VIBRATION OF A 12-STORY BRICK TOWER.

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With Plate XXVI.

Ryoun-kaku tower. The 12-story Ryoun-kaku, in the park of Asaksa, Tokyo, built in 1890, is a sort of observation tower and has the total height of 172′ 4″. The lower 10 stories are of brick and form an octagonal shaft, 130′ 4″ in height, with a uniform external diameter of 40′. The wall thickness of the brick shaft is (i), 3′ 2″ for the three lowest stories; (ii), 2′ 8.″4 for the 4th and the 5th stories; (iii), 2′ 4.″8 for the 6th and 7th stories; and (iv), 2′ 1″ for the three upper stories: the internal wall-to-wall distance varied from 31′ for (i) to 34′ for (iv). The buttresses at the 8 angular points extend up to the 9th story. The brick shaft is surmounted by a small wooden structure forming the 11th and 12th stories. According to Messres. T. Watanabe, P. Takahashi, and K. Takegoshi, who executed the measurement of the tower in 1911 and made the construction drawings reproduced in fig. 1, the total weight of the structure is about 4.3 million lbs., and the height of the centre of gravity is about 59.′5.

Seismic stability. The Ryoun-kaku tower, which is apparently quite simple in form, is virtually a kind of large brick chimney, and ought to have high stability against seismic fracturing but for

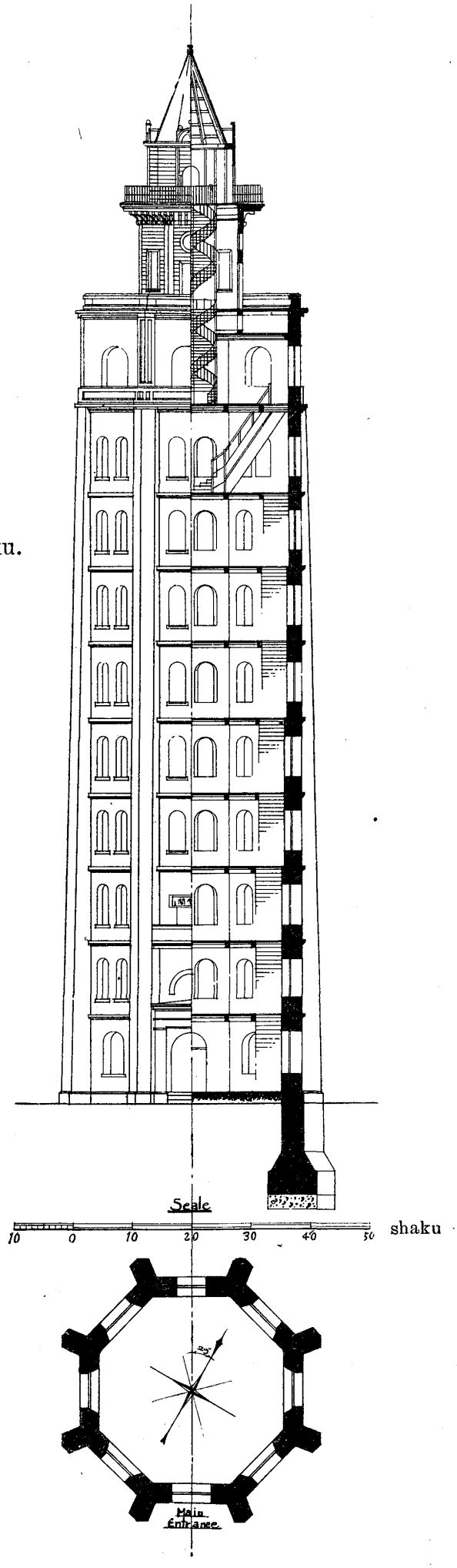


Fig. 1. The Ryoun-kaku.

(From the drawing by Messres. T. Watanabe, P. Takahashi, and K. Takegoshi.)

Dimension of the Ryoun-kaku (凌雲閣) Tower.

(According to Messres. I. Watanabe, P. Takahashi, and K. Takegoshi.)

No. of Story.	Height (floor to ceiling).	Thickness of Wall.	Number of Openings.
1st Story.	12′ 5″	3′ 2″	{Main Entrance and Rear Entrance, and 6 Windows.
2nd	12 5	3 2	14 Windows.
3rd	12 5	3 2	14 Windows, 1 doorway.
4th	12 5	2 8.4	16 Windows.
5th	12 5	2 8.4	16 „
6th	12 5	2 4.8	16 „
7th	12 5	2 4.8	16 „
8th	12 5	2 1	16 „
9th	15	2 1	16 „
10th	16	2 1	8 „
11th	17	——	4 Windows, 4 doorways.
12th	10	——	4 „ 4 „
Roof.	15	——	——

the existence of too numerous windows. These considerably reduce the sectional area of the masonry wall, both vertically and horizontally, and furnish easy lines of cracks to be caused by earthquake shocks. In the case of the strong Tokyo earthquake of June 20th, 1894, at 2 P.M., the intensity of motion calculated from the seismograph register at Hongo, where the soil is hard, was 444 mm./sec.^{2} In the soft park ground of Asaksa the seismic motion on the same occasion was probably about 1,000 mm./sec.^{2}, and the Ryoun-kaku was much cracked along the lines connecting the vertical rows of the windows. The damage was immediately repaired by binding the wall, both inside and outside, above and

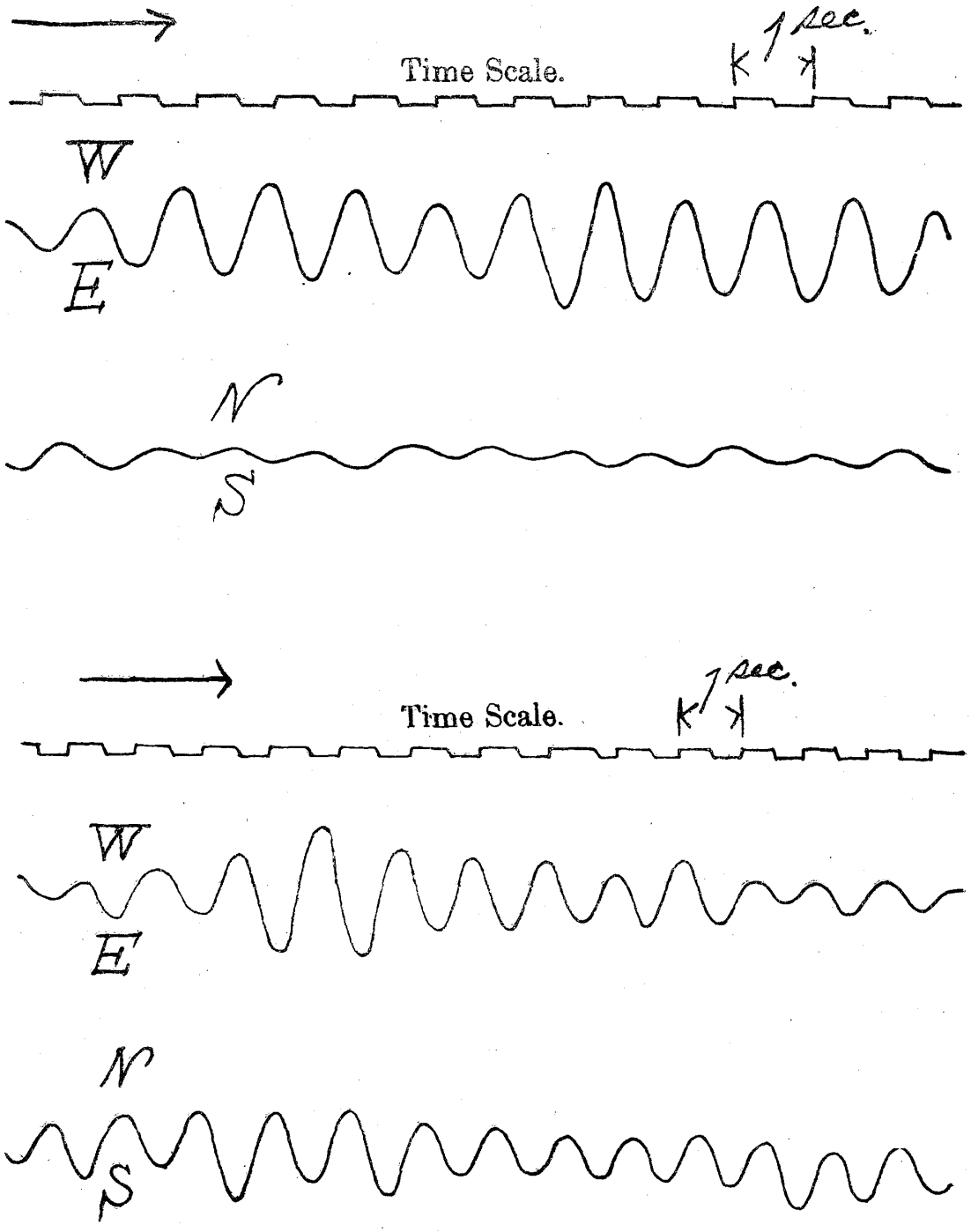
below each flooring with $3'' \times \frac{5''}{16}$ flat iron bands fixed with $\frac{1''}{2}$ bolts passed through the masonry, and tied diagonally at the ceiling with iron band of the same size and with iron rods of $1''\frac{1}{8}$ diameter. Thanks to these repairing measures, the tower sustained no further injury on the occasion of the severe earthquake on Jan. 18th, 1895, except slight opening of cracks or rather renewal of the old ones, on the W. side wall of the 3rd, the S.E. side of the 5th, the W. and S.E. sides of the 6th, and the W. side of the 7th story. It may be added that the intensity of motion in Tokyo of this latter earthquake was only about half of that of the semi-destructive shock in the preceding year.

Vibration measurement. The measurement of the vibration of the Ryoun-kaku was executed on Aug. 5th, 1919, between $0\frac{1}{2}$ and $2\frac{1}{3}$ P.M., with a portable tremor-recorder composed of a pair of horizontal pendulums, of magnification of 5 to 50 times. The instrument was set up on the floor of the 10th story, and the two component pointers were oriented to register the E.W. and N.S. movements. During the experiments, the winds at the tower top were strong and seemed to be some 10 m./sec. in velocity, the direction being westerly or N.N.W.* The motion of the tower produced thereby was, however, very slight and just barely sensible at intervals. (Specimen diagrams are reproduced in Fig. 2.) The average period of vibration was 1.08 sec., and the maximum motion was 0.56 and 0.36 mm. respectively in the E.W. and N.S. directions.

* The observation at the Central Meteorological Observatory, Tokyo, was as follows:—

10 A.M.	11 A.M.	Noon.	1 P.M.	2 P.M.	3 P.M.
S.S.W. 11.0	S.S.W. 10.2	S.S.W. 7.3	W.S.W. 4.6	N.W. 5.9	N.N.W. 7.2

Fig. 2. Vibration of the 12-Story Brick Ryoun-kaku Tower at Asaksa Park, Tokyo.
(Aug. 5th, 1919). Multiplication = 30.



Motion of the Ryoun-kaku (凌雲閣) Tower Caused by Wind.

{T = Complete Period of Tower Vibration.
2a = Range of Motion.

Time of Observation.	E.W. Component.		N.S. Component.	
	T (sec.)	Max 2a.	T (sec.)	Max 2a.
0.30–1.33 P.M.	1.08 sec.	0.17 mm.	1.02 sec.	0.23 mm.
	1.06	0.23	1.11	0.13
	1.09	0.39	1.07	0.10
	1.08	0.89	1.07	0.16
	1.07	0.12	1.07	0.10
	1.08	0.07	1.05	0.09
	1.07	0.23	1.09	0.06
	1.07	0.07	1.11	0.04
	1.05	0.63	1.06	0.07
1.40–2.20 P.M.	1.04 sec.	0.13 mm.	1.05 sec.	0.09 mm.
	1.06	0.23	1.06	0.10
	1.09	0.43	1.07	0.16
	1.10	0.43	1.05	0.06
	1.09	0.56	1.07	0.10
	1.14	0.54	1.10	0.36
	1.10	0.30		
	1.09	0.23		

Comparison with Toji gojunoto. The Ryoun-kaku is nearly equal in height to the five-story wooden Buddhist stupa of Toji, whose total height is 183.7 shaku=182.6 feet, and the height of whose tower body is 133.5 shaku=132.7 feet. (See p. 120.) The base dimension of the Toji tower, whose oscillation period is 1.8 sec., is 31.5 shaku or about $5\frac{1}{2}$ feet less than that of the Ryoun-kaku. Had the base dimension of the

gojunoto in question been made equal to that of the latter, with proportionate increase in the size of the different upper stories, its oscillation period would be reduced to some $1\frac{1}{2}$ sec. In other words, the brick Ryoun-kaku, whose period is 1.08 sec., moves quicker in the ratio of some 2:3 than a gojunoto of similar dimensions, built of wood. The observed range of motion of the latter, with the maximum E.W. component amount of 0.92 mm. is remarkably small.

Conclusion. As the vibration period (=1.08 sec.) of the Ryoun-kaku is by no means longer than the period of the destructive earthquake motion to be expected anywhere, it follows that the tower is, whatever may be the nature of the soil, seismically weakest at the base; being in this respect quite different from ordinary brick chimneys which are weakest about the two-third of the height.

The period of the earthquake motion in the soft park ground of Asaksa is probably about 0.9 or 1.0 sec, or nearly equal to the period of the proper oscillation of the Ryoun-kaku. This approximate coincidence in period must contribute to increase by synchronization the movement of the structure during a strong earthquake. There is, of course, no risk of an overturning of the entire tower as a whole. The worst to be expected in a future destructive shock, whose intensity of motion may reach 2,000 mm./sec.^{2}, would be much cracking of the wall, which would, however, be prevented from falling down in large masses, owing to the repair iron bindings already referred to.