Note on the Vibration of Chimneys.

By

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With Plates XII-XVI.

1. *Introduction.* The period of natural vibration or of rocking of a body is a very important factor in the discussion of the overturning and fracturing phenomena. If this period be much greater than that of the earthquake motion, the body may be regarded as rotating about its centre of percussion with respect to the base. In other cases, however, the body is to be supposed as being acted on by a force equivalent to the product of its own mass and the maximum acceleration of the earthquake motion applied at its centre of gravity. From these considerations, I have distinguished different structures in the case of overturning into *small* and *large* bodies,* and in the case of fracturing into *short* and *tall* bodies.†

The discussion of the seismic stability of chimneys,‡ which I have given in the *Publications*, No. 4, pp. 117–124, is based on the supposition that their vibration is much slower than the earthquake motion. It is extremely desirable to measure the movements of some large chimneys; experimental investigation in this connection being yet very scarce.

The present note gives the results of the instrumental registration of the vibration of two small chimneys, which I have recently carried on in Kyoto and Tokyo respectively.

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* This volume, p. 8.

† The *Publications*, No. 4, pp. 76, 121.

‡ A *chimney* means here a brick factory chimney.

2. *Chimney of the Institute of Mechanical Engineering, Kyoto Imperial University.* (Dec. 3rd and 4th, 1900.)

The chimney (Pl. XIII), constructed about two years before the date of the experiments, is 51 *shaku** high, and square in section, the thickness of the wall being as follows:—

for the lowest 6 *shaku*,.....2 bricks, or 1.54 *shaku*;
„ „ middle 7 „ .....1½ „ „ 1.15 „ ;
„ „ upper 38 „ .....1 brick, „ 0.75 „ .

The record-receiver,† on which the vibration in question was recorded, was put up on an independent frame of wooden beams specially erected close to the chimney; the writing index being a pen hinged to the end of a strong brass rod firmly attached to the top of the latter. The observer himself got also on the top of the wooden frame, whence the chimney was seen to oscillate gently with every blow of moderate wind. The chimney was caused to vibrate by cutting suddenly a rope fastened to it, whose end passed over a pulley and carried a stretching weight. The pulley was fixed to the top of a triangular frame of wooden beams, whose height was 24′ 9″ and whose horizontal distance from the base of the chimney was 53′ 7″. (See Pl. XII, Fig. 1.) The observation was repeated three timess with different stretching weights.

Two of the diagrams obtained are reproduced in Pl. XIV; the rate of motion of the paper being accurately gauged by means of a small time ticking pendulum, whose complete oscillation, corresponding to two successive tick intervals in the records, was 0.68 second.

The results of the experiments are summarised in the following table.

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* 1 *shaku* = 0.994 foot.

† The record-receiver was similar to that used in the *Seismic experiments* (the *Publications*, No. 4) and consists of white paper moved by two rollers by means of a clock-work.

TABLE I.

VIBRATION OF THE CHIMNEY OF THE INSTITUTE OF MECHANICAL ENGINEERING, KYOTO.

{2a = Range of motion, or double amplitude at the top.
T = Complete period of vibration.

	1st. Expt.	2nd. Expt.	3rd. Expt.
Stretching weight.	24.5 kg	59.0 kg	67.0 kg
Its horizontal component.	22. ,,	53. ,,	60. ,,
Initial, or maximum, 2a.	4.6 mm.	7.4 mm.	8.1 mm.
1st 10 vibrations —	——	——	——
1st 10 vibrations Average T.	1.04 sec.	0.99 sec.	1.03 sec.
2nd 10 vibrations Max. 2a.	2.3 mm.	3.5 mm.	4.5 mm.
2nd 10 vibrations Average T.	1.02 sec.	1.01 sec.	1.02 sec.
3rd 10 vibrations Max. 2a.	1.45 mm.	2.0 mm.	3.0 mm.
3rd 10 vibrations Average T.	0.99 sec.	0.99 sec.	1.02 sec.
4th 10 vibrations Max. 2a.	1.0 mm.	1.2 mm.	1.45 mm.
4th 10 vibrations Average T.	0.99 sec.	0.99 sec.	1.01 sec.
Toward the very end Max. 2a.	——	——	Very small.
Toward the very end Average T.	——	——	1.01 sec.
General mean T.	1.01 sec.	1.00 sec.	1.02 sec.

Thus the mean value of the average period of vibration was about 1.01sec., the maximum or initial range of vibration being 8.1mm. The horizontal or effective stretching forces were in the three experiments 22, 53, and 60 kg respectively; the deflections of the chimney at the

top due to these different weights being half the initial ranges of motion, or 2.3; 3.7; and 4.1mm respectively.

The observation was not made with very great stretching weights, lest damage should happen to the chimney, which was evidently a very flexible one, due probably to bad quality of the mortar and to its slender form. Had the stretching been carried so far that the initial (top) range of motion amounted to 2 or 3 inches, the period of vibration would be considerably increased. I believe that the period of vibration of the chimney would, on the occasion of a destructive earthquake, amount to 2 seconds or more.

3. *Chimney of the Hygienical Institute, Tokyo Imperial University.* Oct. 3rd and 4th, 1901.

The chimney of the Hygienical Institute* was square in section and only 24 *shaku* in height, the thickness of the wall being as follows:—

the lower 13.6 *shaku*, ...1.2 *shaku* thick,

„ upper 10.6 „ , ...0.7 „ „ .

The mortar contained no cement, but was composed probably of 4 parts of lime and 6 parts of sand. (See Pl. XII, fig. 2; and Pl. XV.)

The method of observation was exactly similar to that in the preceding case, except that the rope fastened to the top of the chimney was drawn gradually by means of a lever arrangement managed by a few men. The experiments were repeated five times; the chimney having been finally broken in the 5th experiment at about 2 feet from the base. The diagrams obtained in the 3rd to 5th experiments are reproduced in Pl. XVI; the complete period of the time-ticking pendulum being here 0.73 second.

The results of the experiments were as follows.

* A flat wooden building burnt down in 1901.

TABLE II.

VIBRATION OF THE CHIMNEY OF THE HYGIENICAL INSTITUTE, TOKYO IMPERIAL UNIVERSITY.

{2a = Range of motion, or double amplitude at the top.
T = Complete period of vibration.

Expt.	Absolute maximum, or initial, 2a (mm)	1st 10 Vibrations	2nd 10 Vibrations		The next 20 Vibrations	
		Average T (sec).	Max. 2a (mm).	Average T (sec).	Max. 2a (mm).	Average T (sec).
1	7.2	0.35	2.6	0.34	0.9	0.34
2	5.2	0.34	2.0	0.34	0.9	0.33
3	17.2	0.37	4.5	0.34	1.2	0.34
4	19.2	0.36	4.5	0.35	1.8	0.34
5	(Broken at an initial displacement, $a=19$mm).					

Thus the average period of vibration of the chimney was 0.36 or 0.37 sec. with a large initial 2a of 17 to 19mm, while it was distinctly smaller and equal to 0.34 sec. with very small amplitude.

NOTES.

In the 4th experiment, the 2a's of the first 20 successive vibrations were as follows:—

17.8 mm	7.0 mm	3.0 mm
15.0	6.1	2.9
13.3	5.5	2.3
11.9	4.9	2.0
10.2	4.0	1.9
9.0	3.8	1.9
8.0	3.2	

The motion became practically *nil* at 19.7 seconds from the commencement, after having executed altogether about 57 vibrations.

In the 5th experiment, the column was broken while the rope was being stretched, probably at a deflection, a=19 mm. The 2a just after the fracture, or the top motion due to the initial rocking, was 58.5 mm, and its period 0.58 sec.; the amplitude thence rapidly decreasing. The first five vibrations lasted together 2.3 seconds, so that the average period was 0.45 sec., the 2a of the last (5th) vibration being 15.8 mm. The next five vibrations lasted together 2.2 seconds and had an average period of 0.44 sec., the 2a of the last (10th) vibration being 1.9 mm. The motion lasted 9.2 seconds more, the successive 10;10; and 5 vibrations giving average periods of 0.39;0.36; and 0.34 sec. respectively. It will thus be seen that, in the 5th experiment, the amplitude decreased very rapidly and the period of the very small oscillations was essentially the same as that before the fracture of the chimney.

Tensile strength of the brick work. After the above experiments, a number of test pieces were made from the brick work fragments of the chimney and their tensile strength was determined by means of a testing machine in the Workshop of the Engineering College; the test pieces of the form (*a*) giving the strength of the joint, while the pieces of the form (*b*) that of the bricks. The result was as shown in Table III, the mean tensile strength of the joints being 23.5 lbs per square inch, and that of the bricks 144 lbs per square inch. The test pieces have been taken from the base, the middle and the top parts of the chimney respectively.

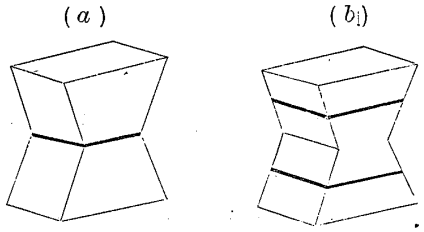


TABLE III.

CHIMNEY OF THE HYGIENICAL INSTITUTE, TOKYO IMPERIAL UNIVERSITY.

(*a*) Tensile strength of the joints.

17 test pieces taken from the lowest part of the chimney.		17 test pieces taken from the middle part of the chimney.		15 test pieces taken from the upper part of the chimney.	
Tensile strength. lbs per □″	Remark.	Tensile strength. lbs per □″	Remark.	Tensile strength. lbs per □″	Remark.
38.9	Broke through mortar.	45.1	Broke by separation.	11.0	Broke through mortar.
16.8	,,	42.6	Broke $\frac{3}{4}$ through mortar, $\frac{1}{4}$ by separation.	15.5	,,
56.5	,,	46.9	Broke through mortar.	32.3	,,
5.6	,,	15.8	,,	24.4	Broke mostly through mortar.
6.6	,,	31.7	Broke mostly by separation.	16.6	Broke through mortar.
41.4	,,	27.4	,, by separation.	11.7	,,
11.9	,,	19.5	Broke $\frac{1}{2}$ through mortar and $\frac{1}{2}$ by separation.	20.5	Broke mostly through mortar.
36.5	Broke mostly through mortar, the rest by separation.	10.2	Do.	34.2	Broke through mortar.
19.4	Broke through mortar.	32.7	Broke through mortar.	22.2	,,
14.6	,,	43.4	Broke mostly through mortar.	34 5	,,
15.9	,,	42.9	,, through mortar.	10.5	Broke mostly through mortar.
10.6	,,	13.9	Broke mostly by separation.	30.5	Broke through mortar.
25.1	,,	9.9	Broke mostly through mortar.	33.5	,,
10.6	,,	23.8	,,	16.1	,,
21.5	,,	24.1	Broke through mortar.	17.2	Broke by separation.
7.5	,,	27.2	,,		
13.6	Broke by separation.	10.2	Broke mostly through mortar.		
20 8 (mean).		27.5 (mean).		22.0 (mean).	

(*b*). Tensile strength of the bricks.

10 test pieces taken from the lowest part.	9 test pieces taken from the middle part.	9 test pieces taken from the top part.
lbs per □″	lbs per □″	lbs per □″
135.2	135.5	136.1
195.7	241.2	138.0
150.6	171.0	136.9
199.9	118.9	129.6
170.5	86.3	104.6
120.9	121.5	136.9
132.1	122.3	136.1
139.6	107.1	138.5
135.0	142.1	156.1
202.8		
158 (mean).	138 (mean).	135 (mean).

LIST OF PLATES.

Pl. XII. *Fig. 1.* Chimney of the Institute of Mechanical Engineering, Kyoto Imperial University.

Fig. 2. Chimney of the Hygienical Institute, Tokyo Imperial University.

Pl. XIII. *Fig. 3.* Chimney of the Institute of Mechanical Engineering, Kyoto Imperial University. (Section).

Pl. XIV. Vibration of the chimney of the Institute of Mechanical Engineering, Kyoto Imperial University. *Natural size.* Dec. 4th, 1900.

Fig. 4. 2nd Experiment.

Fig. 5. 3rd Experiment.

Pl. XV. *Fig. 6.* Chimney of the Hygienical Institute, Tokyo Imperial University. *Elevation* and *sections.*

Pl. XVI. Vibration of the chimney of the Hygienical Institute, Tokyo Imperial University. *Natural size.* Oct. 4th 1901.

Fig. 7. 1st Experiment.

Fig. 8. 2nd „

Fig. 9. 3rd „

Fig.10. 4th „

Fig.11. 5th „

Time marks: the value of two consecutive tick intervals, corresponding to one complete oscillation of the time-marking pendulum, is 0.68 sec. in Pl. XIV, and 0.73 sec. in Pl. XVI.

Fig. 1.
Chimney of the Institute of Mechanical Engineering, Kyoto Imperial University.

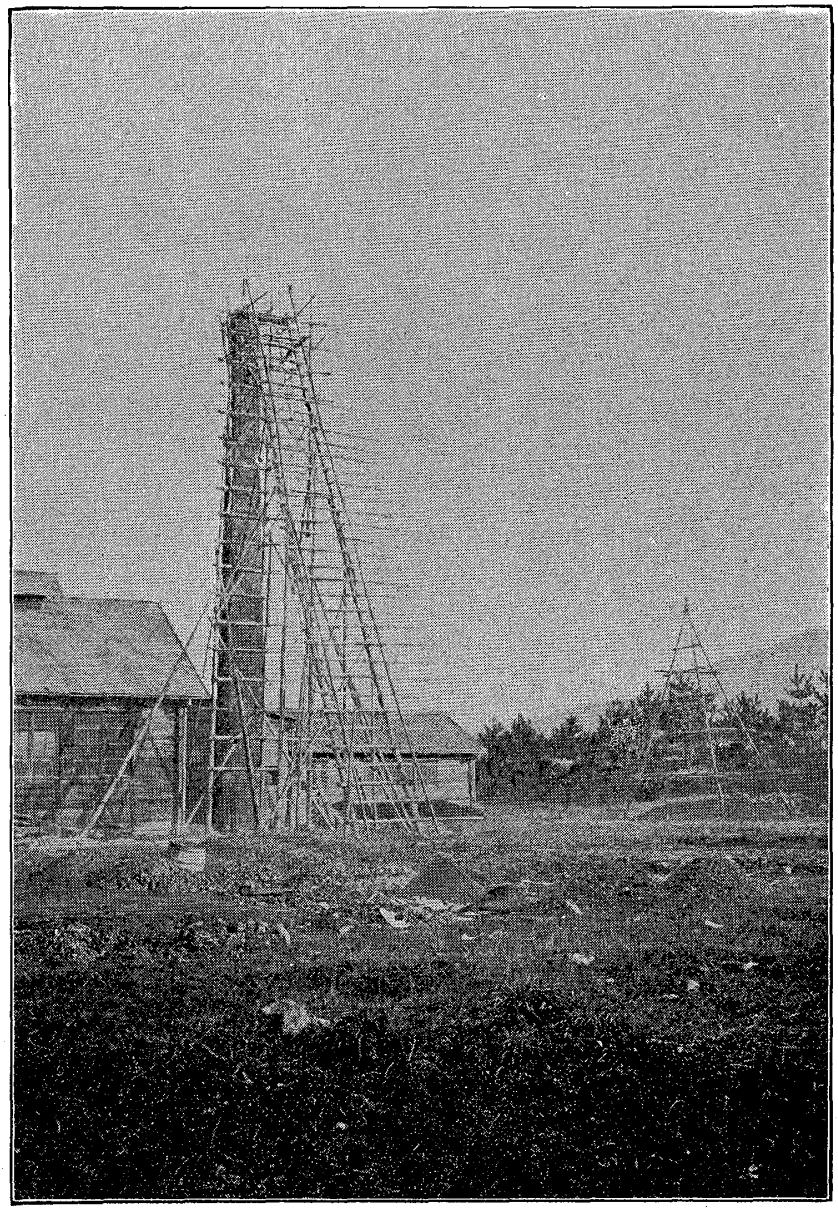


Fig. 2.
Chimney of the Hygienical Institute, Tokyo Imperial University.

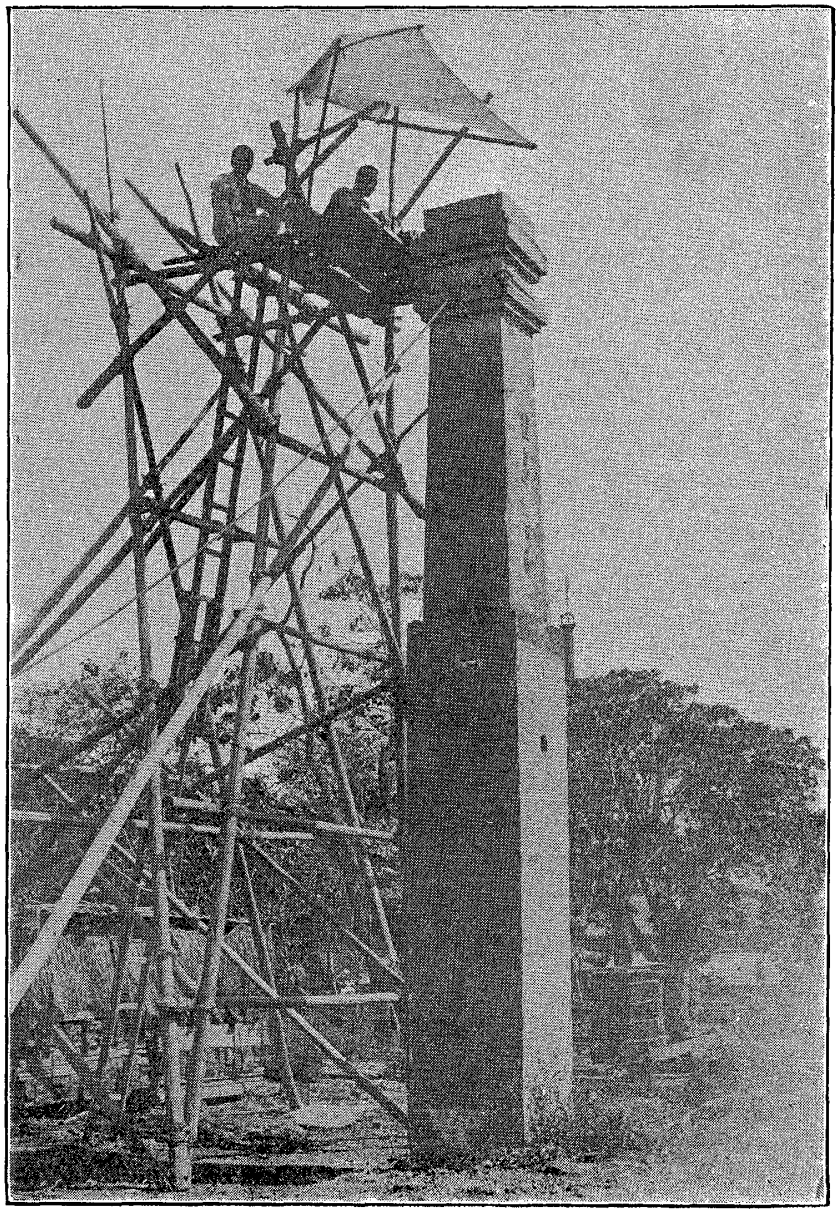
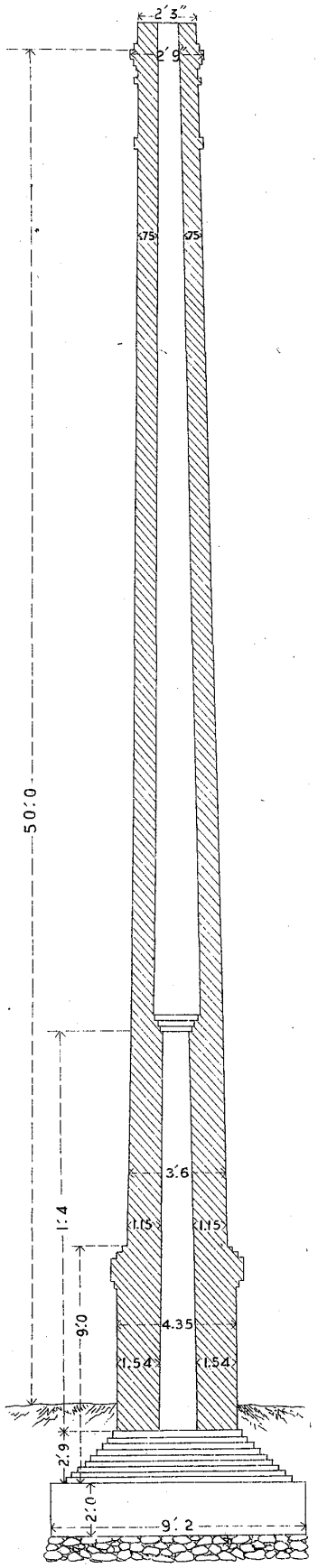


FIG. 3. CHIMNEY OF THE INSTITUTE OF MECHANICAL ENGINEERING, KYOTO IMPERIAL UNIVERSITY.

(Section.)

第三圖

京都帝國大學器械工學教室附屬烟突斷面圖



京都帝國大學器械工學教室

附屬煙突ノ振動（實動）

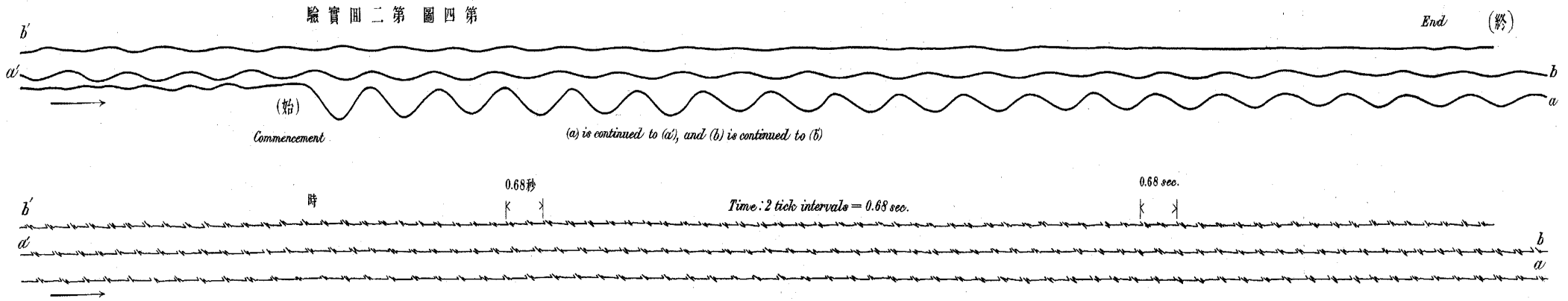
明治卅三年十二月四日驗測

VIBRATION OF THE CHIMNEY OF THE INSTITUTE OF MECHANICAL ENGINEERING,

KYOTO IMPERIAL UNIVERSITY. *Natural size.* Dec. 4th 1900.

第四圖　第二回實驗

Fig. 4. 2nd EXPERIMENT.



第五圖　第三回實驗

Fig. 5. 3rd EXPERIMENT.

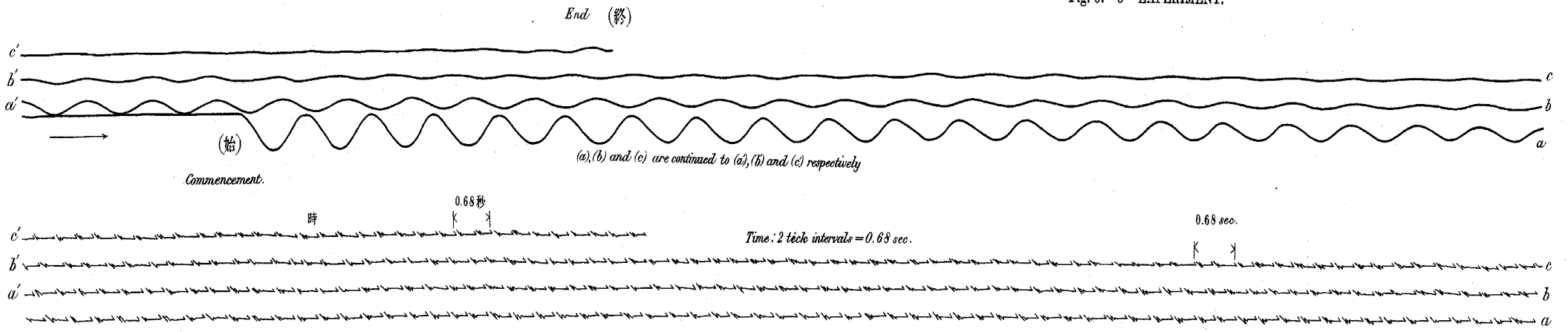
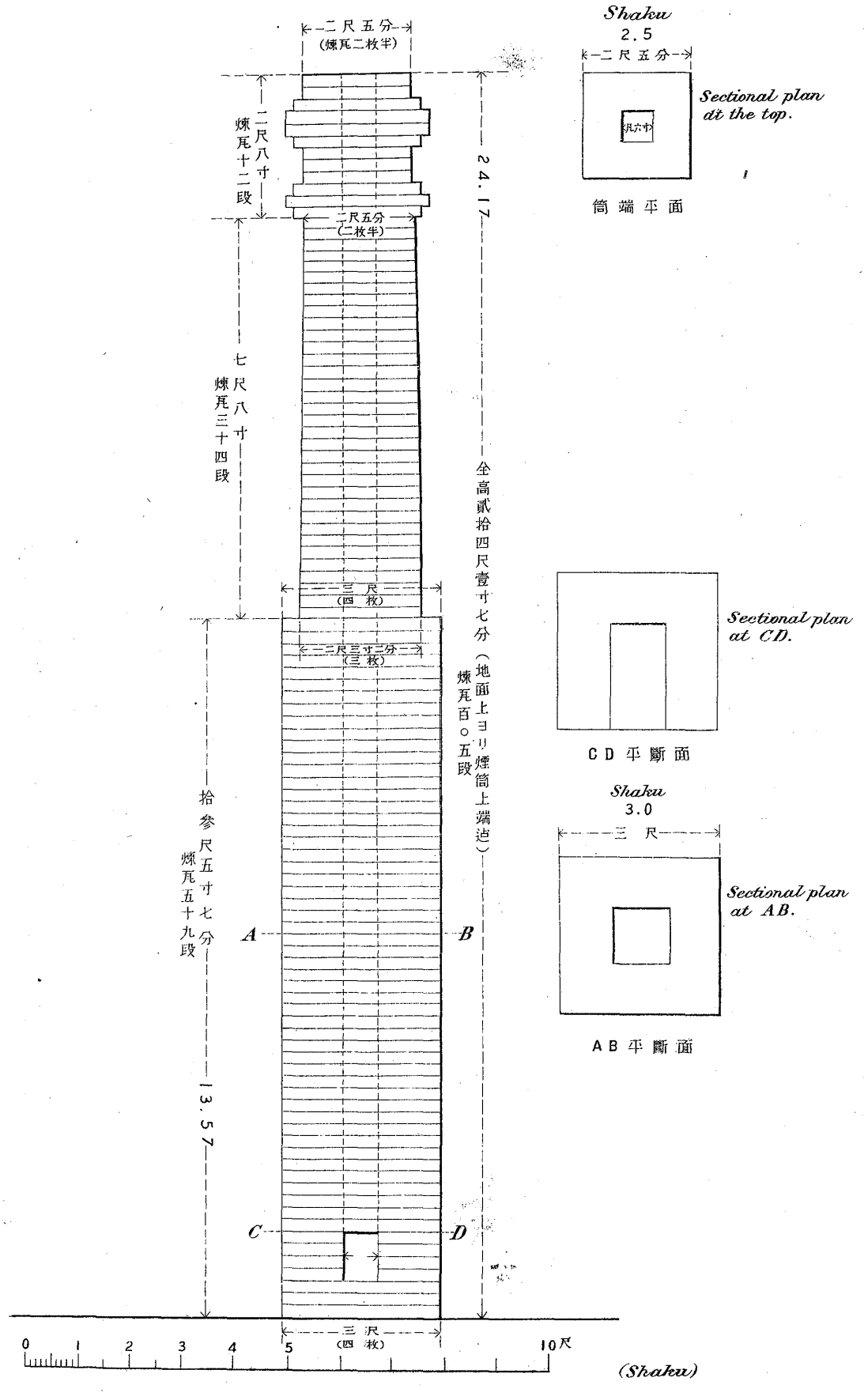


FIG. 6. CHIMNEY OF THE HYGIENICAL INSTITUTE, TOKYO IMPERIAL UNIVERSITY.

(Elevation and Sections.)

第六圖

醫科大學衛生學室燒掃跡之煙筒



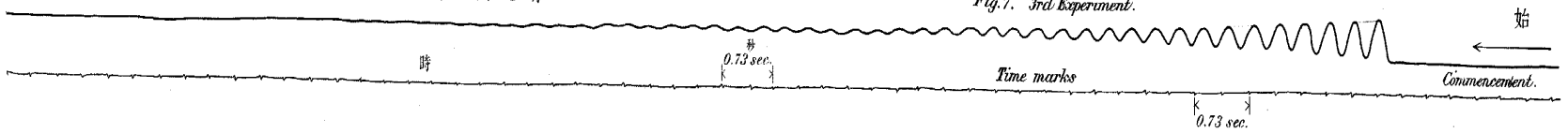
(實大)動振ノ突烟跡燒室教學生衛學大國帝京東

測驗日四月十年四十三治明

VIBRATION OF THE CHIMNEY OF THE HYGIENICAL INSTITUTE, TOKYO IMPERIAL UNIVERSITY. *Natural size.* Oct. 4th 1901.

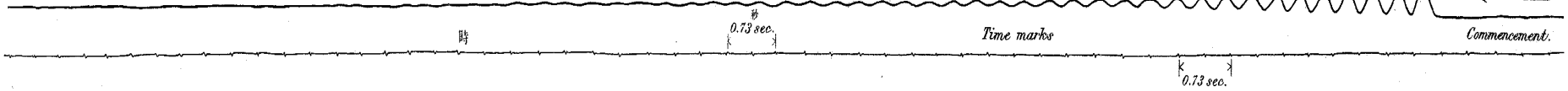
測驗回三第　圖七第

Fig. 7. 3rd Experiment.



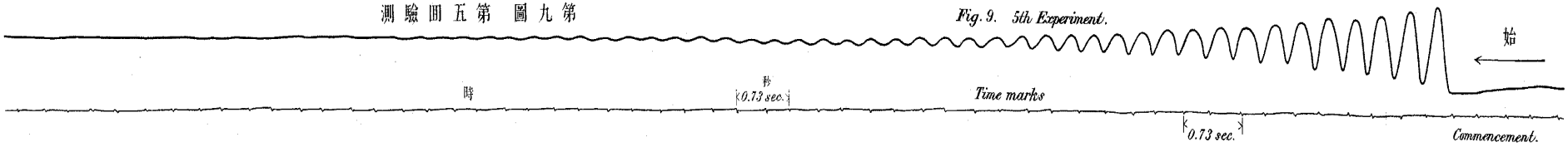
測驗回四第　圖八第

Fig. 8. 4th Experiment.



測驗回五第　圖九第

Fig. 9. 5th Experiment.



測驗回六第　圖十第

Fig. 10. 6th Experiment.

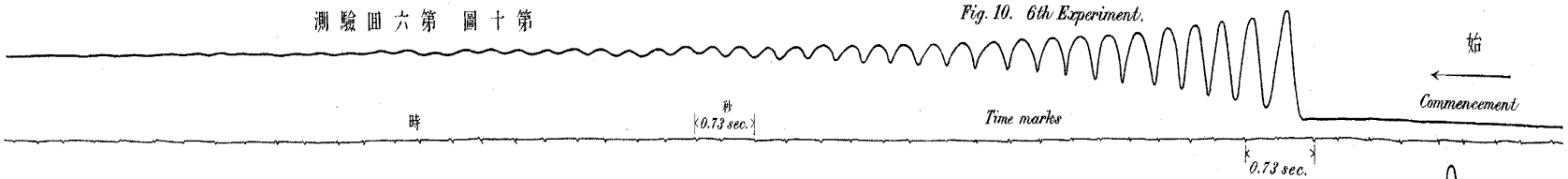


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Fig. 11. 7th Experiment.