IV–9. Earthquake Resistance of Old Brickwork

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ABSTRACT

This paper reports the diagnostic method and results of examinations about earthquake resistance of the non-reinforced brick warehouse designated cultural asset to apply for different use.

This warehouse is a seventy year old, three-storied (partly four-storied) brick building, but data of bricks used or joint mortar are lost. The building had some cracks by the Kanto Great Earthquake and has been used as warehouse without repair.

The earthquake resistance was examined as follows: (1) Among properties of bricks, ones to affect bearing strength of brick masonry was elucidated experimentally; (2) Presumption of materials and mix design of joint mortar by the unique chemical method; (3) Elucidation of strength of prism formed with bricks and joint mortar cut from the building; (4) According to (1) & (2), the bricks and joint mortar similar to ones in the building were manufactured and specimen to measure shear strength of the non-reinforced brick masonry and prism of same shape to (3) were prepared; (5) Shear strength was measured experimentally using specimen (4); (6) The necessary data for examination of earthquake resistance such as load or wall quantity were collected by inspecting the building; (7) Diagnosis of safety factor of the whole construction from results of (5) & (6).

PREFACE

This paper is to report results of examinations on the strength of the brick warehouse built in 1908 at Yokohama Harbor in Japan. This paper reports a method of strength research of an old brick building and results of investigation about strength, durability of walls and materials used in this building.

It was necessary to measure the shear strength of brick walls for estimation of shearing strength, but this building was an important historical asset and it was impossible to cut out the testing specimen from the building. Therefore, bricks of the same property to ones used in this building were manufactured and after presumption of the mix design of the joint mortar taken from the building, the wall specimens were constructed for examination of earthquake resistance.

METHOD OF RESEARCH

The following are the subjects of this research:

(1) Properties of bricks used.
(2) Mix proportion of joint mortar.
(3) Strength of the specimen cut out from the building.
(4) Prediction of structural strength.

The following are the flow of research of structural strength:

(1) Experimental elucidation of properties affecting the bearing strength of the building, e.g. strength or water absorption of bricks.
(2) Presumption of the mix proportion of joint mortar used in the building.
(3) Experimental elucidation of the strength of the brick masonry prism cut out from the building.
(4) From the results of (1), bricks of the same compressive strength and same water absorption are manufactured.
(5) From the result of (2), the specimens to measure shear strength and the prism specimens are constructed.
(6) Measurement of shear strength by the specimen (5).
(7) By experiments of the prism specimen (5), shear strength of the building is presumed from the shear strength of specimen (6).
(8) From the results of structural examinations and (7), earthquake resistance of the building is diagnosed.

RESULTS OF PROPERTY EXAMINATIONS

Property of Brick Units

Table 1 shows properties of bricks used. The ordinary bricks used in the largest quantity showed rather low quality with compressive strength of about 110 kg/cm^2 and water absorption of about 30°/vol. The other hand, saturation coefficient was large and rate of swelling was comparatively large, and it was presumed that the baking temperature was generally low.

Strength of Brick Masonry

For the purpose of confirming strength as brick masonry, the prism was cut out from the building by a R. C. breaking cutter. Two pieces of prism (section of 160 × 160 mm) were taken from the corner of the inner wall. First flexual strength of the prism was tested, and compressive strength and shear strength were tested by pieces from the flexual strength test. The compressive strength was tested using the five-row prism capped with

plaster of Paris on both edges. The method of shear strength test is shown in Fig. 1.

Examination of Durability

The neutralization test of joint was made at ten points inside and outside. Weakened points were inspected with eyes. The following are results of examination:

(1) The neutralization of joint mortar which borders ordinary bricks was deeply advanced over 13 cm from the surface of both inside and outside.
(2) The neutralization of joint mortar bordering over-baked bricks was very little (1–3 mm).
(3) Metal fittings buried in the outer wall were badly corroded and many cases of fracture of bricks caused by swelling of ironwares by corrosion were observed.

From the above results, it is predicted that the neutralization of joint is largely influenced by quality of bricks. It is necessary to use bricks of less water absorption for reinforced brickwork in the viewpoint of protection of reinforcing steel bars.

RESULT OF ESTIMATION OF SHEAR STRENGTH

Mix Proportion of Joint Mortar

Mix proportion of joint mortar was presumed by the specimen from the building. The following are the method of presumption:

(1) The quantity of CaO (Calcium Oxide) was measured by the method in "Joint Examination on presumption of mix proportion of hardened concrete" by the Cement Association of Japan.
(2) Chemical composition (SiO_2, Al_2O_3, CaO, etc.) were analyzed quantitatively by chemical analysis method of cement composition (JISR 5202).

Manufacture of Specimens for Shear Strength Test and Adapatability to the Building

Trial bricks were manufactured and the prism for shear strength test was built. To examine adaptability, the actual building, eight-row section of the prism (210 × 105 mm) was made, and compressive strength, flexual strength and shear strength were measured. Table 5 and 6 show the property of trial bricks and results of strength test of the prism using trial bricks and joint mortar of presumed mix proportion. This trial prism was proved to have the same strength to the prism cut out from the building.

Method of Shear Strength Test

Specimen

With the basic specimen size 1.2 m × 1.2 m × 21.3 cm by ASTM E519-74, three specimens with different height (width was same)—λ (width / height ratio of brick wall) = 1, 1.5 and 2 making height of the wall 1/1 time, 1/1.5 times and 1/2 times of width—were manufactured. Fig. 2 shows the specimen of λ = 2 and Table 2 shows the size de facto of each specimen. The specimens are aged about 32 days.

Loading Method

Load was diagonal compressive load, and Fig. 3 shows the loading plate for the specimen of λ = 1. For specimens of λ = 1.5 and 2, loadings plates with the adjusted angle to set the specimen in the vertical direction for diagonal load were manufactured. Plaster was poured between the specimen and the loading plate to make them one body and to make even loading surface not to occur eccentric load. Fig. 4 shows the loading method.

Results of Shear Strength Test

The Maximum Bearing Strength

Table 8 shows results of the maximum bearing strength of each specimen. P_u means the maximum diagonal compressive load, Q_u means the maximum shear load obtained by the following formula and t_u, the maximum average shear stress. (See Fig. 5) Length (L) and height (h) of specimen in this formula are the size de facto in Table 7.

$$Q_u = \frac{L}{\sqrt{L^2 + h^2}} P_u$$

$$t_u = \frac{Q_u}{Lt} \quad (L = \text{thickness})$$

Fig. 6 shows experimental results. σ in Fig. 6 means the value that vertical load (v) in Fig. 4 is divided by horizontal section (L • t). Experimental results of relation between width / height ratio and strength showed irregular values. λ = 1.5 showed higher average strength than λ = 1 and influence of width / height ratio on strength was not elucidated quantitatively. However there is a tendency that strength reduces with increase of width / height ratio. Fig. 7 shows average values of each width / height ratio in this experiment and experimental results to back up the Code of Structural Designs of the Architectural Institute of Japan. This result is very small. Against the backing data of the Code that is more than two times of the short term permissible shear stress by the Code (less than 1/80 and 2.25 kg/cm² of compressive strength of a brick unit), the value of this experiment was less than 1.5.

Pattern of Fracture

With occurence of initial cracking and momentary running of cracks in the diagonal direction, each specimen collapsed brittlely with big sound. Cracks occured in joint mortar or on bonding surface of bricks and joint mortar, and bricks showed no cracks in any specimen. The fact that there was no crack before start of collapse is clear also from the relation between load and shear strain (mentioned later) which shows the constant curve.

Relation Between Stress and Strain

Fig. 9–10 show experimental results of shear strain at the center of wall panel. The dotted lines in the Figures show the values of the elementary theory of bending, with

Young's Modulus (E) of $9.3 \times 10^4 kg/cm^2$ obtained by the compression test of brick units. Poisson's ratio (ν) of 0.2 and shear stiffness of wall panel G by the following formula.

$$G = E/2\,(1 + \nu)$$
$$t = G\,\gamma/K$$
$$= 2.583 \times 10^4 \gamma \; (kg/cm^2)$$

τ = average shear stress

λ = shear strain at the center of wall panel

$\chi = 1.5$ = shear stress / average shear stress ratio at the center of wall panel by elementary theory of bending

CONCLUSION

The purpose of this paper was to introduce one of examination methods of earthquake resistance of a historical brick building. It is our great pleasure if this study is useful for the safe utilization of cultural asset constructions.

TABLE 1—Kinds and property of bricks used in the investigated building

		Mechanical property		Density		Water absorption rate			
Name	Places used	Compressive strength (kg/cm^2)	Static modulus of elasticity ($\times 10^5 kg/cm^2$)	Surface drying	Absolute drying	24 hour absorption in static water (°/vol.)	5 hour absorption in boiling water (°/vol.)	Saturation ratio	Rate of swelling ($\times 10^{-4}$)
Common bricks	General walls	111	0.34	1.91	1.59	32.3	32.6	99.0	5.92
Glazed bricks	Outer walls and under windows	135	1.65	1.95	1.58	17.5	18.2	96.2	4.46
Over-baked bricks	Foundation	217	2.61	2.13	2.02	11.5	11.8	97.5	1.54

TABLE 2—Strength of prism cut from building

	Compressive strength (kg/cm^2)	Flexual strength (kg/cm^2)	Shear strength (kg/cm^2)
Average value	82	6.1	2.2
Standard variation	7.5	0.40	0.05
Rate of variation (%)	9.2	6.6	2.2

TABLE 3—Results of chemical analysis

Items of measurement		Measured value
Density	Surface drying	2.149
	Absolute drying	1.915
Chemical composition (%)	Igloss (° /wt)	13.2
	Insol	68.7(79.4)**
	SiO_2	1.3 (1.5)**
	Al_2O_3	1.3 (1.5)**
	Fe_2O_3	0.6 (0.7)**
	CaO	14.2 (16.4)**
	MgO	0.3 (0.3)**
	SO_3	0.1 (0.1)**

** Values in ( ) are percentage after exclusion of igloss.

TABLE 4—Presumed results of mix proportion of joint mortar

	Water	Portland cement	Lime	Sand	Note
Mix proportion by weight (kg/m³)	213	133	304	1398	
Density	1.00	3.16	2.60	2.50	
Ratio of capacity proportion		1	3	12	*1
Fractional volume of solid phase		52.4	48.3	57.3	*2

*1 adjusted by value of *2

TABLE 5—Property of trial bricks

	Density		Compressive strength (kg/cm²)	Young's modulus (× 10⁵kg/cm²)		Water absorption (% /val)
	Surface drying	Absolute drying		Static	Dynamic	
Experimental value (average value)	2.09	1.80	151	0.93	1.38	25.2

TABLE 6—Experimental results of trial prism

	Compressive strength (kg/cm²)	Flexual strength (kg/cm²)	Shear strength (kg/cm²)
Average value	96	5.6	2.0
Standard variation	7.6	1.13	0.10
Rate of variation (%)	7.9	20.3	5.0

TABLE 7—Size of specimen and width / height ratio

Specimen	Width(cm)	Hight(cm)	Thickness(cm)	Width/Height ratio
1-2	122.43	123.32	21.3	0.993
1-3	123.60	123.75	"	0.999
1-4	122.83	123.67	"	0.993
1.5-1	122.58	84.30	"	1.454
1.5-2	122.57	83.20	"	1.473
1.5-3	123.03	83.00	"	1.482
2-1	122.33	61.37	"	1.993
2-2	123.03	61.63	"	1.996
2-3	123.30	61.47	"	2.006

TABLE 8—The largest load and shear stress

No	Pu (ton)	Qu (ton)	τu (kg/cm²)	average of τu (kg/cm²)	standard variation of τu (kg/cm²)
1-1	13.5	9.51	3.63		
1-2	11. 5	8.13	3.07	3.08	0.441
1-3	9.5	6.70	2.55		
1.5-1	10.38	8.56	3.26		
1.5-2	10.6	8.77	3.34	3.25	0.078
1.5-3	10.0	8.29	3.15		
2-1	7.5	6.71	2.56		
2-2	7.75	6.93	2.63	2.76	0.230
2-3	9.07	8.12	3.08		

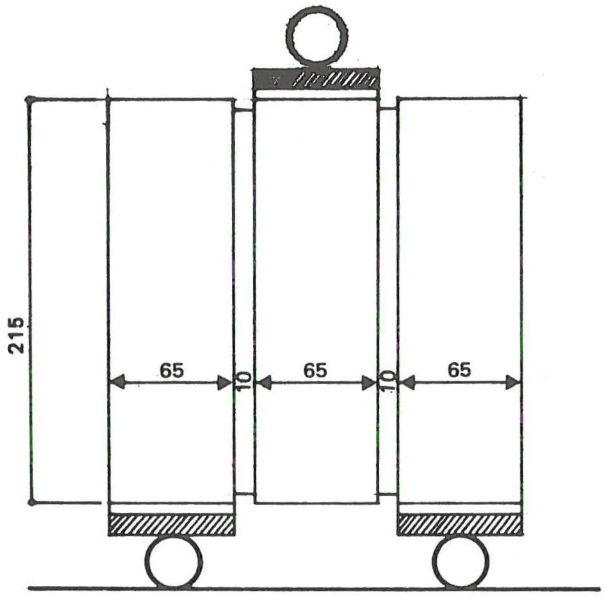

Figure 1. Shear strength test

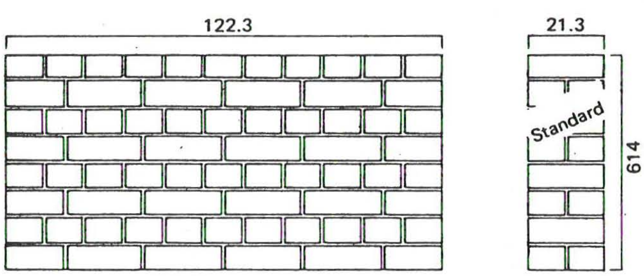

Figure 2. An example of specimen for shear strength ($\lambda = 2$)

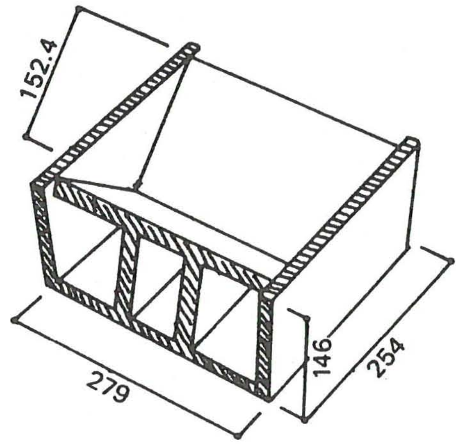

Figure 3. Loading plate for specimen of 1

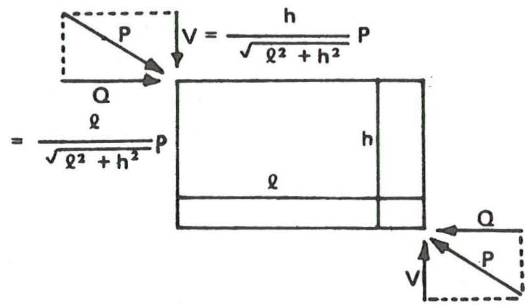

Figure 4. Relation between diagonal load and horizontal or vertical load

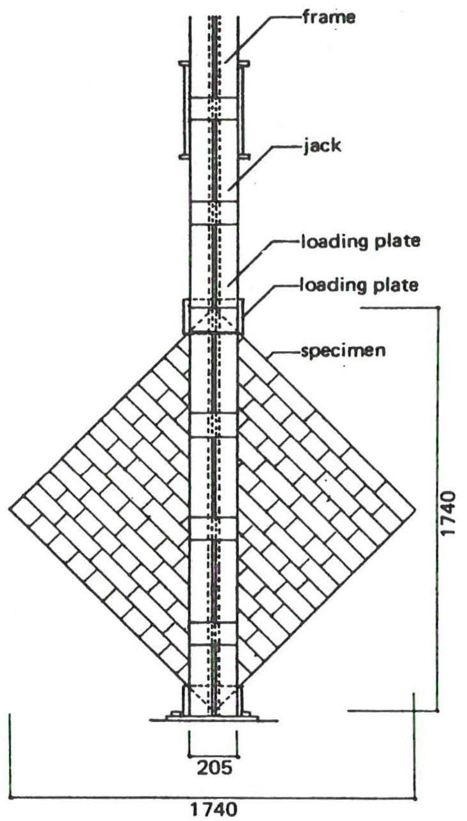

Figure 5. Loading device (unit mm)

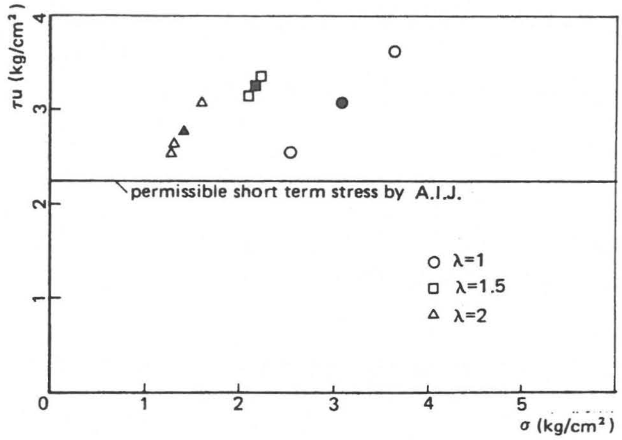

Figure 6. Average shear strength

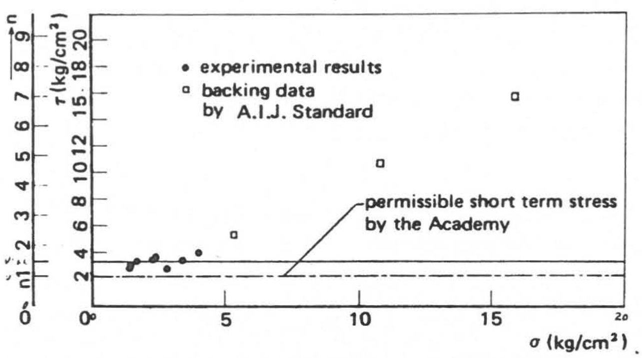

Figure 7. Experimental results and backing data by A.I.J. Standard (n: ratio of experimental results against)

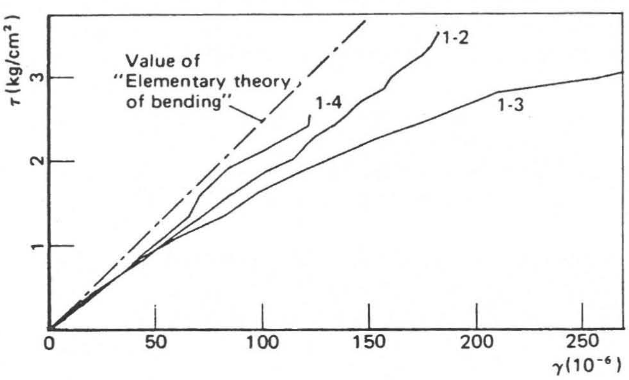

Figure 8. Shear strain at center of wall panel (λ = 1)

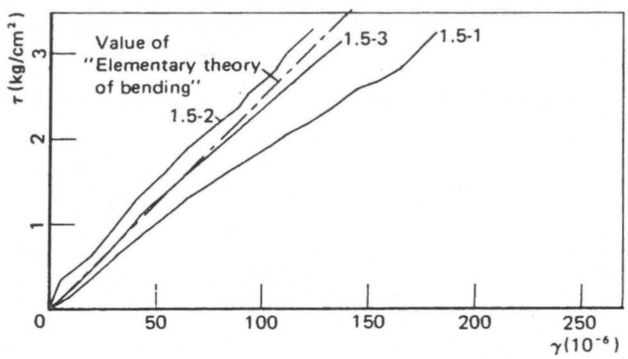

Figure 9. Shear strain at center of wall panel (λ = 1.5)

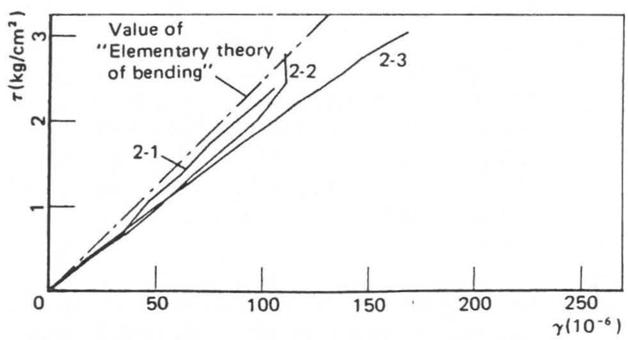

Figure 10. Shear strain at center of wall panel (λ = 2)