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STUDY ON EARTHQUAKE RESPONSE OF TWO-STORIED STEEL FRAME WITH Y-SHAPED BRACES

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SUMMARY

The main objective of this study is to examine the behavior of two-stoies, one-bay steel frames with Y-shaped braces subjected to a severe earthquake by the "On-line Computer Test Contorol Method". This on-line test is carried out to demonstrate the good earthquake-resistant behavior during the servere earthquake. Emphasis is placed in the capacity of the structure to sustain large deflections and to dissipate substantial energy in its inelastic range. On the other hand, an earthquake response analysis of the structure's hysteretic behavior is performed. The correlation between experimental and analytical results is studied.

INTRODUCTION

Recently, studies on sevral types of eccentric braces have been presented (Refs.1 and 2). This steel frame with Y-shaped brace has been developed by the authors(Ref.2). The basic principle of structural design is that the shear steel panel connected to the braces and the beams takes place the shear yielding and on the other hand, the braces supporting the shear panel keep within the elastic stress subjected to a strong earthquake. The merits of using the shear panel in steel frame comparing with the conventional braced frame are as follows; (1) High strength and high ductility can be obtained, (2) As the damage is concentrated mainly to the shear panel, it may be replaced easily after an earthquake and (3) The strength of a steel frame can be changed independently of the stiffness by ajusting the dimension of shear panel. In this paper, some tests and anlyses on the steel frames with Y-shaped brace are shown. Static loading tests and "On-line Earthquake Response Tests" are carried out for a study on the inelastic behavior during the earthquake.

OUTLINE OF EXPERIMENTS

<u>Design Principle of Specimen</u> Two types of model are employed as follows;

(1) Model-1: Linear distribution of story shear coefficient (Cu) defined as the ratio of story shear force to the weight of structure are employed along the story. It is expected that energy induced by the ground motion will be dissipated mainly by the first story.

(2) Model-2: The distribution similar to the Ai-distribution prescribed in the Japanese seismic code are employed. The input energy will be dissipated equaully by the first and second story. However, the dynamic properties, ie.,

fundamental period and vibrational mode, within the elastic range of restoring force are designed to be almost same one another.

Specimen Model The specimen, as shown in Fig.1 and Table 1, was a two-stories steel frame provided with Y-shaped braces. Beams have sufficient stiffness and strength, and the foundation is fixed tightly to the testing floor. Two types of shear panel are employed for the earthquake resisting elements in the steel frame. As shown in Fig.2, one is rolled H-shaped steel with thick web (hereafter called S-panel) and another is the built up H-shaped steel with thin web strengthened by a stiffener (called W-panel). The ultimate shear strength of the former becomes larger than that of latter. These two types of panel are installed between the beam and the top of brace. The distribution of story shear coefficient can be obtained by the moderate placing of S- and W-panel to the each story; in Model-1, S-panel are installed to the both the first and second story, respctively; on the other hand, in Model-2, S-panel is installed to the first story and W-panel is to the second story. The fundamental properties; strength distribution and dynamic properties, are illustrated in Fig.3.

Loading Program In static loading tests, the cyclic displacements are applied in gradually increasing manner to the each story until the story drift angle of 1/50. In on-line earthquake response tests, the 7 seconds of EL Centro 1940 NS was used as the input seismic wave, and further, free vibration was allowed for 1 second. The maximum accerelations of 200 gals and 350 gals were employed. A Rayleigh type damping where damping factors would be 0.1 percent for primary mode and 80 percent for secondary mode was considered in order to reduce the secondary mode vibration caused by the loading condition.

Loading Apparatus Test setup is shown in Fig.1. Test specimen is set in parallel to the testing floor. Each electric-hydraulic actuator is attached to one side of the beam of specimen obtaining the reaction force from the reinforced concrete wall.

RESULTS OF STATIC LOADING TESTS

The test results of Model-2 specimen is discussed in this paper as a representative case of both static loading tests and the on-line tests. The relationships between story shear force and story drift of specimen ST-2 is shown in Fig.4. Deformation patterns of shear panels at the ultimate stage are shown in Photo.1(a). Intitial stiffness was around 100 t/cm for both stories. When story shear force reached shear panel yield strength Qy in Table 1, the stiffness started to decrease gradually and when shear buckling took place, the load could not increase. There was no prominent deterioration of restoring force characteristics even when the story drift angle of 1/50 corresponding to drift angle of 1/7 for the panel was applied. However, at the cycle of 1/50 on the negative side, a part of the web in the S-panel ruptured and the load began to decrease. The W-panel strengthened by a stiffeners is less damaged than the S-panel though the same story drift was applied. It is indicated that a stiffener will be able to improve the buckling behavior. Maximum strength of test was higher than the calculated strength Qu. This was because strength increase due to strain hardening after yielding of the shear panel was not taken into consideration in calculations.

RESULTS OF ON-LINE EARTHQUAKE RESPONSE TESTS

PS-2-350 for Model-2 subjected to 350 gals maximum accerelation is discussed as a representative case of on-line test. The time history of response displacement is shown in Fig.5, and story shear force-story drift relationships in

Fig. 6. The shear panels yielded between 1.2 and 1.8 sec. Maximum response displacements occurred at around 2.1 sec, when the shear panel of the first story took place the shear buckling. The deformation patterns are shown in Photo. 1 (b), and it can be seen that the degree of damage was smaller comparing with the results of static loading tests. The distribution of bending moments and shear forces shown in Fig. 7 were calculated from measured strain of beam and braces in the on-line response test. From this fugure, it can be seen that a large shear force occurred at the shear panel and that the bending moment at the joint of beam and the shear panel became larger. This concentration of bending moment should be considered in actual design of the beam. In case of Model-1, damage was concentrated at the first story, while in case of Model-2, damage of the first story was decreased by scattering to the second story. Accumulated hysteretic energy dissipation is shown in Fig. 8. The share to the first story of Model-2 was less than that of Model-1.

ANALYTICAL RESULTS

Outline of Anaysis In the on-line earthquake response test, reaction force of specimen is used as restoring force in the equation of motion subjected to a earthquake motion. In this analysis described here, a mathematical model expressed by Ramberg-Osgood function (Ref. 3) was used.

Results of Analysis The analytical results of the static loading test by Ramberg-Osgood function are shown in Fig. 4 (b). The analysis could simulate well the test results. Therefore, this model can be employed as restoring force models for earthquake response analysis. Time history of response displacement is shown in Fig. 5 (b), and restoring force characteristics in Fig. 6 (b). It was succeeded in simulating the occurrence time of maximum response displacement, maximum value, vibration period, and vibration mode. However, there were some difference of the skelton curve of restoring force because the restoring force model was determined in a manner that equivalent viscous damping which are calculated by the hysteretic loop would coincide with the large deformation at the inelastic range. Another earthquake response analysis in large intensity accerelation to 450 gals and 550 gals were examined. These had the values of 0.74 and 0.64, which are the ratio of the base shear coefficient to the input seismic coefficient (Cb/Kg). Fig. 9 shows the maximum response story drifts in the on-line response tests and analysis on the ordinate, and the ratio of the base shear coefficient to input seismic coefficient on the abscissa. The following were found from this figure; (1) Story drift increases as input ground motion becomes larger; and (2) With increases in input ground motion, whereas incresing rate of the response displacement of the first story is larger than that of the second story with Model-1, they are almost same degree for both stories with Model-2.

CONCLUSION

As a result of static loading tests, on-line earthquake response tests, and earthquake response analysis of two-story steel frames with Y-shaped braces, the following were obtained :

(1) The computer-actuator on-line test is very useful in predicting the real behavior of structure during the earthquake.

(2) According to the static loading tests, this braced frame had a large energy dissipation capacity through shear yielding of shear panels.

(3) According to the on-line response tests, the specimen of base shear coefficient of 0.34 was kept within the story drift angle of about 1/200 under earthquake input of 200 gals, and showed stable behavior even against 350 gals. With linear distribution of shear coefficient, damage was concentrated at the first story especially when input was 350 gals,

but with close to Ai-distribution, damage was scattered to the second story and damage to the first story was reduced.

(4) The numerical analysis using Ramberg-Osgood function model could simulate well the results of on-line tests.

ACKNOWLEDGEMENT

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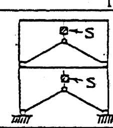
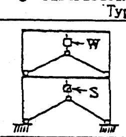
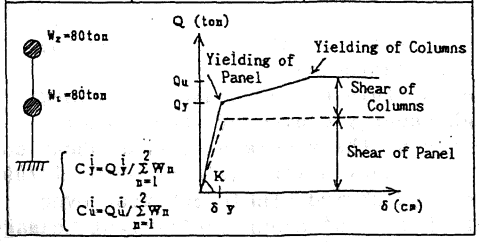
REFFERENCES

1. Roeder, C.W., and Popov, E.P.,; Eccentrically Braced Steel Frames for Earthquake, Journal of Structural Division, ASCE, Vol.104, No.ST3, Mar. (1978).
2. Takeda, T., Takahashi, Y., etc.; Experimental Study of Frames with Steel Brace (Part 3 Study on New Types of Steel Brace), Summaries of Technical Papers of Annual Meeting, AIJ, Oct. (1972).
3. Ramberg, W., and Osgood, W.R.; Description of Stress Strain Curves by Three Parameters, Technical Notes, No.902, NACA, (1943).

Table. 1 Test cases

		Model-1 (Damage Concentrating Type)		Model-2 (Damage Distributing Type)	
Specimen					
Static Test		ST-1		ST-2	
On-line Test	200 gal	PS-1-200		PS-2-200	
	350 gal	PS-1-350		PS-2-350	
Story		1	2	1	2
Qy (ton)		36	36	36	22
δy (cm)		0.27	0.27	0.27	0.19
K (ton/cm)		134	134	134	119
Qu (ton)		54	54	54	41
Cy		0.23	0.45	0.23	0.28
Cu		0.34	0.68	0.34	0.51
T (sec)		0.25		0.26	



$$C_y^i = Q_y^i / \sum_{n=1}^{2} W_n$$
$$C_u^i = Q_u^i / \sum_{n=1}^{2} W_n$$

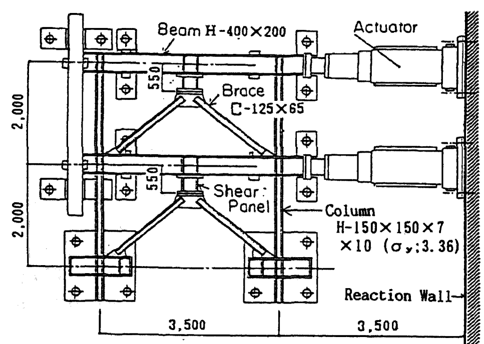


Fig. 1 Specimen and Test Set up

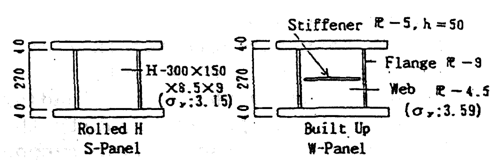
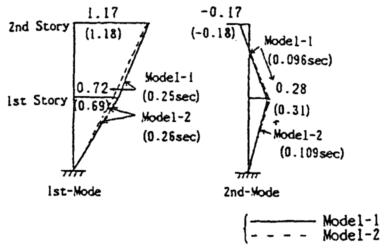
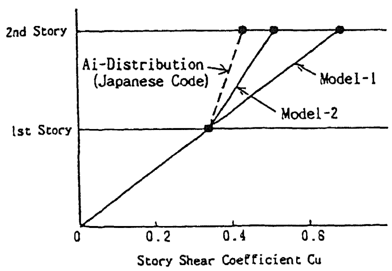


Fig. 2 Detail of Shear Panels

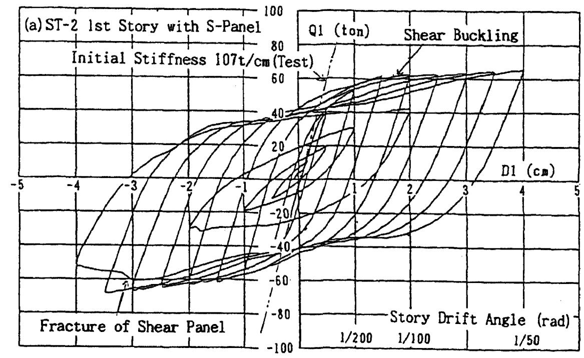


(a) Dynamic propeties



(b) Strength Distribuotion

Fig. 3 Property of Specimen



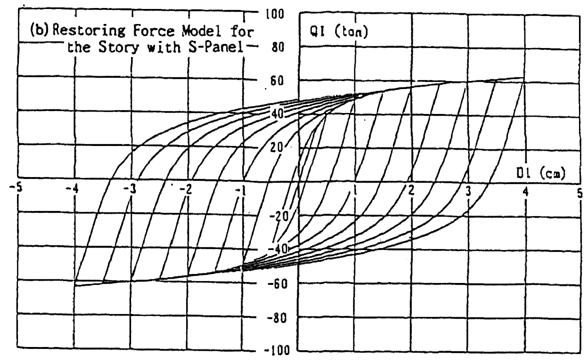
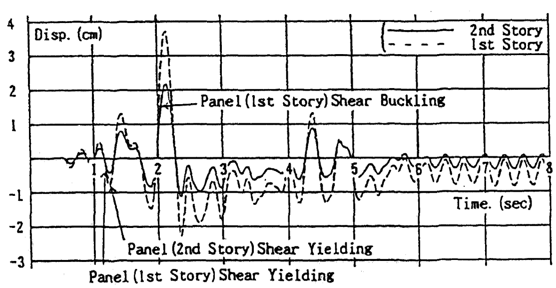
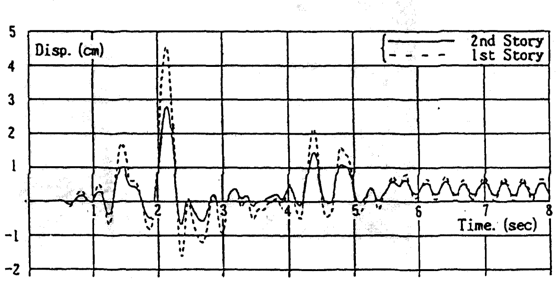


Fig. 4 Story Shear-Story Deift Relation in Static Loading Test

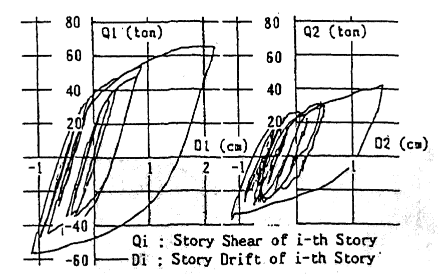


(a) On-line test result (PS-2-350)

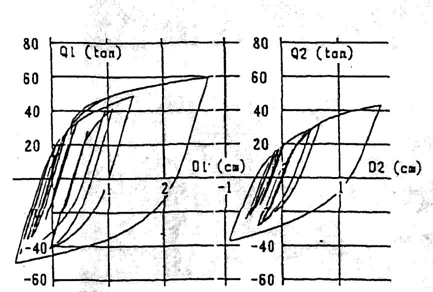


(b) Analytical simulation result (Ramberg-Osgood Model)

Fig. 5 Time History of Displacement

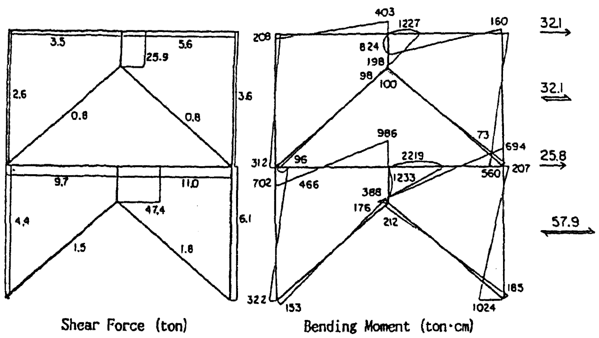


(a) On-line test result (PS-2-350)



(b) Analytical simulation result (Ramberg-Osgood Model)

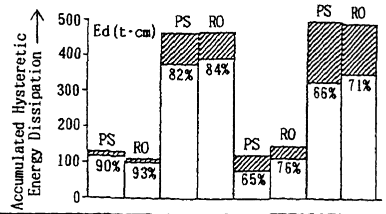
Fig. 6 Story Shear-Story Drift Relation in On-line Test



Remark ; Response of PS-2-350 at 2.03sec (On-line Test) D_1=1.08cm, D_2=0.70cm

⟶ External Force ⟺ Story Shear Force (unit;ton)

Fig. 7 Internal Force



Cu/Kg	1.66	0.95	1.66	0.95
Input	200gal	350gal	200gal	350gal
Specimen	Model-1		Model-2	

Remark:Accumulations at the end of test are shown.
"~%" indicates percentage of 1st story for total.

□ 1st Story ▨ 2nd Story

Fig. 8 Energy Dissitation

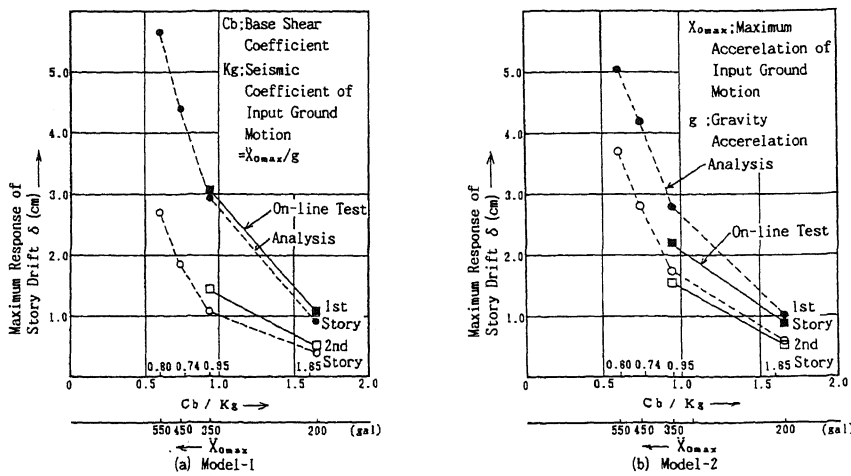
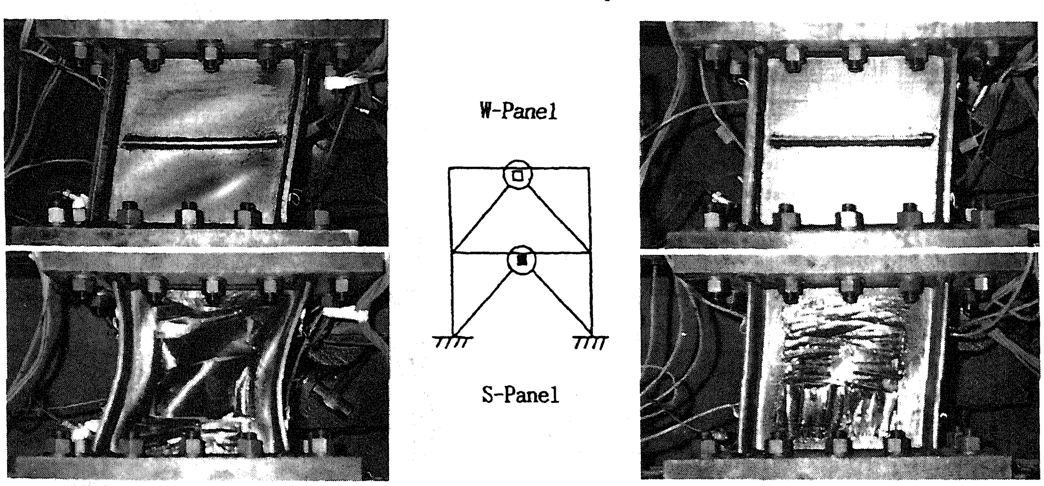


Fig. 9 Input Level and Response



(a) Static Loading Test
D1=4.0cm D2=4.0cm

(b) On-line Test at 2.03sec
D1=1.08cm D2=0.70cm

Photo. 1 Deforwation of Shear Panel