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ELASTIC PLASTIC DEFORMATION AND COLLAPSE BEHAVIOR OF BRACED FRAMES

Bunzo TSUJI and Takayoshi NISHINO

Department of Environmental Planning, Kobe University,
Rokkodai-cho, Nada-ku, Kobe-shi, Hyogo 657 Japan

SUMMARY

To make clear the effects of the brace arrangement on the deformation and collapse behavior of braced frames, alternating cyclic loading tests with incremental amplitude and numerical analysis were performed for Λ-type and Z-type braced frames of one story and one span with H-shape members. In the Λ-type braced frame, the lateral resistance of braced frame was made small because the brace did not take tensile force effectively, while its deformation capacity was large because the progress of the cracks was minimal, as the strength of beam decreased. In a Z-type braced frame, the cracks of the brace progressed rapidly because of large elongation of the brace, which resulted in a small deformation capacity.

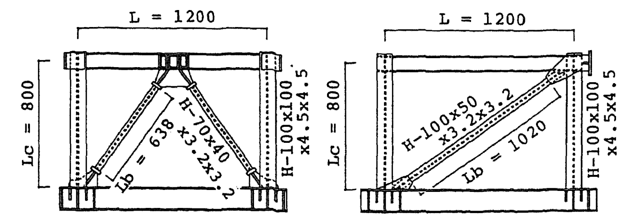
INTRODUCTION

The load carrying and deformation capacities are deteriorated because of the overall buckling, local buckling and low cyclic fatigue cracks induced at the brace, as well as the plastic deflection and local buckling at the surrounding frame. The braced frame collapses finally when the brace fractures. Deformation and collapse behaviors of the braced frame are concerned with brace arrangement in the frame. In the Λ-type braced frame, the difference in the axial load between the tension and compression braces acting on the beam is significant, and in a Z-type braced frame, the additional axial force imposed to the column is significant.

To make clear the effects of the brace arrangement on the deformation and collapse behavior of braced frames, cyclic loading tests and numerical analysis were performed for Λ-type and Z-type braced frames.

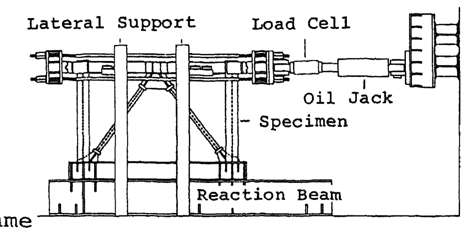
SCOPE OF TEST

Specimens tested are shown in Fig.1. Fig.1(a) shows a Λ-type braced frame, and Fig.1(b) a Z-type braced frame. All specimens were made of a welded built-up wide flange section satisfied the width-to-tickness ratio to be defined as a compact section, and the columns and braces were arranged to be subject to the weak axis bending. To avoid shear failure at the beam-brace connection, doubler plates were welded in the middle of the beam into which the braces were framed. Mild steel was used. The mechanical properties of the material tested and cross sectional properties of beam are shown in Table 1. In the Λ-type braced frame, three specimens were fabricated and the strength ratio C (C=8·Lb·Mp/L·Lc·Ny, Mp:fully plastic moment of beam, Ny:yield axial force of brace) was chosen as the parameter. In a Z-type braced frame, one specimen having the beam and column which equal to those of the Λ-type braced frames with C=0.8 is manufactured. The slenderness ratios of brace were 37 and 51 in the Λ-type and Z-type braced frames. Fig.2 shows the loading system, in which lateral force was applied by an oil jack with a load cell. The beam was supported by two pairs of steel columns to avoid the lateral buckling in the beam. In the loading, the drift angle was increased by 0.01 rad. after every three cycles of loading with a constant amplitude. Cyclic loadings are continued until the failure occurs.

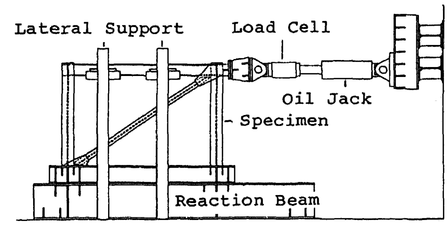


(a) Λ-type Braced Frame (b) Z-type Braced Frame

Fig.1 Specimen



(a) Λ-type



(b) Z-type

Fig.2 Loading System

Table 1 Cross Sectional Properties of Beam

Code	Cross Sectional Shape of Beam	Yield Stress (t/cm²)				C
			beam	column	brace	
Λ11	H-122.1×90.6×4.35×5.65	σ_F	2.94	3.18	3.55	1.1
		σ_W	3.18	3.18	3.55	
Λ08	H-101.0×91.5×4.35×4.35	σ_F	3.05	3.05	3.24	0.8
		σ_W	3.05	3.05	3.24	
Λ05	H- 80.3×71.2×4.35×4.35	σ_F	3.05	3.05	3.24	0.5
		σ_W	3.05	3.05	3.24	
Z08	H-101.0×91.5×4.35×4.35	σ_F	3.03	3.03	3.55	
		σ_W	3.03	3.03	3.55	

C ; Strength Ratio σ_F; Flange σ_W; Web

EXPERIMENTAL RESULTS

Load-Displacement Relationship Fig.3 shows the horizontal load-deflection relationship; Fig.3 (a),(b),(c) for the Λ-type braced frames with C=0.5,0.8,1.1; and Fig.3(d) for a Z-type braced frame. In all specimens, overall buckling of brace and local buckling at the middle and ends of the brace occurred at R=0.01 radian. In specimens of Λ05 and Λ08, local buckling occurred in the flange at the middle portion of the beam because of the large vertical deflection of the beam. In specimen of Z08, local buckling occurred in the web and flange at the upper end of the column because the brace imposed large axial force to the column. The strain amplitude of the local-buckled flange at the middle portion of the brace was larger. Accordingly, low cyclic fatigue cracks occurred at point ▼ shown in the figure. In the Λ-type braced frame, the deterioration of lateral force after the overall buckling of brace decreased as the strength ratio C increased. The Λ-type braced frame with a large strength ratio recovered its lateral resistance as the lateral displacement approached the reversal point, and the lateral load-deformation curves showed hardening type hysteresis loops. In a Z-type braced frame, the lateral resistance after the overall buckling of the brace was reduced significantly. When the brace received compressive force, a Z-type braced frame did not recover the lateral resistance even if the lateral displacement amplitude increased. When the brace sustained tensile force, the lateral load-deformation curves showed slip type hysteresis loops, and the lateral resistance recovered as the lateral displacement amplitude increased.

Variation of Strength Fig.4 shows the relations between the number of the loading cycle and lateral resistance of the Λ-type braced frame at the reversal

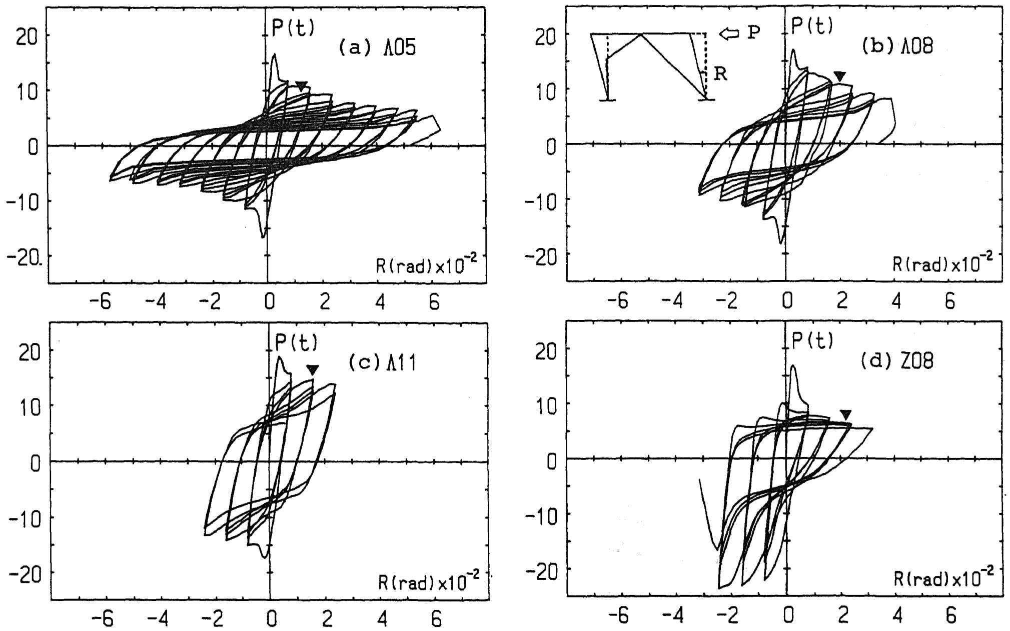
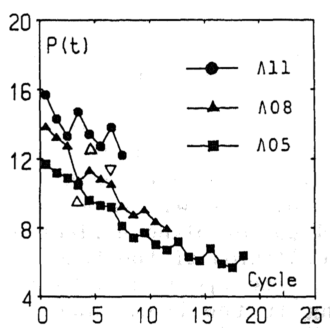


Fig.3 Load-Displacement Relationships

point. ▼ shows the point at which first crack occurred at the concave side flange of the braces. The strength of the braced frame deteriorated with reduction of the strength ratio. The reason is as follows. The vertical deflection of beam increased as the strength ratio decreased, and the brace under taking the tensile force did not work effectively. In all specimens, the concave side flange was cracked at about the same displacement amplitude. The brace was less elongated as the strength ratio decreased. Accordingly, the cracks were developed less significantly and the number of cycles at which the failure of the brace occurred increased.

<u>Vertical Displacement in Beam and Column</u> Fig.5 shows the vertical displacements in the middle of the beam of the Λ-type braced frame and in the column of Z-type braced frame. In the Λ-type braced frame, the vertical displacement of the specimen Λ11 with the largest strength ratio was much smaller, and the beam deflected elastically. In the specimen Λ08 and Λ05 with a small strength ratio, the local buckling occurred in the beam flange because the vertical deflection of beam was large from an early stage (see point ▼ shown in the figure), and the



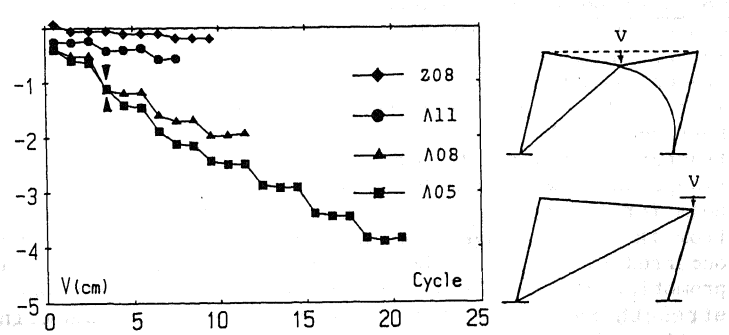


Fig.4 Variation of Strength Fig.5 Vertical Displacement in Beam and Column

local buckling promoted the vertical deflection. In a Z-type braced frame, the axial displacement of the column was kept small although the upper end of column was buckled because of the axial force transfer of the brace.

Axial Displacement of Brace Figs.6 (a)-(c) show the relation between the lateral force and axial displacement of the failed brace in the Λ-type braced frame, and Fig.6 (d) the relation between the lateral force and axial displacement of the brace in a Z-type braced frame. The abscissa is normalized by the length of brace. In the Λ-type braced frame, the axial displacement of brace on the compression side increased and the tension side decreased as the strength ratio decreased because of the vertical deflection of the beam. In the specimen with the strength ratio of 0.5 and 0.8, the axial deflection of brace was not on the tension side. In a Z-type braced frame, the axial deflection was the same on both sides because of the small axial deflection of the column.

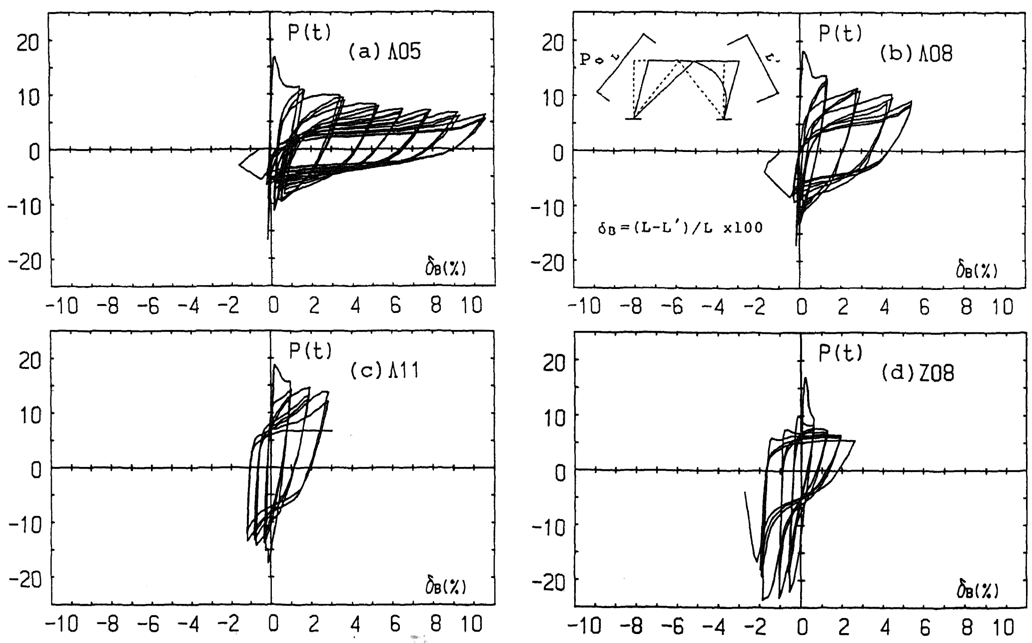
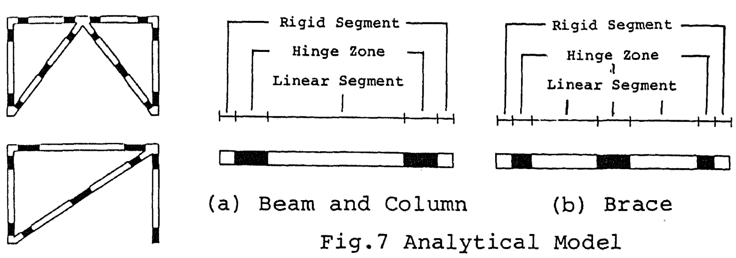


Fig.6 Axial Displacement of Brace

Collapse Behavior Overall buckling of the brace and local buckling at the compression flange in the middle and end portions of the brace occurred when the lateral amplitude was 0.01 rad. regardless of the specimens. Low cyclic fatigue cracks occurred at locally buckled flange of brace because strain amplitude at locally buckled flange is very large, and cracks also occurred at the end portions of the brace because of the stress concentration effect. The brace was fractured finally by these cracks. In the Λ-type braced frame with the beam flange whose width-to-thickness ratio was about 9, the vertical deflection of the beam for the specimens with the strength ratio smaller than 0.8 was very large from the first stage. As a result, local buckling and out-of-plane deflection occurred in the beam. Local buckling and out-of-plane deflection of the beam was promoting the vertical deflection. On the other hand, the specimen with the strength ratio 1.1 did not showed any local buckling in the beam, and the vertical deflection of the beam was very small. In a Z-type braced frame, the local buckling occurs at flanges and web in the column top because of the axial force transfer of the brace, but the axial deflection was still small. Although cracks occurred in the brace at about the same lateral displacement amplitude regardless of the specimen, the number of cycles to the failure of the brace in the Λ-type braced frame increased as the strength ratio decreased. In the Λ-type braced frame, the axial displacement on the compression side increased and the axial displacement on the tension side decreased as the strength ratio decreased. And the brace subjected to tension did not work effectively, and the lateral resistance was small in the small deflection range in the braced frame with a small strength ratio. The lateral resistance was decreased little in the large deflection range and the deformation capacity was large because the cracks did not progress significantly. If there was no the vertical deflection in the beam of the Λ-type braced frame, the brace in a Z-type braced frame should be smaller in the axial deflection amplitude than the brace in the Λ-type braced frame. And the deformation capacity of Z-type braced frame should be larger. Because of the unavoidable vertical deflection, however, the deformation capacity of Z-type braced frame is equal to the specimen Λ11, and is smaller than the specimens Λ08 and Λ05.

NUMERICAL ANALYSIS

Assumptions Elastic-Plastic deformation behavior of a braced frame was analyzed using the following assumptions:



(a) Beam and Column (b) Brace

Fig.7 Analytical Model

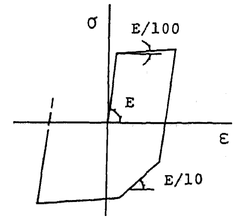


Fig.8 Stress-Strain Relationships

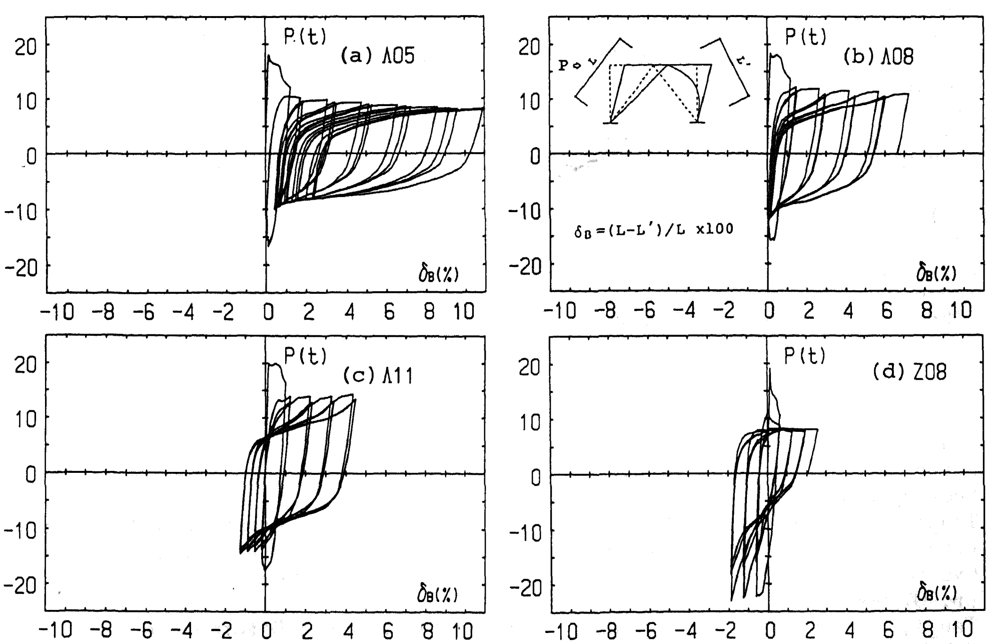


Fig.9 Axial Displacement of Brace (Analysis)

(1) Each of the columns and beam was composed of two hinge zones, a linear segment and two rigid segments as shown in Fig.7(a). The brace was composed of three hinge zones, two linear segments and two rigid segments as shown in Fig.7(b).
(2) A H-shaped cross section in the hinge zone was idealized into a 3-point model having a cross sectional area, moment of inertia, and fully plastic moment equal to those of the original cross section.
(3) Stress-strain relationship was of tri-linear type as shown in Fig.8.

Analytical Result Fig.9 shows lateral load-axial displacement relationships for the brace. In the Λ-type braced frame, as long as no cracks were observed in the experiment, the analytical resistance traced the experimental result accurately. In a Z-type braced frame, although the experimental lateral resistance when the brace is compressed decreased as the lateral displacement amplitude increased, the lateral resistance remained constant in the analysis. The axial contraction deformation of brace arranged in Λ shape increased and the axial elongation decreased as the strength ratio decreased. The axial elongation deformation of the brace is very small for specimen with the strength ratio of 0.5 and 0.8, but increased significantly for specimen with the strength ratio of 1.1. These analytical results coincided with the experimental, therefore, the effectiveness of this analysis was verified.

CONCLUSION

To investigate the effects of the brace arrangement on the deformation and collapse behavior of braced frame, incremental amplitude alternating cyclic loading test and numerical analysis were performed for Λ-type braced frame and Z-type braced frame. Following conclusions were obtained.
(1) In the Λ-type braced frame with a small strength ratio, the brace in tension did not work effectively because of the vertical deflection of the beam, and the axial displacement of brace on the compression side increased and the tension side decreased.
(2) In a Z-type braced frame, the axial deflection of the brace was the same on both directions because of the small axial deflection of the column.
(3) The lateral resistance of the Λ-type braced frames deteriorated rapidly with the reduction of the strength ratio in the range of the small lateral displacement.
(4) The drift angle of the column at which the brace was fractured was 0.08, 0.05, 0.04 and 0.04 rad. for specimens Λ05, Λ08, Λ11 and Z08 respectively.
(5) In the Λ-type braced frame, low cyclic fatigue cracks occurred in the same lateral displacement amplitude regardless of the strength ratio, but the progress of the cracks was more gentle with the reduction of the strength ratio. As a result, lateral resistance was less deteriorated and the deformation capacity increased for specimens with a small strength ratio.
(6) The proposed analytical model could trace experimental behavior accurately.

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