An Experimental Study on the Restoring Force Characteristics in Structural Frames, Part 3.

(An Experimental Study on the Steel Portal Frames)

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構造物の復元力特性に関する実験的研究（III）

―鉄骨構造架構に対する実験―

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The shearing force versus displacement in steel frames is developed, and especialy the effect of the axial thrust in column is considered in this paper.

It is apparent that the collapse load is decided by local buckling in column and the restoring force characteristics is the spindly type strictry in steel structures.

Also, it is confirmed that the maximum horizontal load increase with increasing the axial thrust stress ratio and the ductility factor decrease with the axial thrust stress ratio increase qualitatively.

Then, it has to be the prepared the regulation concerning with horizontal displacement in the design of steel structures.

PREFACE

This experimental study has been developed on 1965, but has been not presented as the report. In the study of the earthquake engineering, the reseach on the ultimates strength of structures is developing once more. Therefore, this paper is presented as the reference of these research.

INTRODUCTION

The shearing force versus displacement is used an elasto-plastic or bi-liner type in the response analysis of structures subjected to earthquake ground motions[1].

The restoring force characteristic in the reinforced concrete portal frames has been developed by authors[2] in former papers.

The shearing force versus displacement for steel structures which is applied an axial thrust in column is presented in this paper.

The ductility factor, residual displacement and the type of shearing force versus diplacement have been investgated by many investgaters[3][4][5][6], especialy the effect of the axial thrust in colum have been studied by authors for the reinforced concrete frames[2]. This paper is also presented this conditions for steel portal frames.

TEST PROCEDURE:

Test Piece: The test is classfied two series which the first series is a preliminary test and the second series is a main test for this study and is shown in TABLE 1.

The type of test piece is shown in FIG. 1 and detail of test piece is shown in FIG. 2. The test piece is produced as caused the yield hinge to the top or base in column (the beam is made to rigid for column) for the second series especially.

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TABLE 1   THE TEST PIECE

TEST PIECE	TYPE	DIA. OF BRACING	COLUMN BASE	VIRTICAL LOAD (TON)
SFP-1	M.R.F.	NONE	PIN	NONE
SFP-2	M.R.F.	NONE	PIN	Center of beam 2
SB₁P-2	MRF-B.	4C	PIN	Center of beam 2
SB₂P-1	MRF-B.	9C	PIN	Center of beam 6
SB₂P-2	MRF-B.	9C	PIN	Center of beam 4
SFF-1	M.R.F.	NONE	FIX	Center of beam 6
SFF-2	M.R.F.	NONE	FIX	Center of beam 6
SB₁F-1	MRF-B.	4C	FIX	NONE
SB₂F-1	MRF-B.	9C	FIX	Center of beam 6
SB₂F-2	MRF-B.	9C	FIX	Center of beam 6
SFF-0.1-1	M.R.F.	NONE	FIX	Center of column 3.1
SFF-0.1-2	M.R.F.	NONE	FIX	Center of column 3.1
SFF-0.2-1	M.R.F.	NONE	FIX	Center of column 6.2
SFF-0.2-2	M.R.F.	NONE	FIX	Center of column 6.2
SFF-0.3-1	M.R.F.	NONE	FIX	Center of column 9.3
SFF-0.3-2	M.R.F.	NONE	FIX	Center of column 9.3
SFF-0.4-1	M.R.F.	NONE	FIX	Center of column 12.4
SFF-0.4-2	M.R.F.	NONE	FIX	Center of column 12.4
SFF-0.5-1	M.R.F.	NONE	FIX	Center of column 15.5
SFF-0.5-2	M.R.F.	NONE	FIX	Center of column 15.5
SFF-0.6-1	M.R.F.	NONE	FIX	Center of column 18.6
SFF-0.6-2	M.R.F.	NONE	FIX	Center of column 18.6

NOTE.   M.R.F. denote the Moment Resistant Frame
          MRF-B. denote the Moment Resistant Frame with Bracing
          0.1~0.6 denote the value of σ_c/σ_y
          Where, σ_c denote the axial thrust stress in column and
                 σ_y denote the yield level stress in steel.

TABLE 2   THE RESULTS OF THE TEST OF
            MATERIALS
            (shown in the average value)

	THICKNESS OF PLATE (mm)	AREA OF MATERIAL (m²)	YIELD LEVE STRENGTH (kg/mm²)	MAXIMUM STRENGTH (kg/mm²)	ELONGATION (%)
SERIES (I)	6 and 4.5	130	36.00	49.20	28.00
SERIES (II)	6	390	31.60	46.20	27.40
	4.5	291	31.67	45.43	26.83

Materials : The specimen is taken by J.I.S. from the structural members of flange and web plate of frames, and the tension tests are done. This results are shown in TABLE 2. And the results of TABLE 2 are used for the theoretical calculation of this paper.

Load Equilpment : The load equipment is same with in the case of reinforced concrete frames[2]. The capacity of jack which was used to apply the axial thrust in colmn is 50 ton, and the capacity of load cell using to measured the horizontal load is 20 ton.
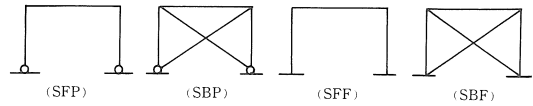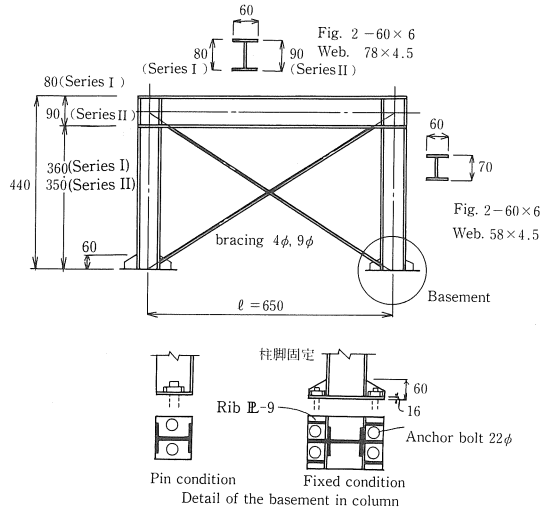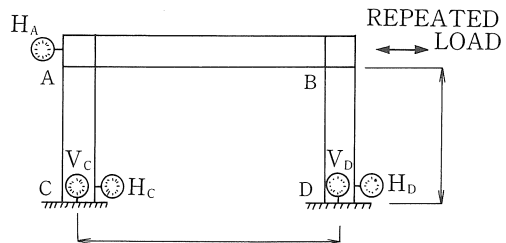

Fig. 1   Type of test piece

Fig. 2   Test piece

Fig. 3   Location of mesure point by dialgauge

The Method of which Applyed Load : The method is same in the case of reinforced concrete frames. The horizontal load is applied every 500 kg and 1 ton for the pin and fixed condition of column respectively. The horizontal load is repeated one time for plus and minus in the elastic range, and is repeated several times for plus and minus in the plastic range.

The Method of Mesure : The horizontal displacement of frames is mesured by dialgage H_A which is shown in FIG. 3. But the displacement of frames is modified by mesuring the dialage H_C, H_D, V_C and V_D, since the test piece does not wholly moveing.

TABLE 3 RESULTS OF EXPERIMENTAL VALUE.

SERIES	TEST PIECE	EXPERIMENTAL VALUE.											
		P_u (t)		X_u (cm)		P_{LB} (t)		X_{LB} (cm)		P_{BC} or P_{FC} (t)		X_{BC} or X_{FC} (cm)	
		Comp. Side	Tens. Side	Comp. Side	Tens Side	Comp. Side	Tens. Side	Comp. Side	Tens. Side	Comp. Side	Tens. Side	Comp. Side	Tens. Side
SERIES (I)	SFP-1	6.950	8.250	> 9.070	>20.700								
	SFP-2	7.900	8.600	>12.249	>19.378								
	SB$_1$P-2	7.600	7.800	>15.700	>12.885					5.800	5.500	6.820	5.160
	SB$_2$P-1	9.200	11.200	>28.300	>25.100					6.900	11.200	4.960	25.100
	SB$_2$P-2	11.000	10.700	>20.640	>19.280	(denote that the local buckling				8.600	10.700	22.220	19.280
	SB$_1$F-1	12.850	12.550	> 9.815	> 8.475	in column is not discovered)				11.950	11.150	5.720	5.860
	SB$_2$F-1	17.000	18.800	>20.915	>32.505								
	SB$_2$F-2	17.600	19.100	>14.570	>41.750								
	SFF-1	15.300	14.700	>30.765	>20.596					(denote the cutting the bracing)			
	SFF-2	14.000	13.400	>13.030	>11.420								
SERIES (II)	SFF-0.1-1	13.800	13.700	>50.62	>32.250	13.500	13.100	38.85	32.25	13.300	13.100	26.93	32.25
	SFF-0.1-2	14.600	14.400	>53.94	>35.85	12.900	12.700	42.13	35.85	13.400	14.400	53.93	55.52
	SFF-0.2-1	15.400	14.500	>37.64	>32.88	13.800	14.500	30.85	22.28		11.100		40.51
	SFF-0.2-2	15.000	14.000	>44.85	>27.13	12.600	13.000	30.75	32.22	13.800	13.000		32.22
	SFF-0.3-1	15.300	12.600	16.22	>53.98	12.600	12.500	16.22	22.80				
	SFF-0.3-2	15.000	14.600	>36.41	>31.26	13.400	12.900	21.10	15.92				
	SFF-0.4-1	12.400	14.300	15.14	7.13	11.100*	11.900*	15.14 *	7.13 *				
	SFF-0.4-2	15.900	16.000	>17.86	23.34	14.200	14.000	13.63	12.26	(denote the crack in column flange)			
	SFF-0.5-1	16.700	16.400	11.39	28.38	15.000	13.400	7.98	15.28				
	SFF-0.5-2	13.400	14.400	18.63	12.57	12.300	13.300*	10.95	7.43 *				
	SFF-0.6-1	15.500	14.900	10.48	12.73	12.600	12.900	10.19	7.59				
	SFF-0.6-2	17.600	15.300	13.02	13.62	13.000	13.300	7.42	11.10				

NOTE : * denote the horizontal load decreased.

P_U and X_U denote the maximum horizontal load and displacement,

P_{LB} and X_{LB} denote the horizontal load and displacement for the local buckling in column.

P_{BC} and X_{BC} denote the horizontal load for the cutting off bracing.

P_{FC} and X_{FC} denote the horizontal load and displacement for crack in column flange.

RESULT OF TEST

The Maximum Load and Displacement : The maximum horizontal load and displacement are shown in TABLE 3. The maximum horizontal load is decided by the displacement when the load decreases in the repeating point, and is decied by the maximum displacement when the test given up in the case that the load does not decreases.

The collapse mode of this test in the case of seriese II are also shown in TABLE 4.

The Condition of Horizontal Load versus Displacement : The initial value of rigidity becomes the value between by elastic theory and plastic theory.

The local buckling is discovered in the compression side of column flange with increasing displacement. And the horizontal load versus displacement in structual frames is the roop of spindly type in this range.

After the local buckling was discovered, the horizontal load versus displacement is not smooth curve and becomes nearly to the elasto-plastic type as shown in APPENDIX.

It has not an effect for the initial of rigidity in the case that the section area of bracings are small value as in this experimental study, and the initial value of rigidity becomes to much same value with the portal frames.

The maximum horizontal load and the load of discovering local buckling are shown in TABLE 3. And the site of dicovering local buckling is shown in TABLE 4.

It is apparent that the horizontal load increase with increaseing the axial thrust in column. And also the maximum displacement and the displacement when the local buckling were discovered decrease with increasing axial thrust in column.

The Condition in Approach to the Collapse :

TABLE 4   COLLASPE MODE IN THE END
OF STRUCTURAL MEMBERS

	END A		END B		END C		END D	
	COMP	TENS	COMP	TENS	COMP	TENS	COMP	TENS
SFF-0.1-1	L	L			L, C	L, C	L H	L
SFF-0.1-2		L			L	L	L	L H
SFF-0.2-1	L	L			L	L H	L	L
SFF-0.2-2	L	L			L, C	L, C	L H	L, C
SFF-0.3-1		L	L	L	L	L	L	L
SFF-0.3-2	L	L	L	L	L	L	L, C	L
SFF-0.4-1	L	L			L		L	L, C
SFF-0.4-2		L	L	L	L, C	L, C	L	L
SFF-0.5-1	L	L	L	L	L, C	L, C	L	L
SFF-0.5-2	L	L	L	L	L	L	L	L
SFF-0.6-1	L	L	L	L	L	L	L	L
SFF-0.6-2	L	L	L	L	L	L	L	L

NOTE : L is shown the local buckling
C is shown the crack
H is shown that the crack increase and cutting off the flange

SFF-0.2   SFF-0.6
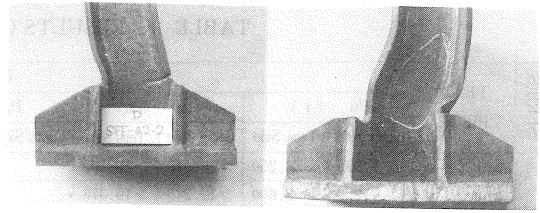
Photograph
Condition of the local buckling in the, SEE-0.2 and SEE-0.6.

When the displacement in plastic zone increase, the local buckling in column is discovered in the range of small displacement for the test piece in which is applied large axial thrust to colum.

That is, this fact are remarkably with increasing the axai thrust in column for the case of the test piece from SFF-0.3 to SFF-0.6 respectivelly.

The local buckling is primarily discovered at C and D and finally at A and B where is compression side of column as shown in FIG. 3.

And the condition of the local buckling is different from by the case that the axial thrust in column is large or small.

The condition of local buckling is shown in photograph for the case of SFF-0.2 and SFF-0.6.

When the horizontal repeating load is applied in after the local buckling was discovered, the crack occured in the tension side of column flange for the case of test piece which the axial thrust in column is small value. And this crack is developed, the column frange is cut off and this crack reach to the column web.

It is estimated that this behaviour is "the collapse by cyclic plastic displacement".

The behaviour of portal frame with bracing is similar to the case of portal frames in the elastic. range. That is, the bracing is not cut in the elastic range and is effective enough, but the bracing is cut off with increasing horizontal load.

As the horizontal load is not applied until the local buckling is discovered in the case of series I, it is not apparent to which is fast times cutting of bracing or local buckling in column flange.

But the local buckling in column is fast discover-

ed than the cutting of bracing in the test piece SB_2-1, 2 which is fixed condition in the base of column and the section of bracing is used 9ϕ bar.

The condition of the end of structural members in the finished of the tests is shown in TABLE 4.

THEORETICAL ANALYSIS

The Method of Analysis : The yield level horizontal load ($_EP_y$) and the maximum load ($_EP_U$) in elastic theory, the yield level load ($_PP_y$) and the maximum load ($_PP_U$) in plastic theory and the displacement ($_EX_y$, $_PX_y$) for these yield level load are calculated by elastic and plastic theory[7]-[12] which is used generally.

The results of this analysis are shown in TABLE 5 and APPENDIX.

The method of analysis is omitted but the main assumption in this analysis is calculated as follows in this paper :

(1) The yield level stress (σ_y) and maximum stress (σ_B) in the steel are dicided by the result of material test as follows : $\sigma_y = 3160$ kg/cm², $\sigma_B = 4620$ kg/cm² and $E_s = 2.1 \times 10^6$ kg/cm².

(2) The horizontal load and displacement in the portal frame with bracing are calculated by means of adding the strength of portal frame to the strength of bracing.

(3) The plastic analysis is used the method of inequality in this paper. And the influence of shear on the plastic moment beams is calacu-lated by the decreasing ratio in the plastic moment.

(4) The buckling and local buckling in flange and web of structual members are confirmed for safety.

The story height of frame in concerned with the fixed condition of base in column is applied to the two cases which is h = 35 cm and h = 29 cm for the

TABLE 5   RESULTS OF THEORETICAL VALUE.

SERIES	TEST PIECE	By the elastic theory						By the plastic theory					
		Story height of test piece is 300mm (350)			Story height of test piece is 300mm (290)			Story height of test piece is 350mm (350)			Story height of test piece is 300mm (290)		
		$_eP_Y(t)$	$_eP_U(t)$	$_eX_Y(cm)$	$_eP_Y(t)$	$_eP_U(t)$	$_eX_Y(cm)$	$_pP_Y(t)$	$_pP_U(t)$	$_pX_Y(cm)$	$_pP_Y(t)$	$_pP_U(t)$	$_pX_Y(cm)$
SERIES (Ⅰ)	SFP-1	4.600	6.287	3.818	5.520	7.544	3.687	5.290	7.245	4.204	6.310	8.640	3.141
	SFP-2	3.851	5.538	3.196	4.581	6.605	3.060	5.280	7.220	5.361	6.290	8.610	4.306
	SB₁P-2	4.238	6.066	3.517	4.968	7.133	3.319	5.667	7.748	5.361	6.677	9.138	4.806
	SB₂P-1	4.311	6.715	3.578	4.659	7.401	3.112	7.178	9.846	6.845	8.178	11.236	5.356
	SB₂P-2	5.060	7.464	4.200	5.600	8.343	3.740	7.218	9.886	5.976	8.213	11.266	4.628
	SB₁F-1	9.587	13.101	2.522	11.427	15.616	2.319	10.977	15.628	2.980	13.007	17.778	2.301
	SB₂F-1	8.364	12.455	2.199	9.526	14.371	1.933	12.398	17.046	11.673	14.388	19.776	9.002
	SB₂F-2	8.364	12.455	2.199	9.526	14.371	1.933	12.398	17.046	11.673	14.388	19.776	9.002
	SFF-1	6.406	9.779	1.685	7.568	11.695	1.536	10.440	14.370	11.673	12.430	17.100	9.002
	SFF-2	6.406	9.779	1.685	7.568	11.695	1.536	10.440	14.370	11.673	12.430	17.100	9.002
SERIES (Ⅱ)	SFF-0.1-1	7.460	11.300	1.204	9.010	13.650	0.886	9.360	13.880	2.012	11.220	16.600	1.512
	SFF-0.1-2	7.460	11.300	〃	〃	〃	〃	〃	〃	〃	〃	〃	〃
	SFF-0.2-1	6.650	10.500	1.077	8.040	12.660	0.790	8.800	13.470	1.890	10.520	16.140	1.419
	SFF-0.2-2	6.650	10.500	〃	〃	〃	〃	〃	〃	〃	〃	〃	〃
	SFF-0.3-1	5.810	9.660	0.939	7.010	11.650	0.689	7.870	12.880	1.700	9.470	15.400	1.273
	SFF-0.3-2	5.810	9.660	〃	〃	〃	〃	〃	〃	〃	〃	〃	〃
	SFF-0.4-1	4.990	8.840	0.806	6.020	10.650	0.592	6.810	11.850	1.465	8.200	14.200	1.104
	SFF-0.4-2	4.990	8.840	〃	〃	〃	〃	〃	〃	〃	〃	〃	〃
	SFF-0.5-1	4.150	8.000	0.670	5.010	9.650	0,492	5.730	10.800	1.234	6.950	13.000	0.934
	SFF-0.5-2	4.150	8.000	〃	〃	〃	〃	〃	〃	〃	〃	〃	〃
	SFF-0.6-1	3.330	7.170	0.538	4.010	8.650	0.394	4.630	9.750	0.994	5.620	11.720	0.756
	SFF-0.6-2	3.330	7.170	〃	〃	〃	〃	〃	〃	〃	〃	〃	〃

series II (h＝36 cm and h＝29 cm for the seties I) as be shown in FIG. 2, and the calculating results are shown in TABLE 5.

THE DISCUSSION ON THE TEST RESULTS

The Relationship between the Experimental and Theoretical Value : According to TABLE 3, 4 and FIG. 4, the maximum horizontal load for the greater part of test piece have been more than the maximum load by the plastic theory in this study. But, if the fixed condition of base in column is considered, it may be estimated that the maximum load in this tests agree with the theoretical value.

And it is sure that the maximum load (the local buckling load) by plastic theory decrease with increasing the axial thrust stress ratio (σ_c/σ_y) in generally, but the maxmum load in this tests increase with increasing σ_c/σ_y.

The Horizontal Load versus Displacement : It is estimated that the horizontal load versus displacement in the steel structures is the roop of spindly type in the range of until be discovering the local buckling in column for the framed structures.

But, it is elasto-plastic type in near point of where the local buckling is discovered and the maximum load.

It is discussed in the domain where the horizontal load versus displacement is the normal spindly type and the structure is not received damage. As the portal frame with bracings is not different from the portal frames in this tests, it is considered as same as in the portal frames.

It is better do assuming that the horizontal load versus displacement is normally bi-linear type in the range of which the ductility factor is small value.

But, if the condition of horizontal load versus displacement is considered strictly, this condition becomes to the spindly type which is connected the original point with the repeating point.

As be shown in FIG. 5, this condition is shown by the parallelgram consisting of the line AB and DE which is connected the yield level point A with the repeating point B and the line BC and EF which is parallel with the line of initial rigidity k_1 (is shown by the line OA).

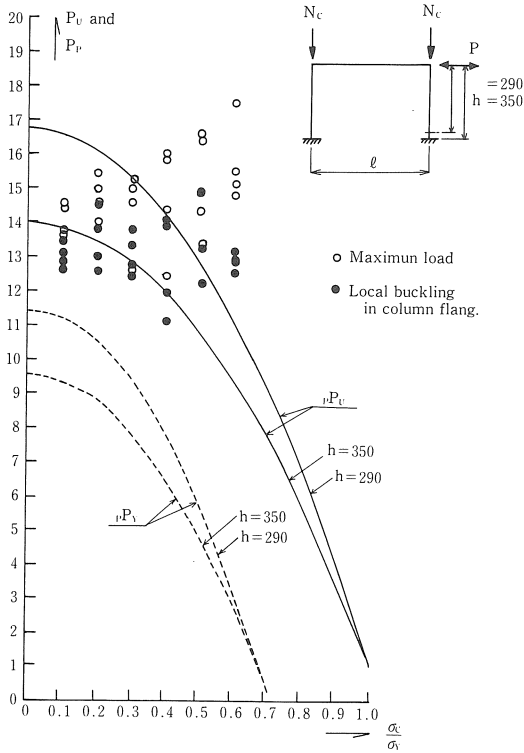The horizontal load versus displacement is

Fig. 4   The comparison with the experimental value and theoretical value in plastic theory.

Fig. 5   The type of restoring forces in the experimental test
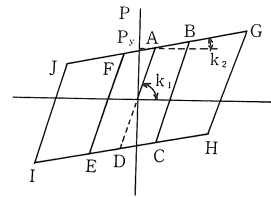
Fig. 6   The typical type of restoring force

shown in FIG. 5 is not convenience to using the response analysis subjected to earthquake ground motions. Then, it becomes simplicity and safety zone to be considering by the bi-linear type.

This type is shown as the parallelogram which is constructed by the line AG, DI, GH, and IJ in FIG. 6. In where, the line AG and DI are connected yield level load A with the discovering local buckling load G, and also the line GH and IJ pass at the point G and I and are parallel to the initial value of rigidity k_1.

Also, the condition of the horizontal load versus displacement in the frame structures shows very conplicated behaviour and is connected with small or large of the axial thrust in column.

The Problematical Thing for the Calculation of Ductility Factor : The problematical things to defined the ductility factor in structures are as follows :

(1) The method to definition of the yield level load and displacement

(2) The method to definition of the maximum load and displacement.

(3) The judgment of the local buckling at the compression side of members and the definition of the displacement for these.

(4) The residual displacement of the structures.

(5) The ductility factor decrease with increasing axial thrust in column.

The definition of Yield Level Load and Displacement :

The yield level load by elastic theory ; The yield level load ($_EP_y$) is defined by the load in which the plastic hinge occured at the one part or two parts on the same time in structural members.

In the case that the axial thrust is added to column, the compression side of column yield in general. Therefore, it is assumed that the compression side of column yield in the test piece which the axial thrust is added to column, and also, it is assumed that the compression and tension side of column yield on the same time in the case that is not applying the axial thrust to column.

The yield level load by the plastic theory : The yield level load ($_PP_y$) is defined by the condition when the plastic hinge are constructed in the structural members. And the condition of stress in structural members are plastic condition and also are restrained by the plastic moment.

TABLE 6   THE DUCTILITY FACTOR

SERIES	TEST PIECE	Yield level displacement (mm)		Local buckling displacement X_{LB} (mm)		Maximum displacement X_U (mm)		Ductility factor μ							
								$_E\mu_{LB}=\dfrac{X_{LB}}{_E X_y}$		$_E\mu_U=\dfrac{X_U}{_E X_y}$		$_P\mu_{LB}=\dfrac{X_{LB}}{_P X_y}$		$_P\mu_U=\dfrac{X_U}{_P X_y}$	
		$_E X_y$	$_P X_y$	Comp. Side	Tens. Side	Comp. Side	Tens. Side	Comp. Side	Tens. Side	Comp.lSide	Tens. Side	Comp. Side	Tens. Side	Comp. Side	Tens. Side
SERIES (I)	SFP-1	3.818	4.204			> 9.07	> 20.70			> 2.38	> 5.42			> 2.16	> 4.92
	SFP-2	3.196	5.361			> 12.25	> 19.38			> 3.83	> 6.06			> 2.29	> 3.61
	SB₁P-2	3.517	5.361			> 15.70	> 12.88			> 4.46	> 3.66				
	SB₂P-1	3.578	6.845			> 28.30	> 25.10			> 7.91	> 7.01				
	SB₂P-2	4.200	5.976			> 20.64	> 19.28			> 4.91	> 4.59				
	SFF-1	1.685	11.673			> 30.76	> 20.59			> 16.26	> 12.20			> 2.64	> 1.76
	SFF-2	1.685	11.673			> 13.07	> 11.42			> 7.75	> 6.78			> 1.12	> 0.98
	SB₁F-1	2.522	2.980			> 9.82	> 8.48			> 3.89	> 3.36				
	SB₂F-1	2.199	11.673			> 20.92	> 32.50			> 9.50	> 14.80				
	SB₂F-2	2.199	11.673			> 14.57	> 41.75			> 6.64	> 19.00				
SERIES (II)	SFF-0.1-1	1.204	2.012	38.85	32.25	> 50.62	> 32.25	32.25	26.80	> 42.00	> 26.80	19.33	16.04	> 25.20	> 16.03
	SFF-0.1-2	1.204	2.012	42.13	35.85	> 53.94	> 35.85	35.00	29.80	> 44.75	> 29.80	20.97	17.84	> 26.80	> 17.93
	SFF-0.2-1	1.077	1.890	30.85	22.28	> 37.64	> 32.88	28.65	20.70	> 34.95	> 30.60	16.33	11.80	> 19.93	> 17.40
	SFF-0.2-2	1.077	1.890	30.75	32.22	> 44.85	> 27.13	28.53	29.90	> 41.65	> 25.20	16.27	17.07	> 23.70	> 14.34
	SFF-0.3-1	0.939	1.700	16.22	22.80	16.22	> 53.98	17.30	24.28	17.30	> 57.50	9.54	13.40	9.54	> 31.75
	SFF-0.3-2	0.939	1.700	21.10	15.92	> 36.41	> 31.26	22.50	17.00	> 38.80	> 33.25	12.41	9.37	> 21.40	> 18.40
	SFF-0.4-1	0.806	1.465	15.14※	7.13※	15.14	7.13	18.78	8.85	18.78	8.85	10.33	4.86	10.33	4.86
	SFF-0.4-2	0.806	1.465	13.63	12.26	> 17.86	23.34	16.90	15.20	> 22.13	28.95	9.30	8.36	> 12.20	15.92
	SFF-0.5-1	0.670	1.234	7.98	15.28	11.39	28.38	11.90	22.80	17.00	42.35	6.46	12.36	9.22	23.00
	SFF-0.5-2	0.670	1.234	10.95	7.43※	18.63	12.57	16.35	11.10	27.80	18.76	8.86	6.02	15.10	10.18
	SFF-0.6-1	0.538	0.994	10.19	7.59	10.48	12.73	19.00	14.14	19.54	23.70	10.25	7.64	10.55	12.81
	SFF-0.6-2	0.538	0.994	7.42	11.10	13.02	13.62	13.83	20.70	24.30	25.40	7.47	11.18	13.10	13.72

NOTE : The story height in calculation of yield level displacement is used h＝36cm and 35cm

※denote the volue in when the horizontal load decreased.

The yield level load in based on the elastic and plastic theory are calculated by these assumption, and is shown in TABLE 5 as theoretical value.

The Definition of Maximum Load and Displacement : The maximum load of structures are considered as follows :

(1) When the plastic hinge in structural members is bring to completion at the sveral or all structural members.

(2) When the plastic hinge in structural members is bring to completion at the one part of structural members, but it is may be bring to completion in the many parts of girder.

If the plastic hinge in structral member is bring to completion at the base or top of all columns, it does not like that the girders sink and the structure is affected by the disadvantage force.

The judgement of which the plastic hing is bring to completion is defined in this paper as follows :

(1) In the case that the local buckling is discovered in column.

(2) In the case that the horizontal load decrease, and the local buckling in column does not discovered.

The horizontal load and displacement also increase in after the local buckling are discovered in colum. Then, the displacement for the occuring the local buckling in column (X_{LB}) and the maximum displacement (X_U) in this tests are used the value as be shown in TABLE 3 and 5.

On the Ductility Factor : The yield level displacement are calculated be these assumption and the maximum displacement in this tests are also defined. And the ductility factor (μ) is estimated and is shown in TABLE 6.

According to TABLE 6, it is apparent that the ductility factor (μ) decrease with increasing the axial thrust in column for the structure which the plastic hinge occur in the top and base of column.

The relationship between the ductility factor (μ) and the axial thrust stress ratio (σ_c/σ_y) is shown in FIG. 7 and 8. Whereas σ_c denote the axial thrust
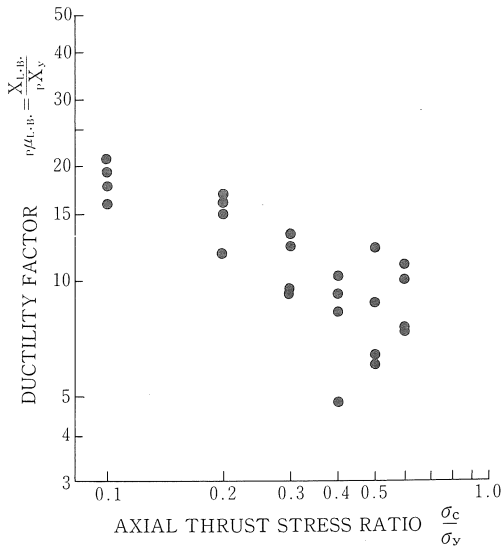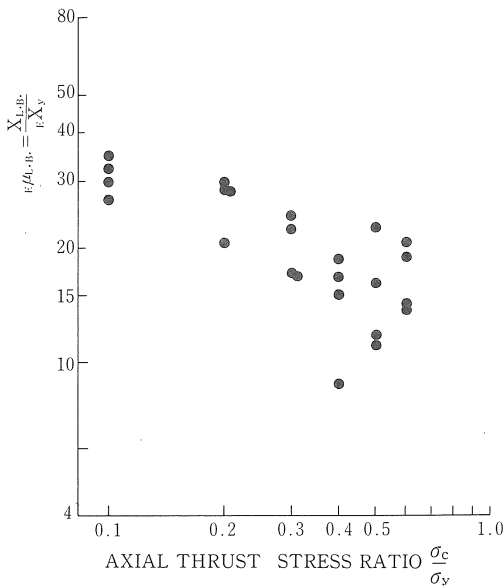
Fig. 7   Relationship between the ductility factor $_P\mu_{LB}$ and the axial thrust ratio in a column σ_c/σ_y. Where $_P\mu_{LB}$ is the ratio of displacement for local buckling to displacement for plastic strength load.
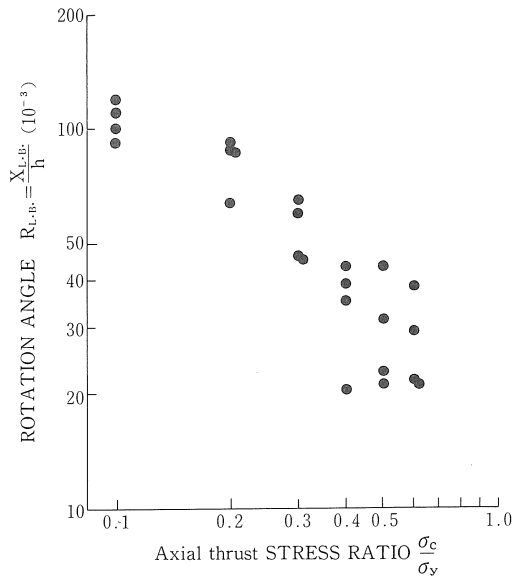
TABLE 7   THE ROTATION ANGLE IN STRUCTURES.

TEST PIECE	The rotation angle for local buckling $R_{LB}=\dfrac{X_{LB}}{h}$ (10^{-3})		The rotation angle for maximum displacement. $R_U=\dfrac{X_U}{h}$ (10^{-3})	
	Comp. Side	Tens Side	Comp Side	Tens Side
SFP-1			> 25.20	> 57.50
SFP-2			> 34.00	> 53.85
SB$_1$P-2			> 43.60	> 35.80
SB$_2$P-1			> 78.60	> 69.70
SB$_2$P-2			> 57.40	> 53.55
SFF-1			> 85.50	> 57.15
SFF-2			> 36.30	> 31.75
SB$_1$F-1			> 27.30	> 23.55
SB$_2$F-1			> 58.10	> 90.10
SB$_2$F-2			> 40.50	>116.00
SFF-0.1-1	111.00	92.20	>144.70	> 92.20
SFF-0.1-2	120.40	102.50	>154.00	>102.50
SFF-0.2-1	88.30	63.70	>107.50	> 94.00
SFF-0.2-2	87.80	92.00	>128.00	> 77.50
SFF-0.3-1	46.40	65.10	46.30	>154.00
SFF-0.3-2	60.20	45.50	>104.00	> 89.40
SFF-0.4-1	43.25	20.40	43.25	20.40
SFF-0.4-2	38.94	35.00	> 51.00	66.75
SFF-0.5-1	22.80	43.60	32.55	81.00
SFF-0.5-2	31.30	21.20	53.25	35.90
SFF-0.6-1	29.10	21.70	30.00	36.40
SFF-0.6-2	21.20	38.60	37.20	39.00

Fig. 8   Relationship between the ductility factor μ_{LB} and the axial thrust in a column σ_c/σ_y. Where μ_{LB} is the ratio of displacement for local buckling to yield displacement.

Fig. 9   Relationship between the rotation angle R_{LB} for the local buckling and the axial thrust stress ratio σ_c/σ_y in a column.

stress in column and σ_y denote the yield level stress of steel.

The Rotation Angle in Structure : The yield level rotation angle in structure is estimated by applying the elastic and plastic yield level displacement ($_EX_y$ and $_PX_y$) in the theory.

As well as the rotation angle in structure ($R_{LB}=X_{LB}/h$ and $R_U=X_U/h$) is also calculated by using the displacement for the local buckling in column (X_{LB}) and for the maximum load (X_U), and these value are shown in TABLE 7.

Also, the relationship between the rotation angle (R_{LB}) for the local buckling and the axial thrust stress ratio (σ_c/σ_y) in column is shown in FIG. 9.

It is apparant that the rotation angle (R_{LB}) decrease with increasing the axial thrust stress ratio (σ_c/σ_y) in column.

CONCLUSION

The following problematical thing is proposed and some thing is developed in this experimental study.

(1) In the structural design of steel structures which is portal frames and portal frame with bracings that the portal frame has an enough strength, it has to be prepared the regulation concerning with the horizontal displacement.

(2) It is sure that the maximum horizontal load by theory decrease with increasing the axial thrust stress ratio in generally, but the maximum horizontal load (the local buckling load) increase with increasing the axial thrust stress ratio in this tests.

(3) The condition in the horizontal load versus displacement in portal frames is the spindly type strictry, and also its condition have not an effect on the axial thrust in column.

The condition in the horizontal load versus displacement may be assumed the elastoplastic type which is in parallel with displacement-axis in the yield level load and displacement approxmately.

(4) If the yield level displacement is determined by means of theoretical method, ductillity factor is calculated. Of course, the ductility factor defferent from by the method in the determination of the yield level and maximum displacement, then, the ductility factor is not determined quantitatively.

But it is apparent that the ductility factor

decrease with the axial thrust in column increase qualitatively.

Therefore, the ductility factor has to be given small value in connection with increase the axial thrust in column for the frame structures which the yield hinge occured in the top or base of column.

(5) The yield level rotation angle in structure is not apparent in this tests. But, it is estimated that the maximum rotation angle in structure decrease with increasing the axial thrust in column qualitatively.

Also, it is difficult to determine the maximum rotation angle in the structure in connection with the determination of maximum displacement qualitatively.

In this paper, the horizontal displacement is mainly considered, and it was defined that the horizontal displacement in the frame structures becomes to small value with increasing the axial thrust in column.

One recommend to make the limitation of the displacement in connected with the defference of axial thrust in column of steel structures.

Then, it is important that the study on the displacement and rotation capacity is developed in the case that the axial thrust, bending moment and shearing force apply to the structural members.

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APPENDIX : Restoring Force versus Displacement Curves.
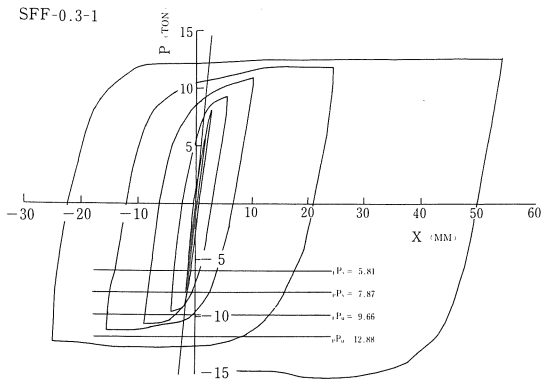
Simbols in Figures :

$_pP_y$ and $_pP_U$ denote the yield level and maximum load in plastic theory.

$_EP_y$ and $_EP_U$ denote the yield level and maximum load in elastic theory.
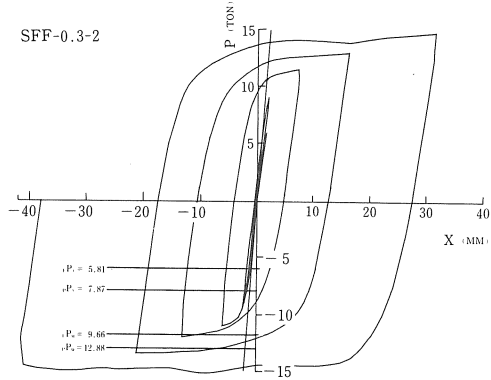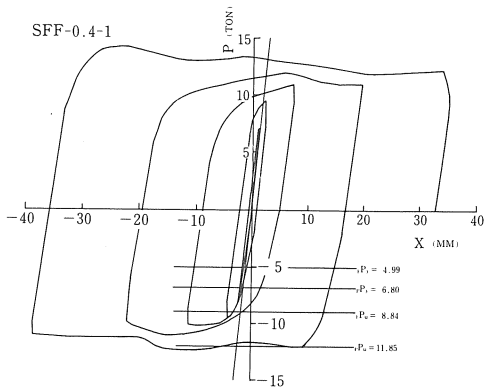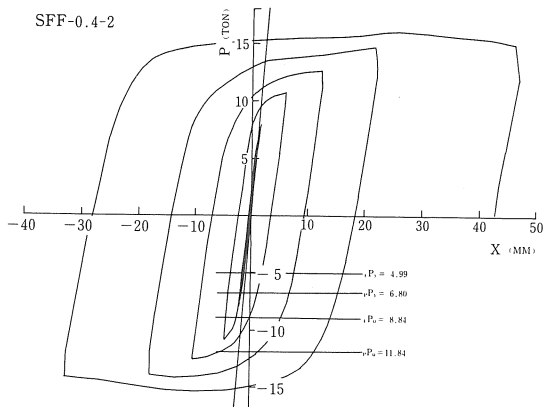
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$_tP_c = 6.666$
$_tP_s = 7.748$

SB₁F-1

$_tP_s = 9.587$
$_tP_t = 10.977$
$_tP_u = 13.101$
$_tP_u = 15.028$

SB₂F-1

$_tP_s = 8.364$
$_tP_t = 12.401$
$_tP_u = 12.455$
$_tP_u = 17.046$

SB₂F-2

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$_tP_u = 12.455$ $_tP_u = 12.455$
$_tP_u = 17.046$

SFF-0.1-1

$_tP_s = 7.46$
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SFF-0.1-2

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SFF-0.2-1

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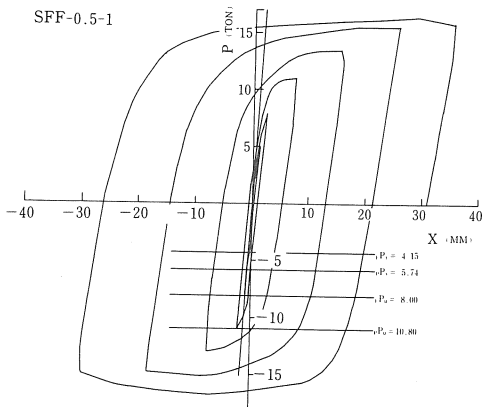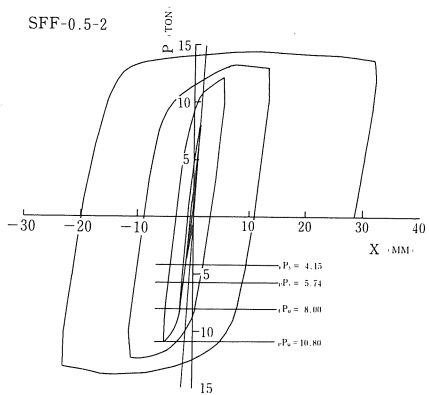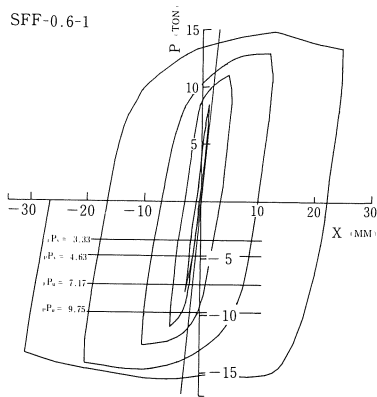$_tP_t = 8.80$
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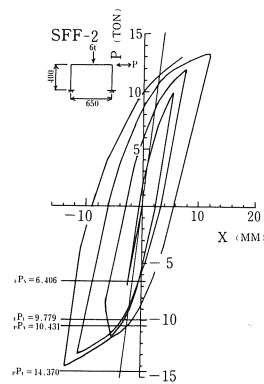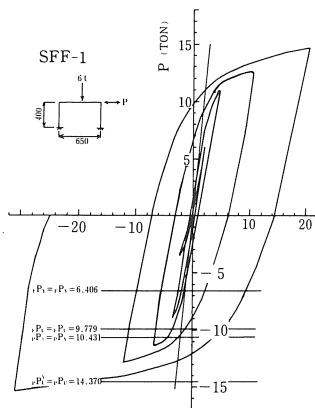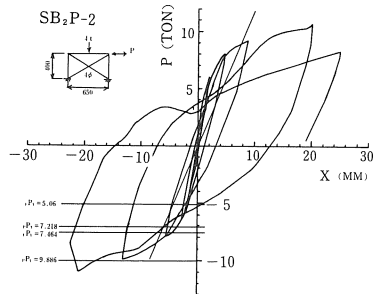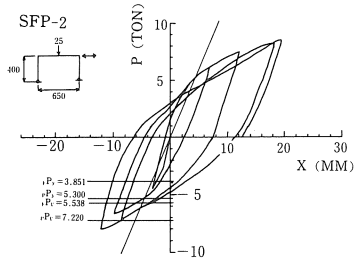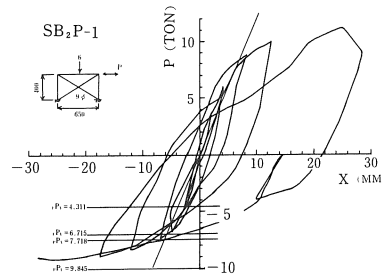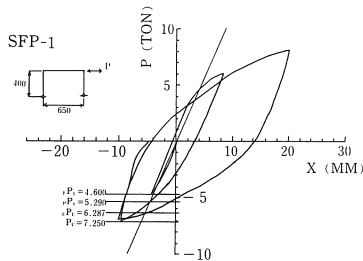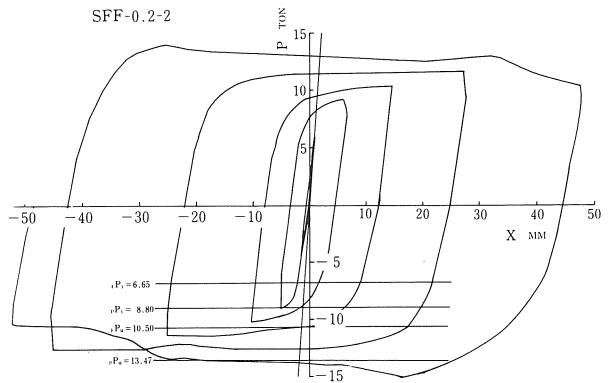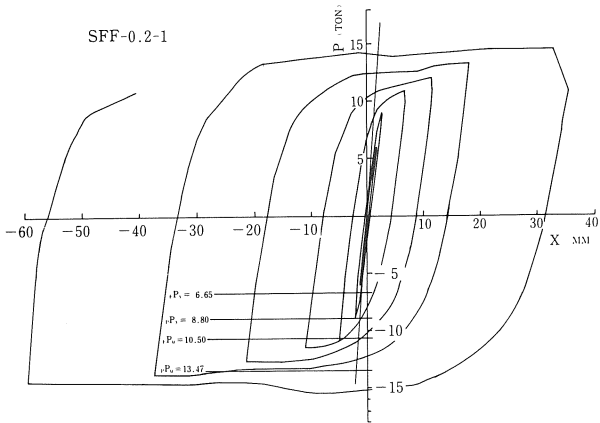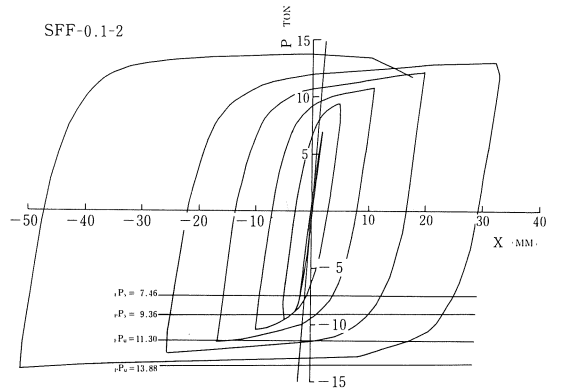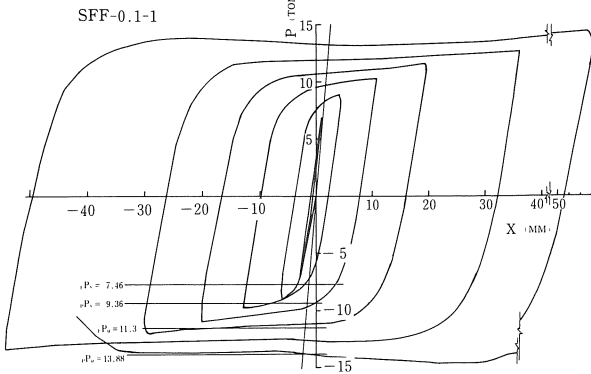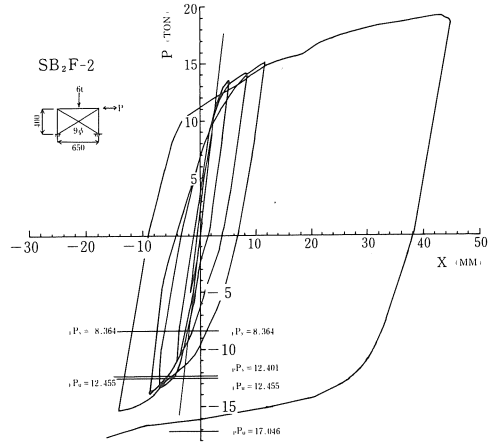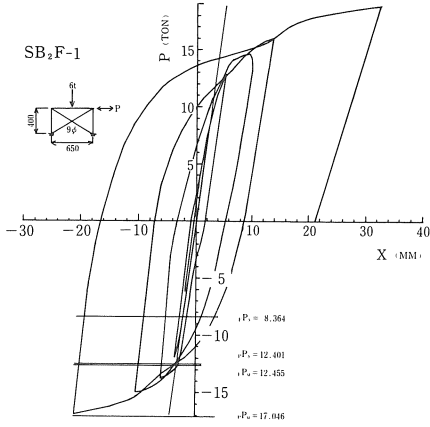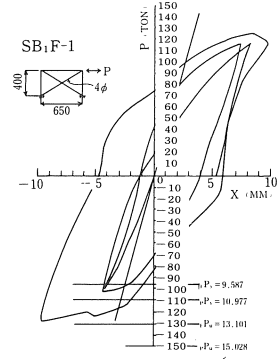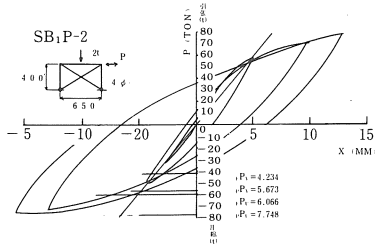
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