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DEVELOPMENT OF MEDIUM-RISE REINFORCED MASONRY SYSTEMS

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SUMMARY

Under the U.S.-Japan joint earthquake research program of building structures involving large-scale experiments, masonry building structures are focused to be investigated for five years since 1984.

At present in Japan, only the reinforced masonry buildings which height from the ground is equal to or less than 12 meters (one to three story buildings) are permitted to be constructed. Under this program in Japan, the new design guidelines for medium-rise reinforced masonry buildings (up to five stories maximum) are to be proposed.

This paper introduces: i)overall research plan, ii)seismic test for wall and beam components, and iii) seismic test of a full scale five story reinforced masonry building.

INTRODUCTION

Masonry structural system was first imported to Japan from Europe, and, therefore, little attention was given to the earthquake resistance of then constructed masonry structures. Accordingly, those structures sustained great damage in the Great Kanto Earthquake. Since then, masonry structures practically disappeared in Japan, and very little effort was made for the study of seismic resistance of the masonry structural system. Since late 1960's various types of new masonry construction systems have been developed in order to make the construction more reliable and competitive.

At present in Japan, however, the masonry buildings are designed predominantly in the form of structural specifications which restrict design flexibility to the buildings and allow only low-rise ones up to three stories.

RESEARCH OBJECTIVES

Japanese side final target through the joint research program is to propose rational engineering aseismic design guidelines of medium-rise(up to five stories) reinforced masonry building structures in Japan.

In order to establish the design guidelines, the following objectives in structural design of masonry buildings are considered to be solved:

i. To ensure sufficient aseismic performance:
   Aseismic performance which is substantially equal to the one to be required for present wall type R/C buildings in Japan is expected for newly developed reinforced masonry buildings (designated as RM buildings in the following) under the program.

ii. To propose decreased wall length rate (sum of wall length in each story devided by floor area):
   15cm/m^2 for five story buildings in proposal, instead of 21cm/m^2 for three story ones under present regulations

iii. Not to use reinforced concrete collar beams:
   Reinforced concrete collar beams are required to be used in reinforced masonry buildings under present regulations.

iv. To simplify joint works of reinforcing bars:
   Lap joint system for placing vertical reinforcing bars in walls is proposed.

Japanese side research items through five years program are as follows:

1. Material Test
2. Static Test of Walls and Beams
3. Static Test of Wall and Beam Assemblies
4. Full-Scale Three Story Planar Frame Test
5. Full-Scale Five Story Structure Test
6. Establishment of Aseismic Design Guidelines

Time schedule for the above research items except the material test program is shown in Fig. 1. The material test program includes experimental study on units, joint mortar, grout and prism. Construction system and durability also are investigated.

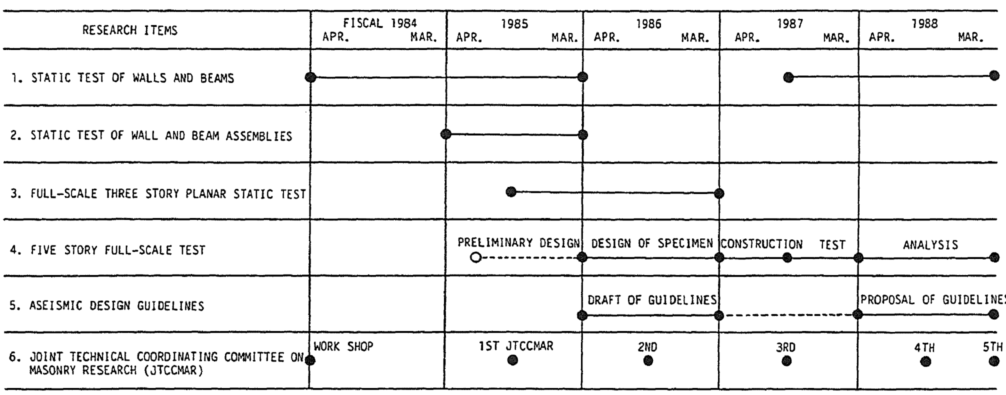

Fig.1 Research for Structural Performance on RM Buildings

Through Japanese side research works, high strength concrete masonry units in which design prism strength is more than 180kg/cm^2 are used. Standard concrete and clay masonry units used in Japanese research program, which were newly designed and produced for the program, are shown in Fig. 2. To allow setting necessary amount of reinforcing bars into unit sells, large size sells are prepared for the units, and are fully grouted.

SEISMIC TEST OF MASONRY WALLS AND BEAMS

Specimens The details of specimens are listed in Table 1. Main parameters are the amount of shear reinforcement, axial stress, shear-span ratio, and existence of reinforced concrete (R/C) slab or transverse wall. Typical wall specimen, WS4, is shown in Fig. 3. Specimens were fully grouted by concrete (concrete strength; 252 ~ 333kg/cm^2). The prism strength for concrete and clay masonry units are 212 ~ 233kg/cm^2 and 268 ~ 275kg/cm^2, respectively.

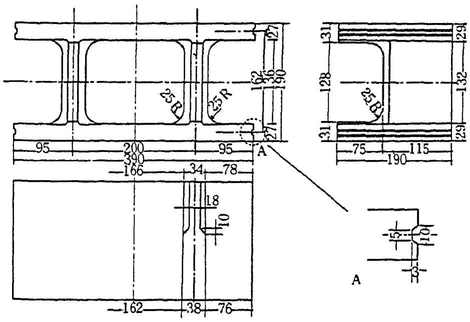

Fig.2a Standard Concrete Masonry Unit

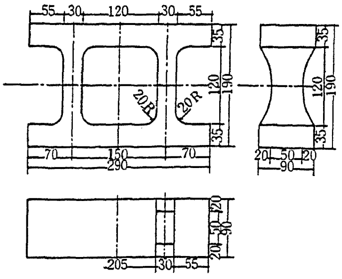

Fig.2b Standard Clay Masonry Unit

Table 1 Details of Specimen

(a) Wall

M/QD (Transverse wall)	At(cm²)	Pw = 0 ×	Pw = 0 ○	D13@400 (0.167%) ×	D13@400 (0.167%) ○	D13@200 (0.334%) ×	D13@200 (0.334%) ○	2D13@200 (0.668%) ×	2D13@200 (0.668%) ○
0.45	D16 (1.99)								
h/l= 180/200	2D19 (5.74)			WS1, WSR1					
	2D25 (10.1)								
0.75	D16			WS3, WSR3					
h/l= 180/120	2D19	WSR2 WSJ1 WS2×2		WS4, WSB1 WSR4, WSN1 WSN2, WF1, WFR1 WFL1, WSRC, WFJ1 WFLM, WFRC WSB10, WSJ2	WTT1 WTC1 WTRC	WS5 WSR5		WF2, WFB1 WFR2 WFJ2 WFB10 WS6 WSR6	WTT2
	2D25	WS8		WS11		WS9		WS10	
1.13	D16								
h/l= 180/80	2D19			WS7, WSR7					
	2D25								

VERTICAL REINFORCEMENT D16@400

WS; SHEAR FAILURE TYPE
WF; FLEXURAL FAILURE TYPE
WT; TT:T-SHAPE, TC:CROSS-SHAPE SPECIMEN
R; CLAY BLOCK
J; EFFECT OF LADDER STEEL

B1; 300mm LENGTH C/B SPECIMEN
RC; R/C SPECIMEN
O; OPEN JOINT SPECIMEN
N; AXIAL FORCE SERIES SPECIMEN

Transverse wall is 19cm thick and 200cm wide.

(b) Beam

M/QD (R/C slab)	At(cm²)	D13@400 (2D10@400)*1 D13@400 *2 ○	D13@400 (2D10@400)*1 D13@400 *2 ×	D13@200 D13@150*2 ○	D13@200 D13@150*2 ×	2D13@200 D16@150*2 ○	2D13@200 D16@150*2 ×
0.71	2D16 (3.98)			GF1			
l/h= 120/95	2D19 (5.74)		GF6, GFR4				
	2D25 (10.1)	GS1	GS2, GSR1 GSH1, GSB1 GSH2				GS3, GSR2
1.18	2D16						
l/h= 200/95	2D19	GF2	GF3, GFR1		GF4, GFR2		GF5, GFR3
	2D25		GS4				

HORIZONTAL REINFORCEMENT D16@400

*1 FOR HOOP SERIES SPECIMEN
*2 FOR 300mm LENGTH UNIT SPECIMEN
GS; SHEAR FAILURE TYPE
GF; FLEXURAL FAILURE TYPE
R; CLAY BLOCK

B1; 300mm LENGTH C/B SPECIMEN
H; HOOP SERIES SPECIMEN

R/C slab is 15cm thick and 200cm wide.

Test Setup Figure 4 shows the test system. In this test, two actuators set vertically were controlled by the computer in order to restrain the rotation of the top end of the specimen and to keep constant vertical compressive stress produced in the specimen. Another actuator set horizontally applied cyclic lateral displacement to the specimen.

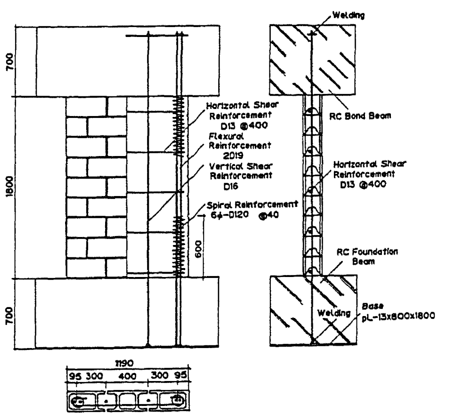

Fig.3 Typical Wall Specimen

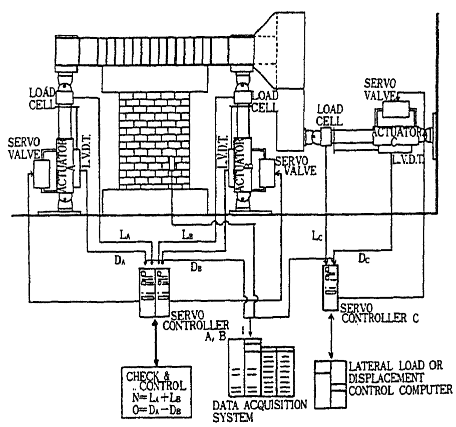

Fig.4 Loading System

Test Results The flexural failure type specimens reached the maximum strength when the drift angle reached about 4×10^{-3} to 10×10^{-3} radian. These maximum strength were about 1.0 to 1.2 times as much as the calculated ultimate flexural strength*. In the case of the specimens that have a transverse wall or R/C slab, test results agreed with the calculated ones when taking account of all reinforcements effective for flexure in the transverse member (Fig. 5 (a)).

The maximum strength of shear failure type specimens appeared when the drift angle reached about 2×10^{-3} to 5×10^{-3} radian in wall specimens, and about 4×10^{-3} to 7×10^{-3} radian in beam specimens. The specimens failed in shear had 50% deformation capacity as compared with the flexural failure type specimens. The maximum strength of shear failure type specimens showed 1.0 to 1.2 times as much as the calculated shear strength* except for the specimen which has small shear-span ratio or has no shear reinforcement. The maximum shear strength of the specimens to which a transverse wall or R/C slab attaches, was also estimated well using equivalent thickness or width which is equal to 1.5 times as much as geometrical thickness or width (Fig. 5(b)).

Note: * experimental formulas proposed for R/C components (Ref. 1)

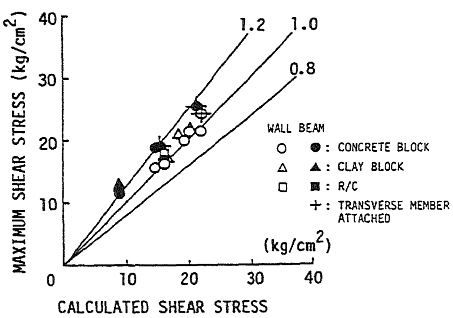

Fig.5 (a) Shear Strength of Test and Calculation (Flexural Failure Specimens)

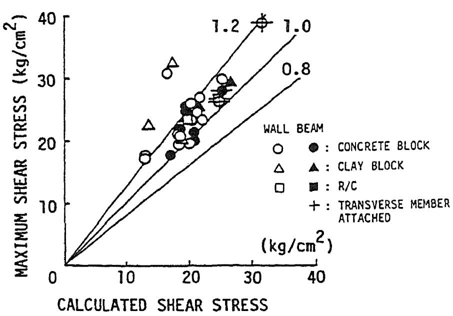

Fig.5 (b) Shear Strength of Test and Calculation (Shear Failure Specimens)

SEISMIC TEST OF A FIVE STORY FULL SCALE RM BUILDING

Test Building A five story full scale test on a reinforced concrete masonry building was carried out in order to experimentally verify analytical models which are assumed and dealt with in the draft of the design guidelines. In the main portion of the full scale test, the test structure was subjected to increasing cyclic lateral load with the lateral load distribution derived from the Japanese Building Code.

The test specimen represents one module of a typical 5-story apartment building in Japan. The floor plan and elevations of the test specimen are shown in Figs. 6 and 7. The test specimen consists of four frames, Y1-Y4, in the loading direction. The floor area is 13.79m (loading direction) x 15.19m (transverse direction, including 2.4m wide balcony) and the total building height is 14m from the top of foundation to the roof slab (each story is 2.8m in height). Wall length rate is 15.20cm/m^2 in the loading direction, and 23.30cm/m^2 in the transverse direction respectively. Deformed reinforcing bars, 19mm(D19, #6), were arranged in most of all walls as flexural reinforcement. Vertical reinforcing bars D16 (#5) were arranged with a spacing of 400mm(16"). Horizontal reinforcing bars D10(#3) or D13(#4) were arranged with spacing of 200mm(8"). Deformed reinforcing bars, D19, 2D19, D22, D19 & D22 or D25 were arranged in beams as flexural reinforcement. Deformed reinforcing bars D13 basically were arranged in beams with a spacing of 200mm as shear reinforcement. Design strength of masonry prism is $240kg/cm^2$.

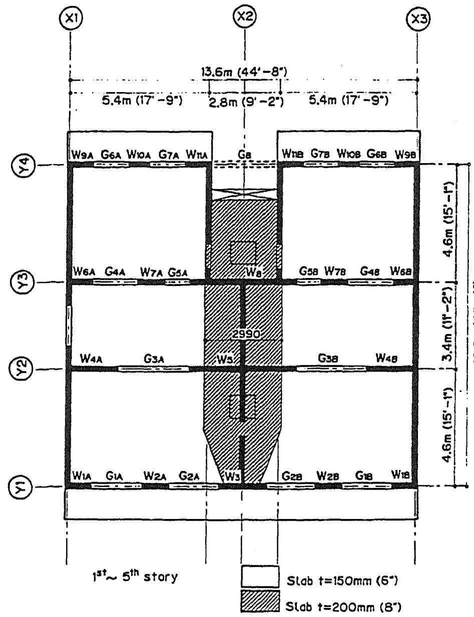

Fig.6 Plan of the Test Building and Member Designation

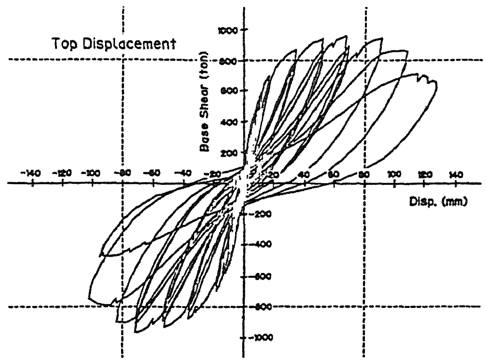

Fig.8 Base Shear vs. Top Displacement Relationship Obtained through Static Cyclic Loading Tests

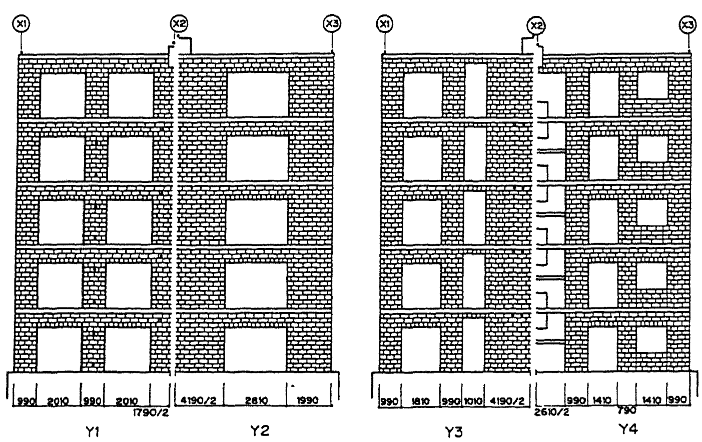

Fig.7 Lateral Load Resisting Frames Y1 through Y4 [scale in mm]

Outline of Test Result Hysteresis curve for the base shear vs. the top displacement is shown in Fig. 8. Figure 9 shows the base shear vs. the top displacement envelop curve with description of major events during loading. The test structure behaved almost linear in force vs. displacement relationship for the nominal shear stress level below $10 \sim 11kg/cm^2$. The maximum strength of the test structure was 968ton in base shear which corresponds to total weight of the structure apploximately. The top and the first story displacements corresponding to the maximum strength was 69mm (1/200rad. drift angle) and 22.3mm (1/130rad.) respectively. The test structure responded for cyclic loading with stable force vs. deflection loop up to about 5/800rad. drift angle displacement. It changed, however, into unstable response after 6/800rad. displacement, namely deflection concentrated on the first story as shown in Fig. 10 and strength also greatly decreased. The first story displacement at final stage was about 69mm, 1/40 rad. drift angle, which is approximately 53% of the top displacement.

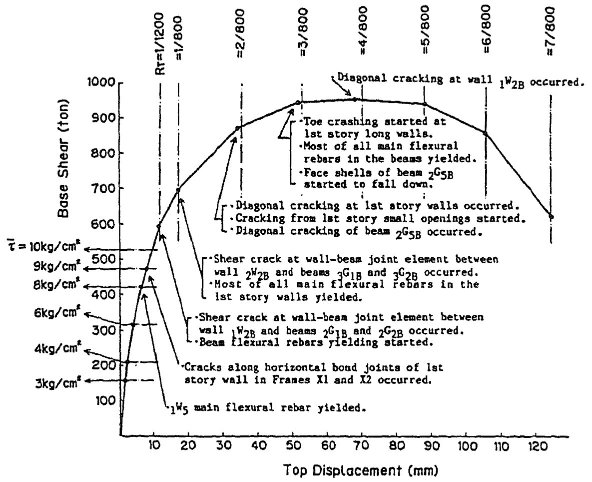

Fig.9 Base shear vs. Top Displacement Envelop Curve for Static Cyclic Loading Tests

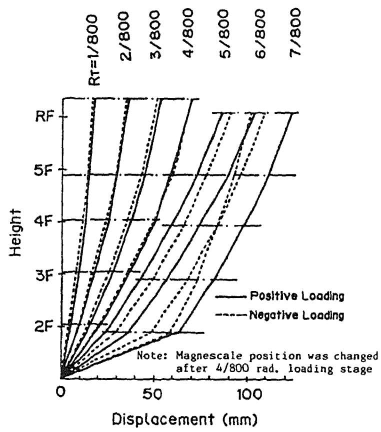

Fig.10 Change in Deflection Mode with Increasing Top Displacement

CONCLUSION

Japanese side research plan for reinforced masonry buildings which is going to be held under U.S.-Japan Joint Earthquake Research Program involving Large-Scale Experiments was introduced herein. A draft of design guidelines for the RM buildings was provided at the end of the fourth year of the project. This may be modified according to the result of a detailed analysis on the full scale five story test and also suplementary component tests which are to be carried out in 1988 and finally be proposed March 1989.

ACKNOWLEDGEMENT

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REFERENCE

1) T. Okada, S. Okamoto, Y, Yamazaki and A. Baba, "U.S.-JAPAN COORDINATED EARTHQUAKE RESEARCH PROGRAM ON MASONRY BUILDINGS -JAPANESE SIDE RESEARCH OUTLINE-", The 4th North American Masonry Conference, August 1987