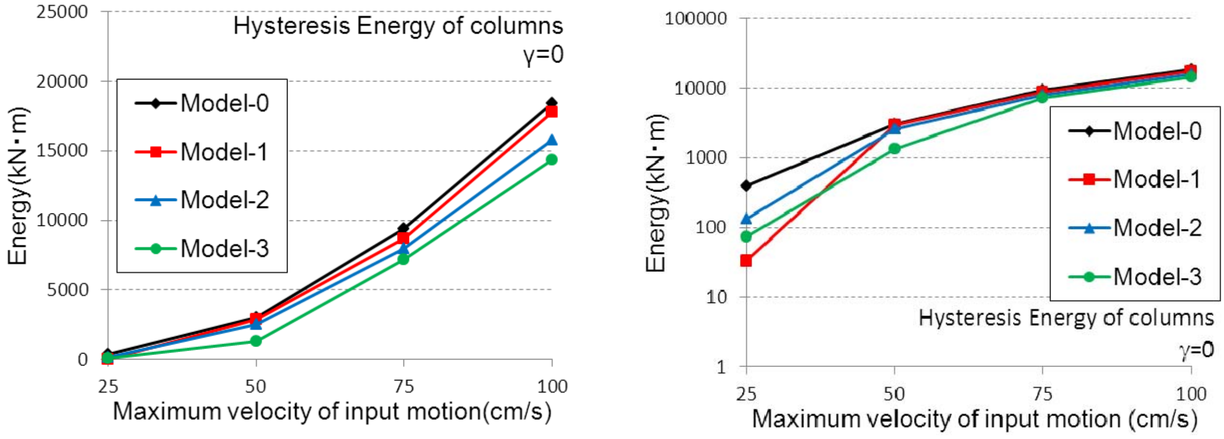


Figure 3.6 Hysteresis energy of columns (left : normal graph , right : semilog graph)

Fig 3.7 shows hysteresis energy of wing walls (left : normal graph , right : semilog graph).The scale of vertical axis is different from Fig.3.5 and Fig.3.6. Hysteresis energy of wing walls is considerably smaller compared to that of columns. However there is the same tendency as Fig.3.5 and 3.6 about the number of wing walls of analytical model and the amount of energy absorption.

From these results of analyses, the number of wing walls does not much effect on response energy.

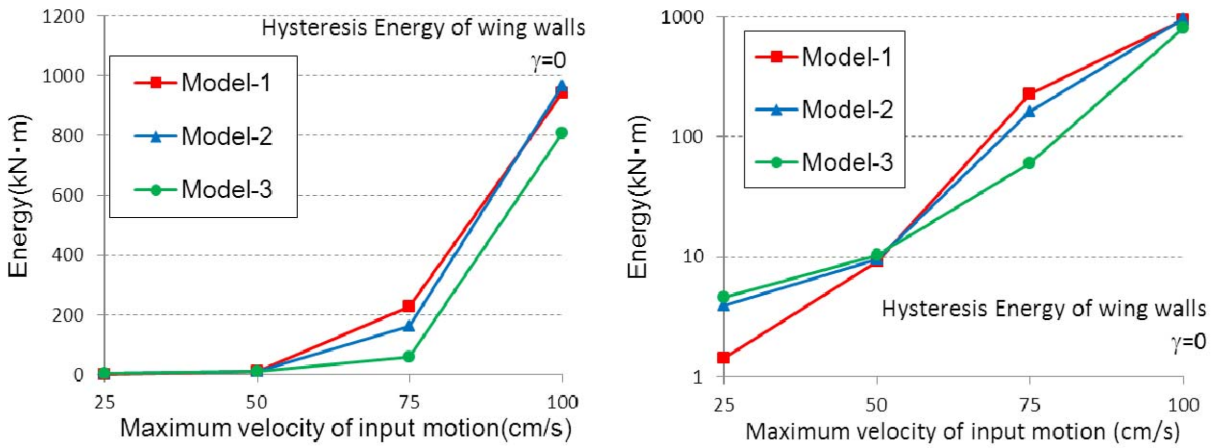


Figure 3.7 Hysteresis energy of wing walls (left : normal graph , right : semilog graph)

4. CONCLUSIONS

1. To install low strength and high ductility precast wing walls for the steel frame structure is effective to improve the stiffness, the strength and the capacity of energy absorbing.

2. In this study, it is found that the effects of amounts of steel bars and PVA fiber grid of the wing wall panels on the structural characteristics to horizontal loads are small. However, in order to aim practical application of the super ductile precast panel wing walls proposed in this paper, more detailed experiments and verifications are needed.

3. By the results of earthquake response analyses, it is shown that wing walls of precast panel can be expected to decrease the earthquake response of structure. However, in order to decrease the earthquake response of the structures effectively, it should be considered that the problem that how many wing wall panels are installed and the problem that which distribution of installed panels in vertical direction, from first story to top story of structure, in future.

4. From the earthquake analyses of models assumed different numbers of wing walls, it is found that the difference of earthquake input energy due to amount of wing walls are small relatively. In this study, precast wing walls are effective to decrease the earthquake response displacement; however, hysteresis energies of wing walls are small compared to input energies. So, if the hysteresis energy of wing walls can be increased, the earthquake responses of structures are decreased more effectively. Therefore, the improvements of joints wing wall panels and structures are needed in order to fully demonstrate the energy absorption capacity of wing wall panels.

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