DAMAGE TO A CONCRETE-BLOCK MASONRY HOUSE DUE TO THE 1982 URAKAWA-OKI EARTHQUAKE

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SUMMARY

A house of reinforced concrete masonry was heavily damaged due to the 1982 Urakawa-Oki Earthquake. The house was located on a hill in Mitsuishi Town in Hokkaido Ireland, Japan. The house was demolished without any repairing after the damage. Longitudinal walls on south and north sides were heavily damaged by out of plane forces. Although some construction errors were found, it is concluded that the AIJ standard shall be revised to resist more horizontal force.

INTRODUCTION

At 11:32 a.m., on March 21, 1982, Hidaka district, southern part of Hokkaido, Japan, was struck by a strong earthquake, whose seismic center was about 30 km. west offshore from Urakawa Town, 40 km, deep, and its magnitude in Richter's scale was 7.1. By this earthquake considerable damages were caused in a wide area of Hidaka district, especially in parts of Urakawa Town, Mitsuishi Town and Shizunai Town, and even in those of Sapporo City, which is about 150 km. away from the seismic center.

It was published that the maximum intensity in Hidaka district was IX in MM scale. Fig. 1 shows the epicenter and the intensity at every place.

Twenty-two persons were severly injuries, 145 persons slightly injuried, 13 houses almost totally destroyed, 28 houses partially destroyed, 675 houses slightly damaged. Many public structural installations, agricultural, fishery and forestry installations were also damaged. Most buildings determined as totally destroyed were wooden houses. However, only one house of reinforced concrete block masonry was destroyed totally

Investigation about the damaged house and discussion on the structural design of reinforced concrete block masonry are presented in this paper.

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LOCATION AND STRUCTURE

Location

The house belonged to Mitsuishi Elementary School in Mitsuishi Town in Hidaka district. It was located on a hill about 250 meters distant from the sea. There were two steep slopes 14 meters distant in the west and in the south of the house respectively. The central part of the town, a national road and a railroad are in the south of the steep slopes, shown in Fig. 2.

At the site black surface soil is about 1 m deep. Brown sandy clay layer is 1.5 m to 2 m thick underneath the surface soil. Below them clay sand and sand and course gravel follow. There is the bed rock of the Tertiary formation 10 m below the surface.

Structure

The house of reinforced concrete masonry with wooden roof truss was built in 1963. Its area was 68.5 square meters. Details of the structure were designed according to "Standard for Structural Design of Reinforced Concrete Block Construction" by Architectural Institute of Japan (AIJ Standard, Ref.1). Reinforced concrete continuous footings and 15 cm thick walls of light weight hollow concrete blocks reinforced by round bars in both vertical and horizontal directions were provided. Continuous collar beams were also provided at the tops of the walls. Most of the sections of the collar beams were L shapes, but some of them were rectangular without flange. (See Fig. 6) The intersections of the walls were reinforced by cast-in-place reinforced concrete columns. Fig. 3 shows the elevation of the house and Fig. 4 shows the plan and deformations after the earthquake.

DAMAGE BY THE EARTHQUAKE

This house had not fallen down, but was completely damaged so that it was determined to be demolished. Longitudinal walls were heavily damaged. A point at the top of the north side longitudinal wall moved in the north direction for 80 cm. The collar beam attached to the above mentioned point dropped down about 80 cm. The maximum deflection of the south side wall out of plane was only 13 cm, but a vertical reinforcing bar of 13 mm dia. was torn off such as a testpiece after material test. Wide cracks were concentrated to the above-mentioned two walls. Most cracks were occured along mortar joints between blocks, but several diagonal cracks were also found. The maximum uneven settlement was 151 mm. Permanent displacements at the tops of the walls and uneven settlements of the footings are shown in Fig. 4 together.

INVESTIGATION AND TEST

Reinforcement

The actual reinforcement of the house was investigated. Sizes and spacings were mostly complied with the minimum requirement specified by the AIJ Standard. However, detailing of anchor of vertical reinforcing bars into footings was not complied with the standard. Reinforcement at the corner of the collar beam was not efficient. Layouts of the concrete blocks and the vertical reinforcing bars are shown in Fig. 5.

Material Property

The hollow concrete-blocks, concrete core samples and reinforcing bars, 13 Ø and 9 Ø dia. were taken off from the damaged house and tested. Net strength of the concrete-block was about 8 MPa, yield strength of steel was about 270 MPa and compressive strength of concrete was 11 MPa.

The depths of carbonation of concrete were measured. The data are shown in Table 1. Strength of the concrete block and that of reinforcing steel were moderate. However, strengths of the concretes for collar beams and for footings were slightly low.

Wall Rate

According to AIJ Standard, the minimum wall rate, which is defined as the quotient of the total length of wall (in cm) calculated in two directions separately divided by the floor area (in m^2), is 15 cm/m^2. The wall rate of the house in the longitudinal direction Lx is 19.55 cm/m^2 and that in the transverse direction Ly is 16.04 cm/m^2.

Detail of Collar Beam

A part of the longitudinal collar beam laid on the northside dropped down. According to AIJ Standard, the collar beam should have L shape section, so that the enough strength against horizontal force out of plane was provided. However, the section of the part of the collar beam was rectangular without flange, just changing from L shape. Reinforcing bars were discontinuous for lack of lapped splices at the part. (See Fig. 6 and Fig. 7)

Torn off Steel

A vertical reinforcing bar was torn off at the point C in Fig. 4. This point on the elevation is shown in Fig. 8. The point did not coincide with the maximum point of bending moment assumed in structural calculation and was located at the cross point with a horizontal bar above the maximum point.

It is estimated that the bar was subjected to combined forces of tension and bending from large tension of the horizontal bar.

CAUSE OF DAMAGE

The ground motion in the NW-SE direction was predominant. The maximum ground acceleration was estimated 360 gal based on the investigation on tomb stones. Therefore the both long walls on north and south sides were estimated to vibrate out of plane. Direct causes of damage to the walls can be considered as follows.

a. The dropping down of the part of the collar beam lacking enough section and splices was obvious direct cause of the damage to the longitudinal wall on the north side. That can be thought as a construction error.

b. The two contacting walls to the longitudinal wall on the south side did not have enough strength and stiffness. Therefore they could not restrict the vibration of the longitudinal wall out of plane. That can be thought an error of the design. But the requirements of the AIJ Standard were not sufficient simultaneously.

STRESS OF COLLAR BEAM

The steel bar 13 mm dia. was torn off. Response acceleration was roughly estimated from the maximum tension force of the bar. Simultaneously the behavior of the two contacting walls were analyzed. Thereafter seismic stresses of the collar beam at the top of southside wall were roughly computed.

Estimated Shear Force Applied to the C-C" Wall

As mentioned before, the point C in the Fig. 4 did not coincide with the maximum bending moment point and was a cross point with a horizontal bar. Therefore it is estimated that the maximum tension force of the torn bar closed to the yield load Ty given by material test rather than the maximum load T_B. In this paper the maximum tension force of the bar was assumed as $T_B' = 1.1 \sim 1.2$ Ty. As a result, shear force applied to the C-C" wall was estimated about 1.7 ton.

Boundary Condition of Collar Beam

In order to estimate the stresses of the continuous collar beam at the top of south side wall, one continuous beam, shown in Fig. 9 (a), supported by four springs located at the same positions of the transverse walls was assumed. The sum of the self weight of the upper half of the walls and roof weight carried by the wall was considered as the weight for the distributed earthquake load. The west end of the continuous beam was assumed 50% restricted and the east end was assumed fixed because of the roof slab of reinforced concrete. Spring constances at the supports were given by the stiffnesses of the transverse walls in plane in the horizontal direction. They could be easily computed assuming the walls as canti-levers fixed at the ground. Flexural deformation, shear deformation and rotation due to ground deformation were considered for computation of the horizontal stiffnesses. The constances of materials were adopted as follows:

Young's modulus of masonry wall $_mE = 0.4 \times 10^5$ kg/cm^2
Young's modulus of collar beam and footing $_cE = 2.1 \times 10^5$ kg/cm^2
Coefficient of subgrade reaction k = 3.0 kg/cm^3.

The above constances and the weights of the roof and the walls were calculated with reference to other similar field measurements. Fig. 9 (a) shows the computed spring constances and horizontal loads when the story shear coefficient; the story shear divided by the weight, was assumed 0.5.

Fig. 9 (b) shows stresses of the continuous beam computed on the common assumption that both ends were fixed. On the other hand, the stresses of the beam supported by the above mentioned springs are shown in Fig. 9 (c). Direct stiffness matrix method was used for the elastic computation. Comparing Fig. 9 (b) with Fig. 9 (c), reaction force of the wall B-B' was fairly large in the case of fixed end but it remarkably decreased in the case of spring support. The C-C' wall, however, increased its reaction and the bending moment at the point B also increased in the case of spring support. It is estimated that the horizontal load was concentrated into the C-C' support.

The maximum story shear coefficient Co can be given by proportional calculation as 0.61 from the shear force 1.7 ton of the C-C' wall as mentioned before.

REMARKABLE POINTS ON SEISMIC DESIGN

a. According to AIJ Standard, the reinforced concrete block masonry building without reinforced concrete slab shall be provided with an effective connection of reinforced concrete collar beam or girder on the top of bearing wall, the distance between the central lines of contacting walls of the building shall be 50 times the thickness of bearing wall, and the effective width of collar beam shall be not less than 1/20 of the distance between central lines of contacting walls. The considered house complied with the requirements of AIJ Standard mostly, but with a little construction error.
Insufficiency of the requirements of the AIJ Standard in order to keep horizontal stiffness of the wall out of plane is one of the causes. The requirements about the contacting walls shall be changed to omit the buttress and to form closed plan by connecting opposite walls.

b. The earthquakes with seismic intensity VIII - XI in MM scale have often occured in Japan. The considered flat house located on a little hill was estimated to be applied large response shear force corresponding to that the story shear coefficient Co was $0.5 \sim 0.6$. The similar reinforced concrete building shall be designed against the above mentioned shear force.

REFERENCE

[1] Architectural Institute of Japan "Standard for Structural Design of Reinforced Concrete Block Construction", Oct. 1955.

Table 1 Properties of Materials

Concrete Block		Specific Gravity 1.61		
		Net Area Com. Strength(kg/cm^2) 114.7		
		Gross. Area.C.Strength(kg/cm^2) 74.6		
Steel		Diameter	Yield	Maximum
	Wall	8.75 mm	2.74 t/cm^2	3.74 t/cm^2
	Wall	12.46 mm	-	4.25
	Beam	12.34	2.86	3.95
Concrete		Strength	Specimen	
	Beam	113 kg/cm^2	10 Ø Core	
	Beam	90	Schmidt Hummer	
	Base	101	Schmidt Hummer	
		Depth of Carbonation		
	Beam	20 to 150 mm		
	Wall	60 to 85	at Corner	
	Wall	50	Middle Part	

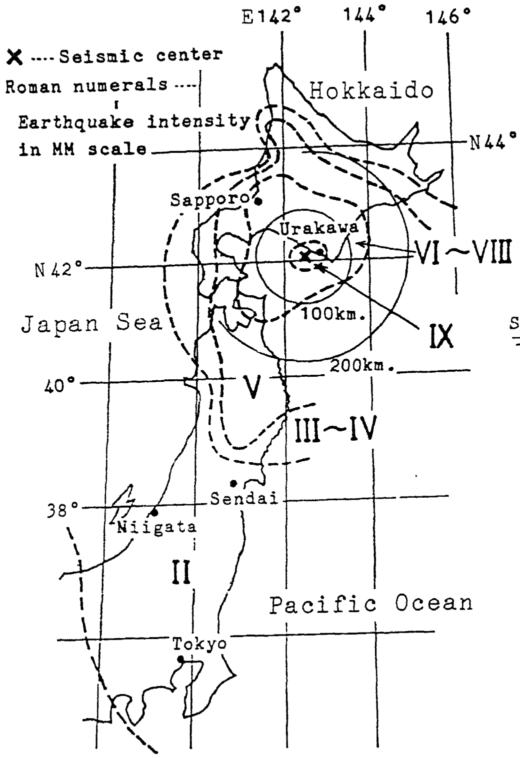


Fig.1
Seismic center and contour of earthquake intensity

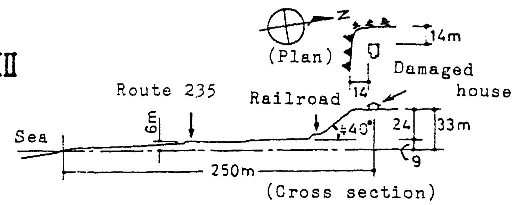


Fig.2 Site of damaged house

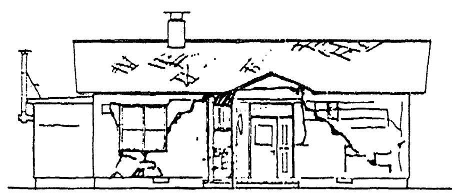


Fig.3 Elevation of north side

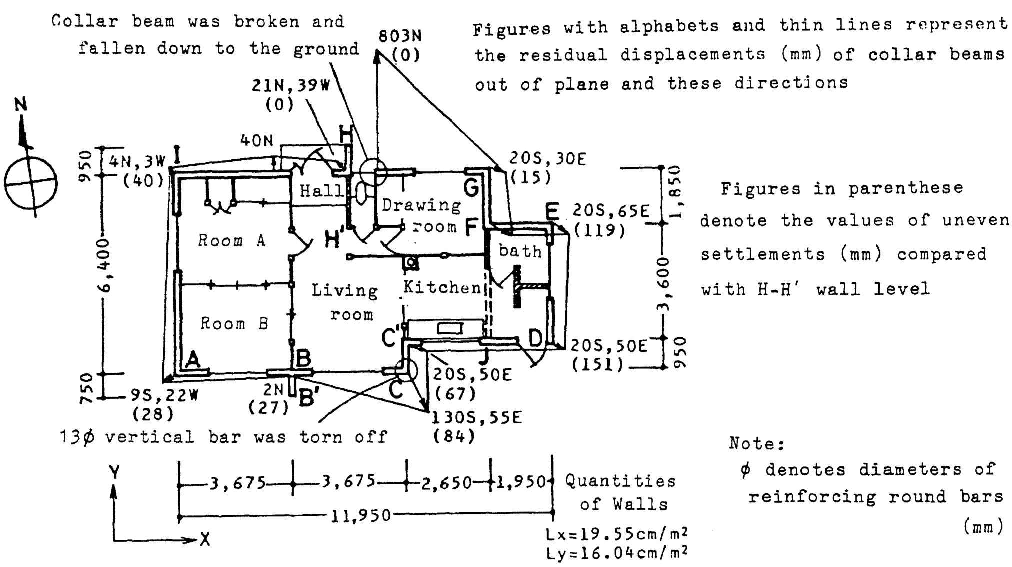
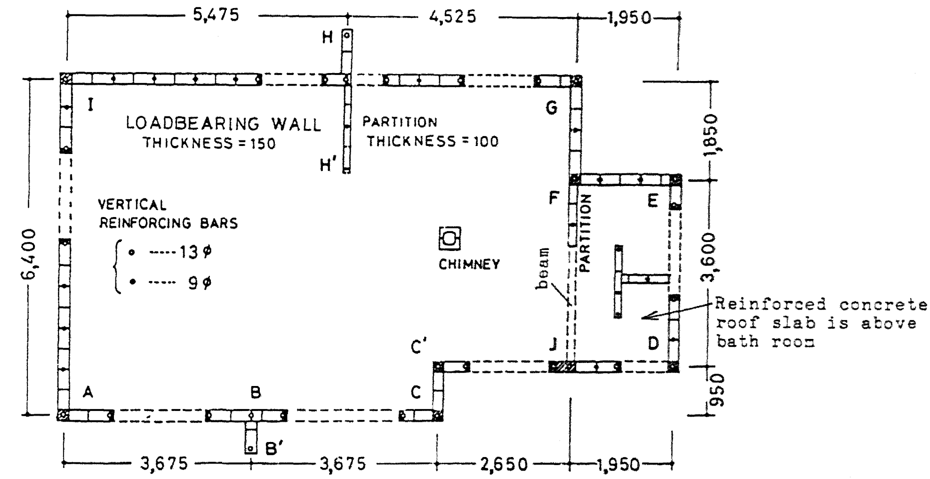
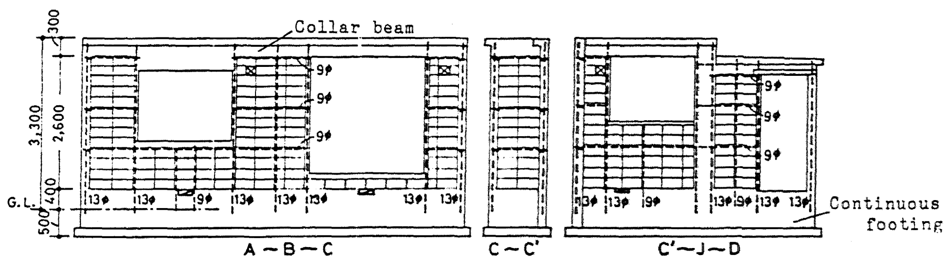


Fig.4 Plan and deformations



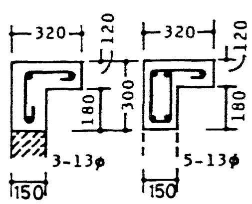
(a) Layouts of concrete blocks and vertical reinforcing bars



(b) Examples of reinforcements in masonry walls (South wall A~D)

Fig.5 Constructions of masonry walls

(Note: φ denotes diameters of reinforcing round bars (mm))



(general) (above the openings)

Fig.6
Cross-sections of reinforced concrete collar beams

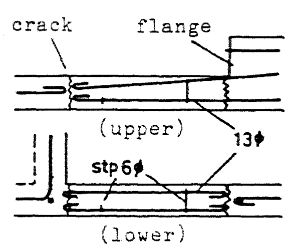


Fig.7
Horizontal cross-sections of failed part of collar beam in north wall

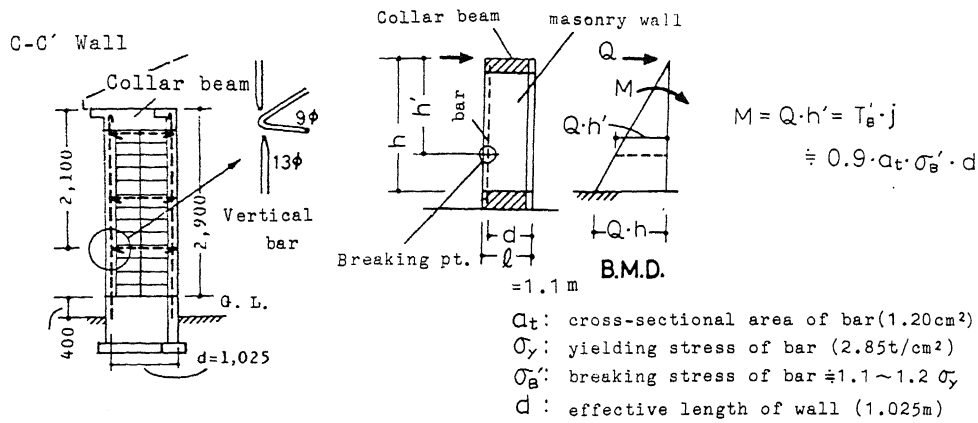


Fig.8 Situation of C-C′wall where vertical reinforcing bar was torn off and formula to estimate force applied to the wall

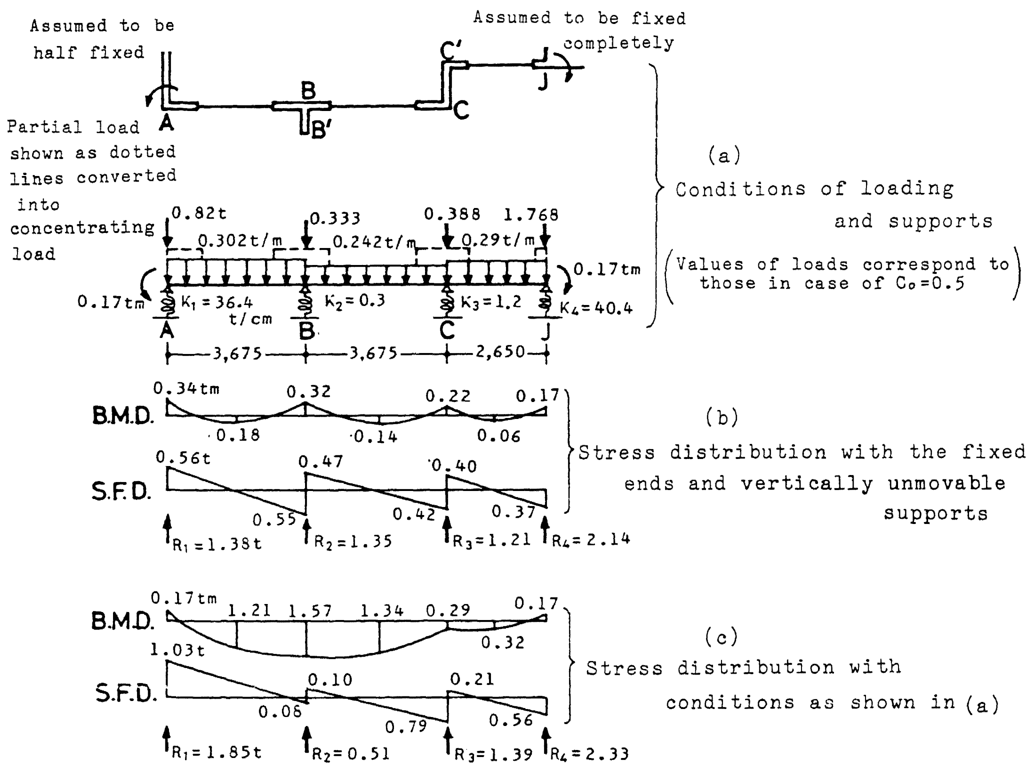


Fig.9 Stress distributions of south wall collar beam on the assumptions that it is a idealized continuous beam with and without spring supports (in case of C_o=0.5)

(Note: Loads and stress are represented by metric gravity units)