MEASUREMENT OF VIBRATION OF THE 660-FOOT WIRELESS TELEGRAPH STATION TOWER AT HARANOMACHI.

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With Plates XVIII—XXV.

1. The Tower. The reinforced concrete column or tower of the new wireless telegraph station of Haranomachi (Pl. XVIII.), designed for the Department of Communications by Professors K. Shibata, Y. Nagayama, and I. Ksama of the Tokyo Imperial University, is a hollow cone, with the apex truncated, which rises to the height of 660 feet (=201.2 metres), or 663.8 shaku[1]; the external base diameter, =57′9″, being to the height in the ratio of 1: 11. The external diameter at the top is 4′ 6″, or nearly 1/13 of that of the base. The thickness of the concrete wall varied from 33″ at the base to 6″ at the top, the steel rods being embedded in the concrete at the depth of 2″½ from the outside surface. The composition of the concrete was 1: 2: 4 both for the shaft and the foundation. The work of construction was carried on by the Oriental Compressol Company of Tokyo. (See figs. 3, 4, and 5.) Table I gives the wall thickness and the median diameter (or the diameter of the cone midway between the internal and external surfaces) for successive 1/24th parts along the height of the shaft.

1) I shaku, or Japanese foot = 0.99421 English foot.

TABLE I. Dimension, and the Amount of Material used in the Construction, of the Tower.

Height.	Median Diameter.*	Thickness of Wall.	Height.	Median Diameter.*	Thickness of Wall.
Base.	660″	33″	357′ 6″	328″.5	18″.38
27′ 6′	634.5	31.88	385 0	303	17.25
55′ 0″	609	30.75	412 6	277.5	16.13
82 6	583.5	29 63	440 0	252	15
110 0	558	28.5	467 6	226.5	13.88
137 6	532.5	27.38	495 0	201	12.75
165 0	507	26.25	522 6	175.5	11.63
192 6	481.5	25.13	550 0	150	10.5
220 0	456	24	577 6	124.5	9.38
247 6	430.5	22.88	605 0	99	8.25
275 0	405	21.75	632 6	73.5	7.13
302 6	379.5	20.63	660 0	48	6
330 0	354	19.5			

Foundation:—

Diameter of the bottom area = 90 feet.
Thickness (Depth) .... = 12 ,,

Shaft:—

Height .... = 660 feet.
External diameter at Base = 57′ 9″
,, ,, Top = 4′ 6″
Wall thickness at Base ... = 33″
,, Top ... = 6″

Amount of Concrete:—

Foundation .... = 225 cubic tsubo = 47,759 c.f.
Shaft.......................... = 550 ,, = 116,745 c.f.

Steel Reinforcement:—

Foundation .... = 79 tons.
Shaft.......................... = 290 ,,

Diameter of Steel Reinforcement:—

In the Foundation,......... = 1″; 7″/8; 3″/4.
,, Shaft, ... = 9″/8; 1″; 7″/8; 3″/4; 5″/8; 1″/2.

*) Diameter from middle to middle of the concrete wall.

The outer and inner surfaces of the tower are not exactly co-apex cones. The height of the centre of gravity is consequently slightly different from that of a solid cone or a pyramid, although the diameter at the top is sufficiently small in comparison to that at the base. The position of the centre gravity is about 190 feet above the ground, namely, at an elevation nearly equal to 1/3.5 of the total height.

The maximum wind pressure taken into consideration in the designing of the tower was 60 lbs. per square foot at the base, with an increment of 1 lb. per square foot for every 10 feet height ascension, such that the pressure at the top reaches 126 lbs. per square foot.

The amount of the material used in the construction of the tower, with an allowable maximum pressure of 4.2 tons per square foot on the ground, was as follows:—

Structure.	Steel.	Concrete.
Foundation.	79 tons.	225 cubic tsubo* ....2930 tons.
Shaft.	290 „	550 „ ....7160 „
Total.	369 tons.	775 „ ...... 10090 „

The total weight of the shaft is about 7450 tons, of which 7160 and 290 tons are respectively the weights of the concrete and of the steel. Again the total weight of the foundation is 3009 tons, of which 2930 and 79 tons relate respectively to the concrete and the steel. The ratio by weight of the steel to the concrete is 1:37 for the foundation and 1:25 for the shaft.

The work of the foundation construction was started on May

* 1 tsubo = 6 shaku cube = 216 cubic shaku = 212.3 cubic feet.

23rd, 1919, and the shaft, built successively in 147 divisions or layers of concrete deposit, each 4′6″ in height, has been completed on Sept. 26th, 1920, at 3 P. M. The tower wall has no opening except one narrow entrance at the base, and four small windows, each 2 feet square, at successive 132 feet height intervals.

2. Nature of soil. The tower stands on a narrow alluvial plain about the small river Shinden-gawa passing between the low Tertiary hilly districts. For the surface 4 feet the soil is composed of black and red earths. Then comes a layer of sand about 4 feet in thickness, lying upon a layer of clay 2 feet thick. Next below comes a layer of gravel and sand more than 10 feet in thickness, on which the foundation of the tower rests. The different formations are arranged horizontally, a circumstance favourable to the erection of a heavy structure.

TABLE II. Period of Large Earthquake Vibration observed at different Seismological Stations situated on Alluvial Plain.

Place of Observation.	Date.	Time of Occurrence.	Maximum Motion = 2a.	Complete Period = T.
			mm.	sec.
Hitotsubashi. (Tokyo).	Jan. 15, 1887.	6.52.00 P.M.	54.0	0.97
	Nov. 30, 1894.	8.30.57 P.M.	10.5	1.00
	June. 20, 1894.	4.22.44 P.M.	9.6 (E.W.) 6.5 (N.S.)	1.00
Central Meteorological Observatory (Tokyo).	June. 20, 1894.	2. 4.10 P.M.	76.0	1.3
	Jan. 18, 1895.	10.48.24 P.M.	41 0	0.9
	Feb. 20, 1897.	5.49.37 A.M.	22.8	1.5
	July. 22, 1897.	6.31.44 P.M.	7.3	1.3
	April. 29, 1888.	10. 0.33 A.M.	5.6	0.8
Kyoto Meteorological Observatory.	March. 7, 1899.	9.55.01 A.M.	13.6 (E.W.)	0.84
	Jan. 18, 1895.	10.49.35 P.M.	2.0 (E.W.)	0.97
	May. 7, 1896.	6.37 31 A.M.	1.4 (E.W.)	0.97
Gifu Met. Obs.	Aug. 14, 1909.	3.31.38 P.M.	36.0	1.2
Hikone Met. Obs.	„	„	22.	1.1

We have no exact knowledge of the period of the earthquake vibration at Haranomachi as no seismographic observation has been made there. For the sake of reference, I give in Table II the value of the period of large earthquake vibration measured seismographically at different places where the ground is composed of alluvial soil.

Of the different places here taken into consideration, Hitotsubashi, in the lower portion of Tokyo, is to be regarded as an example of deep and very soft alluvial soil; and the vibration period there is invariably about 1.0 sec., both for small and large earthquake movements. At the Central Meteorological Observatory, close to Hitotsubashi, which stands on the castle ground surrounded by the gigantic ishigaki (stone retaining wall), the earthquake motion has a character somewhat similar to that at the hard ground of Hongo, where the Seismological Institute is situated. The Gifu and Kyoto meteorological observatories are situated on alluvial ground close to hills and may be considered as being not much different from Haranomachi with respect to the character of the earthquake motion. The period of the destructive seismic motion at Haranomachi is probably 1.0 to 1.2 sec.

The zone of great destructive earthquakes lies off the Pacific coast at the mean distance of some 200 km. from Haranomachi, whose vicinity is also not likely to become the origin of a violent local shock. The maximum limit of the seismic intensity to be expected at Haranomachi may probably be taken to be about 1,000 mm./sec.^{2}

3. Method of experiment. The measurement of the movement of the tower caused by winds has been carried on during the course, and after the completion of construction, on five different occasions,[1] as follows:—

No. of Experiment.	Date of Experiment. (1920)	Height of Structure.	Weather at the time of Experiment.
1	May. 23.	290 feet.	S.E. Wind, 5-10 m./sec.
2	July. 10.	414 „	Some rain ; very feeble N.E. wind.
3	Aug. 20.	522 „	Some rain ; moderate S.E. wind.
4	Sept. 26. and 28.	660 „	Easterly wind, moderately strong.
5	Nov. 5.	660 „	N.E. wind, moderately strong.

The ascension to the top was effected by means of a sort of elevator which was mounted on the temporary timber frame-work erected inside the shaft, and which supplied the means of carrying up the building materials; no exterior staging having been employed. The total volume of the timber of the interior scaffold was 3,126 cubic feet, weighing about 42 tons. This is equal to only 1/178 of the weight of the shaft.

The motion was registered mechanically with ink on white paper by a portable two-component horizontal vibration recorder of 10 to 30 times magnification (fig. 4), fixed on the top of the concrete wall, where a sort of plank flooring was provided to accommodate the people engaged in the measurement. The recording instrument was properly protected by a cover so that the steady masses and the writing indices received no direct disturbances from the winds. The wind velocity was read off from a Robinson's anemometer set up on the column top during the different experiments.

1) I state here my obligations to Dr. Y. Nagayama, Assistant Professor of Civil Engineering in the Tokyo University, and Mr. I Fujiwara, official superintending the construction of the tower at Haranomachi, who afforded me various kind assistances in the measurement of the vibration.

The double amplitude or range of motion, and the complete period of the tower vibration measured from different portions of the vibration-recorder diagrams are denoted in the following pages by the symbols 2a and T respectively.

Illustrative vibration diagrams are given in Pls. XXI to XXV.

4. Weather during the experiments. In the vibration experiments on the Haranomachi Wireless Tower I had not the good fortune of making observations in a violent storm as had been the case with the measurement relating to the great 550-foot chimney at Saganoseki. In the 2nd experiment, on July 10th, when the tower height reached 414 feet, the weather was calm, the maximum wind velocity being only 4 m./sec. On the other four occasions, the winds were more or less strong, reaching at the top of the column the maximum velocity of 15 to 20 m./sec. This is, however, very much lower than the wind velocity of 35 m./sec. observed on the top of the Saganoseki chimney (on Dec. 26th, 1916).

5. Experiment on May 23rd, 1920. $2\frac{1}{2}$–$4\frac{1}{2}$ P. M. On May 23rd, when the vibration measurement was first tried, the construction work had advanced up to the 63rd concrete layer reaching the height of 290 feet. The external diameter and the thickness of the shaft at the top were respectively 34′ 4″.24 and 21″.14. Although the height attained so far was only $\frac{290}{660}=44\%$ of 660 feet, the amount of the concrete used was a little over 2/3rd of that for the entire structure. Thus, at the 44th concrete layer, or at 44/147=30% of the total height, the volume of the concrete used had already been 325 cubic tsubo, namely 325/550=59% of the total required amount. The weight and the volume of the timbers composing the elevator trestle for the height of the 290 feet were respectively 31 tons and 2,349 cubic feet, these amounts being approximately 3/4 of those for the entire wooden structure. The existence of the trestle, whose weight was quite insignificant, exercised no special influence on the motion of the shaft.

At the time of the experiment, 2½ to 4½ P. M., the wind was S. E.'ly, with the speed of 4½ to 10½ m./sec., averaging about 6.8 m./sec. The vibration recorder was set up at the S. E. part of the top surface of the shaft, the two pointers being oriented to register respectively the component movements normal and parallel to the wall there.

The motion of the shaft caused by the winds were entirely unfelt, and the instrumental diagrams indicated only extremely small vibrations even when registered with 30-time magnification. (See fig. 11.) The result of the measurement was as follows:—

Time of Observation.	Motion Parallel to Shaft Wall.		Motion Normal to Shaft Wall.	
	T	Max. 2a.	T	Max. 2a
3.00—3.10 P.M.	0.73 sec.	0.03 mm.	0.72 sec.	0.017 mm.
3.35—3.42	—	Small.	0.72	Small.

Thus the maximum motion was far below 0.05 mm., the reinforced concrete shaft so far constructed being very rigid.

6. Experiment on July 10th, 1920. 8–10½ A. M. Height=414 feet. (See fig. 12 and TABLE III.) On the occasion of this second experiment the weather was unfortunately very calm, the wind velocity varying between 1.5 and 4.0 m./sec., with the average of 2.3 m./sec. The vibration was as follows:—

E. W. Component. Average T=1.253 sec., max. 2a=0.10 mm.
N. S. ,, ,, =1.252 ,, ,, =0.11 ,,

The general average value of the period was 1.25 sec. There were also the quick movements of the average period of 0.33 sec.

The 660′ Wireless Telegraph Station Tower at Haranomachi.

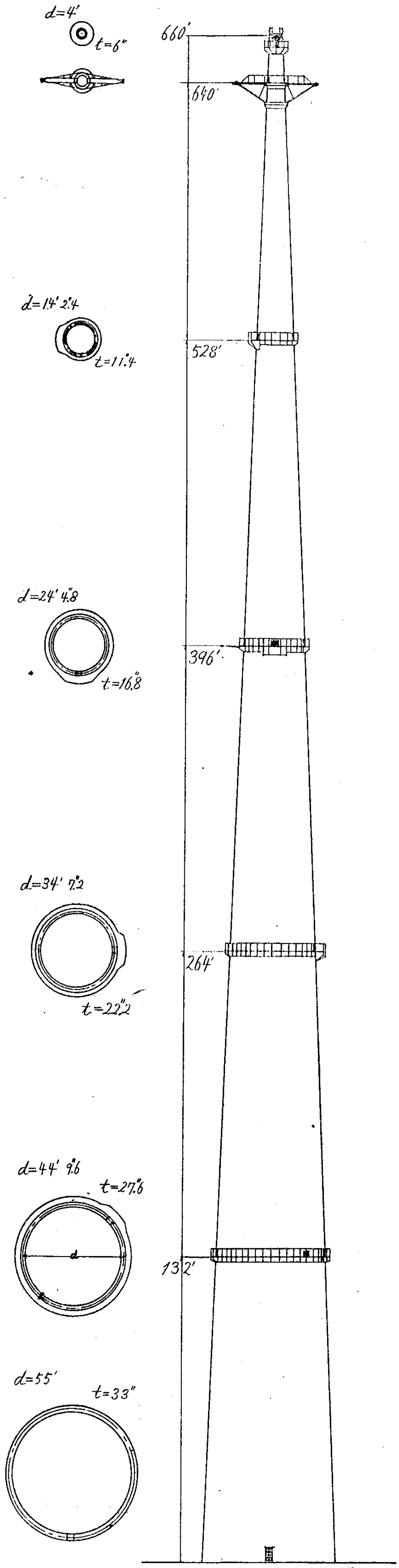


Fig. 1. Elevation and Horizontal Sections.

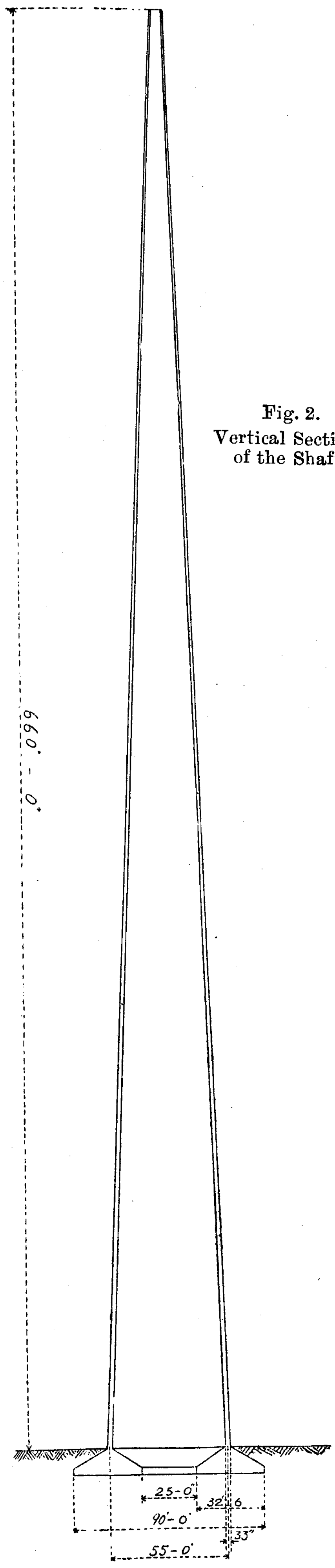


Fig. 2. Vertical Section of the Shaft.

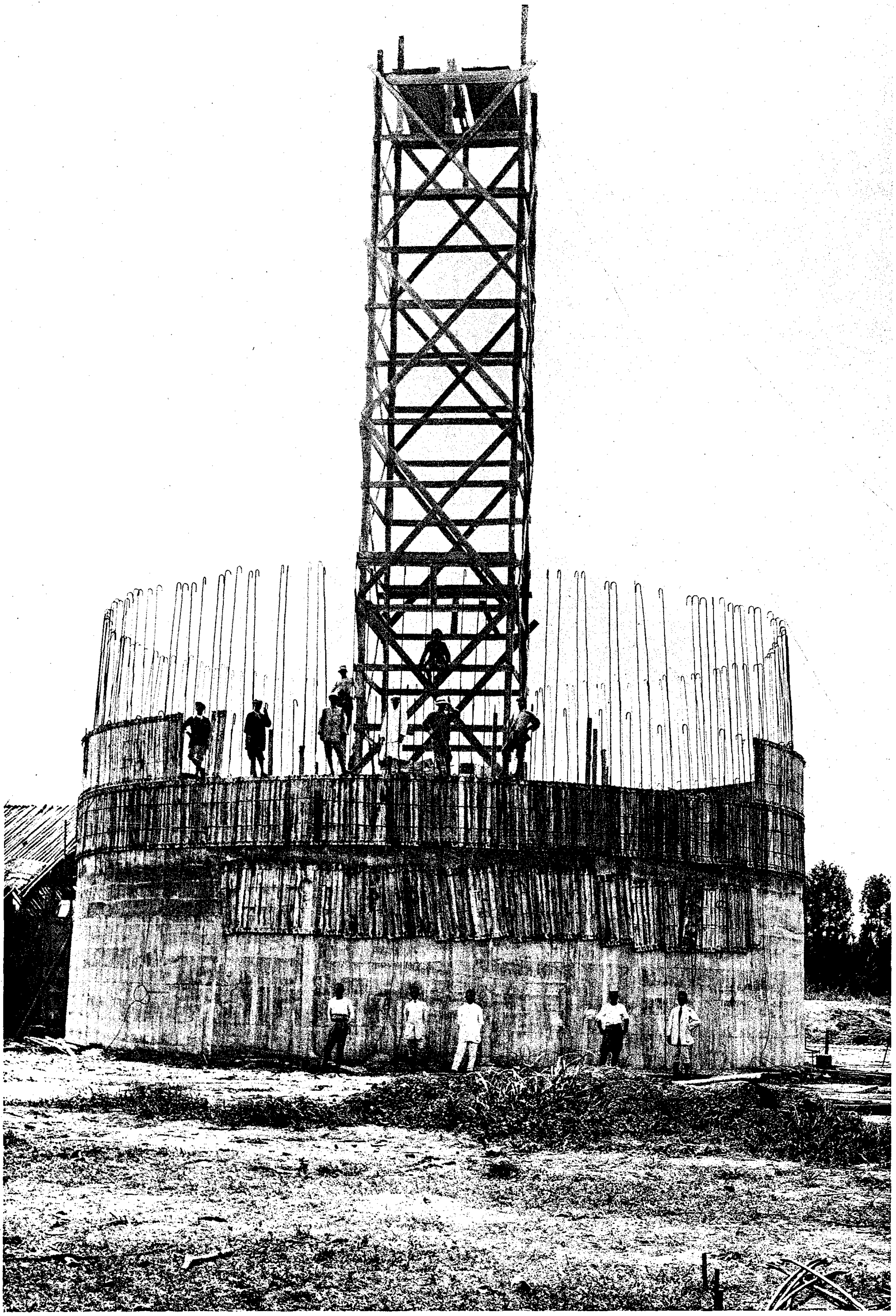


Fig. 3. The Haranomachi Wireless Tower at an early stage of construction.

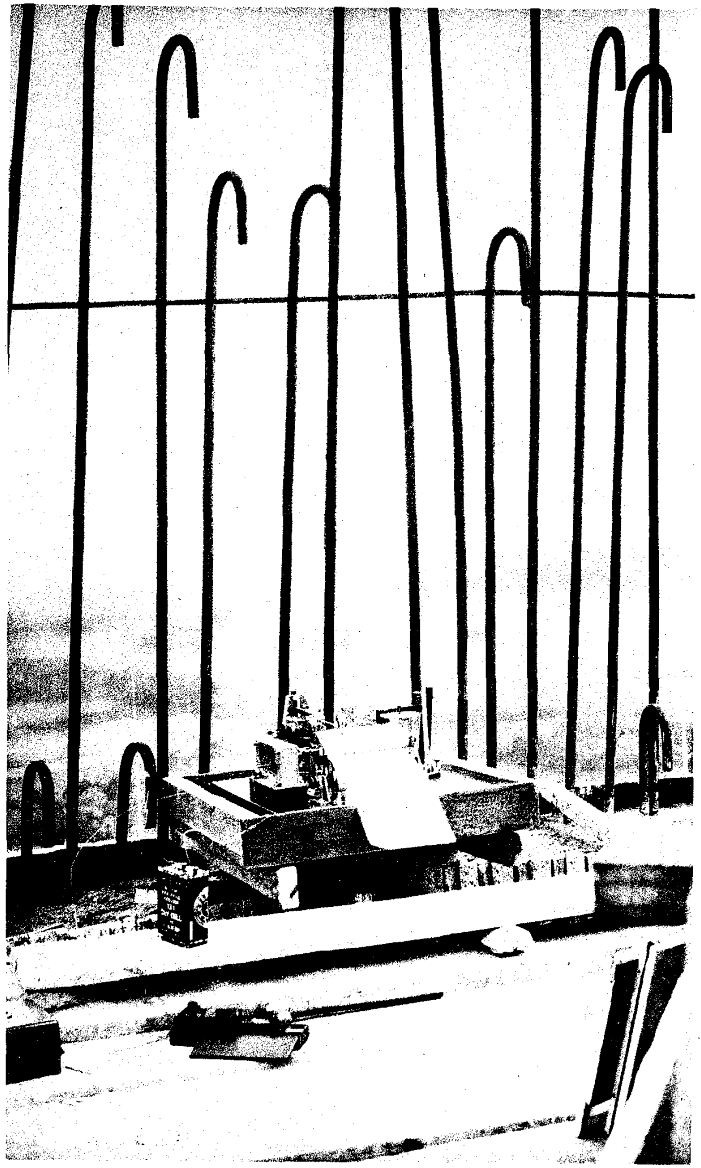


Fig. 4. Vibration-Recorder set up on the top of the Shaft. May 23rd, 1920.

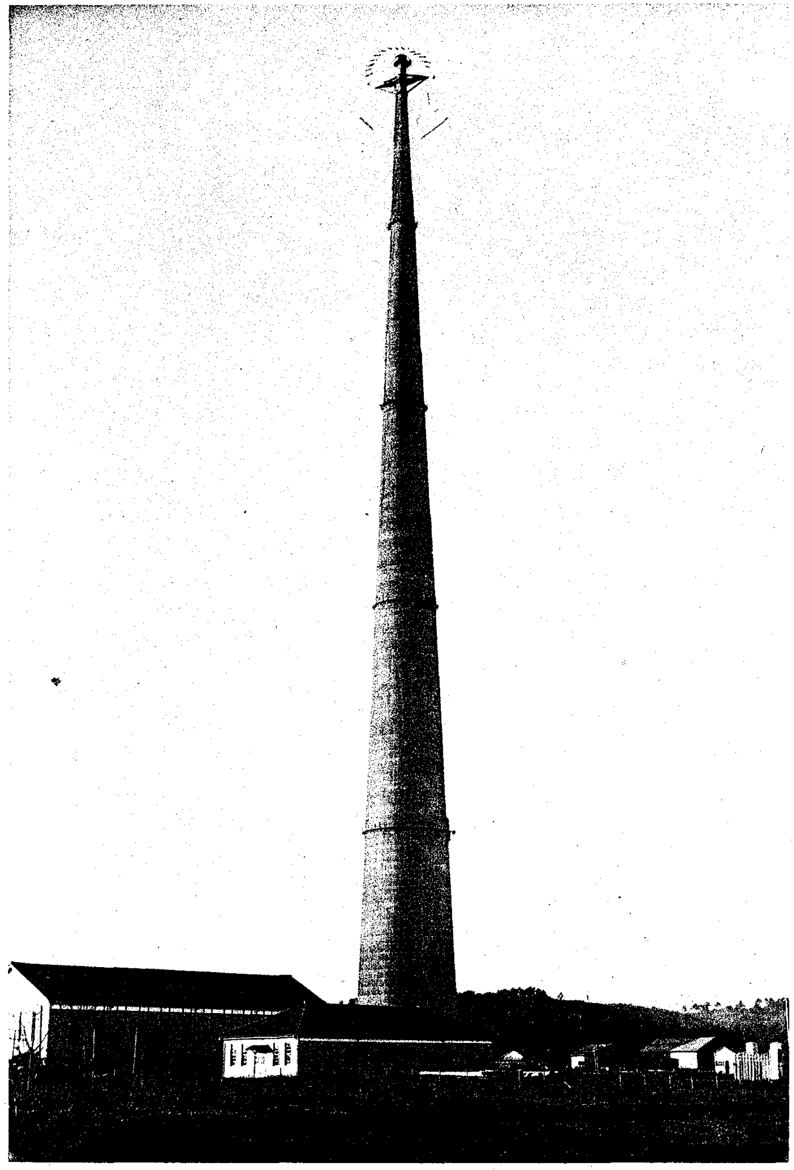


Fig. 5. The Tower after its Completion.

which were due to disturbances given to the inside elevator trestle.

TABLE III. Vibration of the Wireless Tower, 414 Feet in Height.

July 10th, 1920.

Time of Observation.	E.W. Component.		N.S. Component.	
	T	2a	T	2a
8.00–8.20 A.M.	——	Small	1.25 sec.	0.03 mm.
	1.25 sec.	0.03 mm.	1.29	0.04
	1.28	0.03	1.26	0.05
	1.23	0.07	1.27	0.04
	0.33 [1]	0.38	0.35	0.09
8.34–8.55 A.M.	——	Small	1.23 sec.	0.06 mm.
	1.27 sec.	0.04 mm.	1.26	0.05
	——	Small	1.26	0.11
	1.25	0.05	——	Small
9.20–9.40 A.M.	1.25 sec.	0.04 mm.	1.23 sec.	0.04 mm.
	——	Small.	1.25	0.04
	1.27	0.03	1.27	0.06
	——	Small.	1.25	0.05
	1.27	0.03	1.23	0.03
	1.26	0.06	1.26	0.03
	1.23	0.05	1.27	0.07
	——	Small.	1.22	0.08
	0.32, 0.34, 0.31 [2]	0.05, 0.07, 0.03	——	No indication.
9.57–10.15 A.M.	1.23 sec. [3]	0.10 mm.	——	Small
	1.25	0.04	1.25 sec.	0.04
	1.25	0.06	1.23	0.04
	1.25	0.03	1.25	0.05

7. Experiment on Aug. 20th, 1920. Noon to 2.35 P.M. The height of the shaft was 522 feet, the top external diameter being 16 feet. The wind was S.E.'ly and moderately strong, such that

1) One man shaking the staging at the top.
2) Due to the working of the elevator within the staging.
3) Disturbance caused by the falling down of a timber piece inside the shaft.

no workman dared to ascend the shaft, and the work of construction has been abandoned for the day. The wind velocity varied between 10 and 20 m./sec., with the average of 14 m./sec. After 2. 35 P. M., it rained.

The result of the measurement with the tremor-recorder set up at the E. part of the shaft top was as follows:—

TABLE IV. Vibration of the Wireless Tower.
Height=522 Feet. Aug. 20th, 1920.

E.W. Component.		N.S. Component.	
T	2a	T	2a
1.68 sec.	0.93 mm.	1.63 sec.	0.73 mm.
1.68	0.59	1.64	0.14
1.66	0.20	1.66	0.23
1.66	1.73	1.66	0.17
1.70	0.80	1.60	0.21
1.69	1.03	1.65	1.43
1.70	2.27	1.69	0.28
1.67	3.43	1.66	1.95
1.70	0.44	1.70	0.55
1.66	1.10	1.63	0.33
1.70	1.24	1.70	0.94
1.65	2.67	1.64	0.97
1.70	1.67	1.65	1.26
1.70	1.48	1.70	0.32

	Average period.	Max. 2a.
E. W. component.	1.68 sec.	3.43 mm.
N. S. ,,	1.66	1.95 ,,

The general average period was 1.67 sec. The motion was greater in the E.W. than in the N.S. component. (See figs. 13 and 15.)

8. Experiments on Sept. 26th and 28th. Height=660 feet. The vibration measurements were executed immediately after the completion of the construction of the tower. The vibration recorder was set up at the top of the shaft whose internal diameter is only 3½ feet. On the 26th, at the time of the experiment the wind velocity was from 8.7 to 11.8 m./sec., with the average of 10.2 m./sec. On the 28th, the anemometer observation was defective, but the winds were distinctly stronger than on the 26th, and the velocity was probably not much different from 15 m./sec. Pieces of paper thrown from the tower top at about 2 P.M. on the 28th were carried to a little to the left of the Haranomachi Railway Station, indicating that the wind direction was toward the W. slightly S.

The movements in the two component directions are summarized in TABLE V, from which we find

	Average Period	Max. 2a
E. W. Direction :	2.065 sec.	1.86 mm.
N. S. Direction :	2.075 sec.	6.90 mm.

The general average value of the period was 2.07 sec. In the measurements on Sept. 28th, the motion in the N.S. was invariably much greater than that in the E. W. component; the maximum movements in these two directions being respectively 1.86 and 6.90 mm., nearly in the ratio of 1:4. As the wind at the time of the observation was very nearly easterly it follows that the tower made pronounced movements, not parallel, but at right angles to the direction of the wind. (See figs. 6 and 7.)

In the E.W. component diagrams of motion, there occurred often the quicker vibration of the average period of 0.86 sec. (max. 2a=0.4 mm.). This was probably the result caused by the shaking of the inner elevator trestle due to the impact of winds. Its period was exactly double that of the movement in the N.S. component (T=0.43 sec., max. 2a=1.14 mm.) produced by disturbing the trestle.

TABLE V. Vibration of the 660–Foot Wireless Tower.
Sept. 26th-28th, 1920.

Time of Observation.	E.W. Component.		N.S Component.	
	T	2a	T	2a
Sept. 26th; 4.30–5.10 P.M.	0.85 sec. 2.05 }	0.07 mm. 0.20 }	2.06 sec.	0.83 mm.
	2.06	0.60	2.06	1.23
	2.05	0.60	2.06	1.43
	0.86 2.08 }	0.17 0.23 }	2.12	0.22
	0.86	0.10	2.08	0.19
	2.12	1.03	2.10	2.83
	2.07	0.57	2.04	2.57
	0.85	0.13	2.12	0.13
	2 07	0.60	2.06	1.10
	2.01	0.47	2.04	0.57
	2.05	0.53	2.05	0.53
	0.85	0.27	2.05	0.25
	2.05	1.03	{ 2.06 0.84	{ 0.20 0.07
	0.86	0.40	2.10	1.57
	2.11	1.17	2.09	2.03
Sept. 28th; 11.00–11.25 A.M. (E. Wind.)	2.09 sec.	1.86 mm.	2.19 sec.	6.74 mm.
	2.02	0.70	2.02	5.40
	2.10	0.80	2.09	6.34
	2.07	0.50	2.05	6.40
	2.04	1.06	2.10	6.60
	2.01	1.40	2.08	6.90

TABLE V. (*Continued.*)

Time of Observation.	E.W. Component.		N.S. Component.	
	T	2a	T	2a
Sept. 28th ; 11.00–11.25 A.M. (E. Wind.)	2.06 sec.	0.66 mm.	2.05 sec.	6.64 mm.
	2.10	0.46	2.03	6.86
	2.06	0.50	2.07	6.66
	2.04	0.46	2.06	6.34
	0.87 } 2.00 }	0.20 } 0.20 }	2.10	5.46
	2.10	0.60	2.04	3.20
	2.02	1.20	2.07	6.60
	1.98	0.44	2.08	6.54
	2.05	2.00	2.06	6.86
	2.10	0.46	2.07	6.86
	2.03	1.14	2.00	5.16
	2.10	1.14	2.11	5.80
	2.04	0.76	2.04	6.84
	0.86	0.08	2.09	5.76
	2.05	0.76	2.10	6.60
	2.09	0.20	2.04	4.54
	2.03	0.20	2.05	6.70
Sept. 28th ; 1.00–1.40 P.M.	2.09 sec.	0.97 mm.		
	2.09	0.78		
	2.11	0.82		
	2.11	0.99		
	0.84	0.06		
Sept. 28th ; 1.45–2.00 P.M.			2.08 sec.	1.88 mm.
			2.11	2.14
			2.04	1.15
			2.11	1.50

TABLE V. (*Continued.*)

Time of Observation.	E.W. Component.		N.S. Component.	
	T	2a	T	2a
Sept. 28th ; 2.04–2.20 P.M.			2.06 sec.	2.78 mm
			2.15	3.55
			2.08	1.93
			0.43 *	1.90
			0.43 *	1.14
			2.06	1.47
			2.05	1.57
			2.04	1.64
Sept. 28th ; 2.25–2.36 P.M.			2.10 sec.	1.17 mm.
			2.11	1.82
			2.11	3.43
			2.10	3.00
			2.09	2.03
Sept. 28th : 2.40-3.00 P.M.	0.86 sec.	0.10 mm.		
	0.87	0.10		
	2.09	0.31		
	2.09	0.29		
	2.11	0.57		
	0.84	0.07		

9. Experiment on Nov, 5th, 1920. 11 A.M.–1 P.M. Height=660 feet. This experiment was repeated in order to find out the change in motion of the reinforced-concrete shaft caused by the subsequent addition of a rhomboidal iron frame, of length=38 feet and of weight=5200 lbs. attached 20 feet below the top. By this

*) One man disturbed the staging.

time 16 metal pulleys for supporting the antena wires had been fixed on the top surface which forms a ring of the inner diameter of only 3½ feet and of width of 6 inches. Owing to the want of space it was necessary to set up there a single-component tremor-recorder, which measured the E.W. vibrations with 10 times magnification.

The winds were N.W.'ly and fairly strong, the velocity at the tower top being 7.7 to 15.4 m./sec., with the average of 10.6 m./sec. On this occasion there seemed to be no very great difference in the force of wind at the top and the base of the shaft.

TABLE VI. E.W. Component Motion of the Tower.
Nov. 5th, 1920.

T	2a	T	2a	T	2a
(11.15–11.30 A.M.)		(11.40 A.M.–0.10 P.M.)		0.35–0.50 P.M.)	
2.10 sec.	4.5 mm.	2.08 sec.	2.8 mm.	2.0 sec.	1.4 mm.
2.14	2.1	2.12	3.8	2.2	4.0
2.12	10.3	2.05	2.0	2.1	5.3
2.08	10.3	2.09	5.5	2.2	4.5
2.20	9.4	2.10	3.5	2.1	0.9
2.18	5.3	2.15	4.0	2.2	2.1
2.10	3.5	2.09	4.9	2.1	1.4
2.08	5.4	2.10	5.1	2.1	5.4
2.07	4.6	2.10	3.0		
2.10	3.9	2.13	3.6		
2.10	4.3	2.22	2.3		
2.10	5.8	2.18	3.6		
2.08	3.7	2.15	3.6		
2.08	3.2	2.10	3.8		
2.12	5.7				
2.10	4.5				

The wind velocity measured at 2 P. M. on the ground was from 8 to 11 m./sec. As shown in TABLE VI, the tower vibration was greatest at about 11 A. M., and attained the 2a of over 10.3 mm. On one instance the motion remained pronounced for an interval of 83 sec., at whose commencement the 2a increased from 1.0 mm. to the maximum in the course of 19 sec., and at whose end it decreased from the maximum to 1.8 mm. in 13 sec. On another instance, the motion remained active for 15 sec., with the max. 2a=9.4 mm.; the increase from 2a=0.7 up to the maximum taking 12 sec. and the decrease from the latter to 2a=2.3 mm. in 9 sec. The general average value of the period comes out to be 2.12 sec. This is about 0.05 sec. longer than the period of the tower previous to the attachment near the top of the rhomboidal iron frame, and represents the effect due to the addition of the extra weight. The greater motion observed on the present occasion may be due to the exposure of the surface of the frame in question to the winds.

10. Summary. The results of the different measurements are collected in TABLE VII, from which it may be observed that the movement of the structure was insignificantly small (=0.03 mm.) till when the height reached 290 feet. Thus, so far as the amount of motion was concerned, the column formed up to that height virtually a part of the foundation. It was only after the height had got above 500 feet that the vibration became well distinct. (See fig. 8.) The maximum motion of the tower at its completion was 6.9 mm., which was increased to over 10.3 mm. by the addition of the iron frame at the top.

The vibration period of the structure was 0.72 sec. at the height of 290 feet. Thereafter the period gradually increased up to 2.07 sec. at the completion of the full height of 660 feet. (See

Fig. 6. Vibration of the Haranomachi Wireless Telegraph Station Tower.

Height=660 Feet. Sept. 28th, 1920; 11 A.M. (Magnification=15.)

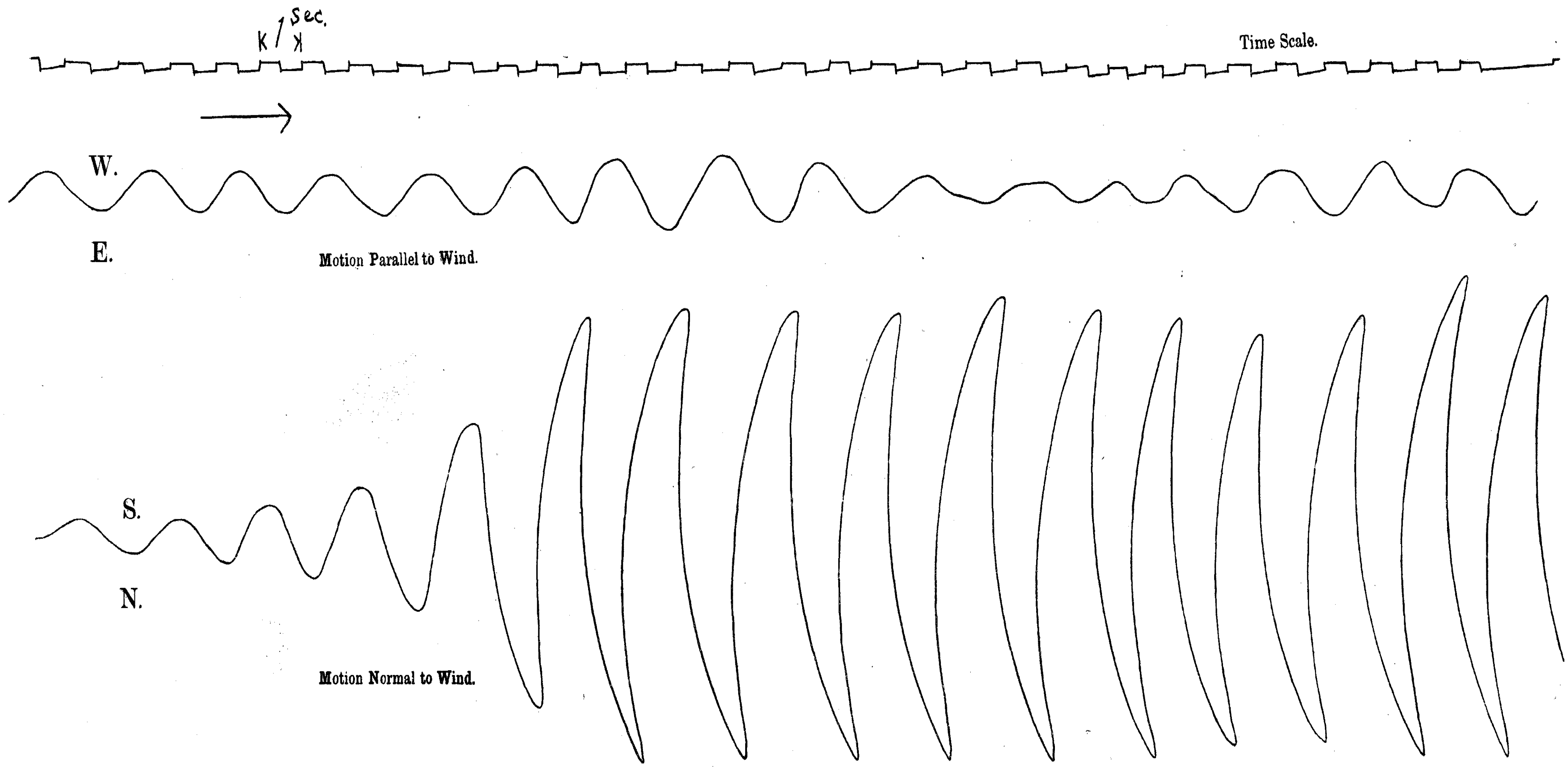
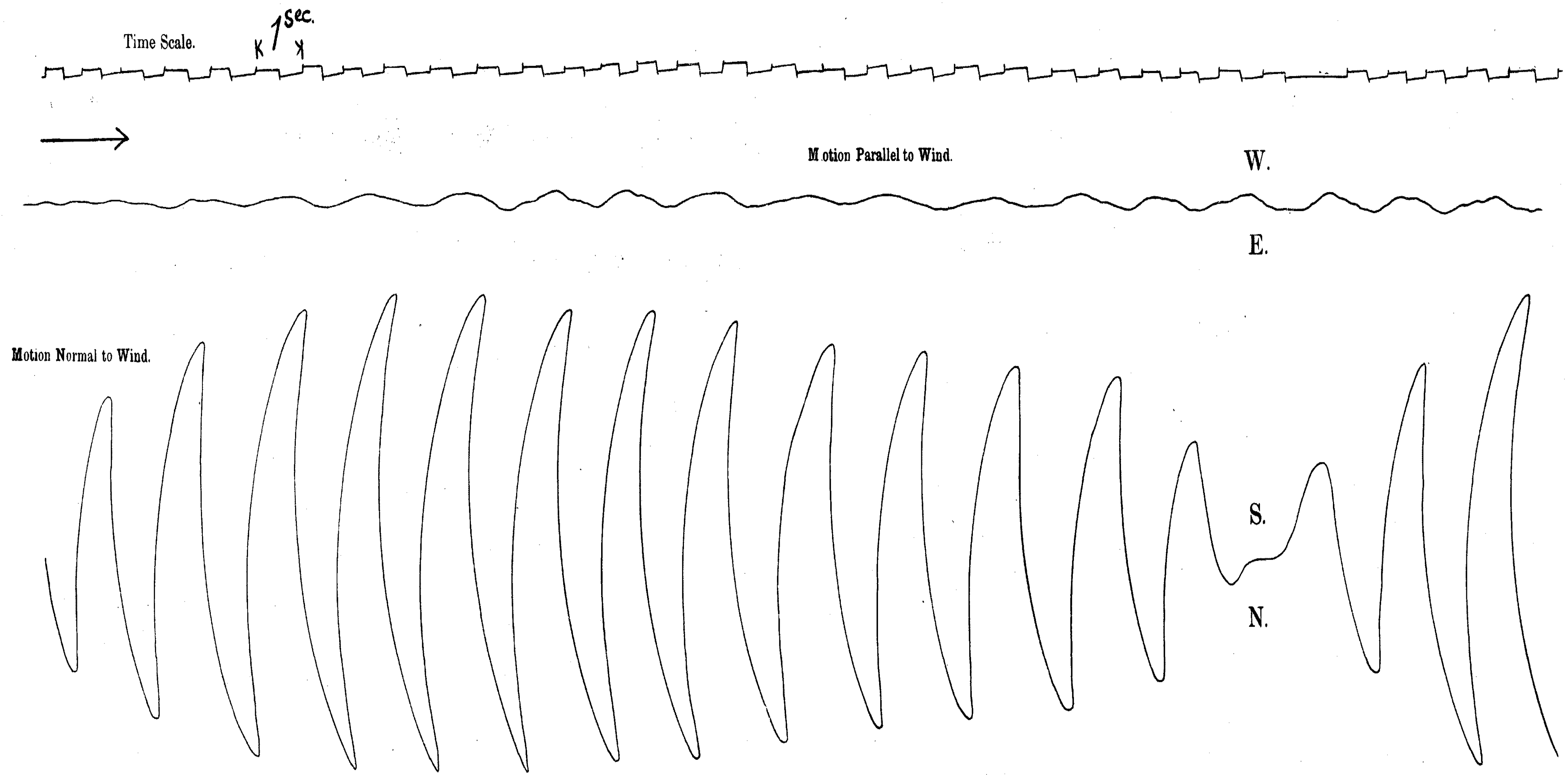


Fig. 7. Vibration of the Haranomachi Wireless Telegraph Station Tower.

Height=660 Feet. Sept. 28th, 1920. (Magnification=15.)



Diagrams showing the Relations to the Height of the Maximum Motion (=2a) and of the Vibration Period (=T) of the Haranomachi Tower.

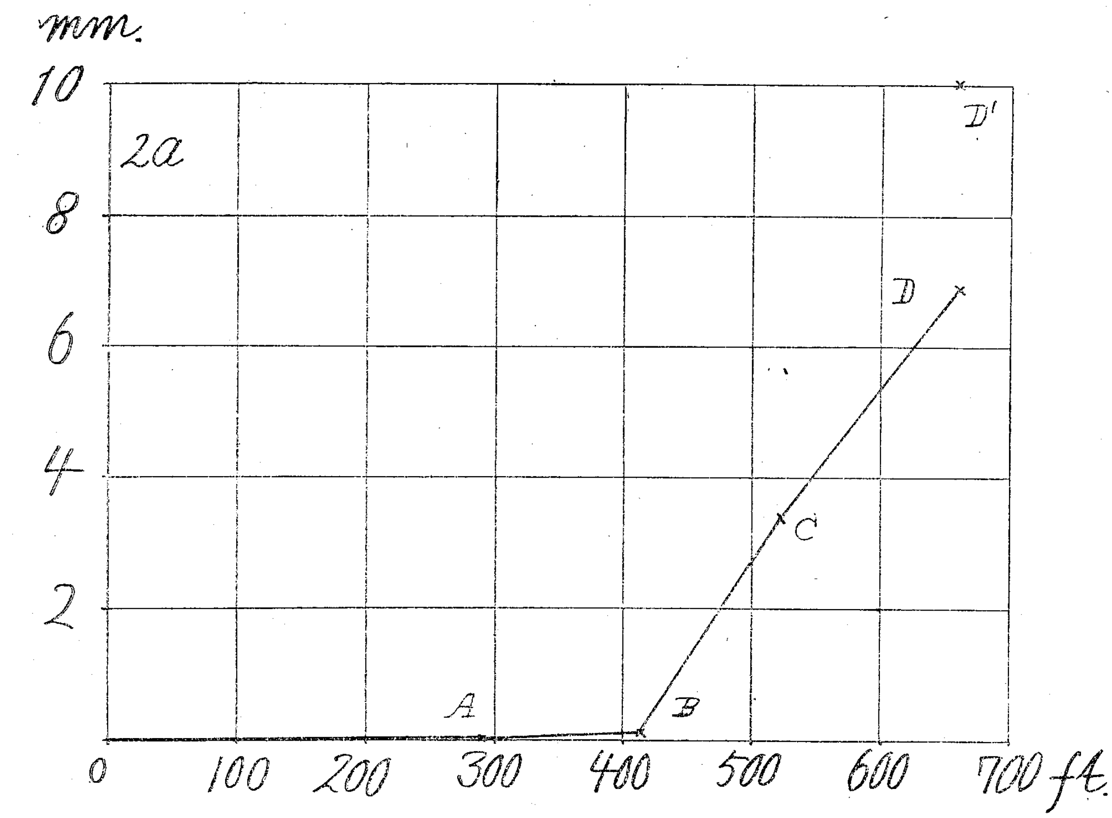


Fig. 8. Relation between the Height and the Amount of Motion.

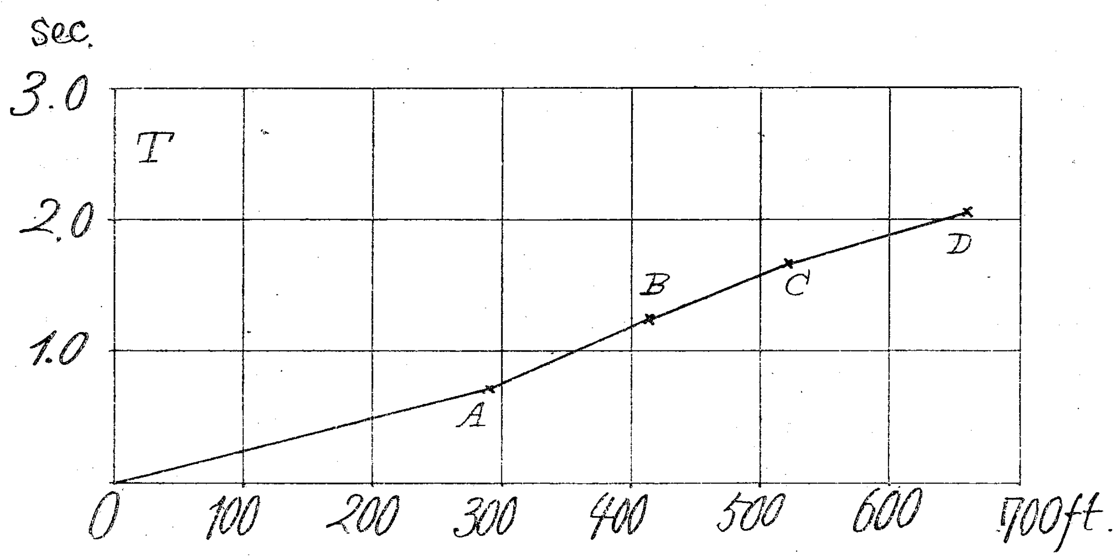


Fig. 9. Relation between the Height and the Vibration Period.

TABLE VII. Maximum Range (2a) and Mean Period (T) of the Vibration of the Haranomachi Wireless Tower at Different Stages of Construction.

Height.	Maximum Wind Velocity.	Oscillation of the Shaft	
		T	Max. 2a.
290′	10.5 m/sec.	0.72 sec.	0.03 mm
414	4.0	1.25	0.11
522	20.0	1.67	3 43
660	15.0	2.07	6.90 [1]
660	15.4	2.12	Over 10.30 [2]

fig. 9.) The addition of the iron frame near the top lengthened the period to 2.12 sec. The subsequent attachment of the antena wires has probably prolonged the period a little further. The tower is thus probably to be considered as a *tall column* with respect to the earthquake motion.

A point of special interest is the verification of the relation of the direction of the maximum vibration to that of the wind already found in the case of the Saganoseki chimney experiments. The measurement on the top of the Wireless Tower on Sept. 28th, 1920, indicated that the structure moved principally, in direction not parallel, but at right angles to the winds which blew nearly from the east; the N.S. vibrations, with the max. 2a=6.9 mm., being invariably much greater than the E.W. vibrations, of max. 2a=1.9 mm. This fact of the transversal motion, which has analogies in the behaviour of banners flowing in winds or of flexible strings and rods immersed in a water stream, must be due to the great pressure of strong winds, which produces a more or less

1) At the first completion of the tower construction.

2) After the addition of the iron frame at the top.

perfect vacuum behind, and sensibly bends, the column. It will be easier for the latter to move transversally than against the winds in the direction of the bending. Professor H. Nagaoka has published a hydrodynamical explanation of the phenomenon in question in the Proceedings of the Physico-Mathematical Society of Japan, Oct. 1919.

11. Comparison with Saganoseki chimney. The great 550-foot reinforced concrete chimney at Saganoseki[1] has the base and top external diameters respectively of 42′ 8″ and 27′ 5″. The Wireless Tower at Haranomachi has a more tapering form, being taller, but broader at base, and narrower at top. For the wind velocity of 1.0 to 6.9 m./sec., the max. 2a of vibration of the Saganoseki chimney was 0.13 to 0.72 mm., which was increased to 20.4 and 186 mm. respectively at the velocities of 24 and 35 m./sec. From the diagrammatic representation in fig. 10, the motion of the same chimney at the wind velocity of 15 m./sec. seems to be some 5 or 6 mm. The motion of the

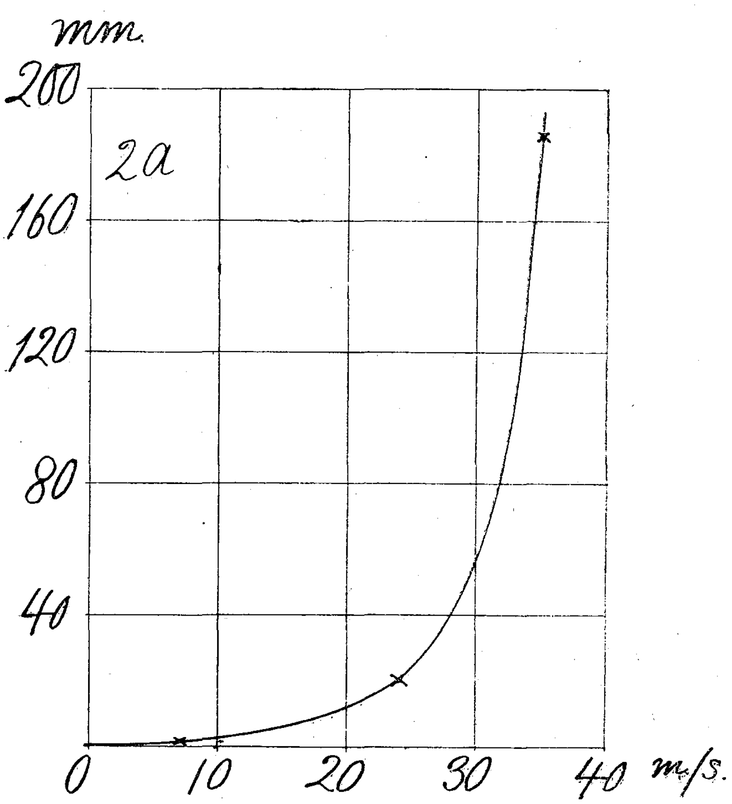


Fig. 10. Diagram showing the relation between the Wind Velocity and the Range of Motion (=2a) of the 550′ Reinforced Concrete Chimney at Saganoseki.

1) This Volume, No. 1.

Wireless Tower due to winds in the condition experimented upon at its completion on Sept. 26th–28th, 1920, was nearly equal or slightly greater than the corresponding one of the Saganoseki chimney, and might have been thrown into vibrations of 2a reaching 3/4 foot to 1 foot in a storm with a wind velocity of 30 to 40 m./sec. at the top of the tower. The addition of the iron frame near, and the stretching of the wires over the pulleys at the top, may modify the motion of the tower to certain extent; the former increasing, and the latter tending to damp and prevent the accumulation of, the vibrations.

12. Stability of columns. To compare the stabilities of different bodies against the earthquake motion let us denote by H and y_0 respectively the total height and the height of centre of gravity of a column. For a solid or hollow cylinder or prism, namely, a column of uniform section, we have: $y_0=\frac{1}{2}\times H$. For a solid or hollow cone, the centre of gravity is only half so high: $y_0=\frac{1}{4}\times H$. For a parabolic column,[1] square or circular in section, which is of a uniform stability against the seismic fracturing, the height of the centre of gravity is only 1/3rd of that of a cylinder or prism: $y_0=\frac{1}{6}\times H$. Now turning our attention to ordinary brick factory chimneys we find that the centre of gravity of the main shaft is situated almost exactly at 1/3rd of the total height. For instance, in a brick chimney of circular section, 100 shaku in height, at the Oji Goryokyok factory, near Tokyo, the height of the centre of gravity is 33.9 shaku, $=\frac{1}{3}\times 100$ shaku nearly. Again, the height of the centre of gravity of the tall 80-metre brick chimney of the Imperial Iron Works at Yawata, Kyushu, is found to be 26.8 metres$=\frac{1}{3}\times 80$ metres exactly.

1) See the Publications of the Imp. Earthq. Inv. Comm. No. 4.

Vibration of the Haranomachi Wireless Telegraph Station Tower.

(Multiplication = 30.)

Fig. 11. Height=290 Feet. May 23rd, 1920.

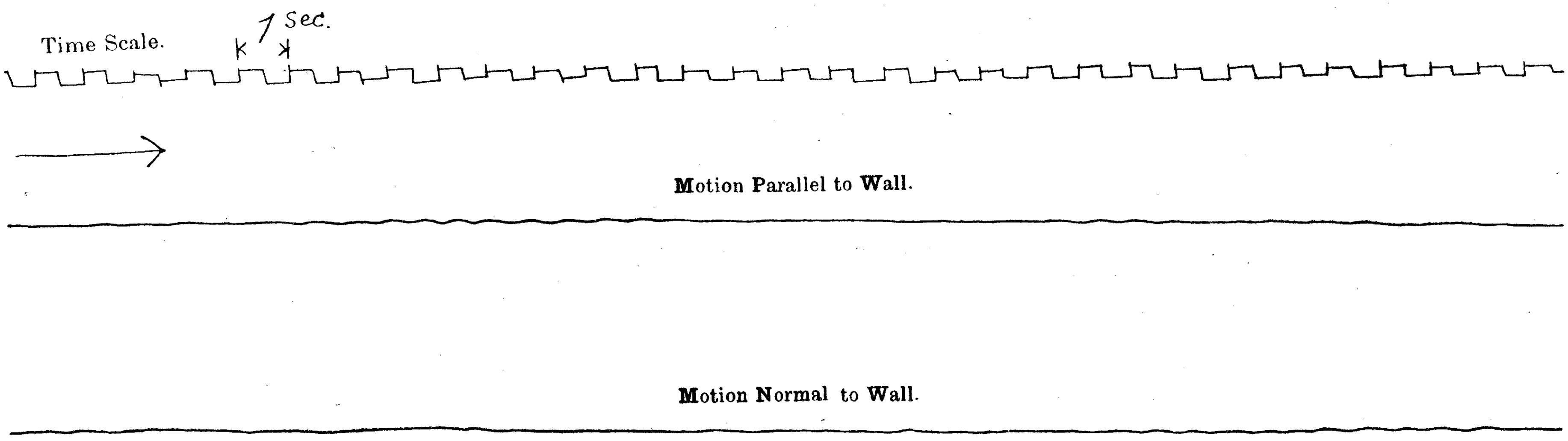
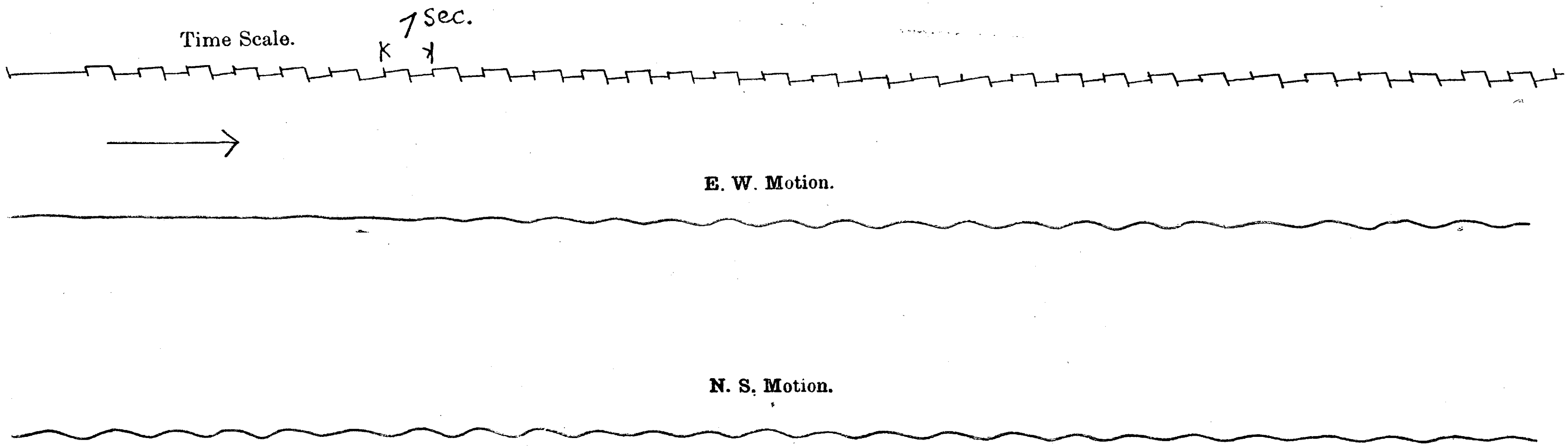


Fig. 12. Height=414 Feet. July 10th, 1920.



Vibration of the Haranomachi Wireless Telegraph Station Tower.

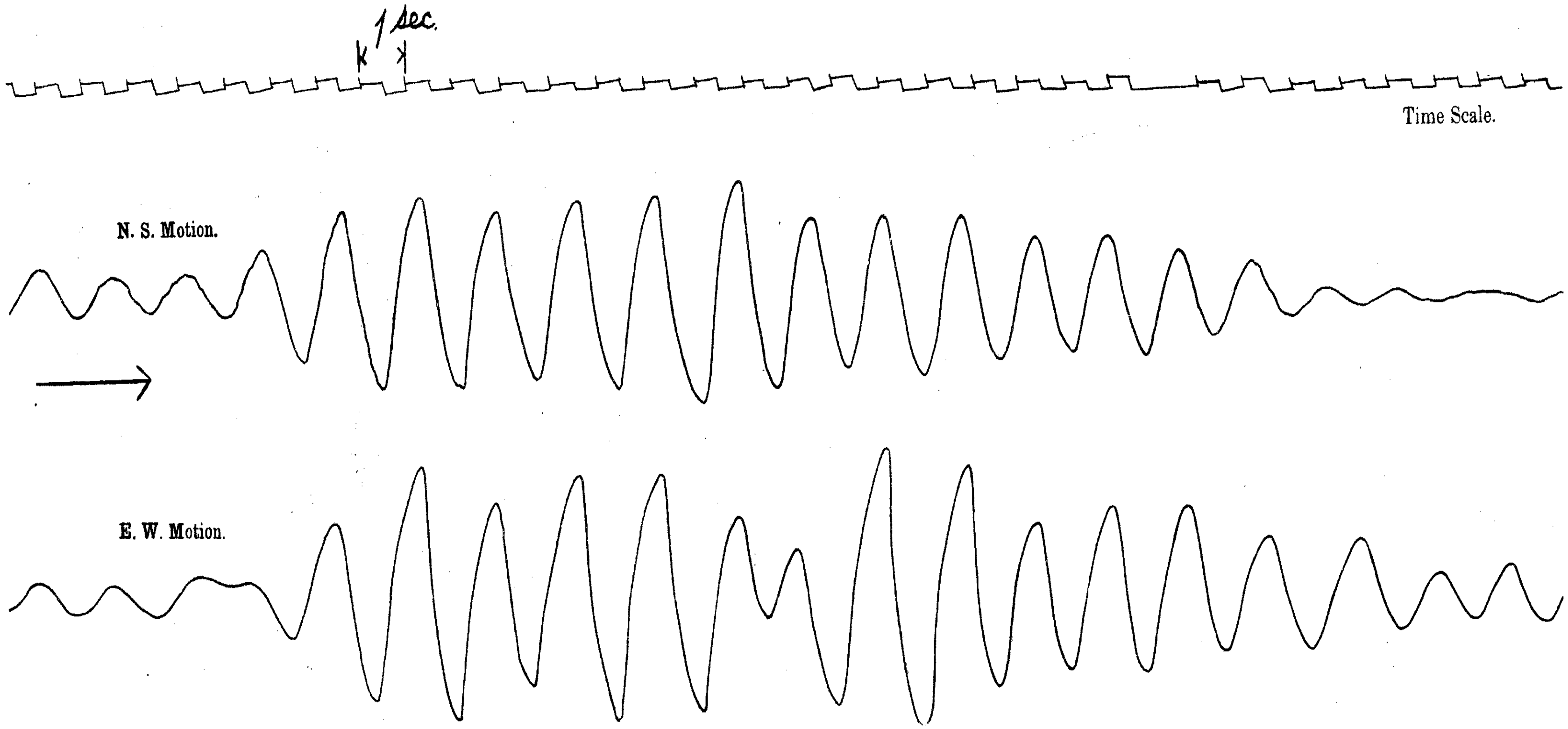


Fig. 13.
Height=522 Feet.
Aug. 20th, 1920; 2.28 P.M.
(Multiplication=30.)

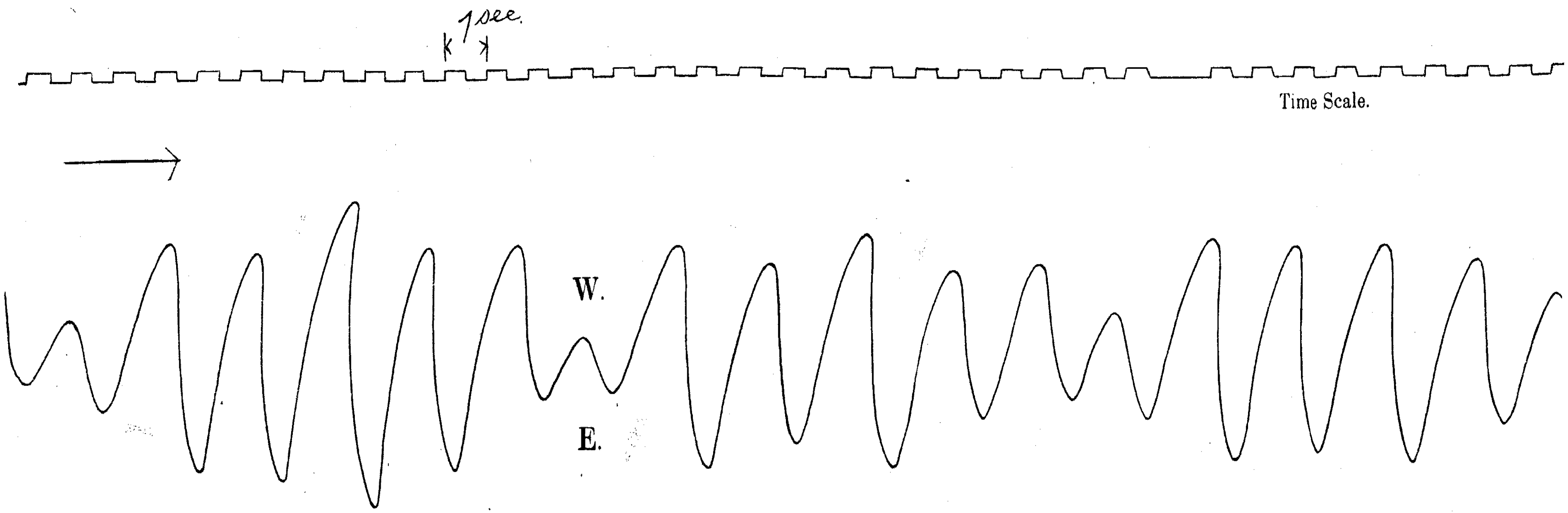
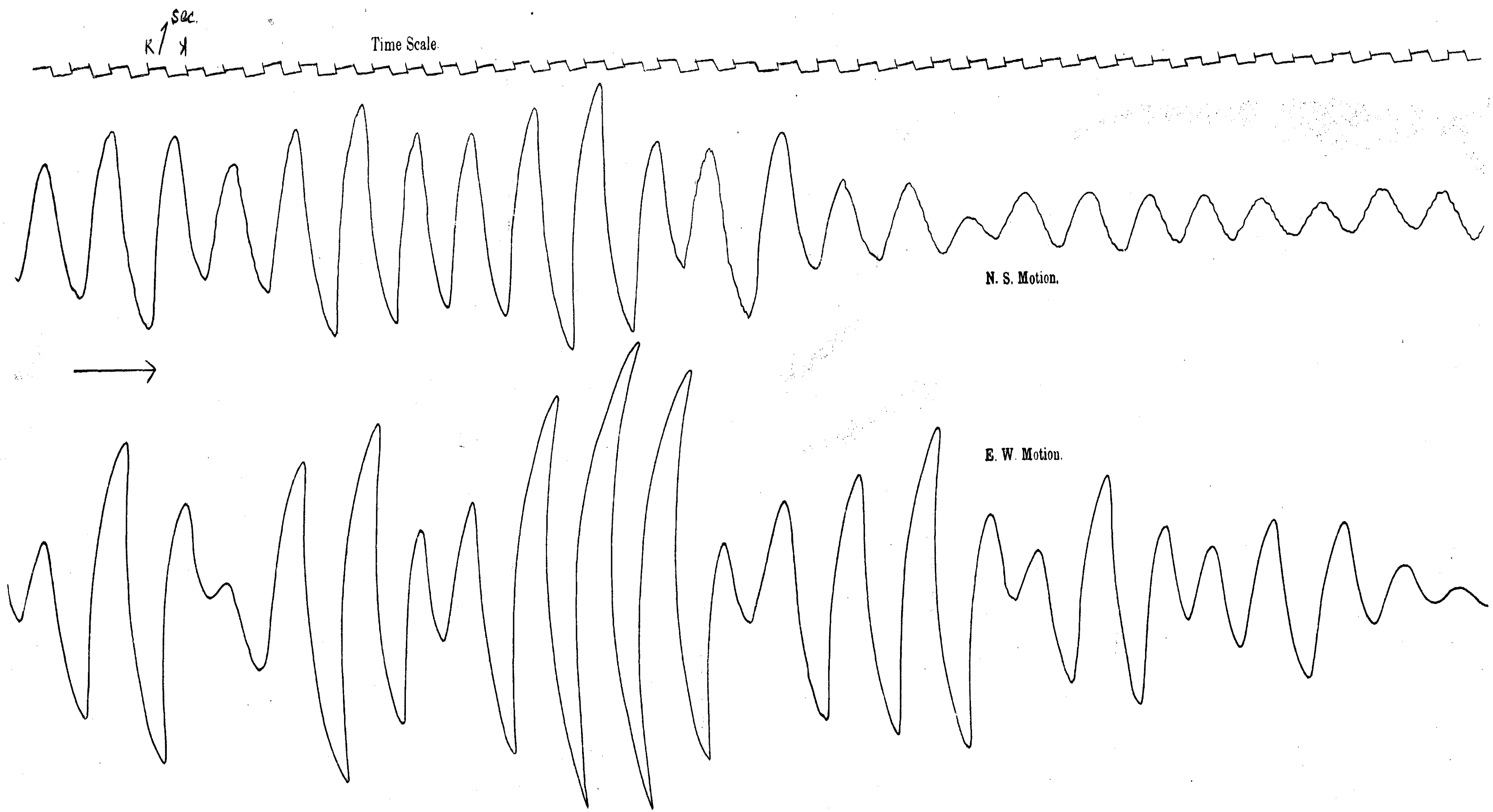


Fig. 14.
Height=660 Feet.
Nov. 5th, 1920; 11.45 A.M.
(Multiplication=10.)

Fig. 15. Vibration of the Haranomachi Wireless Telegraph Station Tower.

Multiplication = 30.

Height = 522 Feet. Aug. 20th, 1920; 0.10 P.M.



Of the Wireless Tower at Haranomachi, the values of the volume (=V) and the height ($=y_0$) of the centre of gravity of the shaft are as follows:—

$$V=H\times 18\times 230\times 2\pi \text{ cubic in.}=119{,}000 \text{ c. ft.}$$

$$y_0=H\times\frac{261}{4\times 230}=187 \text{ feet}=\frac{1}{3.5}\times H, \text{ nearly.}$$

As far as the height of the centre of gravity is concerned the Wireless Tower ranks between a cone and a common brick chimney. In the case of the great 550-foot reinforced concrete chimney at Saganoseki, the centre of gravity is comparatively high and is situated at 194.2 feet above the ground, approximately equal to $\frac{1}{2.8}\times H$; the total volume of the shaft being 73,652 c.ft. (See TABLE VIII.)

TABLE VIII. Stability of Columns.

H=Total Height of Column.

Column.	Height of Centre of Gravity.	h	Seismic Stability.
Cylinder or Prism, (Uniform section Column).	$\frac{1}{2}\times H$	$\frac{2}{3}\times H$	varies as $\frac{1}{H^2}$
Cone.	$\frac{1}{4}\times H$	$\frac{2}{5}\times H$	varies as $\frac{1}{H}$
Parabolic Uniform-strength Column.	$\frac{1}{6}\times H$	$\frac{2}{\ }\times H$	Constant.
100-shaku Brick Chimney at Oji, near Tokyo.	$\frac{1}{3}\times H$ =33.9 shaku.	$\frac{54.4}{100}\times H$ =54.4 shaku.	——
80-metre Brick Chimney at Yawata, G. I. W.	$\frac{1}{3}\times H$ =26.8 metres.	$\frac{53.3}{100}\times H$ =42.6 metres.	——
550-foot Chimney at Saganoseki, Kyushu.	$\frac{1}{2.8}\times H$ =194'.2		
660-foot Wireless Tower at Haranomachi.	$\frac{1}{3.5}\times H=187'$	$\frac{1}{2.24}\times H=295'$	

The stability of a cylinder or prism with a given base dimension, supposed to be a *short column*,[1] against fracture by the horizontally applied earthquake motion, varies inversely as the square of the height. A conical column is likewise weakest at the base, but its seismic stability varies simply as the reciprocal of the height. The seismic stability of a uniform-strength parabolic column is independent of the height. If a structure be treated as a *tall column*,[2] whose natural oscillation period is sufficiently long in comparison to the period of the destructive earthquake motion, it will, or tends to, be broken in the vicinity of the height (=h) corresponding to the centre of percussion of the body with respect to the ground surface. The height h is $\frac{2}{3}\times H$ for a uniform section column, $\frac{2}{5}\times H$ for a cone, and $\frac{2}{7}\times H$ for a parabolic uniform strength column. For brick chimneys, $h=\frac{53}{100}\times H=\frac{2}{4}\times H$ approximately. For the Wireless Tower at Haranomachi, this height is situated at about 295 feet above the ground, or $\frac{1}{2.24}\times H=\frac{2}{4.5}\times H$ approximately. The tower is probably to be regarded as being seismically weakest at the height of about 300 feet, which also marks the point above which the structure becomes comparatively much shaky.

13. Deflection of column. The present series of observations were aimed at the direct measurement of the vibrations of the structure. Only in the case of the experiment on Nov. 5th, 1920, the deflection of the tower, loaded with the iron frame, caused by winds was shown more or less distinctly on the vibration recorder diagram by the displacement of the zero position of the writing pointer. The large horizontal vibrations observed on Sept. 28th, 1920, when the tower had not yet been loaded with the iron frame, were the effect of accumulation of motion dependent on the duration

1) and 2) See the Publications of the Imp. Earthq. Inv. Comm., No. 4.

of the continuance of the wind gust, being augmented much more quickly than the increase of the wind velocity. These movements, which were at right angles to the direction of the strong wind, were probably larger than the deflection of the column in direction of the latter. Again the displacement caused by the sudden occurrence of wind gust after an interval of lull may correspond to the deflection in question. Such a movement in the component parallel to the wind direction was, however, never conspicuously large, a fact verified also in the case of the experiments with the great 550-foot chimney at Saganoseki. From this consideration I am led to the conclusion that the amount of the windward deflection of the last named structure and of the Wireless Tower at Haranomachi were smaller than the range of the vibrations normal to the wind direction.