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SEISMIC TEST OF EXISTING REINFORCED CONCRETE BLOCK MASONRY SCHOOL BUILDING

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SUMMARY

Presented in this paper is the structural test result of an existing single story block masonry school building. A series of field tests such as lateral loading tests, micro-tremor measurements and material tests was carried out for evaluation of seismic performance. Judging from the ultimate strength and the ductility obtained from these tests, it was conformed that the ductility of this school building was better than expected by the present seismic code in Japan.

INTRODUCTION

The object of this study was to obtain the data for evaluating the seismic performance of existing block masonry school buildings in Japan. On the occasion that a single story reinforced concrete block masonry school building was demolished for renewal, a series of field tests such as lateral loading tests, micro-tremor measurements and material tests was carried out. The cracking behavior, ultimate strength and ductility obtained by the tests were discussed in this paper.[Refs.1,2,3 and 4]

OUTLINE OF TEST BUILDING

The building was a single story reinforced concrete block masonry elementary school building constructed in 1959 according to the code requirements for seismic design. The structural planning of the building is shown in Fig. 1. The concrete block unit was hollow concrete block with three cavities as shown in Fig. 2, which was specified as the Type C in the Japan Industrial Standard A5406-1955. The

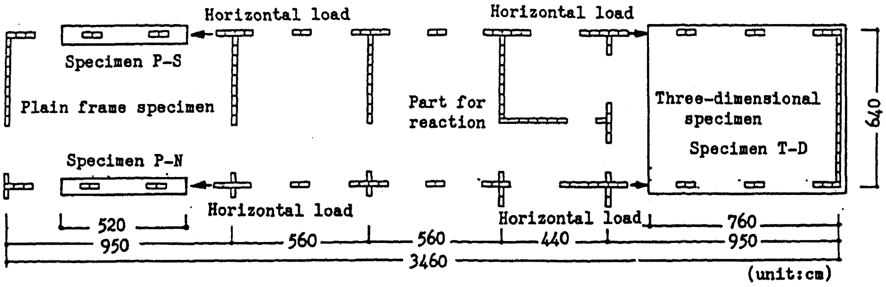


Fig. 1 Structural planning

concrete block walls were partially grouted by small size aggregate concrete and reinforced both horizontally and vertically. Cast-in-place reinforced concrete slabs, tie beams and continuous footing beams were provided for block walls.

TEST SPECIMENS

Test Specimen The specimens for the structural tests were a three-dimensional structure and two plain frame structures as shown in Fig. 3. The three-dimensional specimen (T-D) was made by cutting roof, tie beams and walls except footing beams from west end of the building. The two frame specimens (P-S, P-N) identical to a part of the south and north sides of the three-dimensional specimen, respectively, were made by the east part of the building in similar manner as the three-dimensional structure. The rest of the building was provided for the reaction part for structural tests. The nominal bar sizes and spacings of horizontal and vertical reinforcements in block walls of specimen T-D are shown in Fig. 4. The corner joint of concrete block wall was not properly jointed as shown in Fig. 5. The grouting concrete was kept under considerably good condition.

Test Procedure The horizontal static loads were applied at the center of tie beams by the hydraulic jacks set between the specimens and the rest building. In case of Specimen T-D, loads were applied to north and south side beams. Strokes of the jacks were controlled so that the deflections of north side wall and south side wall became equal. All specimens were applied cyclic loading. The first cycle was small deflection range, and in the second cycle, each specimen was loaded up to failure. The linear differential transformers (LVDT's) were attached on each specimen in order to measure the deformations as shown in Fig. 6.

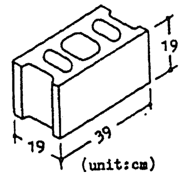


Fig.2 Concrete block unit

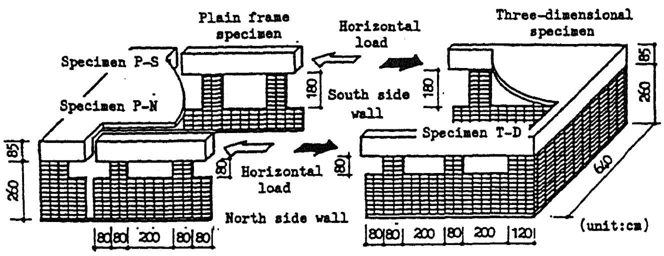


Fig.3 Test specimen

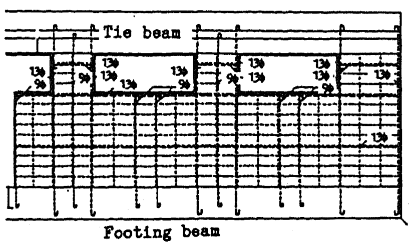
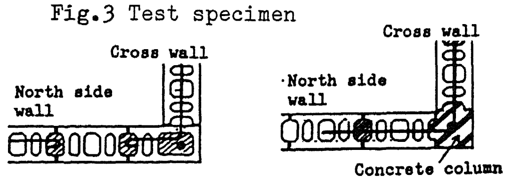


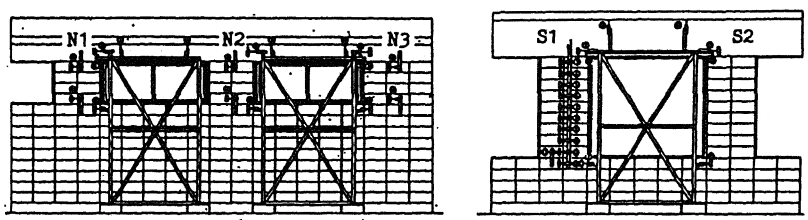
Fig.4 Bar size and spacing of wall reinforcement



Detail in practice

Detail required in the standard

Fig.5 Detail of corner joint



Specimen T-D (North side)

Specimen P-S

Fig.6 Location of LVDT's

Material Test The results of the compressive test of a block unit and the prism test of two layered block unit taken from the test building are shown in Table 1. The ratio of compressive strength of double unit to that of single unit was about 0.7. The average strength of concrete of beams and tie beams estimated by the Schmit hammer test was 220kgf/cm². The tensile strength of reinforcing bars taken from the walls is shown in Table 2.

CRACKING BEHAVIOR

Specimen T-D The final crack pattern of the south side wall shown in Fig. 7(a) was similar to a wall with openings, namely, the main cracks occurred at the top of S1 wall developed toward the bottom corner of west end diagonally. On the north side wall, upper part of the wall failed in shear like shear failure of short column as shown in Fig. 7(b). The detail of the cracking pattern at corner of each wall is illustrated in Fig. 8. On the south side corner, main diagonal cracks developed to the footing beam. On the north side corner, it was observed about 20mm lag between the bottom edge of N3 wall and the cross wall, because proper jointing works had not been provided for corner grouting and reinforcements.

Specimens P-S and P-N The maximum load and final failure mode of Specimen P-S were not confirmed because this specimen fell to out of plain during the test. Judging from the crack pattern shown in Fig. 9 and the load-deflection curve, it was supposed that the final failure mode of this specimen would be flexural failure. On the Specimen P-N, the final failure mode was the shear failure due to diagonal cracks along the joint mortar as shown in Fig. 10. The deformation mode measured with LVDT's attached on each concrete block unit of S1 wall was almost linear, while that of N1 wall indicated that large slipage occurred at the horizontal joint mortar of the midheight of N1 wall as shown in Fig. 11.

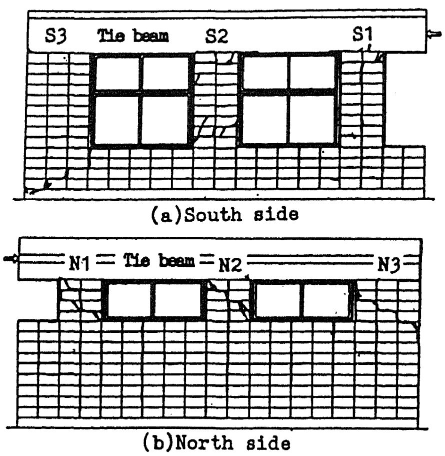


Fig.7 Final crack pattern (Specimen T-D)

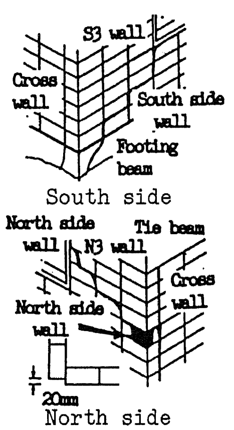


Fig.8 Crack of corner wall

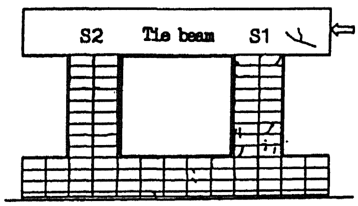


Fig.9 Final crack pattern (Specimen P-S)

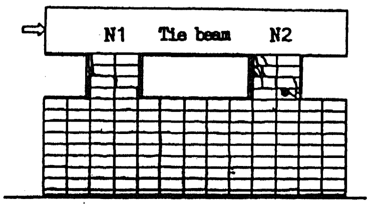


Fig.10 Final crack pattern (Specimen P-N)

Table 1 Compressive strength of concrete block unit

	Gross area (cm²)	Compressive strength (kgf/cm²)
Single unit	737.1	181.3
Double unit	745.8	127.0

Table 2 Yield strength of wall reinforcing bar

Nominal bar size	Diameter (cm)	Yield strength (kgf/cm²)
13φ	1.283	3498
9φ	0.840	4982

INITIAL STIFFNESS AND ULTIMATE STRENGTH

Initial Stiffness The initial horizontal stiffness obtained from the structural tests and the micro-tremor measurements are shown in Table 3. The initial stiffness of Specimen T-D obtained from the structural test agreed with the stiffnes estimated by the micro-tremor measurement pretty well, but it was only 8% of calculated stiffness assuming that the concrete block wall regarded as the cast-in-place concrete wall. Those of Specimens P-S and P-N were about 50% of the estimated values by the micro-tremor measurement, and 4% and 12% of calculated values, respectively.

Ultimate Strength As shown in Table 4, the ultimate shear stresses of the south and north sides of the Specimen T-D estimated the horizontal load and gross area of block wall were 4.1kgf/cm² and 6.5kgf/cm², respectively. The average ultimate shear stress estimated as a whole structure was 5.3kgf/cm², which was almost as same as that from Specimen P-N. The maximum stress of Specimen P-S was smaller than those from other specimens, because this specimen fell to out of plain. The shear forces when flexural yield hinges occurred both at the top and bottom ends were calculated and listed in Table 3. The ultimate flexural strength was calculated by assuming the strength of block unit listed value in Table 1 and the masonry factor of 0.5 specified in AIJ Standards. On Specimen T-D, the ultimate strength of south side wall agreed with calculated strength pretty well, while that of north side wall was smaller than calculated value due to shear failure. On Specimen P-N, the ultimate strength was 74% of calculated flexural strength due to shear failure. Since the large deformation to lateral direction occurred in Specimen P-S, the loading was stopped before yielding stage. Therefore, the test value in Table 4 was smaller than calculated value.

LOAD-DEFLECTION CURVE

Specimen T-D Fig. 12 shows the relationships between horizontal loads and story deflections. They indicated considerably ductile behavior. At the maximum load stage, the deflections in terms of the joint translation angle were about 1/200 with respect to the whole height of block wall of 260cm. Loads increased slightly even after shear failure occurred at north side wall. As the joint translation

Table 3 Initial stiffness

	Structural test (tf/cm)	Micro-tremor measurement (tf/cm)	Calculate value (tf/cm)	Test / Calculate
T-D	384.0	380.3	4736	0.081
P-S	74.0	127.8	1842	0.041
P-N	34.6	66.5	285	0.121

Table 4 Ultimate strength

	Maximum load (tf)	Shear stress (kgf/cm²)	Calculate value (tf)	Test / Calculate
T-D total	56.6	5.3	67.0	0.84
S-side	21.9	4.1	20.8	1.05
N-side	34.7	6.5	46.2	0.75
P-S	(8.7)	(2.9)	(10.0)	(0.86)
P-N	16.6	5.5	22.5	0.74

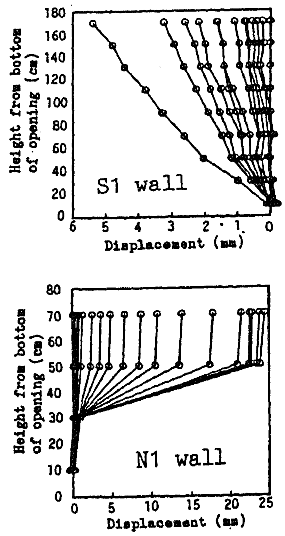


Fig.11 Deformation mode of wall

angle reached about 1/180, loads begun to decrease, and finally, reduced about 75% of the maximum load. The load deterioration of this specimen was a little smaller than that of Specimen P-N failed in shear, due to the contribution of the south side wall and the cross wall of west side. Fig. 13 shows the relationships between the ratio of loads carried by north side wall to total loads and the story deflections. During small story deflections, the north side wall carried about 70% of total load. However as the story deflections increased, the loads carried by north side wall decreased. After shear failure of north side wall, they were between 60% and 65% of total loads, and finally it became about a half amount of total load.

Specimen P-S and P-N Figs. 14 and 15 show the load-deflection curves of the Specimen P-N and P-S, respectively. On the Specimen P-S, the small deflection to out of plain occurred at the first cycle, and this deformation remarkably increased during the second cycle. So, the test of this specimen had to be finished before the ultimate strength stage. On the Specimen P-N, the load decreased to about 70% of maximum load due to the shear failure of N2 wall. By continuing the loading over the joint translation angle of 1/50, the load increased gradually again, and at the same time, the wooden sash crashed owing to confine the deformation of the concrete block wall. It seemed that the load increased due to the confinement by the wooden sash. Finally loads increased up to 90% of the maximum load.

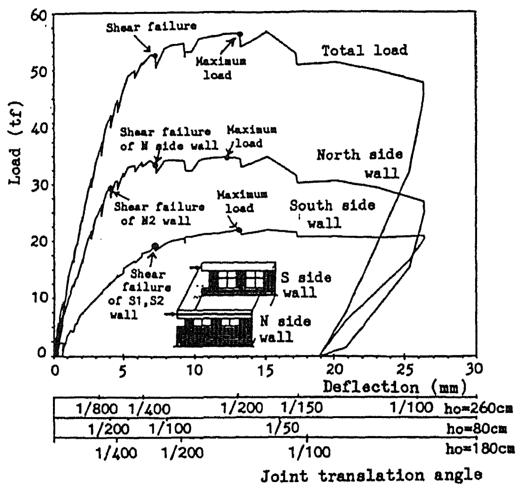


Fig.12 Load-deflection curve (Specimen T-D)

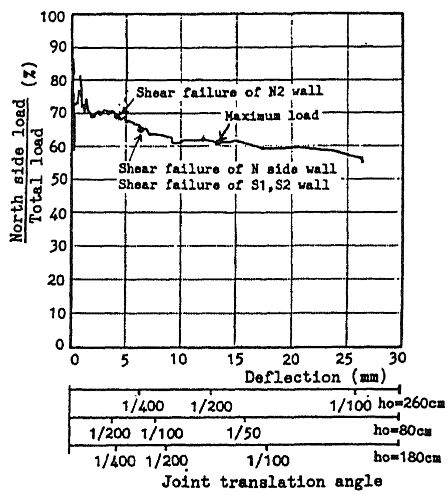


Fig.13 Ratio of north side load to total load

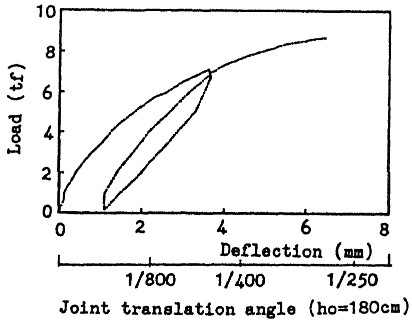


Fig.14 Load-deflection curve (Specimen P-S)

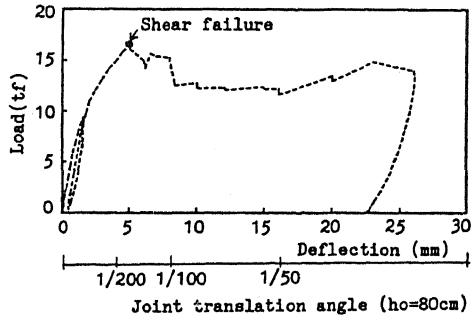


Fig.15 Load-deflection curve (Specimen P-N)

Comparison of Load-Deflection Curves Fig. 16 shows the comparison of load-deflection curves of three specimens with respect to average shear stress and joint translation angle. It was observed that the load deterioration occurred considerably on the load-deflection curve of Specimen P-N due to shear failure. On the other hand, that of Specimen T-D indicated the ductile behavior in spite of shear failure of north side wall. It was confirmed that the strength and ductility of this specimen were increased due to the three-dimensional effects including the effect of the cross wall.

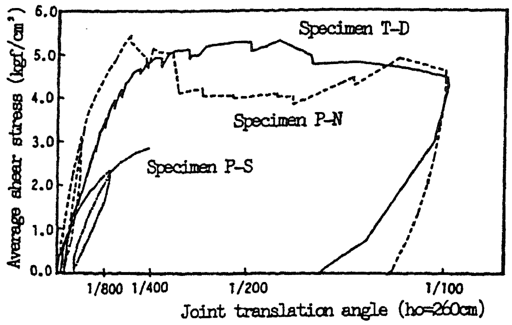


Fig.16 Comparison of load-deflection curve

CONCLUSIONS

Main findings in this test are summarized as follows:

1) The ultimate shear strength the concrete block masonry wall of the three-dimensional specimen was more than 5kgf/cm² in terms of average shear stress.
2) The joint translation angle of the three-dimensional specimen was about 1/200 at the maximum strength, and approximately 1/100 at the ultimate stage.
3) The ultimate strength and ductility of the three-dimensional specimen was a little larger than those from the plain frame tests due to the three-dimensional effect.
4) It was confirmed that the ultimate horizontal strength could be estimated by assuming the average shear stresses of the reinforced concrete block walls, and the ductility of this school building was better than expected.

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