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PROPERTIES OF BRACE ENCASED IN BUCKLING-RESTRAINING CONCRETE AND STEEL TUBE

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SUMMARY

It has been desired to develop such braces as can permit choosing the required rigidity, yield strength independent of the susceptibility to buckling. The brace presented in this paper is a buckling-resistant structural member consisting of a steel core members enclosed in a concrete-filled square steel tube. This brace shows stable hysteresis if the yielding load working on the core member is smaller than the buckling load of the steel tube. This paper reports the results of the tension and compression tests and numerical analysis of these structures.

INTRODUCTION

Rational arrangement of braces in a steel frame is very effective in reducing the deformation and response of a building frame of steel-frame structure caused by earthquake and increasing the resistance to horizontal forces during a strong wind and earthquake. The deformation of a rigid frame structure occurs mostly as the bending of columns and girders; the degree of elastic deformation is large and the plastic deformation capability is also large. A frame fabricated by incorporating in this frame structure braces have the following character and problems. When braces of high slenderness ratio are used, the deformation capability exists unless joints are broken when tensile forces work on the braces. However, when these braces undergo compressive deformation, lateral deformation occurs easily and they cannot bear compressive forces, with the result that they show hysteresis of the slip type under repeated loads. When their slenderness ratios are sufficiently small, these braces also bear compressive forces and buckling is not apt to occur to some degree. As a result, they show good dynamic behaviors, However, because the rigidity of the braces is higher than that of the surrounding frame, they are sometimes required to bear excessive horizontal forces. For a frame in which braces with slenderness ratios intermediate between those of above-mentioned two kinds of braces are incorporated, it is difficult to design in which the energy absorption by plastic deformation is expected, because buckling is of an embrittling nature especially under compressive forces. From the foregoing, it may be judged that it is difficult to design a frame structure containing braces by making the most of the high toughness peculiar to steel-frame structures. If the problem of buckling is solved, it is possible to design the required rigidity, yield strength and deformation at yield point freely to some extent because the yield stress and sectional area of steel products can be appropriately selected.

Against this background, the authors designed an brace that has a stable forth-deflection characteristic and enables compressive yield strength to be considered equal to tensile yield strength in order to further materialize the above-mentioned various ideas. In this brace, a core steel member with a rectangular section is restrained at its ends by the concrete encased in a steel tube insulate from frame to restrain buckling and coating materials are used between the concrete and the core member to prevent the transmission of axial forces to the concrete by friction. This paper deals on an experiment using five specimens of this brace, a buckling analysis in which elasto-plasticity is considered, and the buckling strength of the steel tube required against the yield load of the core member.

TEST SPECIMENS AND EXPERIMENT METHOD

As shown in Fig.1, all the core members used as specimens are 19 x 90 mm in size. The core members were coated with concrete encased in a steel tube. The steel SS41(JIS:Japanese Industrial Standard) was used as the material for the core members and the yield stress in the material test was 2,880 kg/cm2. the steel TSK50(JIS) was used as the material for the steel tubes and the yield stress in the material test was 3,700 kg/cm2. The cross-shaped core member is exposed at the ends of a specimen and a cross-shaped buckling prevention steel member is embedded in the concrete encased in a steel tube at both ends. Furthermore, in view of the effect of Poisson's ratio, vinyl/mastic tape was used in the thickness direction on both sides between the core member and the concrete and 3mm thick foaming polystyrol was also used in the width direction on both sides between the core member and the concrete.

The experiment was conducted on a total of five specimens with the ratio of Euler load, Pe, of the steel tube to the yield load, Py, working on the core member, i.e. Pe/Py between 0.55 and 3.82 by varying the sectional dimensions of the steel tube with the size of the core brace kept constant. Calculated strength values of each specimen are shown in Table 1.

In the experiment, horizontal forces were applied to the frame using a 110-t actuator. The core brace was tested by repeated loading on both direction at 8 cycles until the allowable permanent and temporary design loads and displacement angles between stories of 1/400 to 1/50 were reached.

RESULTS OF EXPERIMENT

Results of the experiment are shown in Table 1. In specimens in which the buckling strength of the exceeded the yield stress of the core member (No.1 to No.3 specimens), buckling did not occur even on the compression loading and, as shown in Figs 5 to 7, much energy was absorbed. Thus the hysteresis characteristic was stable in these specimens. The hysteresis curves on the tension loading are such that loads increase at gradients corresponding to the rigidity in the elastic range of the core member and the bracing member also yields when the yield load of the core member is reached. The displacement angle between stories at yield point is about 1/500. A stable hysteresis characteristic is observed even at the displacement angle between stories at final deformation of 1/50. It may be said, therefore, that these three specimens have hysteresis characteristics which coordinate sufficiently with the deformation of general rigid frames between 1/200 to 1/50.

Because the initial rigidity corresponds almost to the rigidity of the core member only and because the axial force transmitted to the concrete encased in the steel tube was about 5% of the total even on the compression loading, it might be thought that the bond between the core member and the concrete encased in the steel tube could be eliminated. It may be said that the effect of the coating materials (vinyll/mastic tape plus foaming polystyrol) used in the experiment was ascertained.

In specimens in which the buckling yield strength of the concrete encased in the steel tube was lower than that of the core member (No.4 and No.5 specimens), buckling occurred before the yield of the core member during compression and the yield strength decreased abruptly as shown in Figs 8 and 9. The condition of the specimens after the experiment is shown in Photo 2. The specimens shown are No.1 to No.5 from left to right.

ANALYSIS

In the no-nlinear analysis method adopted in this paper, the composite structural member is such that the displacement of the concrete encased in the steel tube and that of the core member only in the normal direction relative to the axis of the structural member, after their deformation, are caused to be equal to each other and they deform independently in the tangential direction. The analysis was made in the step-by-step process. Specimens of three different sections (No.1, No.2 and No.4 specimens) were analyzed. In this analysis, the effects of the concrete on increases in the rigidity and yield strength in the axial direction of the structural member were ignored and only the effects contributing to causing the normal-direction displacement of the core member to be equal to that of the steel tube were taken into consideration.

Symmetrical conditions were used. The specimen has a fixed end and a free end, and half the structural member length (l = 164.5 cm) was divided into 56 elements. Each section of the core member and steel tube was divided into 20 smaller sections and the stress-strain relationship was investigated.

RESULTS OF ANALYSIS

1. Differences in characteristics due to the ratio of Euler load of the steel tube to the yield load of the core member (Fig. 10)
[No.1, 2 and 4 specimen, initial deflection:l/1,000]

When Euler load of the steel tube was heavy, yielding occurred at the yield load of the core member owing to the buckling-restraining effect of the steel tube and a stable hysteresis characteristic was shown after that, as the results of the experiment. Furthermore, the phenomenon that only the core member contracts and slips into the area of the steel tube could be reproduced. When the buckling load of the steel tube was smaller than the yield load of the core member, buckling occurred and the yield strength decreased due to insufficient flexural rigidity before the yielding of the core member.

2. Effect of the initial deflection (Fig. 11)
[No.2 specimen, initial deflection: l/1,000,l/500,l/100]

As shown in Fig. 13, the effect of the initial deflection is great when the buckling load of the steel tube is somewhat high to the yield load of the core member. When the initial deflection was small, yielding occurred on the core member and a stable hysteresis characteristic was exhibited. However, the initial rigidity decreases with increasing initial deflection; at an initial deflection of l/100, buckling occurs before the yielding of the core member and the yield strength decreases.

CONCLUSION

It was found that when this brace is actually incorporated in a frame and the ends of the structural member are subjected to the effects of the bending moment, buckling of the whole structural member does not occur if Euler load of the steel tube is greater than the yield strength of the core member to some extent. Furthermore, it became apparent that a stable hysteresis characteristic is exhibited even after the yielding of the core member. In making actual designs, it seems necessary that the brace member should be encased in a steel tube having Euler load about 1.5 times the yield load of the core member. Furthermore, the concrete in the steel tube also contributes to the flexural rigidity of the steel tube, buckling could be prevented also in the No.3 specimen in the present experiment. In terms of design, it is also possible to reduce the section and wall thickness of the steel tube in consideration of the effect of the concrete. In this case, however, the effect of the concrete was ignored and considered to be a surplus effect. With this new bracing method, it is possible to determine the initial rigidity and yield strength of the bracing member from the behaviors of the core member under compressive and tensile loads independently of the problem of buckling and it is also possible to ensure a stable hysteresis characteristic even during substantial deformation of the frame. As a result, designs can be made in a simple manner. In addition, because a stable behavior is exhibited even after the yielding of the core member, it is possible to utilize this for hysteresis attenuation.

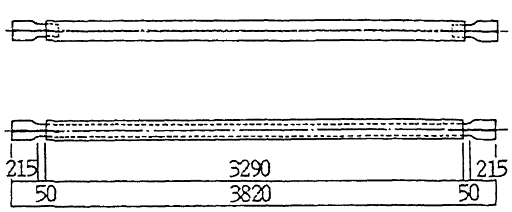

Fig. 1 Test Specimen Configation

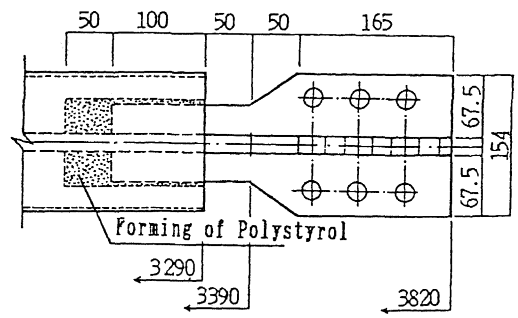

Fig. 2 Ditail of Ends

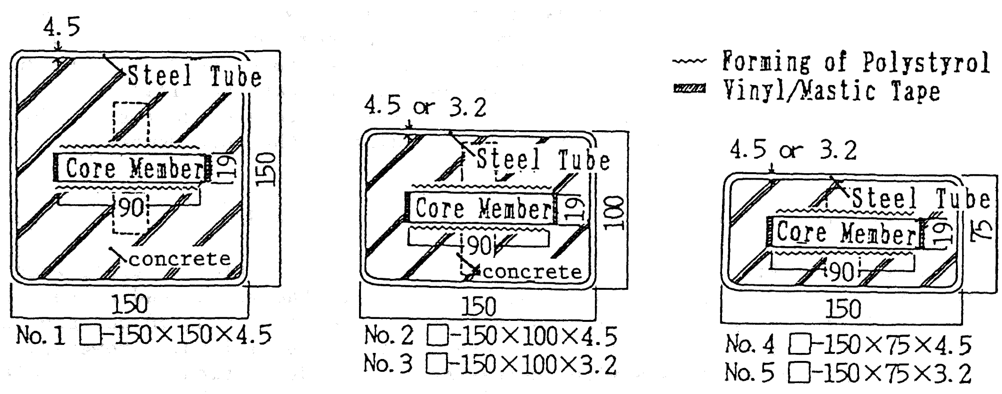

Fig. 3 Section of Specimens

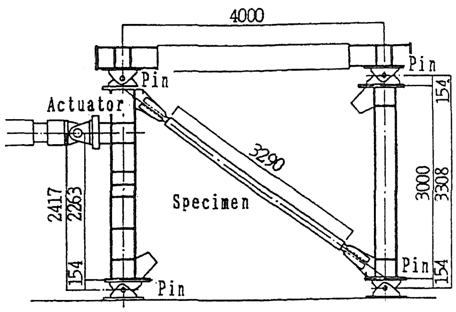

Fig. 4 Loading of System

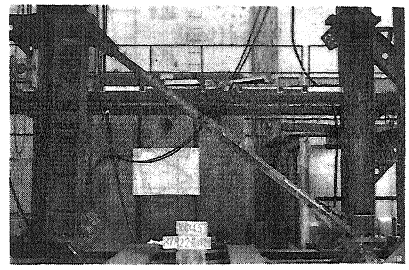

Photo 1 Loading System

Table 1 Culculated strength values and Result of Experiment

No.	parameter	culculated strength					experimental strength				
		steel tube		core member			tensile yield		buckling		
	steel tube size B x D x t mm	morment of inertia I cm4	Euler load Pe ton	area of section A cm2	yield load Py ton	Pe / Py	load Pt ton	Pt / Py	load Pcr ton	Pcr / Py	Pcr / Pe
1	150x150x4.5	896	171.0	16.84	48.50	3.53	48.6	1.00	-	-	-
2	150x100x4.5	352	67.4	16.84	48.50	1.39	48.3	1.00	-	-	-
3	150x100x3.2	262	50.2	16.84	48.61	1.03	47.6	0.98	-	-	-
4	150x75x4.5	183	35.0	16.88	48.50	0.72	48.3	1.00	46.5	0.96	1.33
5	150x75x3.2	137	36.2	16.62	17.87	0.55	47.9	1.00	43.1	0.90	1.65

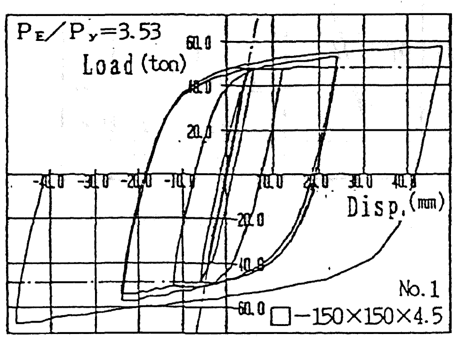

Fig. 5 Load-Displacement relations

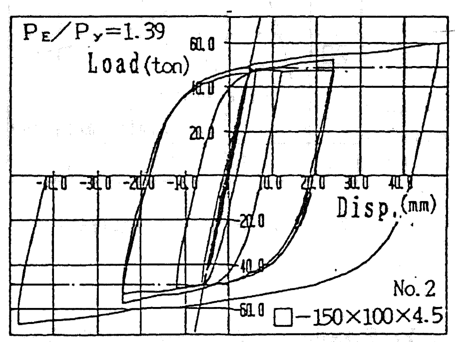

Fig. 6 Load-Displacement relations

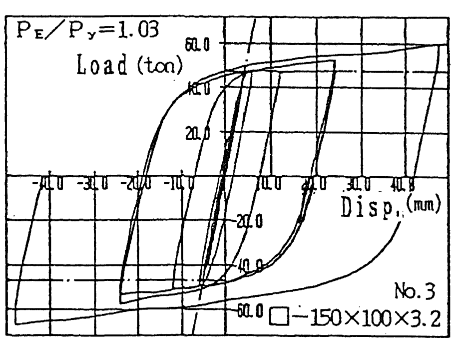

Fig. 7 Load-Displacement relations

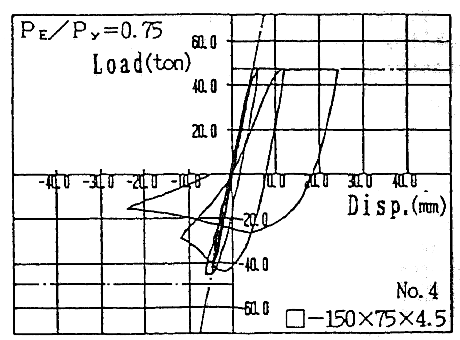

Fig. 8 Load-Displacement relations

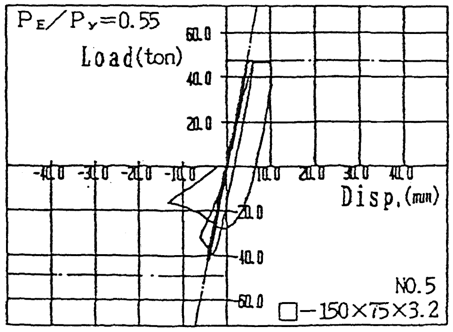

Fig. 9 Load-Displacement relations

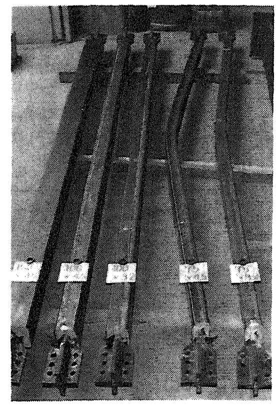

Photo 2 Spacimens after Experiment

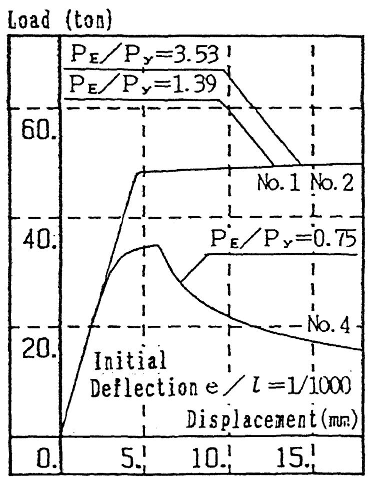

Fig. 10 Result of Analysis (1)

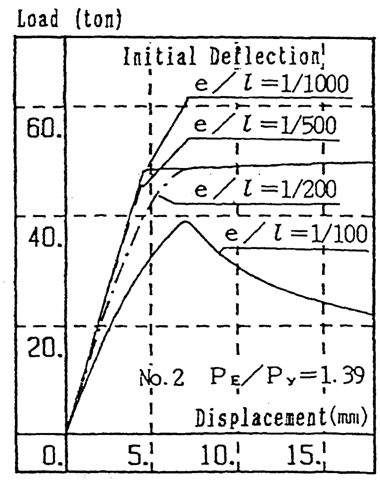

Fig. 11 Result of Analysis (2)

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2) Y. Murata, S. Mochizuki, N. Andou, S. Takahashi : An Experimental Study on Buckling of Unbonded Braces Under Centrally Applied Loads, Annual Meeting Archtectural Institute of Japan, Sep. 1980, pp. 1913-1914, in Japanese