Applications of Seismographs to the Measurement of the Vibrations of Railway Carriages. 3rd Paper.

[Vibrations of Bogie Carriages.]

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With Plates XVII—XXVI.

1. Introduction. The vibrations of railway carriages, whose measurement forms a branch of applied seismology, are principally executed in vertical and lateral (horizontal) directions. The double amplitude ($2a$), and to a certain extent also the period (T), of these movements depend on the condition of the road, the nature of the ground, the construction of the carriage, the velocity and the composition of the train, the position of the carriage in the latter, and other circumstances.

2. Movements of ordinary 4 wheel carriages. Discussions on the vibrations of the ordinary (i.e., non-bogie) four-wheel carriages on the Tōkaidō, Takasaki, and Sanyō lines, in Japan, have been given in Nos. 15 and 20 of the *Publications of the Earthquake Investigation Committee*; the measurements having in each case been made with the instruments set up on the floor of the car. Some of the principal results obtained in these experiments are as follows:—

VERTICAL VIBRATION.

(i) The motion depends very much on the strength of the rail connections; the simple fish plate joint producing the effect equal to twice that due to the improved angle iron joint.

(ii) The maximum movements occurred when the velocity was about 30 miles per hour, the amplitude decreasing with the higher velocities.

(iii) The vibration during the passage over the different bridges was, on the average, the same as when traversing the adjacent grounds. The points and the curves produced no marked effect on the vertical vibration.

(iv) The maximum motion (2a) was 31 mm, while the shortest period of vibration was 0.22 sec.; the greatest value of the maximum acceleration probably exceeded 10.000 mm/sec^2. Thus a very strong vertical motion may cause the wheels to jump up from the rails, leading, under unfavourable circumstances, to the derailing of the carriages.

LATERAL VIBRATION.

(i) The effect of the rail joint was not marked.

(ii) The amplitude, which was small when the train was running slowly, rapidly increased with the speed over 22 or 23 miles per hour.

(iii) The vibration during the passage over the bridges was, on the average, 30% greater than that on the adjacent grounds. It is, however, to be noted that the motion on the bridges never attained such a large magnitude as often happened when the trains were passing with high velocity over the roads laid across plains of very soft soil.

(iv) The displacement or shock produced at the entrance or end of a curve was proportional to the velocity, and inversely proportional to the radius of curvature. The maximum range of motion of the curve effect was about 6 inches.

(v) The effect produced by the points was sometimes as large as that due to the curves.

(vi) The motion was composed essentially of two sets of vibrations, whose periods were respectively 0.7–0.8 sec. and about 1.5 sec., the maximum movements being as follows:—

(1) Quick vibration: max. 2a=47 mm (T=0.66 sec.);

(2) Slow ,, : max. 2a=156 mm (T=1.5 sec.).

The maximum acceleration of each of these two large movements, which occurred respectively in a straight part and at a curve on the Tōkaidō railway, was approximately 2000 mm/sec^2., or not much different from the intensity of the earthquake motion in the city of Nagoya on the occasion of the great Japan disaster of 1891. Consequently a railway train, which is running in a stormy and rainy weather accross a field of very soft formation, becomes, on account of its own strong vibrations, highly unstable and may be overturned by only one-half of the wind pressure necessary for producing the same effect when it is at rest.

With respect to the vertical vibration, it may be noted that the motion on soft soil may be even 4 times larger than that on hard ground. The road crossings, which are apparently insignificant, very often cause sharp upward vertical shocks.

The lateral vibration of a railway carriage will be greatest when coupled directly to the engine or when placed at the very end of the train.

VIBRATIONS OF BOGIE CARRIAGES.

3. "Goryo-sha" (Imperial carriage). In 1910, the authorities of the Central Department of the Government Railways completed the construction of a new court train, consisting of 5 bogie carriages. One of these, the "goryo-sha," or carriage for the use of Their Majesties, had a length of 66′ 7″, with a weight of 36 tons, being of the same type as the first class 6-wheel bogie cars in use on the Tōkaidō, or Tōkyō-Kōbe, line. One of these latter, whose elevation and plan are given in Fig. 5 (Pl. XVII), had a length of 64′ 6″, with a weight of 27.3 tons. It will be observed that the *goryo-sha* was about 9 tons heavier than the first class carriage in question, due principally to the use in the former of stronger timbers and more solid supporting steel frames.

In the following pages I give a summary of the results of the vibration-recorder measurements made, between the 12th and the 18th of October (1910), on the occasion of the trial runnings of the *goryo-sha*; also an account of the preliminary experiments executed, on the 7th and 10th of the same month, for the comparison of the shakings of the latter with those of the above-mentioned first class bogie carriage.

4. Instruments. The vibration-recorders were similar to those used previously and consisted of a single-component horizontal pendulum and a vertical motion seismograph, which were mounted on two different base plates and which registered in ink each on white paper wrapped round a roller, respectively in the half size reduction, and in the natural scale or 2 times magnification. In Figs. 1 and 2, I give diagrammatic sketches of the vibration recorders, with indications of their instrumental constants.* The horizontal instrument was used to record the lateral shakings of the carriages.

In each of the instruments the record-receiving paper had a velocity of about 1 cm per sec., the rate of motion being accurately gauged by means of a clock, which caused a writing index

* Fig. 6 (Pl. XVIII) represents a vibration-recorder, in which the two component movements are registered on one and the same recorder.

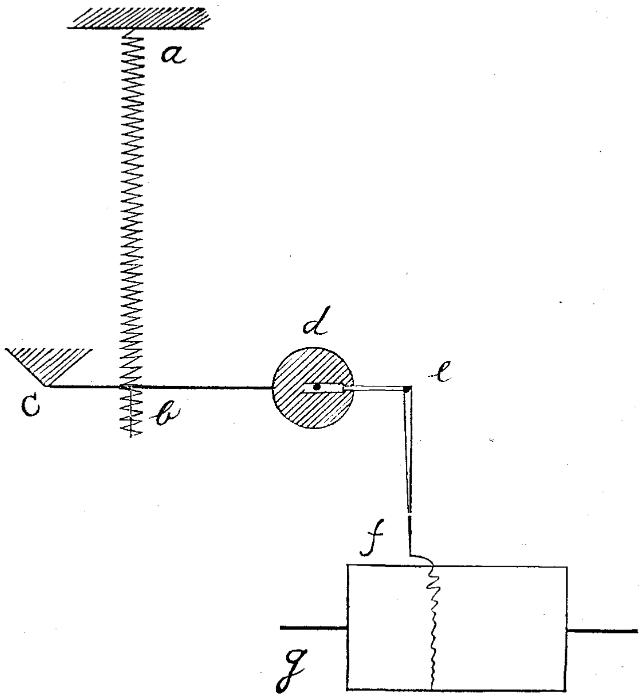


Fig. 1. [Vertical Motion Instrument.]

Natural Oscillation Period = 4 sec.

ab......Suspension Spring:

Length(*ab*)=51 cm.

cd......Horizontal Rod, supporting the Weight(*d*) at end:

Length(*cd*)=29 cm.

Length(*bd*)=23 cm.

Weight (*d*)=1.0 kg.

def.....Recording Pointer:

Length(*ef*)=7.4 cm.

Length(*de*)=7.4 cm, for Natural size
Do =3.7 „ „ Double size

g........Registration Roller:

Diameter=7.6 cm.

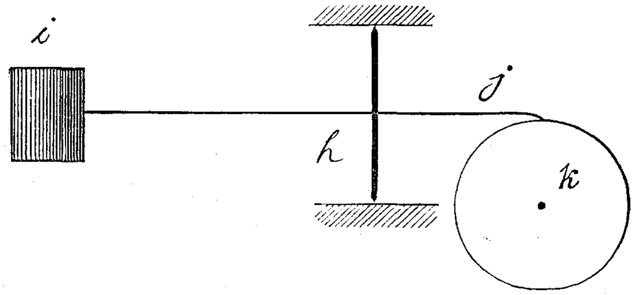


Fig. 2. [Lateral Motion Instrument.

Natural Oscillation Period=3.6 sec.

i........Heavy Bob, weight=2.1 kg.

h.......Axis of Horizontal Pendulum.

Length(*hi*)=20 cm.

Length(*hj*)=10 cm.

k........Registration Roller:

diameter=7.5 cm.

attached to an electro-magnet to make at the margin of the paper a mark every half second of time, with a single omission after each ten seconds interval. On the diagrams were also marked the instants of transit of the carriage under experiment past quater-mile posts, over points, bridges, and road-crossings, through tunnels, along curves, etc.; an observer stationed, for this purpose, near the instruments, giving by means of an electric key, signals for the different cases, according to a fixed code.

The measurement of the up and down *vibration* of the carriages presented no difficulty, the "steady point" of the vertical motion seismograph being adjusted to a period of about 4 seconds. As the period of the movements in question was much shorter, namely, about 0.5 sec., there was no inconvenience of confusing these with the proper instrumental oscillations. With respect to the lateral vibration, however, it must be noted that the horizontal pendulum used in our experiments is also sensible to the change of level; the apparatus, consequently, recording the horizontal (lateral) vibration, mixed with the effect due to the carriage rolling, or rotation about the longer axis. To minimize the influence on the diagrams of the latter component motion, whose period was about 1 sec., the seismograph was adjusted to a long period (3.6 sec.), so as to render itself unable to follow the comparatively much quicker rollings of the carriage; the heavy mass of the instrument, which acts as a "steady point" in regard to horizontal vibrations, being, when subjected to tilting movements, thrown into oscillations with its own period. The records from the horizontal pendulum may thus be taken as giving a fairly good representation of the lateral shakings; at least each individual vibration indicated in the diagrams was not the consequence of the arbitrary proper oscillations of the instrument, but was a faithful indication of the motion of the carriage consequent to the condition at the corresponding point of the permanent way. (See § 7.)

Both in the vertical and the horizontal instrument, there was introduced a certain amount of friction on the writing index so as to make the instruments incapable of being thrown out easily into their proper motion, and also little sensible to such slower movements of the carriage as are due to gradual change in height. This would not materially affect the value of the registration of the vibrations, whose study is the object of our present investigations.

5. Experiments on Oct. 7th and 10th, 1910. The measurements were begun on Oct. 7th, with the trial runnings, on the up and down lines between Shinbashi (Tokyo) and Kōzu, of a train, which consisted of an engine and 5 carriages and differed from the court railway train only in having, instead of the *goryo-sha*, at the middle of the series, the first class 6-wheel bogie carriage. (See Fig. 3.) The vibration-recorders were set up, as indicated in

Fig. 3.

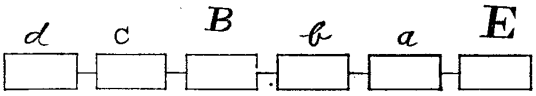
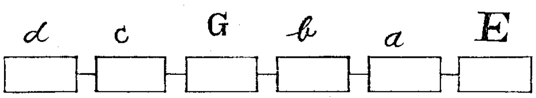


Fig. 4.



G......The "Goryo-sha" carriage.

B......The 1st class 6-wheel Bogie carriage.

a, *b*, *c*, *d*,......Bogie carriages.

E......Engine.

Fig. 5 (Pl. XVII), on the floor of the latter and along the middle axis at a distance of 10 feet from the centre, namely, at one-third of the length. On Oct. 10th, the experiment was repeated with the court railway train (Fig. 4), the positions where the instruments were set up in the *goryo-sha* corresponding exactly to those in the 6-wheel bogie carriage on the previous occasion. As, further, the places of the *goryo-sha* and the bogie carriage in the respective trains were identical, these two sets of experiments enabled us to make a fair comparison of the vibrations of the two carriages under consideration. It may hereby be noted that the weather was fine and calm both on the 7th and the 10th.* The distance between Shinbashi and Kōzu is 46.8 miles, and the maximum velocity of the trains was 41.3 miles per hour.

6. Comparison of goryo-sha and 1st class 6-wheel bogie

* A heavy rainfall softens the soil and consequently tends to augment the vibrations of the carriages.

carriages: vertical vibrations. The vertical motion diagrams for the two carriages were, on the whole, mutually similar, excepting for the difference in amplitude, and admit of more or less definite identification of the individual vibrations at the different parts of the railroads. Thus Fig. 9 (Pl. XXI), gives the reproduction of the records when the two carriages were each running with a speed of 40 to 41 miles per hour along the down line in the vicinity of the Hodogaya tunnel, about $24\frac{1}{4}$ miles from Shinbashi; *a*, *b*, *c*, *d*, ... in the two diagrams indicating some of the well marked vibrations in the motion of the *goryo-sha* and in that of the bogie carriage.

From a comparative list of the velocity and of the amplitude and period of vibration of the two carriages at different places on the down line from Shinbashi to Kōzu, I have obtained the following mean results :—

Period (T)............**0.48** sec. (Goryo-sha.) ...... **0.455** sec. (1st class 6-wheel bogie carriage.)

Ratio : $\frac{\text{st class 6-wheel bogie car.}}{\text{goryo-sha}}$ .... {Velocity......0.97; Max. 2a......**1.56**}

Thus, although the transit velocity was on the whole equal in the two series of experiments, the $2a$ and T of the vertical vibration of the *goryo-sha* were respectively smaller and slower in the mean ratios of 100:156 and of 105:100 than those of the first class bogie carriage. Their maximum accelerations in the vibratory movement were consequently in the mean ratio of 100: 172; in other words, the intensity or violence of shaking of the *goryo-sha* was, in the vertical component, 40% less than that of the first class bogie carriage. Further, the latter often indicated, for certain low values of the velocity, a maximum group consisting of a number of large and regular vertical vibrations, which lasted a few seconds. This movement, which evidently resulted from the flexure of the car body, was entirely wanting in the case of the *goryo-sha*.

7. Comparison of goryo-sha and 1st class 6-wheel bogie carriages: lateral vibration. A comparative examination of the horizontal pendulum diagrams obtained on Oct. 7th and 10th shows that the lateral motion of the *goryo-sha* was smaller but perfectly similar to that of the bogie carriage. As illustrative examples, I reproduce in Figs. 10 and 11 (Pls. XXII and XXIII), the records for the neighbourhood of 14 and 27 miles, on the down line; the velocity being 30.7–32.1 miles per hour in the former, and 33.8–36.0 miles per hour in the latter case. As may be seen from these examples, the individual vibrations as well as slow inclination movements can be identified, even to the small insignificant details, in the diagrams of the two carriages. It thus appears that the lateral motion under consideration must be the result of impressing on the carriages the shocks or displacements arising from the inequalities in the height, gauge, direction, and curvature of the rails, the variation in the nature of the soil, etc. In other words, the lateral vibration diagram is a sort of the tracing of the irregularities on the permanent road manifested as effects on the carriages running over it. As will be easily inferred from the above statements, the lateral vibrations of the *goryo-sha* and the first class bogie carriages were practically identical in period.

From a comparative list of the $2a$ and T of a number of the well defined individual vibrations identified in the diagrams of the *goryo-sha* and the 1st class 6-wheel bogie carriages, I have obtained the following mean results :—

Period............**1.34** sec. (Goryo-sha) .... **1.33** sec. (1st class 6-wheel bogie carriage.)

Ratio : $\frac{\text{1st class 6-wheel bogie car.}}{\text{goryo-sha}}$ .... { Velocity......1.00; Max. $2a$......**1.35** }

It is seen that although the transit velocity was on the whole identical in the two series of experiments, the $2a$ of the *goryo-sha* was smaller than that of the 1st class bogie carriage in the mean ratio of 100:135. As there was no difference in the period, the maximum accelerations of motion of the two carriages were also in the same ratio, namely, the lateral vibration of the *goryo-sha* was about 26 % less intense than that of the other.

8. Experiments on Oct. 12th to 18th, 1910: vibration measurement of the goryo-sha. The long-distance trial runnings of the court railway train were carried on over the Tōkaidō (Shinbashi to Kōbe), the Sanyō (Kōbe to Okayama), the Chūgoku (Okayama to Tadaegawa), the Maizuru (Kyōto to Shin-Maizuru) lines, during one week from the 12th to the 18th, Oct., according to the following schedule, in which the condition of the weather on the different days is also indicated :—

Date (Oct., 1910)	Railway Line.	Weather.
12th	Shinbashi to Hamamatsu	Heavy rainfall during the previous night: rainy in the morning, clearing up on the afternoon.
13th	Hamamatsu to Osaka	Heavy rainfall during the previous night: rainy till about the noon, thereafter cloudy.
14th	Osaka to Okayama, Okayama to Tadaegawa and back.	At first cloudy, then fair.
15th	Okayama to Kyoto.	Fair.
16th	Kyoto to Shin-Maizuru and back.	Cloudy or fair, except at Shin-Maizuru where slight rain fall took place.
17th	Kyoto to Shizuoka.	Fair.
18th	Shizuoka to Shinbashi.	Fair.

In these trial runnings, which were made only in the day time, the composition of the train was the same as that on Oct. 10th, The instruments were, however, set up at the centre of the floor of the *goryo-sha*, and not at one-third the length, as on the latter date. Consequently, the movements recorded on the present occasion (restricting our attention to the line between Shinbashi and Kōzu) differed from those relating to the experiment on Oct. 10th, in so much as the two series of measurements did not allow of an identification of the individual vibrations, although the period remained unaffected. It is evident that a bogie carriage is, during its running, thrown also into a sort of rotation about a a vertical axis, while the vertical vibration, depending much on the elasticity of the supporting springs, and the flexibility of the car floor, will not be uniform at different points of the latter. The complete vibratory motion of a railway carriage must be regarded as composed of the following 6 varieties :—

(i) Linear vibration in the vertical direction ;
(ii) Do. normal to the length ;
(iii) Do. parallel ,, ,, ;
(iv) Rotation about an axis parallel to the length ;
(v) Do. ,, ,, normal ,, ,, ;
(vi) Do. ,, a vertical axis.

Of these the most pronounced are the first two, namely, the vertical and lateral vibrations we are considering. What is discussed in the following §§ relates to the measurements of the linear vibrations of the *goryo-sha*.

9. Large vibrations. The vibrations of railway carriages are generally intensified on newly constructed or newly repaired sections, where the permanent road has not yet attained its settled condition. Now, on the Tōkaidō line there were several portions, where, at the time of the present experiments, the road damaged by the great flood of Aug. 10th–12th of the same year, had barely received provisionary repairs. As, however, the train ran over such districts with a low speed of about 6 miles per hour, the *goryo-sha* indicated there no specially large vibration.

As examples of the localities on the Shinbashi–Kōbe line, where the vibrations were strong, may be mentioned the Ōmori–Hiranuma, Hodogaya–Totsuka, Maibara–Yasu, and Mukōmachi (Kyōto)–Yamazaki sections. On the Kyōto and Shin-Maizuru line, which had been opened to traffic only about 2 months previously, the motion was specially large at $21\frac{1}{4}$–$\frac{1}{2}$ miles distance from Kyōto. (See Fig. 13, Pl. XXV.) As well shown in the case of this line, the vibrations of the carriage were in general distinctly stronger in, than before and after, the tunnels. (See Fig. 15, Pl. XXVI.) The following table gives a list of the larger vertical and lateral vibrations of the *goryo-sha*, exclusive of the effects due to curves and points.

TABLE I. LIST OF THE LARGE VIBRATIONS.

(Cases of the passage over the points excepted.)

Line.	Train.	Mileage.*	Velocity.	Lateral Vibration.		Mileage.*	Velocity.	Vertical Vibration.	
				max. $2a$	Period (T)			max. $2a$	Period (T)
		miles	m/h	mm	sec.	miles	m/h	mm	sec.
(i) Ōsaka-Kyōto.	Up	354.00	28.6	93	1.5	343.70	35.0	35.0	0.60
		351.75	31.7	93	1.5	$334\frac{3}{4}$–335.00	35.3	41.5	0.50
		347.28	23.0	87	1.5	$334\frac{1}{2}$–$\frac{3}{4}$	35.1	34.0	0.49
		332.75	28.3	93	1.3				
		332.38	30.8	91	1.45				
(ii) Kyōto-Ōsaka.	Down	351.60	32.2	67	1.3	352.80	33.0	17.3	0.46
		351.00	32.2	61	1.5	352.70	32.8	20.2	0.47
		342.95	29.7	71	1.6	349.95	38.7	20.5	0.45
		338.60	29.5	61	1.35	347.81	33.0	20.0	...
		337.93	30.0	73	1.4	340.50	35.1	17.0	0.44
		335.25	30.3	61	1.35	335.73	34.0	17.5	0.50
		334.65	32.0	72	1.3				
		333.28	32.8	66	1.28				
		$331\frac{3}{4}$–$332\frac{1}{2}$	38.3	61	1.15				

Line.	Train.	Mileage.	Velocity	Lateral Vibration.		Mileage.	Velocity.	Vertical Vibration.	
				max. $2a$	Period (T)			max. $2a$	Period (T)
(iii) Shinbashi to Fukuroi	Down	miles 17.75	m/h 22.0	mm 86	sec. 1.35	miles 8.30	m/h 42.1	mm 19.0	sec. 0.46
		23.38	28.2	89	1.2	11.38	36.8	21.0	0.5
		77.38	27.2	84	1.5	14.93	37.6	21.0	0.51
		100.44	28.3	81	1.4	28.00	33.7	20.7	0,50
		123.75	28.9	87	1.75	36.93	32.7	22.0	......
						45.93	37.6	21.3	0.60
(iv) Shin-Maizuru to Kyōto	Up	** 22.63	—	116	1.5				

From the above table, it will be seen that the large lateral vibrations of the carriage sometimes reached, when running along the straight parts of the road with velocities of 23 to 42 miles per hour, the $2a$ of 60 to 90 mm ($2''\frac{1}{2}$ to $3''\frac{1}{2}$), the T being from 1.2 to 1.8 sec. The large lateral motion of $2a=116$ mm ($=4''\frac{1}{2}$) observed on the Maizuru line may be regarded as exceptional. The vertical vibration, even when very strong, generally did not exceed 21 mm ($=0.''8$); the period T being 0.44 to 0.6 sec.

The unusually large vertical motion exhibited in the present case on the up line between Ōsaka and Kyōto (Pl. XXIV) was probably due to accidental circumstances attending the change of the sleepers, which was then going on in this railway section, such that on Oct. 13th, the day of the experiment in question, the process of repair was executed over $2\frac{1}{2}$ and 7 miles respectively on the down and up lines. It was afterwards found that the *goryo-sha* had not been tightly coupled to the bogie carriage at its front, with the result that the two foot-boards between them had been distorted in consequence of their striking againt each other. But

* The mileage is for (i) to (iii) from Shinbashi (Tōkyō), and for (iv) from Kyōto.

** This occurred in a straight portion of the railway.

we were not able to ascertain whether the coupling was loose from the start on that morning, or whether it was rendered so by the violence of the vertical movements. The greatest lateral and vertical vibrations were as follows:—

No.	Railway Section.	2*a*	*T*	Max. Acceleration.
	Lateral Vibration.	mm.	sec.	mm/sec.
i	Ōsaka to Kyōto, Up line.	93	1.3–1.5	1100
ii	Maizuru, Up line.	116	1.5	1020
	Vertical Vibration.	mm.	sec.	
iii	Shinbashi to Ōsaka, Down line.	20.5	0.45	2000
iv	Ōsaka to Kyōto, Up line.	41.5	0.5	3280

Of the large vibrations indicated above, (i) and (iii) give the maximun accelerations of 1100 and 2000 mm/sec^2., and (ii) and (iv) of 1020 and 3280 mm/sec^2. The former pair of the accelerations may be regarded as indicating respectively the intensities of motion of the strongest lateral and vertical shakings of the *goryo-sha* under ordinary conditions, and the latter pair those relating to exceptional cases.

The following is a comparative list of the vibrations of the *goryo-sha* on the down and up lines between Kyōto and Ōsaka; the velocity given in the table being each a mean deduced from a number of the approximately equal values, and the 2*a* the mean of the corresponding ranges of motion.

TABLE II. VIBRATIONS* OF THE CARRIAGE "GORYO-SHA," BETWEEN KYŌTO AND ŌSAKA. DOWN AND UP TRAINS.

Lateral Vibration.				Vertical Vibration.			
Down Line.		Up Line.		Down Line.		Up Line.	
Velocity	max. 2a	Velocity	max. 2a	Velocity	max. 2a	Vel city	max. 2a
m/h	mm.	m/h	mm.	m/h	mm.	m/h	mm.
—	—	—	—	—	—	21.2	6.9
—	—	22.7	63.5	24.7	8.8	—	—
—	—	26.6	57.4	—	—	26.0	10.9
28.8	54.2	28.6	68.7	28.6	11.1	28.1	12.7
—	—	29.5	58.8	—	—	29.5	12.5
—	—	30.6	62.0	30.4	10.8	30.5	18.3
—	—	31.4	61.9	31.0	12.7	31.6	13.9
32.4	56.2	32.6	62.5	32.6	12.6	—	—
33.2	46 2	33.3	54.9	33.3	13.7	33.2	18.4
—	—	34.5	65.9	34.1	16.2	34.5	17.5
35.2	48.8	35.1	52.2	35.5	13.4	35.2	28.3
36.2	51.1	36.8	49.5	36.3	12.2	36.6	18.2
38.0	57.0	38.5	52.0	37.9	15.7	38.0	24.4
—	—	—	—	39.5	15.5	—	—
40.5	40.8	—	—	—	—	—	—

* Mean results, including the effects due to curves, road-crossings, etc.

According to the above table, the lateral vibration of the *goryo-sha* on the up line, Ōsaka to Kyōto, was greater only in the average ratio of 1.1:1 than that on the down line, Kyōto to Ōsaka; while the vertical vibrations on these two lines differed in the average ratio of 1.44 : 1. (See also Pl. XXIV) Thus the effect of the loose coupling or of the unsettled condition of the road was greater, in the present case, on the vertical than on the lateral component motion.

10. Period of vertical vibration. From the experiment on Oct. 10th (§ 6), the maximum vertical motion of the *goryo-sha* was, for the transit velocity of 28.4 to 40.1 miles per hour, found to be 13.5 mm, the period varying between 0.39 and 0.6 sec., with the mean value of 0.48 sec. According to the experiment on Oct. 12th–18th, the period of the motion was as follows.

(i) Cases of large movements only (Table I):
Velocity=32.7 to 42.1 miles per hour.
Max. Vertical 2a=17 to 41.5 mm.
Average T=0.50 sec.

(ii) Down line measurements between Shinbashi and Kōzu, and between Nagoya and Gifu (Table IV):
Velocity=17.2 to 42.2 miles per hour.
Max. Vertical 2a=2.9 to 15.9 mm.
Average T=0.50 sec.

Thus, notwithstanding such a great difference in the amplitude of motion as between (i) and (ii), the period of the vertical vibration was constant, with the average value of T=0.50 sec. Further, from Table VI it will be seen that the period of the motion did not depend on the transit velocity.

11. Period of lateral vibration. From the experiment on Oct. 10th (§ 7), the average period of the lateral vibration was found to be 1.34 sec., the transit velocity varying between 22.4 and 39.8 miles per hour. Again, according to measuremants on Oct. 12th to 18th, when the transit velocity was 22 to 38.3 miles per hour, the average period of those large vibrations, whose 2a varied between 61 and 116 mm, was 1.36 sec. (Table I), being the same as that obtained on the previous occasion. It thus seems that the period of the lateral vibration did not depend on the amplitude between the limits of 2a from about 10 mm to over 100 mm. It depended, however, on the transit velocity, as is shown later on. It is likely that the conditions of the road and the transit velocity modify the proper oscillation period of the *goryo-sha.* To find out this quantity, I have taken, from the Ōsaka-Kyōto up line diagram, those cases in which there was a succession of a few or several dozens of regular movements, which may be supposed to constitute the proper car motion; the mean period being as indicated in the following table.

TABLE III. PERIOD OF THE LATERAL VIBRATION OF THE CARRIAGE "GORYO-SHA."

Distance from Shinbashi (Tōkyō)	Velocity (V)	Period (T)	Max. 2a
miles	m/h	sec.	mm.
329½—¾	26.4	1.23	37
329¾—330	?	1.20	40
330¾	19.6	1.24	63
330¾—331	19.6	1.51	24
331 —¼	21.8	1.17	11
331¼—½	23.9	1.17	54
331¾—332	31.8	1.18	62
332¼—½	30.8	1.15	53
336½—¾	32.7	1.13	33
337¼	29.5	1.32	55
337 —½	26.9	1.20	48
337½—¾	29.7	1.33	61
338 —¼	26.2	1.26	54
341½	31.1	1.28	52
342½—¾	29.0	1.03	31
,,	,,	1.27	46
343 —¼	31.0	1.26	63
343¼—½	27.9	1.19	45
343½—¾	31.1	1.16	46
344¾—345	31.2	1.13	74
345 —¼	32.8	1.24	73
345½—¾	34.9	1.18	50
345¾—346	31.7	1.12	50

Distance from Shinbashi (Tōkyō)	Velocity (V)	Period (T)	Max. 2a
miles	m/h	sec.	mm.
347$\frac{1}{4}$—$\frac{1}{2}$	20.1	1.50	51
349$\frac{3}{4}$—350	35.0	1.11	54
350$\frac{3}{4}$—351	29.3	1.17	50
,,	,,	1.26	50
352 —$\frac{1}{4}$	33.2	1.25	26
353$\frac{1}{4}$—$\frac{1}{2}$	30.0	1.14	47
353$\frac{1}{2}$—$\frac{3}{4}$	28.3	1.15	35
353$\frac{3}{4}$—354	26.5	1.24	51
354$\frac{1}{4}$—$\frac{1}{2}$	27.8	1.17	40
354$\frac{1}{2}$	26.0	1.13	19
355 —$\frac{1}{4}$	26.8	1.22	45
Mean	—	**1.24**	—

Thus, we obtain, for the velocity of 19.6 to 35 miles per hour and the 2a of 11 to 74 mm, the period (T) of 1.03 to 1.51 sec., the mean value being 1.24 sec. On the other hand, the principal vibrations were often mixed up with very small regular movements, whose 2a was less than 12 mm, and whose period was, according to the measurement on the Shinbashi-Fukuroi down line, as follows :—

0.52 sec.	0.93 sec.
0.70	0.94
0.75	0.96
0.75	0.97
0.78	1.00
0.85	1.02
0.87	1.05
0.83	1.07
0.90	1.10

Thus, the small vibrations under consideration had most frequently a period of 0.7 to 1 sec., the general average value being 0.90 sec. It may be that the latter is the period of the natural oscillation of the carriage, which is lengthened to about 1.2 sec., when the range of motion becomes a little larger.

12. Relation between velocity and amplitude of vibration. In Table IV are given the different mean values of the transit velocity (V) and the corresponding ranges of motion (2a) of the lateral and vertical vibrations of the carriage *goryō-sha*.

TABLE IV. RELATION TO VELOCITY OF THE AMPLITUDE OF THE VIBRATIONS OF THE CARRIAGE "GORYO-SHA." DOWN TRAIN.

(i) Lateral Vibration. Shinbashi to Fukuroi.		(ii) Vertical Vibration. Shinbashi to Kōzu.		(iii) Vertical Vibration. Shinbashi to Kōzu.		(iv) Vertical Vibration. Nagoya to Gifu.	
V	2a	V	2a	V	2a	V	2a
m/h	mm.	m/h	mm.	m/h	mm.	m/h	mm.
11.7	9.0	—	—	—	—	—	—
16.8	24.8	—	—	17.8	3.0	16.6	4.1
19.5	39.4	18.1	3.3	—	—	—	—
21.1	34.9	—	—	—	—	—	—
22.4	48.0	—	—	—	—	22.8	6.0
23.5	43.2	—	—	—	—	—	—
24.4	46.6	—	—	—	—	—	—
25.5	46.9	—	—	—	—	—	—
26.3	46.3	26.5	7.5	26.5	7.1	26.1	5.9
27.4	41.5	—	—	—	—	—	—
28.3	45.0	28.8	9.0	—	—	28.2	6.1
29.4	44.2	—	—	—	—	29.4	5.7
30.5	47.6	30.5	8.7	30.5	8.9	30.5	9.1
31.5	44.2	31.4	7.6	31.3	7.3	31.5	7.4
32.5	41.2	32.7	10.8	32.7	8.8	32.5	11.8
33.6	46.2	33.5	11.8	33.5	11.5	33.5	9.2
34.4	43.0	34.6	11.0	34.4	10.0	34.2	10.7
35.3	38.3	35.5	8.9	35.6	9.4	35.4	10.7

(i) Lateral Vibration. Shinbashi to Fukuroi.		(ii) Vertical Vibration. Shinbashi to Kōzu.		(iii) Vertical Vibration. Shinbashi to Kōzu.		(iv) Vertical Vibration. Nagoya to Gifu.	
V	2a	V	2a	V	2a	V	2a
m/h	mm.	m/h	mm.	m/h	mm.	m/h	mm.
36.4	42.2	36.3	13.0	36.4	11.6	36.8	10.9
37.4	37.6	37.5	13.1	37.6	11.9		
38.5	35.8	38.3	11.3	38.3	13.8		
39.5	27.5	39.5	10.0	39.5	8.8		
40.9	32.3	41.8	13.8	—	—		
43.3	31.3	—	—	43.6	14.3		

(i)......Excluding the effects due to Curves and Points.

(ii), (iv) ...Including the effects due to Curves, Points, etc.

(iii)......Excluding the effects due to Curves, Points, Road Crossings, Bridges, etc.

Vertical Motion. According to the above table, the 2a of the vertical vibration increased, within the limits of the experiments, at a slow rate with the transit velocity. Thus, as is shown in Fig. 7 (Pl. XIX), which illustrates the relation in question for the Shinbashi–Kōzu section, the mean maximum vertical 2a's for the velocities of 25 and 40 miles per hour were respectively 6.5 and 12 mm. That the curves and points did not cause an appreciable augmentation of the motion may be seen from the comparison of the columns (ii) and (iv) with the column (iii), in Table IV. Again, the rail joints gave very slight vertical shocks to the bogie carriages.

Lateral Motion. The amplitude of the lateral vibration of the *goryō-sha* increased, when running on straight portions of the road, at first with the transit velocity, till it reached the maximum amount when the latter was about 25 miles per hour; the motion decreasing for the higher speeds. Thus, according to Fig. 7 (Pl. XIX), which illustrates the amplitude-velocity relation for the Shinbashi–Fukuroi section, the greatest mean value of the maximum 2a of 46 mm occurred with the velocity of 25 miles per hour;

while the 2a corresponding to the velocity, for instance, of 42 miles per hour was reduced to 30 mm, or only two-thirds of the former amount.

That the lateral 2a of the *goryo-sha*, and probably that of all the other bogie carriages, decreases with the higher transit velocities depends undoubtedly on the principle of the bogie construction, which renders the car body steady when running quickly. A not inappropriate analogy is furnished by the bycicle, which, although unstable when driven slowly, becomes perfectly steady under a high velocity.

13. Relation between velocity and period of vibration. Table V gives for the carriage *goryo-sha*, the different mean values of the transit velocity (V) and the corresponding ranges (2a's) of the lateral and vertical vibrations.

TABLE V. RELATION BETWEEN THE OSCILLATION PERIOD AND THE TRAIN VELOCITY.

{ Lateral Vibration......Shinbashi to Fukuroi
{ Vertical ,, ...Shinbashi to Kōzu, and Nagoya to Gifu.

Lateral Vibration.			Vertical Vibration.		
V	2a	T	V	2a	T
m/h	mm.	sec.	m/h	mm.	sec.
16.6	25.0	**1.70**	—	—	—
19.7	40.1	**1.71**	17.2	2.9	0.43
21.4	40.1	**1.64**	—	—	—
22.4	50.1	**1.60**	—	—	—
23.5	40.6	**1.53**	—	—	—
24.4	48.1	**1.52**	—	—	—
25.5	46.2	**1.51**	25.1	6.2	0.57
26.3	47.4	**1.44**	—	—	—
27.3	39.5	**1.42**	—	—	—
28.3	50.4	**1.40**	—	—	—
29.3	44.5	**1.44**	29.1	6.0	0.52

Lateral Vibration.			Vertical Vibration.		
V	2a	T	V	2a	T
m/h	mm.	sec.	m/h	mm.	sec.
30.5	46.0	**1.42**	30.4	8.5	0.54
31.5	43.4	**1.36**	31.5	7.4	0.50
32.5	37.9	**1.30**	32.5	9.3	0.51
33.5	44.0	**1.32**	33.5	10.6	0.50
34.4	38.7	**1.39**	34.5	10.5	0.48
35.3	37.2	**1.30**	35.4	10.1	0.51
36.3	39.9	**1.34**	36.4	12.9	0.51
37.4	39.1	**1.22**	37.6	14.1	0.50
38.5	35.9	**1.22**	38.3	12.1	0.45
39.4	31.0	**1.17**	39.5	10.2	0.51
41.8	28.5	**1.25**	42.2	15.9	0.48
Mean	—	—	—	—	**0.50**

As stated before, the period of the vertical vibration was about 0.5 sec., and did not depend on the velocity. The period of the lateral vibration, however, indicated some decrease with the increase of the velocity. As illustrated in Fig. 8, the lateral period, which was 1.7 sec. when the velocity was 18 miles per hour, was reduced, at the velocity of 42 miles per hour, to 1.2 sec., or to 2/3 of the former value. Taking the amplitude-velocity relation into account, it follows that the maximum acceleration, or the intensity of the lateral motion increases at a slow rate, with the transit velocity. Thus, the values of the maximum accelerations for the two above mentioned velocities of 42 and 18 miles per hour are in the ratio of 130 : 100.

The relation between the velocity (V) and the lateral vibration period (T), based on Table V, may approximately be represented by the formula :

$$T^{sec.} = \frac{91.03}{35.25 + V^{m/h}} \quad \cdots\cdots\cdots (1)$$

The result of calculation of the T by means of Equation (1) is satisfactory as shown below :

Velocity (V).	Lateral Period.	
	Actual, T.	Calculated, T′
m/h	sec.	sec.
(1) 19.2	1.68	1.67
(2) 23.4	1.55	1 55
(3) 26.4	1.46	1.47
(4) 29.9	1.41	1.39
(5) 33.5	1.34	1.32
(6) 36.3	1.29	1.27
(7) 39.9	1.21	1.21

In the above table, the V and T are the means obtained by dividing the different values in Table V suitably into 7 successive groups ; the T′ being the value corresponding to the velocity V calculated by (1).

14. Effect of curve on lateral vibration. The following table, which relates to the measurements on Oct. 12th-18th, gives a list of the well defined individual lateral vibrations (2a), which occurred when the carriage *goryo-sha* entered or left the different curves.

TABLE VI. CURVE EFFECT : LATERAL VIBRATION OF THE CARRIAGE "GORYO-SHA"

{Down Train, Shinbashi to Fukuroi.
{Up and Down Trains, between Kyōto and Ōsaka.

Velocity.	2a	Period (T).	Curve Radius.
15.5 m/h	72 mm.	1.8 sec.	20 chains
19.1	59	1.75	20
22.3	68	1.6	20

Velocity.	2a	Period (T).	Curve Radius.
22.7 m/h	56 mm.	1.45 sec.	20 chains
23.3	26	1.45	20
24.9	74	1.55	30
25.0	38	1.48	40
26.0	46	1.2	40
26.0	44	1.35	30
27.5	42	1.75	60
28.1	41	1.45	20
28.2	89	1.2	30
29.2	49	1.3	40
29.3	45	1.3	40
30.2	50	1.55	60
30.6	30	1.35	20
30.8	53	1.3	60
34.9	41	1.3	40
35.6	50	1.3	40
36.3	37	1.25	80
37.6	76	1.25	40
39.5	76	1.2	32

According to the above table, the period of the lateral vibration had, for the velocity of 15 to 39.5 miles per hour, the average value of 1.4 sec.; the greatest of the movements being 89 mm ($=3''\frac{1}{2}$), with a period of 1.2 sec.*

Table VII. gives for the different mean velocities, a comparison of the lateral vibrations of the *goryo-sha* when passing along the straight portions of the road and when passing along the curves. These latter had in the majority of cases radii of 20, 40, or 60 chains.

* The movement of the horizontal pendulum was, when the carriage was passing along the curve, greatly influenced by the tilting motion. Table VI gives only those cases in which the period of the sudden shock caused by the curve was satisfactorily measured.

TABLE VII. LATERAL VIBRATION OF THE CARRIAGE "GORYO-SHA" CAUSED BY CURVES, COMPARED WITH THE MOTION ON THE STRAIGHT (OR NON-CURVED) PORTIONS OF THE RAILWAYS.

{Down Train, Shinbashi to Fukuroi.
{Up and Down Trains, between Kyōto and Ōsaka.

Motion at the beginning or end of a curve.		Motion on straight (non-curved) parts of the railways.	
Velocity.	2a	Velocity.	2a
15.0 m/h	43 mm.	16.8 m/h	24.8 mm.
21.9	70	21.8	41.5
23.4	51	23.5	43.2
24.8	62	24.4	46.6
26.3	55	26.3	46.3
28.1	65	28.3	45.0
29.4	56	29.4	44.2
30.4	46	30.5	47.6
31.7	76	31.5	44.2
33.0	69	33.1	43.7
34.5	71	34.4	43.0
35.3	72	35.3	38.3
36.4	47	36.4	42.2
37.6	80	37.4	37.6
39.7	66	39.5	27.5

According to the above table, the curves seem, for the transit velocity of 25 to 30 miles per hour, to have caused no marked augmentation of the lateral vibration of the *goryō-sha*. The curve effect was, however, distinctly manifested for the velocities under 25 miles per hour or those above 30 miles per hour, culminating at the velocities of 15 miles per hour, and of 40 miles per hour when the lateral movements due to the curves became double those produced on the straight, or non-curved, portions of the road. It seems that the curve effect vibrations increased with the velocity more rapidly than the ordinary ones.

Table VIII gives the 2a's of the individual vibrations produced by the three sets of the curves, whose radii were respectively equal to 20, 40, and 60 chains, arranged in order of the velocity. Further, Table IX gives the mean figures relating to the velocity-amplitude relation obtained by suitably grouping the values contained in Table VIII.

TABLE VIII. LATERAL VIBRATION OF THE CARRIAGE "GORYO-SHA," CAUSED BY CURVES OF 20, 40, AND 60 CHAINS RADII.

{ Down Train, Shinbashi to Fukuroi.
{ Up and Down Trains, between Kyōto and Ōsaka.

Velocity.	2a	Velocity.	2a	Velocity.	2a	Velocity.	2a
R = 20 chains		m/h	mm.	m/h	mm.	m/h	mm.
m/h	mm.	29.8	45	26.0	39	37.8	56
15.1	37	29.8	46	26.0	46	37.8	55
15.1	64	30.0	74	26.9	63	37.7	114
15.5	72	30.6	30	28.5	53	44.1	88
19.1	59	30.6	26	28.3	43	R = 60 chains	
21.1	70	31.7	122	29.1	44	m/h	mm.
21.1	54	31.7	170	29.2	49	10.2	9
21.6	47	31.8	47	29.2	55	23.3	18
21.6	88	32.1	74	29.3	45	23.2	51
22.3	113	32.5	75	29.5	57	24.5	60
22.3	68	33.3	120	29.5	61	26.1	57
22.7	56	33.5	44	31.5	62	27.5	42
23.0	59	33.7	60	31.8	85	27.5	92
23.8	104	33.9	80	31.7	93	31.3	54
23.3	26	34.4	53	32.2	40	30.2	50
24.6	52	34.4	87	34.0	86	30.8	53
24.5	64	34.0	104	34.5	82	31.8	29
24.5	70	35.0	83	34.9	41	31.8	66
25.0	72	35.0	80	34.7	102	34.2	58
26.0	76	35.5	72	34.8	97	34.6	83
26.5	49	35.6	20	35.6	37	37.5	102
28.6	100	37.0	148	35.6	50	37.5	110
28.6	93	R = 40 chains		36.4	58	38.3	55
28.1	41	m/h	mm.	36.4	46	38.3	61
28.5	52	13.0	30	37.5	60		
28.3	96	22.8	63	37.5	130		
29.5	74	25.0	38	37.6	76		

TABLE IX. LATERAL VIBRATION OF THE CARRIAGE "GORYO-SHA," CAUSED BY CURVES OF 20, 40, AND 60 CHAINS RADII.

Mean Group Values deduced from Table VIII.

R = 20chains		R = 40chains		R = 60chains	
Velocity.	2a	Velocity.	2a	Velocity.	2a
m/h	mm.	m/h	mm.	m/h	mm.
16.2	58	—	—		
—	—	20.3	44		
21.4	65	—	—		
22.9	71	—	—		
25.2	64	—	—	25.4	52
—	—	27.1	49	—	—
28.9	69	—	—	—	—
—	—	29.3	52	—	—
31.1	78	—	—	31.2	50
—	—	32.2	73	—	—
33.2	76	—	—	—	—
35.1	81	35.4	66	—	—
—	—	—	—	36.7	78
—	—	38.6	83	—	—

In the case of the curve effect (=2a) on an ordinary, or non-bogie, 4-wheel carriage, measured on the Sanyo-Railway, I have obtained the following formula :

$$2a^{mm} = \frac{64\ V^{m/h}}{R^{chains}} \ \ldots\ldots\ (2)$$

in which 2a is the range of the lateral vibration caused by a curve of radius R, V being the transit velocity.* Now the formula (2), or another similar to it, is found entirely inapplicable to the case of

* See the *Publications*, No. 20.

the curve effect on the *goryo-sha*. For the latter, let us assume an equation of the form

$$2a = \frac{k\,V}{h+R} \;\;\dots\dots\;(3)$$

k and h being constants. Calculating the values of these by means of the data contained in Table IX, we find :—

$$2a^{mm} = \frac{167\;V^{m/h}}{39.7+R^{chains}} \;\;\dots\dots\;(3')$$

Equation (3′) represents fairly well the relation for the case in question. Now, comparing the curve effects ($=2a_1$) on the ordinary 4-wheel carriage and that ($=2a_2$) on the *goryo-sha* (bogie carriage), for a set of given values of V and R, we have

$$\frac{2a_1}{2a_2} = \frac{64\,(R+39.7)}{167\,R} \;\;\dots\dots\;(4)$$

Calculating by Equation (4), we obtain :—

R (chains) ……	20	40	60
$\frac{2a_1}{2a_2}$ ……………	1.14	0.76	0.63

Thus it appears that the effect caused by the curves of comparatively large radii of 40 and 60 chains was greater for the *goryo-sha* than for the ordinary 4-wheel carriage. The reverse was, however, the case with the curves of small radius of 20 chains.

List of Plates.

(Pl. XVII.) Fig. 5. 1st Class 6-wheel Bogie Carriage. (L) and (V) respectively indicate the positions on the floor where the lateral and the vertical instruments were set up.

(Pl. XVIII.) Fig. 6. Vibration Recorder, to be used for the measurement of the lateral and vertical vibrations of a railway carriage.

(Pl. XIX.) Fig. 7. Relation to the Velocity (V) of the Double-amplitudes (2a's) of the Lateral and Vertical Vibrations of the Carriage *Goryo-sha.*

Lateral Vibration { Down Train, from Shinbashi to Fukuroi, the effects due to points and curves being excluded.

Vertical Vibration { Down Train, from Shinbashi to Kōzu, including the effects due to points, curves, etc.

(Pl. XX.) Fig. 8. Relation between the Velocity (V) and the Period (T) of the Lateral Vibration of the Carriage *Goryo-sha.* Down Train, from Shinbashi to Fukuroi.

(Pl. XXI.) Fig. 9. Comparison of the Vertical Vibrations of the *Goryo-sha* and the 1st Class 6-wheel Bogie Carriages. Magnification of motion=2. Down Trains, from Shinbashi to Kōzu ; at $24\frac{1}{4}$–25 miles.

[A] Vibration of the Carrriage *Goryo-sha.* Velocity=39.3 miles per hour. (Oct. 10th, 1910.)

[B] Vibration of the 1st class 6-wheel Bogie Carriage. Velocity=41 miles per hour. (Oct. 7th, 1910.)

(Pl. XXII.) Fig. 10. Comparison of the Lateral Vibrations of the *Goryo-sha* and the 1st Class 6-wheel Bogie Carriages. (Half size.) Down Trains, from Shinbashi to Kōzu ; at $14\frac{1}{4}$–$\frac{3}{4}$ miles.

[A] Vibration of the Carriage *Goryo-sha.* Velocity=30.7 miles per hour. (Oct. 10th, 1910.)

[B] Vibration of the 1st Class 6-wheel Bogie Carriage. Velocity=32.1 miles per hour. (Oct. 7th, 1910.)

(Pl. XXIII.) Fig. 11. Comparison of the Lateral Vibrations of the *Goryo-sha* and the 1st Class 6-wheel Bogie Carriages. (Half size.) Down Trains, from Shinbashi to Kōzu; at 27 miles.

[A] Vibration of the Carriage *Goryo-sha*. Velocity=33.8 miles per hour. (Oct. 10th, 1910.)

[B] Vibration of the 1st Class 6-wheel Bogie Carriage. Velocity=36 miles per hour. (Oct. 7th, 1910.)

(Pl. XXIV.) Fig. 12. Lateral and Vertical Vibrations of the Carriage *Goryo-sha*. Up Train, from Ōsaka to Kyōto; at 350 miles. Velocity=33.5 miles per hour. (Oct. 15th, 1910.)

[A] Lateral vibrations. (Half size.)

[B] Vertical vibrations. (Magnification=2.)

(Pl. XXV.) Lateral Vibration of the Carriage *Goryo-sha*. (Half size.) **Fig. 13.** Shin-Maizuru Line; Up Train, at 21 to 21½ miles. Velocity=26.2 miles per hour. **Fig. 14.** Effect caused by a Point, the Up Train stopping at the Saga station.

(Pl. XXVI.) Fig. 15. Lateral Vibration of the Carriage *Goryo-sha* (half size) during the passage through the Tunnel at 10¼ miles on the Shin-Maizuru Line; Up Train, Velocity=26.5 miles per hour. (Oct. 16th, 1910.)

Fig. 5. 1st Class 6-wheel Bogie Carriage.

(*L*) and (*V*) respectively indicate the positions on the floor where the lateral and the vertical instruments were set up.

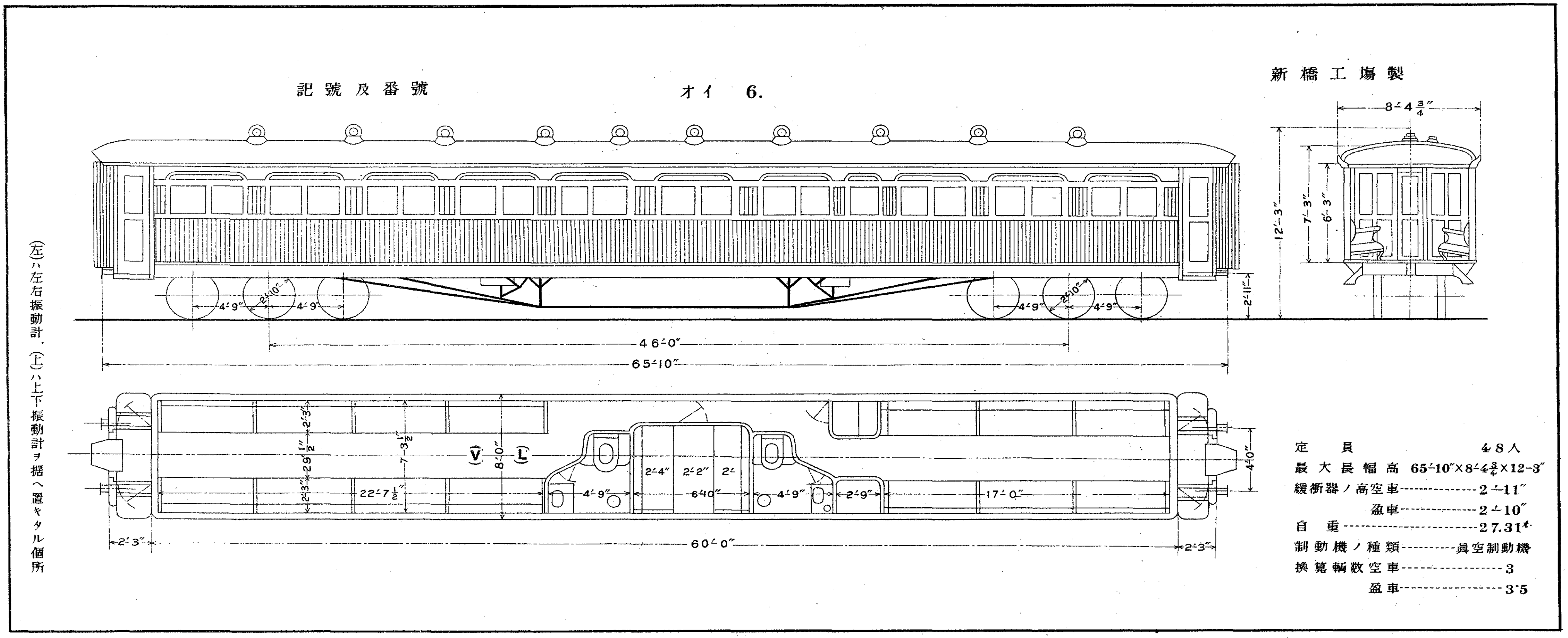
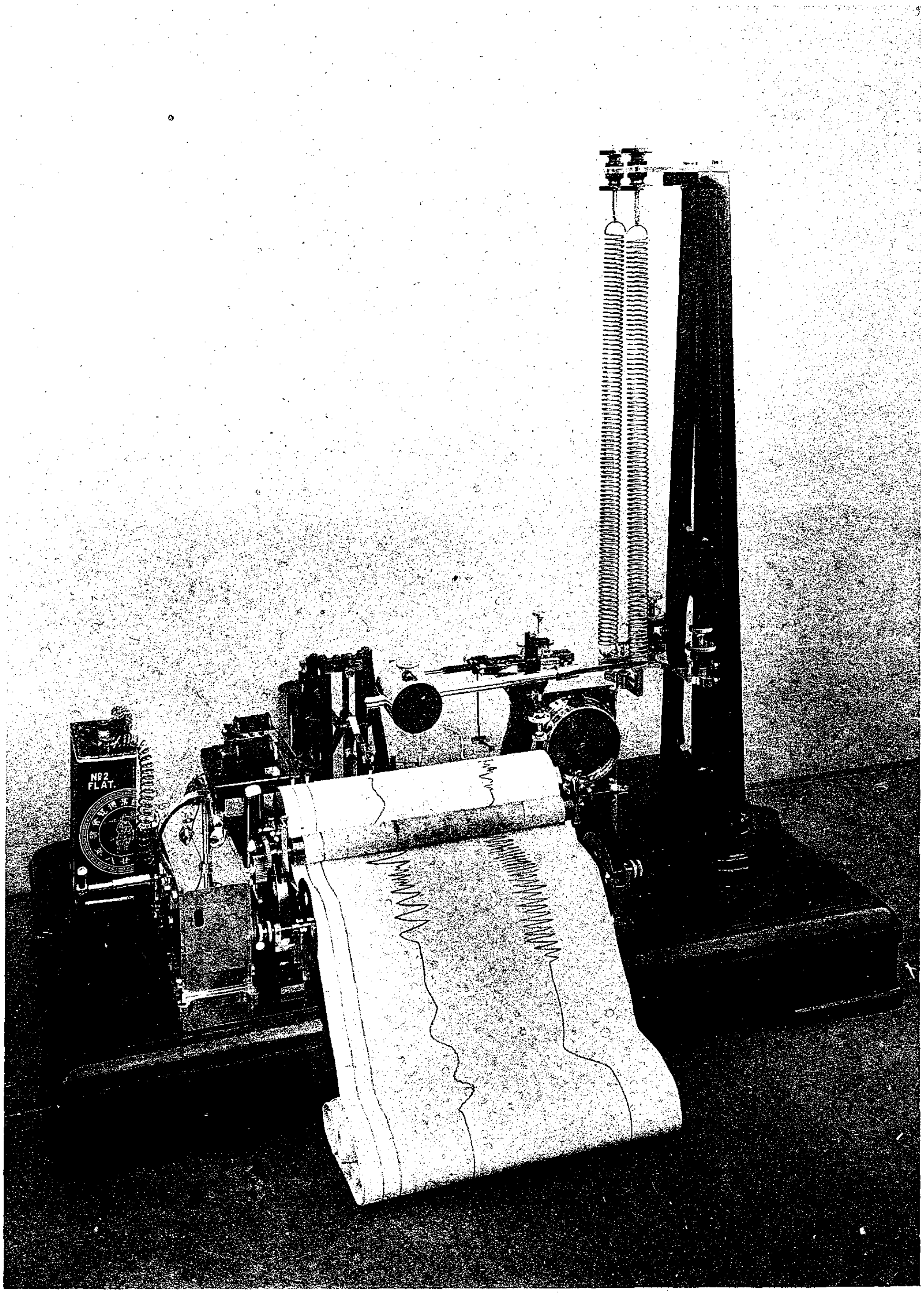


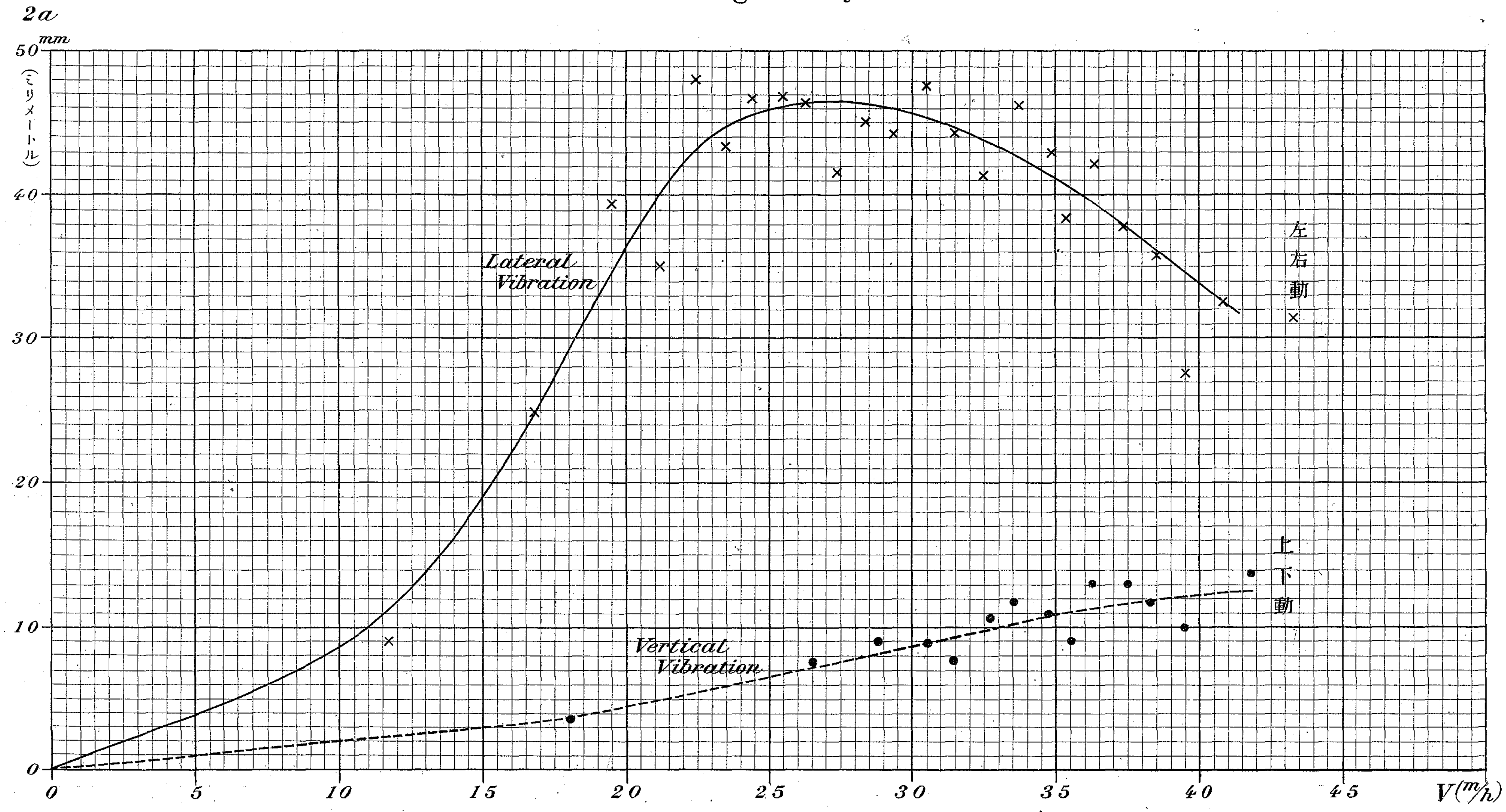
Fig. 6. Vibration Recorder.

For the measurement of the lateral and vertical vibrations of a railway carriage.



Scale 1 : 8.

Fig. 7. Relation to the Velocity (V) of the Double-amplitudes (2a) of the Lateral and Vertical Vibrations of the Carriage "Goryo-sha."



Lateral Vibration.........Down Train, fram Shinbashi to Fukuroi, the effects due to points and curves being excluded.

Vertical Vibration.........Down Train, from Shinbashi to Kozu, including the effects due to points, curves, etc.

Fig. 8. Relation between the velocity (V) and the period (T) of the Lateral Vibration of the Carriage "Goryo-sha."

Down Train, from Shinbashi to Fukuroi.

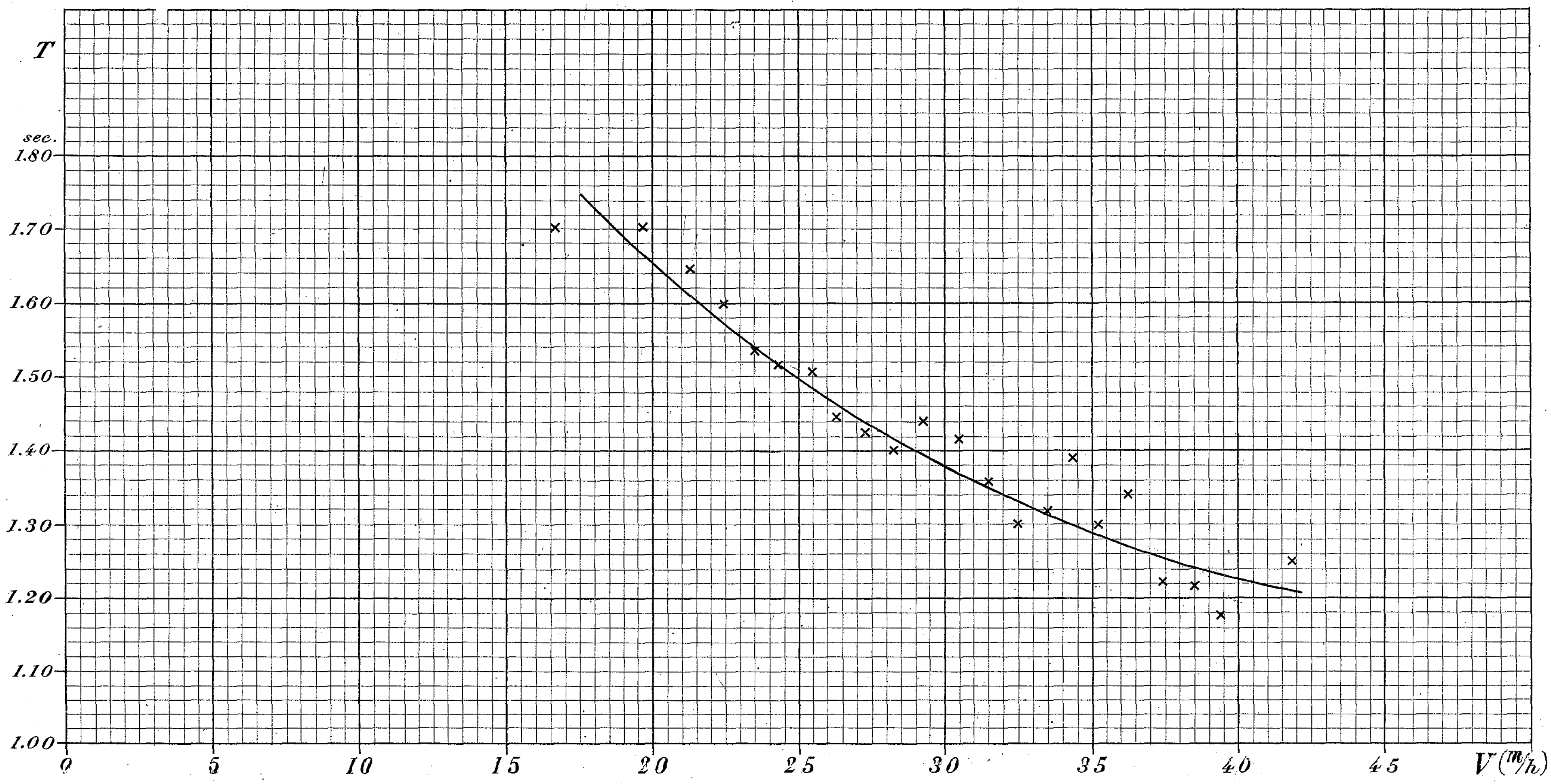
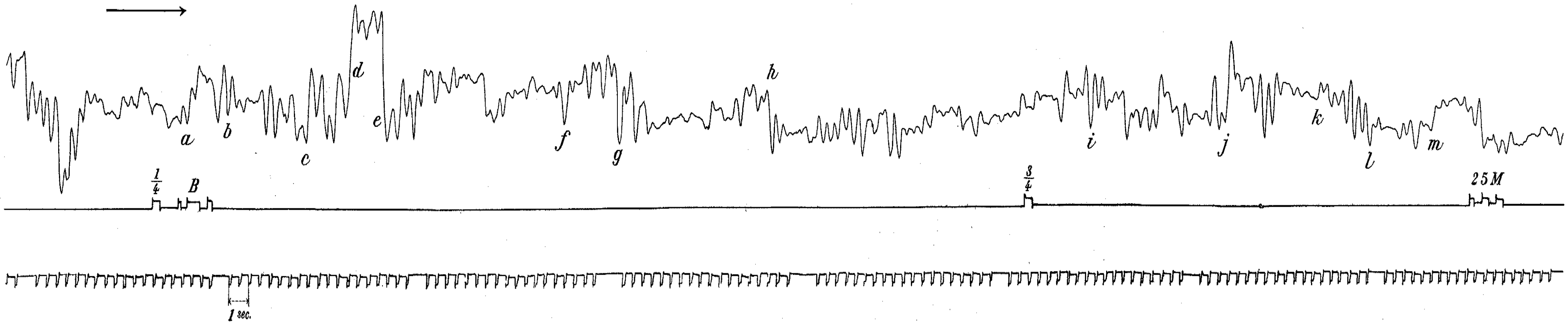


Fig. 9. Comparison of the Vertical Vibrations of the "Goryo-sha" and the 1st Class 6-wheel Bogie Carriages.

Magnification of motion=2. Down Train, from Shinbashi to Kozu; at $24\frac{3}{4}$–25 miles.

(*a*, *b*, *c*,......*l*, *m*)......Corresponding vibrations in the two diagrams. (*B*)......Bridge.

[A] Vibration of the Carriage "Goryo-sha." Velocity=39.3 miles per hour. (Oct. 10th, 1910.)



[B] Vibration of the 1st Class 6-wheel Bogie Carriage. Velocity=41 miles per hour. (Oct. 7th, 1910.)

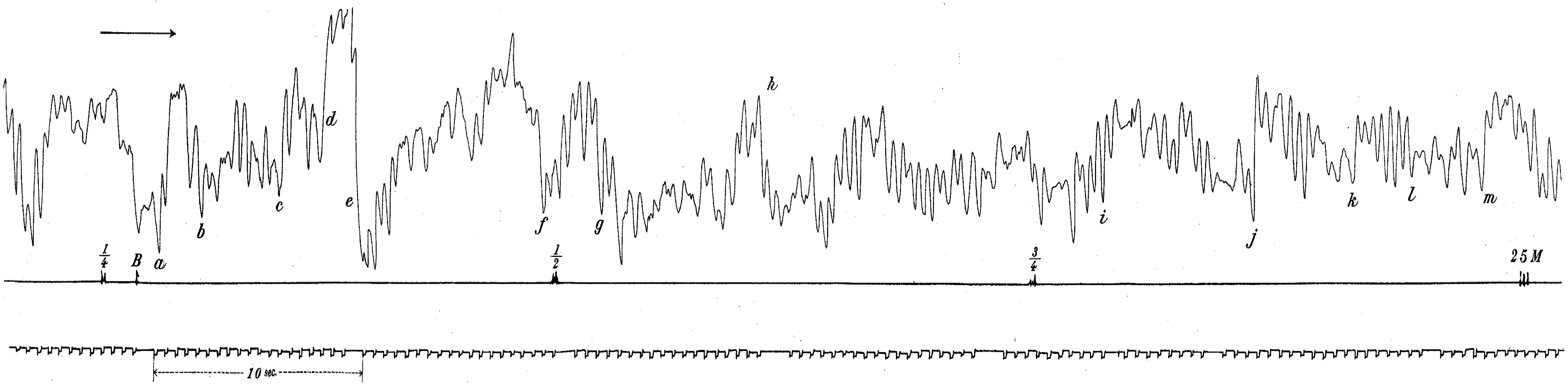
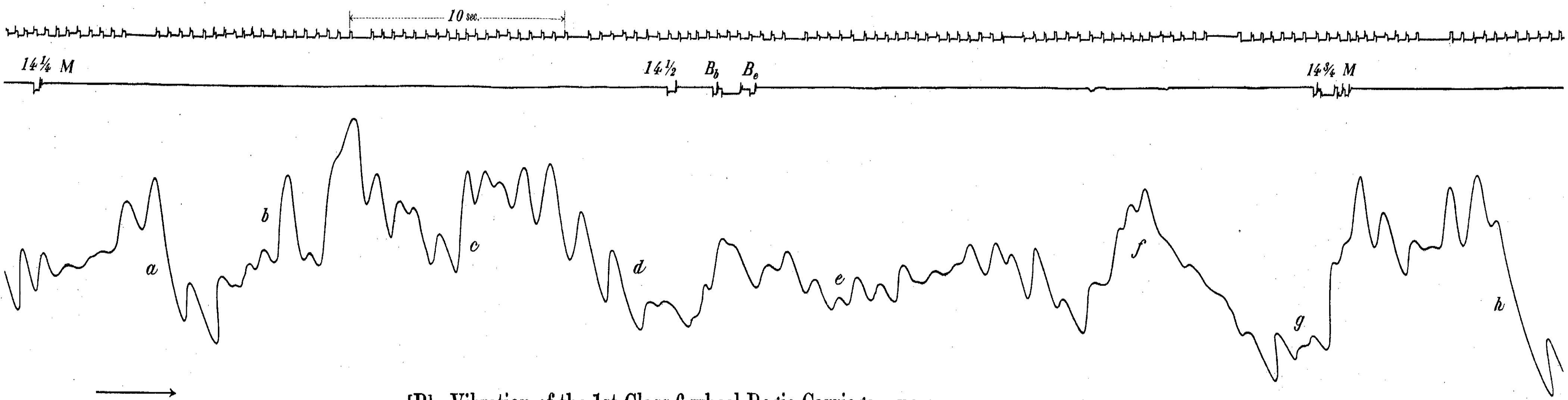


Fig. 10. Comparison of the Lateral Vibrations of the "Goryo-sha" and the 1st Class 6-wheel Bogie Carriages. (Half size.)

Down Trains, from Shinbashi to Kozu; at $14\frac{1}{4}$–$\frac{3}{4}$ miles.

(a, b, c,......g, h)......Corresponding vibrations in the two diagrams. (Bb), (Be)......Bridge commencement and bridge end respectively.

[A] Vibration of the Carriage "Goryo-sha." Velocity=30.7 miles per hour. (Oct. 10th, 1910.)



[B] Vibration of the 1st Class 6-wheel Bogie Carriage. Velocity=32.1 miles per hour. (Oct. 7th, 1910.)

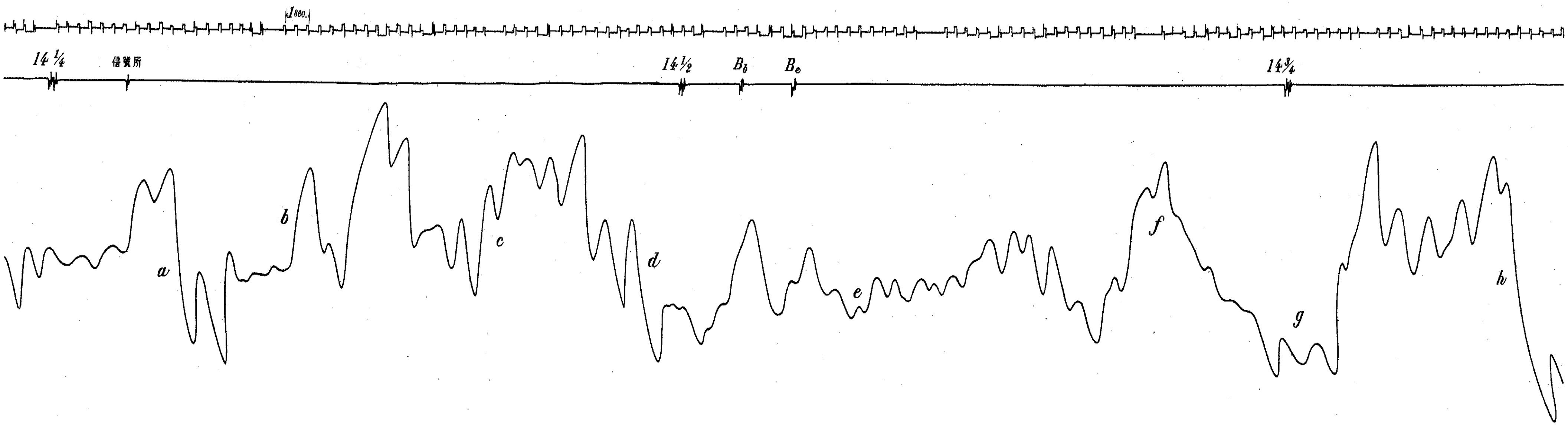
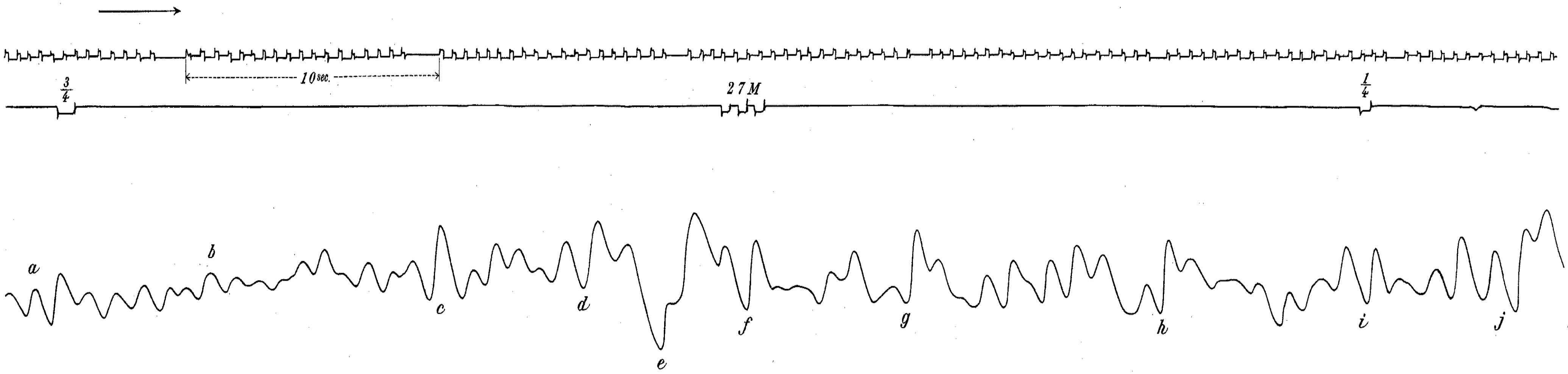


Fig. 11. Comparison of the Lateral Vibrations of the "Goryo-sha" and the 1st Class 6-wheel Bogie Carriages. (Half size.)

Down Trains, from Shinbashi to Kozu; at 27 miles. (a, b, c,......i, j)......Corresponding vibrations in the two diagrams.

[A] Vibration of the Carriage "Goryo-sha." Velocity=33.8 miles per hour. (Oct. 10th, 1910.)



[B] Vibration of the 1st Class 6-wheel Bogie Carriage. Velocity=36 miles per hour. (Oct. 7th, 1910.)

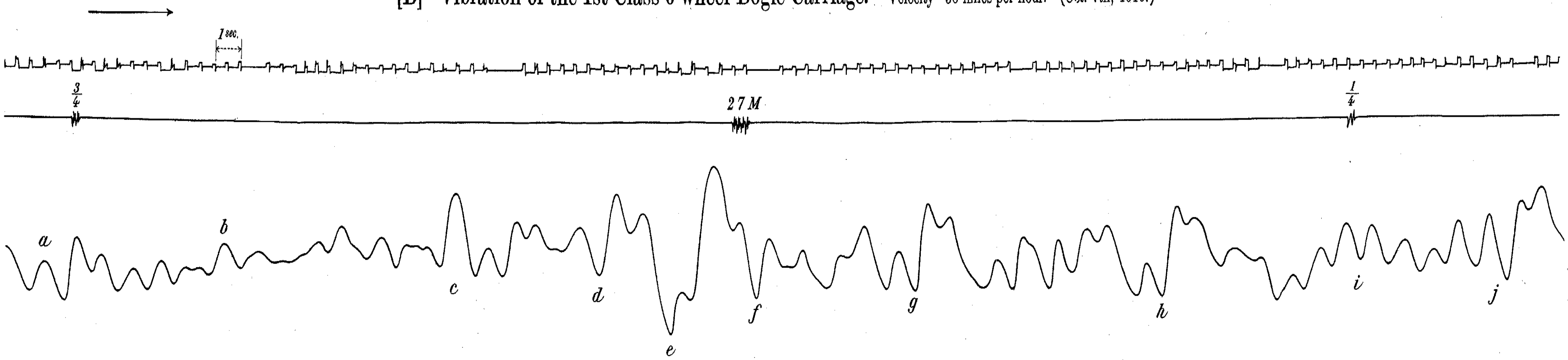
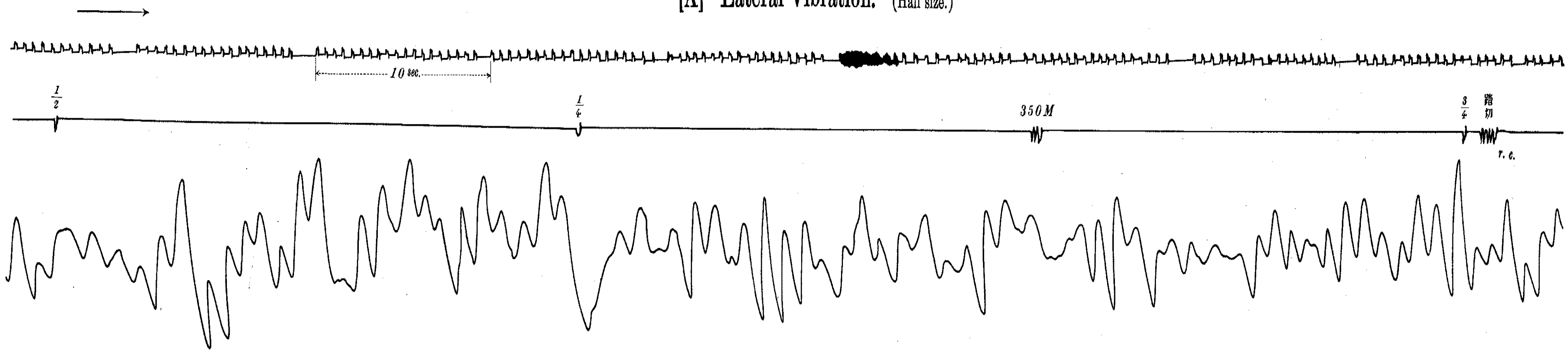


Fig. 12. Lateral and Vertical Vibrations of the Carriage "Goryo-sha."

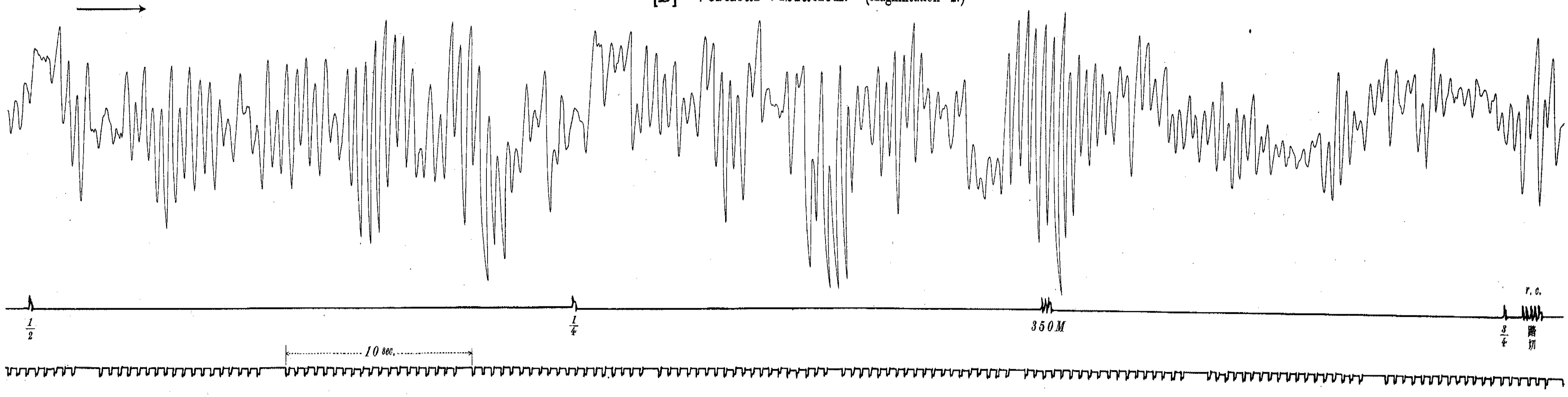
Up Train, from Osaka to Kyoto; at 350 miles. Velocity=33.5 miles per hour. (Oct. 15th, 1910.)

(r. c.)......Road crossing.

[A] Lateral Vibration. (Half size.)



[B] Vertical Vibration. (Magnification=2.)



Lateral Vibration of the Carriage "Goryo-sha." (Half size.)

B.......Bridge. P.......Point. Cb.......Curve, begining. Ce.......Curve, end. r. c.......Road crossing.

Fig. 13. Shin-Maizuru Line; Up Train; at 21 to $21\frac{1}{2}$ miles. Velocity=26.2 miles per hour.

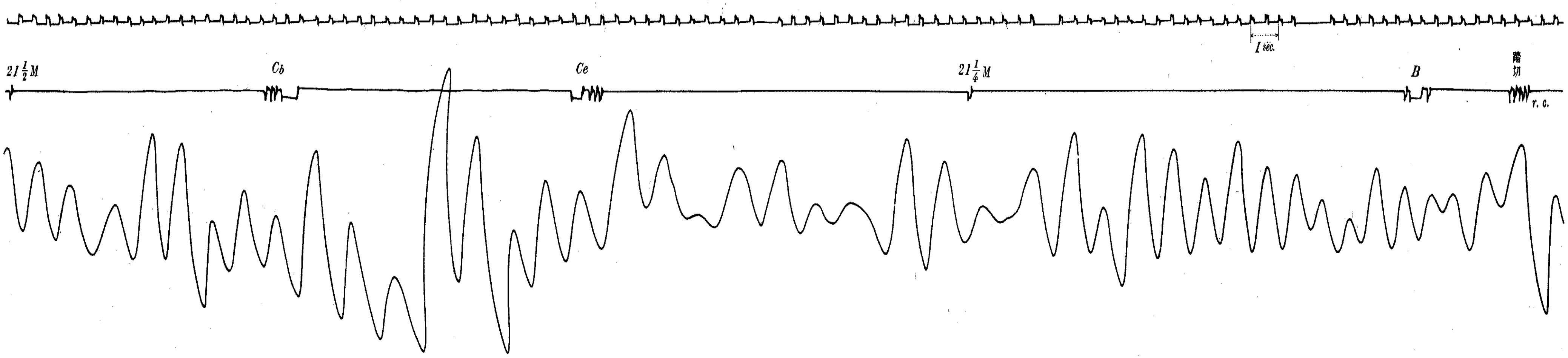


Fig. 14. Effect Caused by a Point, the up train stopping at the Saga Station.

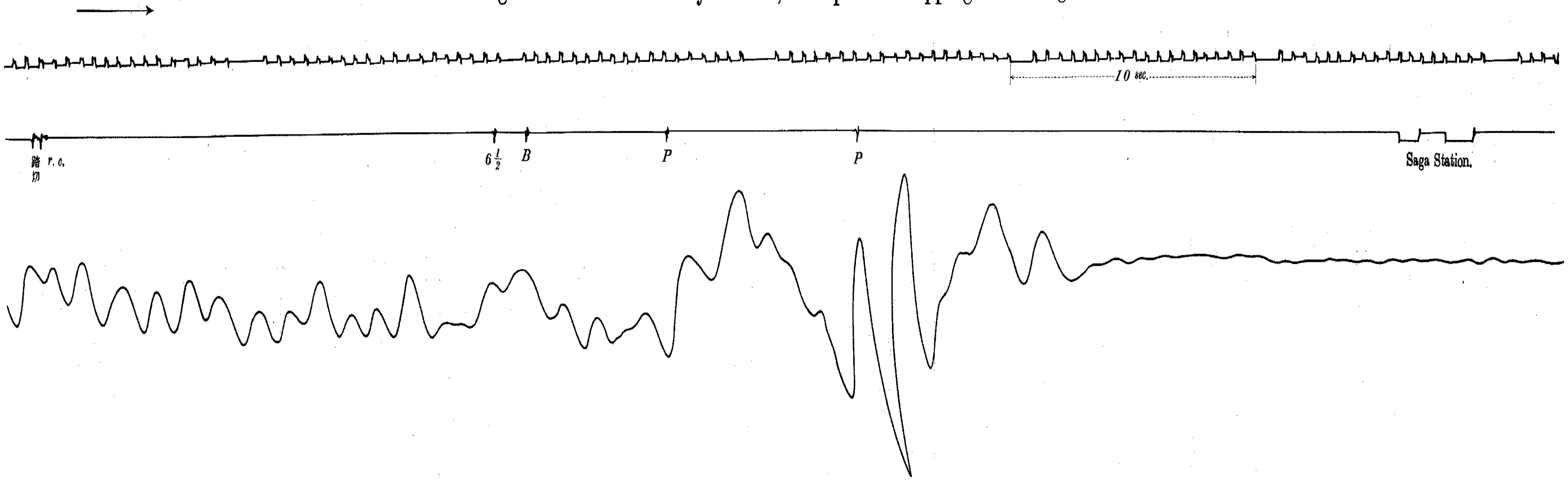


Fig. 15. Lateral Vibration of the Carriage "Goryo-sha" during the passage through the Tunnel at 10$\frac{1}{4}$ miles on the Shin-Maizuru Line. (Half size.)

Up Train; Velocity=26.5 miles per hour. (Oct. 16th, 1910.)

Tb.......Tunnel, begining. *Te*.......Tunnel, end.