EXPERIMENTAL STUDY ON REINFORCED CONCRETE TRUSS FRAMES AS EARTHQUAKE RESISTANCE ELEMENTS

by

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SYNOPSIS

About twenty of one-storied and one-spanned reinforced concrete braced frames with small scale, were tested, subjected to alternating repeated horizontal loads at the top beam level with constant axial load at the tops of the columns. These tests were intended for obtaining some basic data on earthquake resistance capacities of reinforced concrete frames. The variables considered in this investigation are the longitudinal reinforcement ratios of the members composing a frame, the level of axial load the slenderness of the members and the reinforcement arrangements in connections. The test results show that braced frames have considerable ductility in addition to high stiffness and high strength.

INTRODUCTION

In such countries having the large temporary load (seismic load) as Japan, it is necessary to have such strong members or frames which can resist against the above load as earthquake resistance walls. The objective of this paper is to review recent research carried out at Hiroshima University and to use these results to provide a means of determining seismic design for truss frames of reinforced concrete, including braced frames which can be arranged more freely in buildings than walls.

TEST PROGRAM

A specimen consists of two symmetrical braced frames with the dimensions of the height, the span of frames and the standard section of members being 60 cm, 60 cm and 10 cm x 10 cm respectively (Fig. 1). Seventeen frames were tested in total as shown in Table 1. Five frames (I)

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including one rahmen frame were subjected to monotonic horizontal load at beam level while eight frames (II, and III) subjected to alternating reversed horizontal load. The other three frames (N) were subjected to alternating reversed horizontal load, with constant vertical loads at the tops of columns. Only the specimens designated B-H and B-Hp have the members of non-standard sections (5 cm x 10 cm). The reinforcement ratio of main bars ranged from about 1-3.8%, with the hoop reinforcement ratio being about 0.1% and 0.2% for the members having standard section and non-standard section respectively. Much more amount of hoops were, on the other hand, used to enclose main bars in connections against anchor failure except for five frames (I) of monotonic loading as shown in Fig. 1. Maximum size of aggregate of concrete was 5 mm and the cylinder strength at test was 0.21-0.23 t/cm^2. Main bars were 6ø with yield strength of about 2.70 t/cm^2 except for two frames (4.65 t/cm^2 for B-I, R-I). Hoops were 2ø. Horizontal displacement at beam level as well as elongation of each member and strains of main bars embedded were measured by dial gauges and wire strain gauges respectively.

TEST RESULTS

In Table 1 are listed up the results of tests on strength. In Figs. 2 and 3, are shown typical failure pattern and load-deflection envelope curves. Based on the results of 17 tests, the following trend were observed:

(1) The stiffness before crack can be estimated for braced frames, by assuming every connection as a pin-joint and both concrete and main bars in every member as linearly effective (Fig. 3). The calculated value as rigid joint is only 6% higher even for the specimens with the depth to length ratio of 5 than that as pin-joint.

(2) First cracks were observed at the bottom of column subjected to tension. The stress at first crack is about 0.08 - 0.125 $C\sigma B$ ($C\sigma B$; cylinder strength), obtained by assuming as rigid joints. The deflection (ratio to height) at first crack is about 0.15 mm (0.25×10^{-3} rad.) for the specimens without axial loads and about 0.30 mm (0.5×10^{-3} rad.) for the specimens with axial load of 40 kg/cm^2 (Table 1).

(3) The yielding load is 14 - 40% higher for the specimens (II, III and N) except for the I type specimens, than that calculated by assuming every connection as a pin-joint and all main bars in tension members as yielding, that means that yielding strength is proportional to the

reinforcement ratios of main bars. Those percentages can be attributed mainly to bending and shear resistances of compression members. The deflection (ratio to height) at yielding load is about 1.5 - 2.1 mm (2.5 - 3.6 x 10^{-3} rad.) increasing with main bar reinforcement ratios and with axial loads (Table 1).

(4) The I type specimens failed at connections before or about reaching the yielding strength calculated as pin-joints. For these specimens, being preliminary test specimens, the failure at connections might be able to be avoided if projecting parts were made at laoding points in the same way as the specimens (II, III and N), but test results indicate, at the same time, that some amount of hoops are needed to prevent the breaking out of main bars in connections. As regards this, one bolting anchor as shown in Fig. 1 will be hopeful as simplier anchor method in connection.

(5) The specimens (II, III and N) hold the load higher than the yielding load calculated as pin-joints, up to the deformation angle of frames (ratio of deflection to height) of 1/50, except for the specimens of B-3-N (Fig. 5). It should be noted that truss frames of reinforced concrete have considerable ductility, compared with shear walls, usually having the deformation angle of only 1/250 at ultimate. This can be inferred from the fact that the members composing truss frames have much larger ratio of length to depth than walls.

(6) It is found desirable for braced frames having the members with little amount of hoops to obtain sufficient ductility, that axial force (ratio to cylinder strength times concrete area) of the compression members at the yielding load, calculated as pin-joints mentioned above, is below 0.4, which is the axial force level around balanced point in axial force - moment diagram, although there were the ductile specimens having the members with the axial force ratio of more than 0.4 (B-2-N and B-3-II). It is also clarified that maximum shear stress (nominal) for the members of braced frames should be within 0.1 $C\sigma B$ ($C\sigma B$ = cylinder strength)[1] to obtain sufficient ductility. (Figs. 4 - 7)

(7) The column of B-H-II specimen failed in buckling, shortly after the negative horizontal load following unloading at the deformation angle of 1/40 in the positive loading were applied. The load of this specimen was not well recovered even at the reversal of small deflection (Fig. 9), while the loop of the specimens other than B - H type are stable even at large deflections as shown in Fig. 8. The scale of the specimen leaves room for discussion but columns with the length to depth ratio of more

than 10 seem undesirable for truss frames as earthquake resistance elements.

CONCLUSIONS

The main conclusions of these experimental studies are as follows; The truss frames of reinforced concrete including braced frames can be considerably ductile in addition to high stiffness and high strength if much care is taken of the both compression members and connections. Further researches are needed on practical simple anchor methods in connections.

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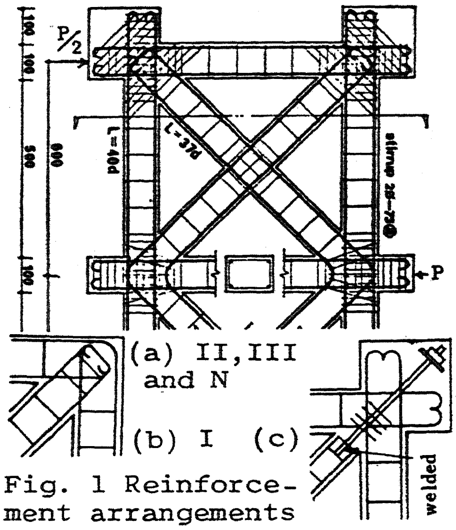

Fig. 1 Reinforcement arrangements of Specimens

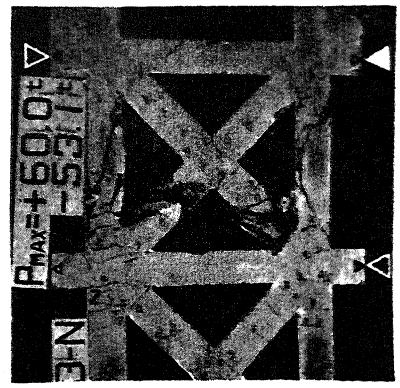

Fig. 2 Failure Pattern (B - 3 - N)

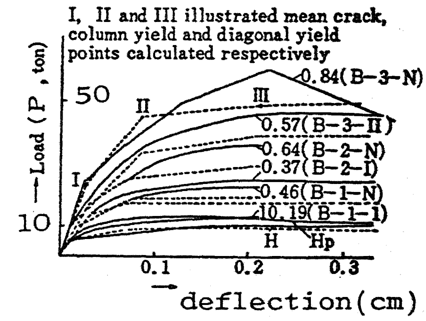

Fig. 3 Envelope Curves of Braced Frames in the Range of small Deflection

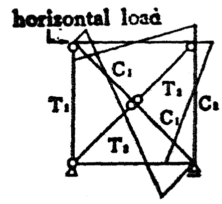

Fig. 4 Resistance Mechanism at Ultimate

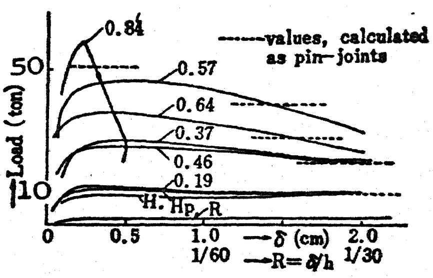

Fig. 5 Envelope Curves of Braced Frames at Ultimate

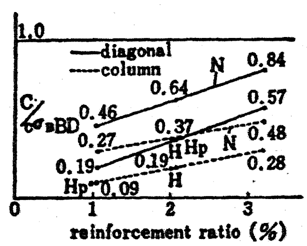

Fig. 6 Axial Force Ratio of Both Compression Members at Ultimate

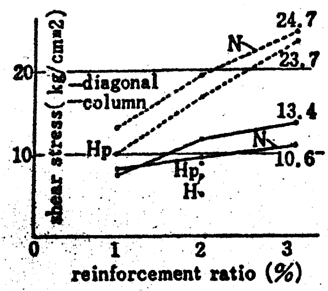

Fig. 7 Shear Stresses of Members at Ultimate

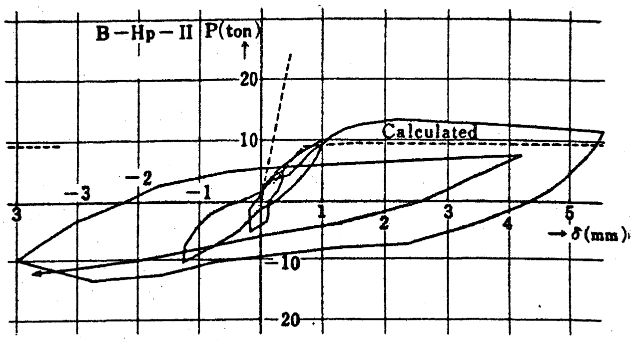

Fig. 8 Load - Deflection Curve (B - Hp - II)

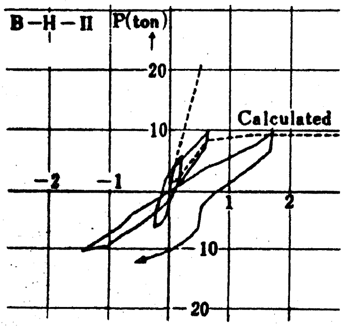

Fig. 9 Load- Deflection Curve(B-H-II)

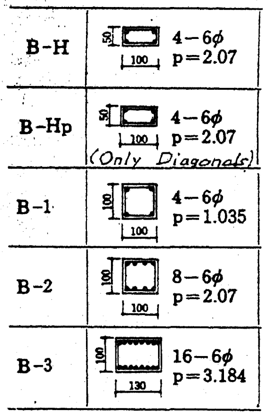

Fig. 10 Sections of Diagonals and Columns

TABLE 1 RESULTS OF TESTS

Symbols of Spesimens Kind 1)	Ty.	First Crack Load (ton)	First Crack Deflection (mm)	Yield Load Load (ton)	Yield Load Ratio to Calculated Value 2)	Yield Load Deflection (mm)	Maximum Load Load (ton)	Maximum Load Ratio to Calculated Value 2)	Maximum Load Deflection (mm)
B-H	I	3.0	0.14	7.0	0.73	1.5	8	0.83	4.0
	II	2.6	0.12	11.0	1.14	1.6	12.8	1.33	1.7
B-Hp	I	3.5	0.14	9.0	0.94	1.5	9.8	1.02	4.0
	II	3.5	0.16	13.0	1.36	1.6	13.7	1.42	2.2
B-1	I	5.0	0.15	16.0	1.05	2.1	16.0	1.05	3.0
	II	5.5	0.14	13.5	1.40	1.6	13.7	1.43	5.0
	III	6.0	0.16	13.2	1.38	1.7	13.7	1.43	3.0
	N	12.0	0.3	24.0	1.36	1.7	24.0	1.36	1.8
B-2	I	5.5	0.14	18.0	0.92	1.8	23.0	1.17	6.0
	II	7.0	0.16	25.0	1.30	1.9	26.0	1.35	3.5
	III	6.0	0.14	23.0	1.19	1.9	23.3	1.21	4.5
	N	16.0	0.3	35.0	1.28	1.9	36.0	1.32	2.1
B-3	I	7.0	0.16	36.0	0.96	2.2	40.0	1.06	3.6
	II	8.5	0.17	46.0	1.19	2.1	48.0	1.25	7.0
	III	10.0	0.14	45.0	1.17	2.0	47.7	1.24	7.5
	N	21.0	0. 3	60.0	1.22	2.1	60.0	1.22	2.2
R	I	0.9	0.13	2.3	0.92	4.0	3.27	1.31	12.0

Note 1) B = Braced Frame R = Rahmen

2) Calculated values for braced frames were obtained by assuming every connection as a pin-joint and all main bars in tension members as yielding