

Note on the Vibration of Railway Bridge Piers.

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With Plates XVII-XXII.

1. *Introduction.* In the course of the measurement of the movements of the different railway bridges,* I have often noticed the existence of certain longitudinal vibrations of a comparatively long period, which were found to be no other than those of the piers supporting the girders under examination; the pier motion, which consists of gentle shakings, being in some cases so large as to be distinctly felt without instrumental aid. The following preliminary series of the experiments carried on in Oct. and Nov., 1901, relates to six different piers of single track railway bridges in Central Japan. The knowledge of the movements of bridge piers would be important in determining their strength to resist earthquake shocks and wind pressure.

The measurement was made by means of a *vibration measurer*, (described in the *Publications*, No. 9) set up on a pier to be examined; the motion being recorded in three rectangular directions, namely, the vertical, transverse and longitudinal. The two last components are respectively the movements normal and parallel to the faces of a pier. In the following analysis of the diagrams of the pier motion, 2a denotes the range of vibration at the top of a pier.

2. *Tone-gawa Bridge, near Toride Station, Nippon Railway.* Oct. 21st, 1901.

The bridge consists of eight 200' Double Warren trusses and twenty-two 60' plate girders. The piers experimented upon were those respectively between the 1st and 2nd and between the 7th and

* See the *Publications*, No 9.

8th 200' trusses, counted from the Tokyo end; their elevations and sectional plans being given in Pl. XVII.

The motion of the piers was distinctly felt for some time before and after the passage of a train over the girders adjacent to them. At the time of the experiments there was no wind.

The Pier between the 7th and 8th 200' trusses.

The total height of the pier was 94.'2, of which 29.'35 was above the ground surface, while the remaining 64.'86 formed the well; the depth of the water being about 10'.

Expt. 1. Down goods train; engine No. 62.

Vertical vibration. There were only very slight traces of vertical motion, the average period being 0.41 sec.

Transverse vibration. The record-receiver was started 26 seconds before the arrival of the engine on the pier, but the vibrations were then already distinctly shown. During that preliminary portion the average period was 0.35 sec. In the principal portion, the max. 2a was 1.3mm, the average period being 0.42 sec. The motion died out very gradually.

Longitudinal vibration. Some slight traces of motion existed already at the start of the record-receiver. In the principal portion, the max. 2a was 0.8mm and the average period 0.87 sec.

Expt. 2. Up goods train; engine No. 55.

The train took 30 seconds to pass completely over the 8th 200' girder, there being practically no motion during the first 2.0 sec. after the entrance of the engine on the latter. The motion was not yet ended at the 54th second after the start, when the clock-work of the record-receiver was stopped.

Vertical vibration. The motion was very slight.

Transverse vibration. In the most active part of motion, when the engine was passing over the pier, the max. 2a was 0.5mm and the average period 0.37 sec. The mean values of the period deduced from two successive series of 20 vibrations, when the train was passing on to the 7th 200' girder, were 0.31 and 0.38 sec. respectively.

Longitudinal vibration. During the passage of the engine over the pier, the motion consisted entirely of vibrations of an average period of 0.33 sec. On the other hand, the succeeding motion, which was slightly larger, consisted entirely of slow movements of an average period of 0.85 sec., the max. $2a$ being 0.7mm. Toward the end, the vibrations had an average period of 0.45 sec., these being superposed more or less distinctly on slower ones.

The Pier between the 1st and 2nd 200' Girders.

The total height of the pier is 121'.19, of which the well sinking amounts to 95'.57; the height above the ground surface being 19'.07. The diagrams obtained are reproduced in Pl. XXI.

Expt. 1. Up passenger train; engine No. 209.

Vertical vibration. There existed only very slight traces of motion, whose average period was 0.40 sec.

Transverse vibration. The passage of the train over the pier lasted 18.5 seconds; the vibrations lasted, however, for further 8.6 seconds. The motion was already distinctly shown 8.6 seconds before the entrance of the engine on the 2nd 200' girder, when the record-receiver had been started. The motion in the preliminary portion, or before the passage of the engine over the pier, was already well pronounced (max. $2a=0.3$ mm, average period=0.38 sec.), being much greater than that during the passage of the wagons. In the most active portion, the max. $2a$ was 0.7mm, the average period being 0.37 sec.

Longitudinal vibration. The motion consisted of regular oscillations, whose max. $2a$ was 1.2mm, and whose average period in the most active portion was 0.86 sec. The amplitude gradually accumulated to the maximum, thence again gradually decreasing.

Expt. 2. Down passenger train; engine No. 515.

The train passed over the pier in 22 seconds.

Vertical vibration. The motion was small but distinctly shown, the average period being 0.39 sec.

Transverse vibration. The earlier slight movements had an

average period of 0.79 sec. The motion in the principal portion was not uniform, but consisted of three different groups of maximum vibrations of which the 1st and 2nd were nearly alike. In the 1st group, which occurred immediately after the passage of the engine over the pier, the max. 2a was 0.5mm, the average period being 0.47 sec. In the 2nd group, the average period was 0.45 sec. In the 3rd group, the vibrations, which had an average period of about 0.87 sec. were superposed with others of about half the period. Toward the end, the average period was 0.83 sec.

The different maximum groups were evidently caused by the passage of the engines over the successive piers.

Longitudinal vibration. The max. 2a was 0.6mm, the average period being 0.91 sec. in the most active portion and 0.85 sec. toward the end.

3. *Ibi-gawa Bridge, (near Kuwana Station), Kansai Railway.*

The Ibi-gawa bridge on the Kansai Railway, between the stations of Kuwana and Nagashima, has a total span of 3263' and consists of fifteen 200' Double Warren girders and one 120' Pratt truss, supported by fifteen piers numbered 1 to 15 from the Nagoya (Tokyo) to the Osaka end. The piers chosen for examination were Nos. 4 and 5, which are the most shaky among the series and whose height above the well was in each case 20'8'', the thickness at top and base being 10' and 11'.87 respectively. (See Pl. XVIII.) On Nov. 12th 1901, when the experiments were made, the weather was stormy and it was very difficult to walk over the bridge; the winds having been particularly hard between 10 a.m. and 1½ p.m. The motion of the piers Nos. 4, 5, 10 and some others, which was caused by winds, was distinctly felt as slow transverse and longitudinal oscillations.

Pier No. 4.

The well is 84'.48 deep and consists of concrete filling an iron frame of two concentric ellipses joined together, whose outside and inside major diameters are 30'6'' and 25'4'' respectively. The diagrams of the transverse and longitudinal vibrations in the 1st and

2nd experiments are reproduced in Pl. XXII.

Expt. 1. Up train, composed of engine No. 44, eight passenger cars and two break-vans; 11 $\frac{1}{2}$ a.m. The engine passed over each of the adjacent 200' girders in about 5.5 seconds.

Vertical vibration. Very slight.

Transverse vibration. For the sake of convenience, let t_5 denote the moment when the engine passed over the No. 5 pier and entered on the 5th girder. Between the start of the record-receiver, which was 7.7 seconds before t_5 , and the latter moment, the max. 2a was 0.5mm and the average period 0.45 sec., the motion being active between 4.0 sec. and 0.9 sec. before t_5 . The motion was then again active for an interval of 2.5 seconds between $t_5+1.7$ sec. and $t_5+4.2$ sec.; the max. 2a being 0.67mm and the average period 0.55 sec. At $t_5+5.5$ sec., the engine passed over the No. 4 pier, or that under experiment; let this moment be denoted by t_4 . The 3rd maximum motion occurred during a time interval of 3.3 seconds between $t_4+2.5$ sec. and $t_4+5.8$ sec.; the max. 2a being 0.73mm and the average period 0.45 sec. Again, denoting by t_3 the moment when the No. 3 pier was passed over, or putting $t_3=t_4+5.5$ sec., the 4th maximum occurred during a time interval of 2.2 seconds between $t_3+2.6$ sec. and $t_3+4.8$ sec.; the max. 2a being 0.53mm and the average period 0.46 sec. The next maximum motion was small and occurred at $t_3+9.4$ sec.; the max. 2a being 0.13mm and the average period 0.44 sec. Hereafter the movements became very slight. The train passed completely over the No. 4 pier at $t_3+3.6$ sec.

Longitudinal vibration. The motion was most active between t_4 and $t_4+8.8$ sec., the max. 2a being 1.0mm and the average period 0.88 sec. Before and after the above time interval the motion was small.

Expt. 2. Down train, composed of engine No. 41, eight passenger cars and two break vans; 11 $\frac{3}{4}$ a.m. The engine passed over the 4th girder in 3.4 seconds, while the whole train passed completely over the same in 6.4 seconds.

Vertical vibration. Nil.

Transverse vibration. As in the preceding experiment, the maximum transverse vibration occurred slightly after the moments of passage of the engine over the successive piers. The record-receiver of the instrument was started 3.6 seconds before t_3 , when the engine was passing over the 3rd pier; t_3 having the same signification as above. The motion was active during the 1.7 sec. after t_3 , the max. 2a being 0.67mm and the average period 0.34 sec. It was again active during the 1.6 sec. between $t_3+0.56$ sec. and $t_3+2.2$ sec.; the max. 2a being 1.3mm and the average period 0.33 sec. A second maximum group occurred for 1.4 sec. between $t_3+4.5$ sec. and $t_3+5.9$ sec.; the max. 2a being 0.84mm and the average period 0.35 sec. Similarly there followed seven other maximum groups at an average interval of 2.3 seconds, the 2a becoming gradually smaller. Thus:—

in the 4th group, max. 2a = 0.67mm

„ 5th „ „ „ = 0.53 „

etc.

Longitudinal vibration. The max. 2a was 0.78mm, the average period being 0.82 sec.

Expt. 3. Effect of the winds.

Vertical vibration. Nil.

Transverse vibration. Max. 2a was about 0.6mm, the average period being 0.83 sec.

Longitudinal vibration. Max. 2a was 0.5mm, the average period being 0.77 sec.

Pier No. 5.

The well, which is 82'33 deep, is elliptical in section and made of brick.

Expt. 1. Up train, composed of engine No. 40, eight passenger cars, two break vans, and five goods wagons.

Vertical vibration. Nil.

Transverse vibration. There were five different maximum groups of vibrations, whose average interval was 5.7 seconds; the 2nd group having occurred a little after the entrance of the engine on the 6th

girder. The maximum movements were as follows:

1st group,	max. $2a=0.4\text{mm}$	
2nd „	„	0.6 „
3rd „	„	0.6 „
4th „	„	0.5 „
5th „	„	0.5 „

The average period of vibration deduced from the 2nd and 3rd groups were 0.47 and 0.46 sec. respectively.

Longitudinal vibration. The max. $2a$ was 0.77mm, the average period being 0.92 sec.

Expt. 2. The effect of the winds.

Vertical vibration. *Nil.*

Transverse vibration. The max. $2a$ was about 0.5mm.

Longitudinal vibration. The max. $2a$ was 0.54mm, the average period being 0.89 sec.

4. *Tone-gawa Bridge, (near Maebashi Station), Nippon Railway.*

The bridge which spans over the Tone-gawa, in the immediate vicinity of the city of Maebashi, consists of two 200' Double Warren girders and three 70' plate girders. The river bed was partly dry and hard, consisting of boulders and gravels embedded in sand.

The pier experimented upon was No. 1 pier, or that between the two 200' girders, whose height above the ground was 40' 9'', the depth of the well being 38'. (See Pl. XIX). The pier, which had been damaged some years ago by floods, was repaired by means of iron bands, which bind the top portion cracked vertically down-wards to a distance of about 10'. The object of the following experiments, which were made on Nov. 25th 1901, was to examine the effect of the existence of the cracks on the vibration of the pier.

Expt. I. Down train, composed of engine No. 38, and seventeen passenger cars; 9.50 a.m. The train ran very slowly, the engine and the entire train taking 5.7 and 14.5 seconds respectively to pass over the 1st 200' girder.

Vertical vibration. The motion was slight but distinct; the max.

2a being 0.1mm and the average period 0.42sec.

Transverse vibration. The motion was most active when the engine was passing over the pier; the max. 2a was 0.3mm and the average period 0.40 sec. When the train completely passed over to the 2nd 200' girder, the average period was 0.24 sec.

Longitudinal vibration. The max. 2a was 0.3mm, and the average period 0.84 sec.

Expt. 2. Up train, composed of engine No.38, and eleven passenger cars; 10.20 a.m.

Vertical vibration. The max. 2a was 0.1mm, the average period being 0.42 sec.

Transverse vibration. The max.2a was 0.2mm, the average period being 0.22 sec.

Longitudinal vibration. The max. 2a was 0.4mm, the average period being 0.85 sec. At first there were also small vibrations of an average period of 0.21 sec.

Expt. 3. Down train, composed of engine No. 38, two goods wagons, and eleven passenger cars; 11.10 a.m.

Vertical vibration. The motion was nearly the same as in the preceding case; the max. 2a being 0.15mm and the average period 0.44 sec.

Transverse vibration. The motion consisted of vibrations of an average period of 0.34 sec. (max. 2a=0.4mm) superposed on those of an average period of 0.92 sec. (max. 2a=0.5mm). Towards the end the average period was 0.25 sec.

Longitudinal vibration. The max. 2a was 0.4mm, the average period being 0.81 sec.

5. *Kizu-gawa Skew Bridge, Kansei Railway.*

The Kizu-gawa bridge on the Nagoya-Osaka line of the Kansei Railway, consists of a series of five spans as follows: one 100' Warren girder (Nagoya end), one 200' Pratt truss, one 100' Warren girder, and two 70' plate girders (Osaka end). The four piers were very tall, the height varying between 45'.5 and 60'. There was no well sinking, the

piers having been directly built on the solid native rocks. (See Pl. XX).

The pier experimented upon was the No. 1 pier, or the tallest one, which supports the 200' truss and the 100' girder at the Nagoya end. In the first of the following two experiments, the two horizontal pendulums of the *vibration measurer* were placed respectively, at right angles and parallel to the length of the bridge; while in the second, they were placed in similar relations with respect to the pier plane.

Expt. 1. Up train, composed of engine No. 33, three goods cars, and 10 passenger wagons; 1.30 p.m.

Vertical vibration. The motion was slight (max. $2a=0.15\text{mm}$), the average period being 0.73 sec.

Transverse motion. The motion consisted of vibrations of an average period of 0.30 sec. (max. $2a=0.5\text{mm}$), mixed up with those of an average period of 0.16 sec. (max. $2a=0.2\text{mm}$).

Longitudinal vibration. The principal motion had an average period of 0.31 sec., the $2a$ being small.

There were also some traces of small vibrations of an average period of 0.14 sec.

Expt. 2. An express down train, composed of engine No. 36, and ten passenger cars; 2.10 pm.

Vertical vibration. The average period was about 0.53 sec., the $2a$ being very small.

Transverse vibration. There were two sets of vibrations, whose average periods were respectively 0.30 and 0.15 sec., the max. $2a$ in each being 0.1mm.

Longitudinal vibration. Very slight.

Abutment.

In the following experiment, the *vibration measurer* was put on the Nagoya end abutment.

Down train, composed of engine No. 38, one passenger car and eleven goods wagons.

The instrument indicated no motion.

6. *Summary of the Results.*

The elements of motion of the different bridge piers are collected in the following table.

TABLE I.

VIBRATIONS OF THE BRIDGE PIERS.

(2a=Range of motion, or double amplitude, at the top of a pier.)

TONE-GAWA BRIDGE (TORIDE); PIER BETWEEN THE
7TH AND 8TH 200' DOUBLE WARREN GIRDERS.

No. of expt.	Train	Vert. vibration.		Trans. vibration.		Long. vibration.		Engine.
		max 2a	Period	max. 2a	Period	max. 2a	Period	
1.	Down goods train	mm. small	sec. 0.41	mm. 1.3	sec. 0.39	mm. 0.8	sec. 0.87	62
2.	Up " "	"	—	0.5	0.35	0.7	$\left\{ \begin{array}{l} 0.85 \\ 0.39 \end{array} \right.$	555

TONE-GAWA BRIDGE (TORIDE); PIER BETWEEN THE
1ST AND 2ND 200' DOUBLE WARREN GIRDERS.

1	Up passenger train.	Small	0.40	0.7	0.38	1.2	0.86	209
2	Down " "	"	0.39	0.5	$\left\{ \begin{array}{l} 0.46 \\ 0.83 \end{array} \right.$	0.6	0.88	515

IBI-GAWA BRIDGE (KUWANA); PIER NO. 4.

1	Up passenger train.	Small	—	0.7	0.47	1.0	0.88	44
2	Down " "	0	—	1.3	0.34	0.8	0.82	41
3	Winds.	0	—	0.6	—	0.5	0.77	—

IBI-GAWA BRIDGE (KUWANA); PIER NO. 5.

		mm.	sec.	mm.	sec.	mm.	sec.	
1	Up train.	—	—	0.6	0.47	0.8	0.92	40
2	Wind.	—	—	0.6	—	0.5	0.89	—

TONE-GAWA BRIDGE (MAEBASHI); PIER NO. 1.
(CRACKED PIER).

1	Down train.	0.1	0.42	0.3	{ 0.40 0.24	0.3	0.84	38
2	Up train.	0.1	0.42	0.2	0.22	0.4	{ 0.85 0.21	38
3	Down train.	0.15	0.44	{ 0.3 .. 0.34 0.5 .. 0.92 — .. 0.25		0.4	0.81	38

KIZU-GAWA BRIDGE; PIER NO. 1.

1	Up train.	0.15	0.73	{ 0.5 .. 0.30 0.2 .. 0.16	Small .. 0.31 „ .. 0.14	33
2	Down train.	Small	0.53(?)	{ 0.1 .. 0.30 0.1 .. 0.15	Small —	36

Remarks.

(a) *Period and range of motion.* The vertical vibration was always very small, while the transverse and longitudinal vibrations were usually well pronounced, their ranges being nearly equal to each other.

With the exception of the Kizu-gawa pier, the periods of the *vertical* and *longitudinal* vibrations were nearly constant; the mean values being 0.41 and 0.85 sec. respectively. These are probably not the periods of the true elastic vibrations of the piers themselves, but are rather those of the rocking motion of the latter due to the vertical and transverse vibrations of the 200' girders which rest upon them. Thus, taking averages from the five bridges of the Ibi (near Ōgaki, on the Tokaidō Railway), the Ibi (Kuwana), the Ōi, the Tone (Toride), and the 1st Ishikari-gawa, we obtain the periods of 0.40 and 0.90 sec. respectively for the *vertical* and *transverse* vibrations of the

200' Double Warren girders, which are practically identical with the mean values of the *vertical* and longitudinal periods of the piers. The maximum $2a$'s of the pier motion was 0.15mm for the vertical and 1.2mm for the longitudinal component.

The periods of the transverse, or real elastic, motion of the different piers varied between 0.22 and 0.47sec.; the maximum range of motion varying between 0.1 and 1.3mm.

From what has been said above it is evident that the periods of vibration of the bridge piers are roughly speaking between 0.2 and 0.9 sec., that is to say, not very much different from the periods of motion in ordinary *weak* and *strong* earthquakes. At the time of a destructive earthquake, the motion of the piers would be much greater than that caused by ordinary railway traffic and the period may become upward of 1 sec. As, however, the period of destructive earthquake motion is generally between 1 and 2 sec., we may conclude that the bridge piers are, when considered with respect to their fracturing, to be regarded as *short columns*, and not as *long columns* like tall factory chimneys.

(b) *Effect of winds.* In the case of the Ibi-gawa bridge (Kuwana), the movements of the piers caused by strong winds were nearly the same as those due to the actual passage of the trains. In very violent storms the motion would be much greater and the range of the transverse and longitudinal vibrations may, when coupled with those produced by the passage of a train, amount to a few mm.

(c) *Iron frames.* The two piers, Nos. 4 and 5, of the Ibi-gawa bridge (Kuwana) were nearly alike, except that the former has elliptical iron frames embedded in the well. The motion of the No. 4 pier was, however, not less than that of the other. This seems to show that iron frames, unless very strong, have no sensible effect on the vibration phenomena of large masonry columns in which they are embedded. The following table, which has been constructed from the preceding, gives the maximum and mean values of the $2a$ and the period.

TABLE II.
MAXIMUM AND MEAN VALUES OF THE VIBRATIONS OF THE BRIDGE PIERS.

$\left. \begin{array}{l} 2a = \text{Range of motion, or double amplitude, at the top of a pier.} \\ T = \text{Complete period of vibration.} \end{array} \right\}$

Bridge pier.	Vertical vibration.				Transverse vibration.				Longitudinal vibration.			
	Max. 2a		T		Max. 2a		T		Max. 2a		T	
	Abso- lute. mm.	Mean. mm.	Max. sec.	mean. sec.	Abso- lute. mm.	Mean. mm.	Max. sec.	Mean. sec.	Abso- lute. mm.	Mean. mm.	Max. sec.	Mean. sec.
Tone-gawa Bridge (Toride); pier between 7th and 8th 200' girders.	Small	Small	—	0.41	1.3	0.9	0.39	0.38	0.8	0.8	0.87	0.86
Same bridge; pier between 1st and 2nd 200' girders.	"	"	0.40	0.40	0.7	0.6	—	0.42	1.2	0.9	0.88	0.87
Ibi-gawa Bridge (Kuwana); Pier No. 4.	"	"	—	—	1.3	0.9	0.47	0.41	1.0	0.8	0.88	0.82
Same bridge; Pier No. 5.	"	"	—	—	0.6	0.6	—	0.47	0.8	0.7	0.92	0.91
Tone-gawa Bridge (Maebashi); Pier No. 1.	0.2	0.1	0.44	0.43	0.5	0.3	0.40	$\begin{cases} 0.21 \\ 0.37 \end{cases}$	0.4	0.4	0.84	0.83
Kizu-gawa Bridge; Pier No. 1.	0.2	—	0.73	0.63	0.5	0.3	0.30	0.21	Small	Small	—	$\begin{cases} 0.14 \\ 0.31 \end{cases}$

7. *Note on the longitudinal vibrations of bridge girders.*

The following table gives the pier motion indicated in the longitudinal vibration diagrams of some of the bridge *girders* measured in 1900 and 1901.

TABLE. III.

TRANSVERSE PIER VIBRATION DEDUCED FROM
THE LONGITUDINAL MOTION DIAGRAMS OF THE
DIFFERENT BRIDGE GIRDERS.

Bridge Pier and date of expt.	No. of expt.	Max. 2a. (mm.)	Period. (sec.)	Bridge. Pier and date of expt.	No. of expt.	max. 2a. (mm.)	Period (sec.)
Tone-gawa (Toride); 8th 200' Double Warren girder. Oct. 21, 1901.	1	0.3	0.36	Kuji-gawa; 100' Warren girder. Oct. 18, 1901.	1.	0.3	0.30
	2	0.4	0.37		2.	0.6	0.31
	3	0.7	0.39		3.	Small	0.38
	4	0.6	0.38		4.	0.5	0.28
	5	0.8	0.40		Mean	0.4	0.32
	6	0.7	0.40	Tone-gawa (Mae- bashi); 70' plate girder. Nov. 25, 1901.	1.	Small	0.23
	7	1.2	0.38		2.	"	0.20
	Mean	0.7	0.38		3.	"	0.20
					Mean	—	0.21
Kizu-gawa; 200' Pratt truss. Nov. 7, 1901.	1	Small	0.22	Ibi-gawa (Ōgaki); 1st 200' Double Warren girder. April 16, 1900.	1.	0.35	0.32
	2	"	0.19		2.	0.3	0.33
	3	"	0.20		3.	0.7	0.36
	4	"	0.23		4.	—	0.33
	5	"	0.19		5.	0.2	0.30
	6	"	0.21		6.	—	—
	Mean	—	0.21		Mean	0.4	0.33
Ibi-gawa (Kuwana); 200' Double War- ren girder. Nov. 12, 1901.	1	0.5	—	2nd Ishikari-gawa; 70' plate girder. Oct. 11, 1900.	1.	Small	0.16
	2	0.4	0.43		2.	"	0.17
	3*	Small	—		Mean	—	0.17

* Due to the winds.

From the above table it will be seen that the average period for the girders of the *Tone-gawa* (Toride), the *Ibi-gawa* (Kuwana), and the *Kizu-gawa* bridges are respectively 0.38, 0.43, and 0.21 sec.; these being exactly identical with the mean values of the periods of the transverse vibration of the corresponding bridge piers, given in Table II.

A striking fact, which is apparent from tables I and II is that the motion of a pier does not depend simply on its height above the well. Thus the motion of the pier of the *Kizu-gawa* bridge, whose height was 60', was markedly smaller than that of those of the *Tone-gawa* (Toride) and the *Ibi-gawa* (Kuwana) bridges, although in the cases of the two latter bridges the heights of the piers above the river bed were much smaller and only about 20.' The motion of the pier of the *Tone-gawa* bridge (Maebashi) was also very small. These peculiarities are obviously due to the fact that the river beds of the *Kizu-gawa* and the *Tone-gawa* (Maebashi) are hard, while the beds of the *Ibi-gawa* (Kuwana) and the *Tone-gawa* (Toride) are muddy and very soft. In other words, the piers with solid foundations are rigid; while those, whose foundations are weak, are very shaky.

From the above it is evident that a pier does not, in general, behave as if it were rigidly fixed to the ground at the surface of the latter. Thus, taking as examples the *Kizu-gawa* and the *Tone-gawa* (Toride) piers, we see that the period of the transverse vibrations are 0.21 and 0.38 sec.* respectively, while the heights of the piers above the ground are 60' and 29'.35 respectively. If now h and h_1 denote the heights of the *Kizu-gawa* and the *Tone-gawa* piers, supposed to be of an equal and uniform section, we have

$$\frac{h^2}{h_1^2} = \frac{0.21}{0.38}.$$

Now the *Kizu-gawa* pier has no well at all; its thickness at the base being, however, nearly identical with that of the well of the *Tone-gawa* pier. For the sake of a very rough calculation, let us take

* Taking for the *Tone-gawa* bridge the pier between the 7th and 8th 200' girders.

for h , not the actual height of 60', but an arbitrary value of 55', and we obtain

$$h_1 = h \times \sqrt{\frac{0.38}{0.21}} = 74';$$

that is to say, the pier, whose well sinking amounts to 64'.86, vibrates about a point in it 45' below the ground surface as centre.

Tokyo. June 1902.

LIST OF PLATES.

- Pl. XVII.** The *Tone-gawa* Bridge, near Toride Station, Nippon Railway. Elevations and sectional plan of the pier between the 1st and the 2nd, and of that between the 7th and the 8th 200' Double Warren girders.
- Pl. XVIII.** The *Ibi-gawa* Bridge, near Kuwana Station, Kansei Railway. Elevations and sectional plans of the piers.
- Pl. XIX.** The *Tone-gawa* Bridge, near Maebashi Station, Nippon Railway. Elevations and plans of Pier No. 1, or that between the two 200' Double Warren girders.
- Pl. XX.** The *Kizu-gawa* Skew Bridge, near Kasagi Station, Kansei Railway. Elevations and plans of the abutment at the Nagoya (Tokyo) end and of Pier No. 1, or that between the 200' Pratt truss and the 100' Warren girder.
- Pl. XXI.** Vertical, transverse and longitudinal vibrations of the pier between the 1st and the 2nd 200' Double Warren girders, *Tone-gawa* Bridge (Toride); Expt. 1 and Expt. 2.
- Pl. XXII.** Transverse and Longitudinal vibrations of Pier No. 4 of the *Ibi-gawa* Bridge, Kansei Railway; Expt. 1 and Expt. 2.

In the vibration diagrams, Pls. XXI and XXII, the multiplication ratios are as follows:—

Vertical vibration 2 times;

Transverse „ 1.5 „

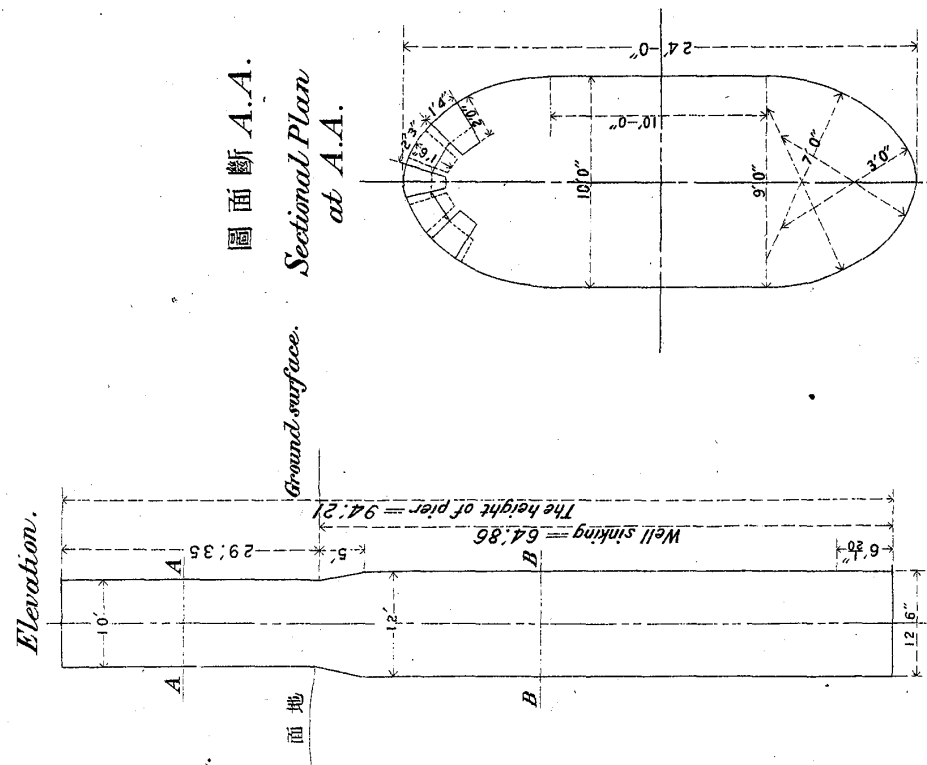
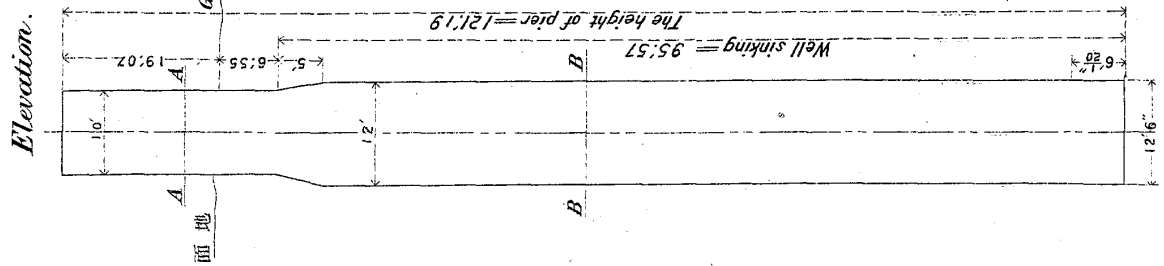
Longitudinal „ 1.3 „

Time marks. The value of two consecutive tick intervals, corresponding to one complete oscillation of the time-marking pendulum is 0.66 sec. in each case.

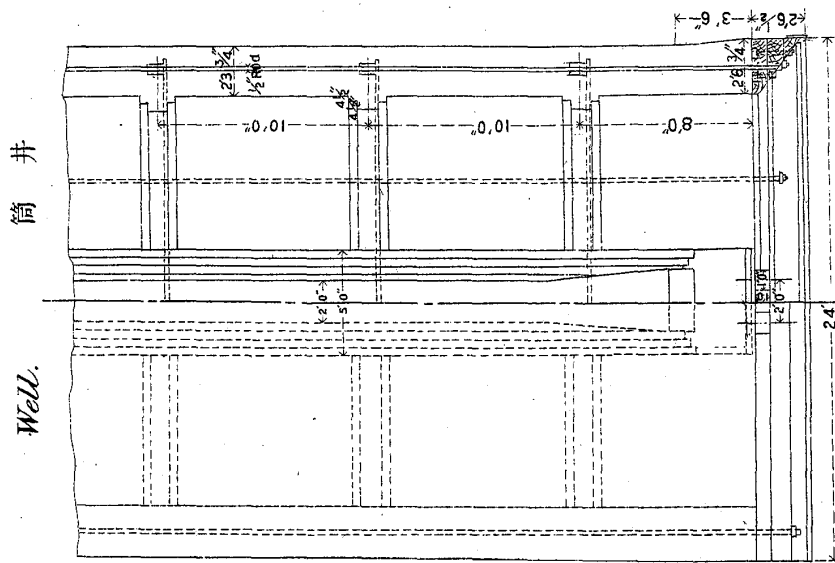
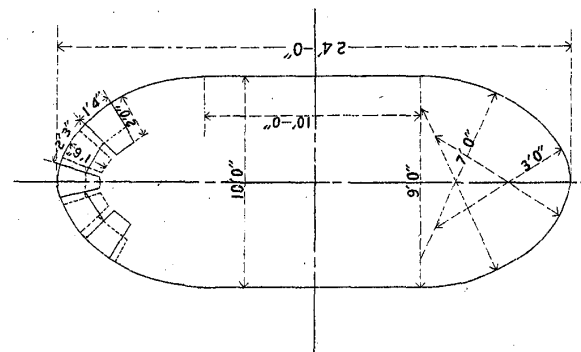
PIERS OF THE TONE-GAWA BRIDGE (TORIDE), NIPPON RAILWAY.

PIER BETWEEN THE 1ST AND 2ND 200' GIRDERS.

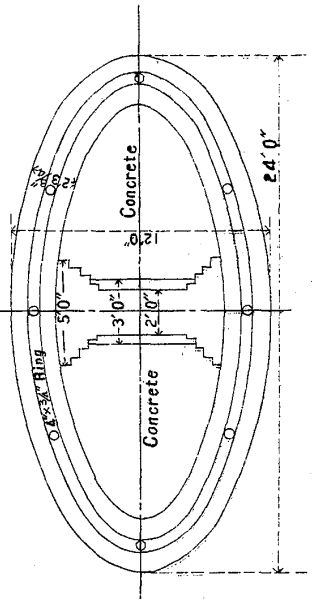
PIER BETWEEN THE 7TH AND 8TH 200' GIRDERS.



圖面斷 A.A. Sectional Plan at A.A.



Sectional Plan at B.B.



Scale: Sectional Plan, Well: 1" = 10' Elevation: 1" = 25'

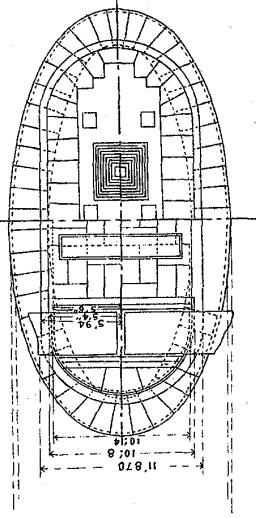
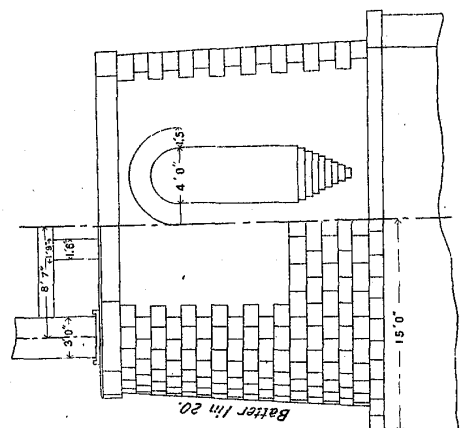
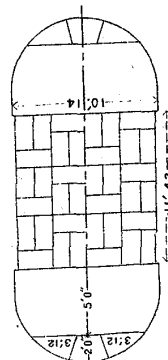
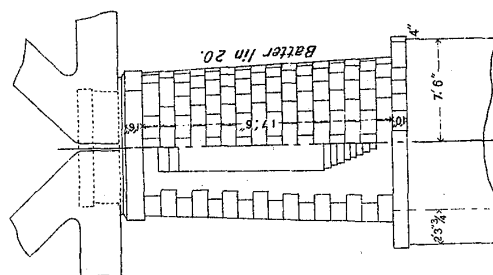
THE PIERS AND WELLS OF THE IBI-GAWA BRIDGE,

(KUWANA), KANSEI RAILWAY.

脚橋 橋川 斐 揖 道 鐵 西 關

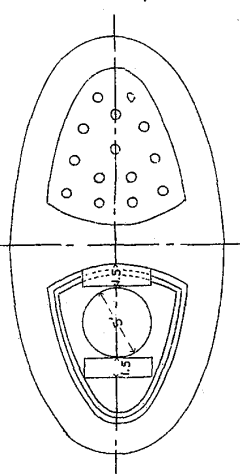
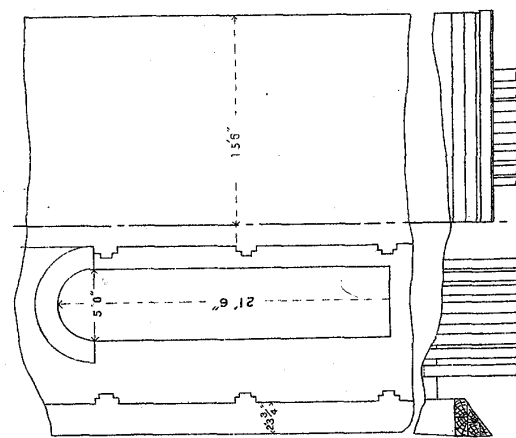
Pier

脚 橋



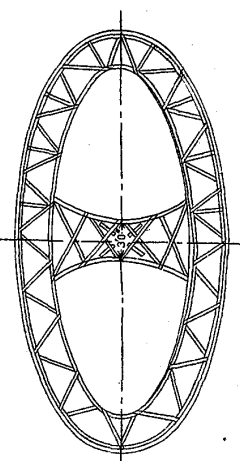
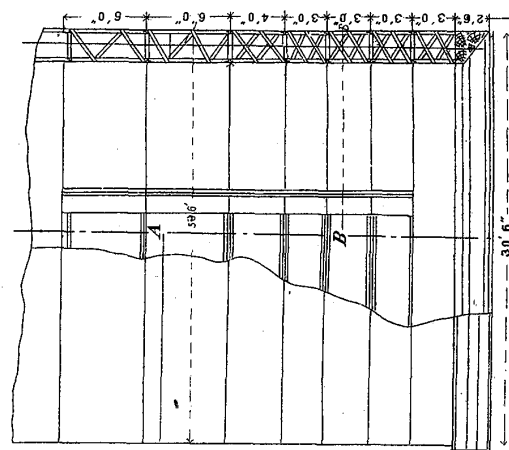
Brick Well

筒 井 瓦 煉



Iron Well

筒 井 製 鐵

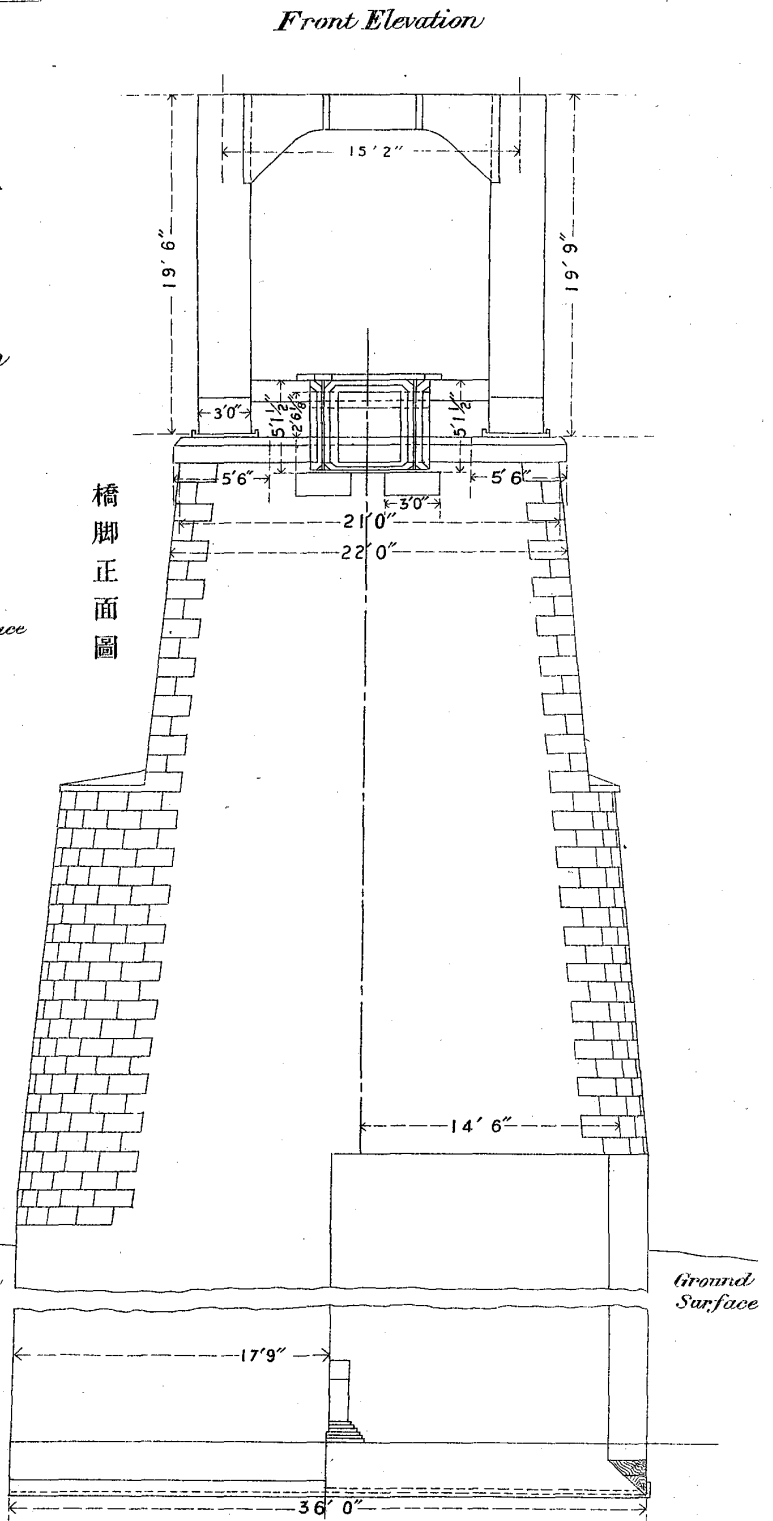
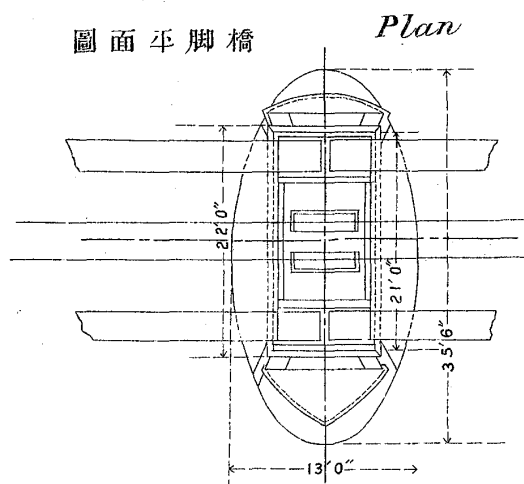
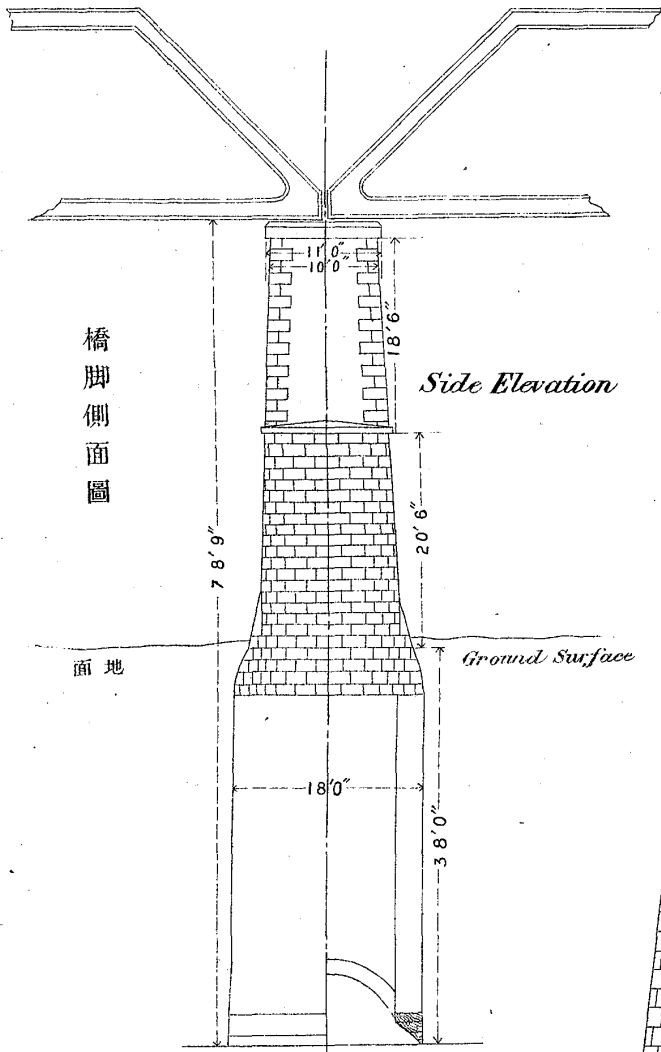


PIER No. 1 OF THE TONE-GAWA BRIDGE

(MAEBASHI), NIPPON RAILWAY.

圖之脚橋壹第川根利線毛兩 社會道鐵本日

(脚橋用桁鐵尺百二間徑)

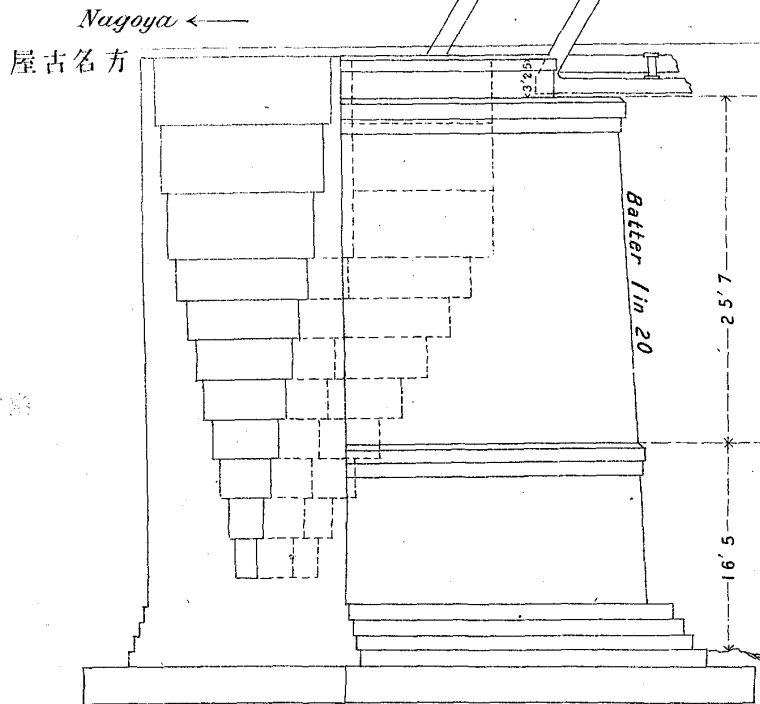


PIER AND ABUTMENT OF THE KIZU-GAWA BRIDGE, (KASAGI), KANSEI RAILWAY.

圖臺橋及脚橋梁橋川津水 社會道鐵西關
(呎六十爲吋一以尺縮)

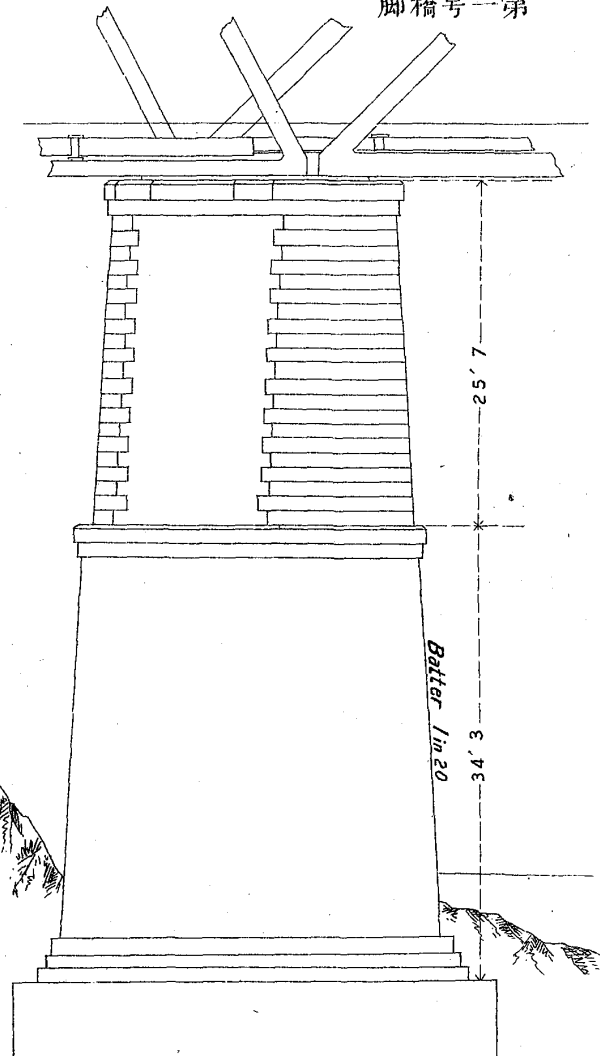
Nagoya end Abutment

(臺橋ノ側屋古名)

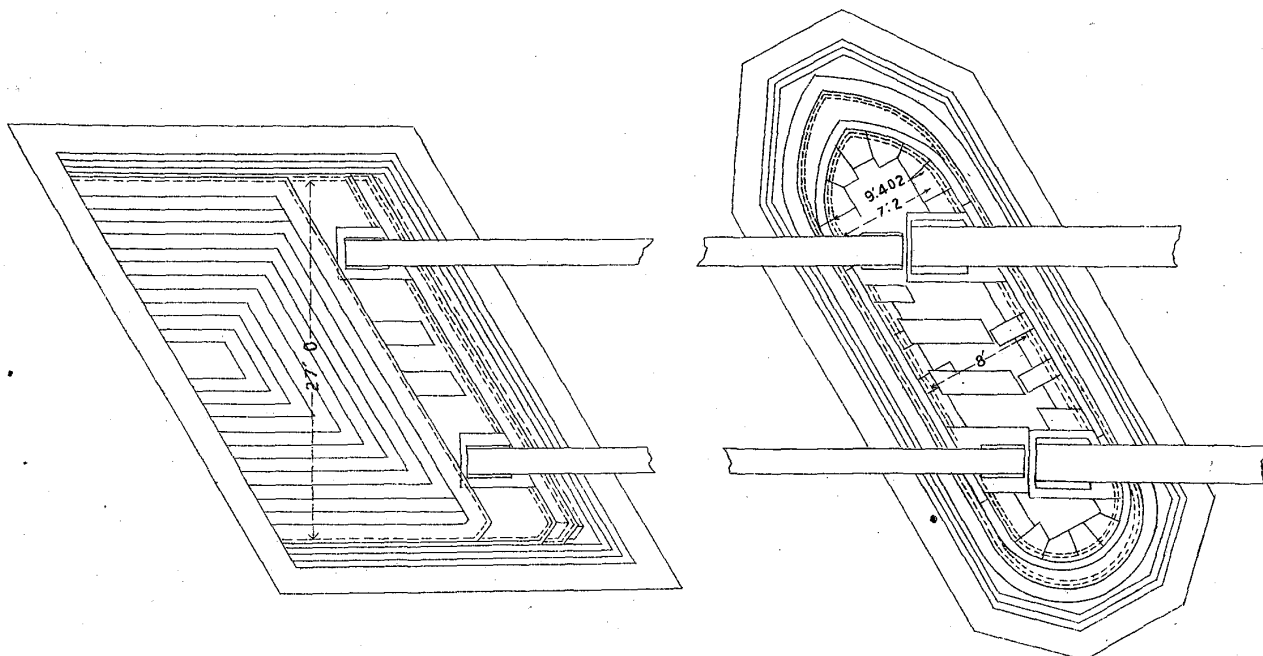


Pier No. 1.

脚橋号一第



Scale: 1 in = 16 ft



橋川根利近附驛手取社會道鐵本日

動振 / 脚橋 / 間和呷百二第号一第

VIBRATION OF THE PIER BETWEEN THE 1ST AND 2ND DOUBLE WARREN
GIRDERS, TONE-GAWA BRIDGE (TORIDE), NIPPON RAILWAY.

驗實圖一第

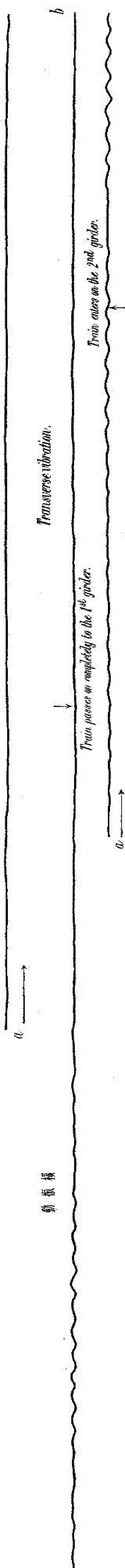
EXPT. 1.

Vertical vibration.



動振橋

Transverse vibration.



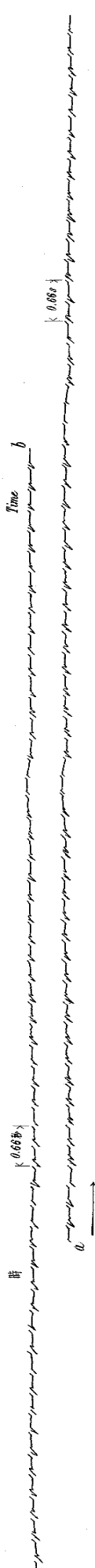
動振縱

Longitudinal vibration.



時

Time



驗實圖二第

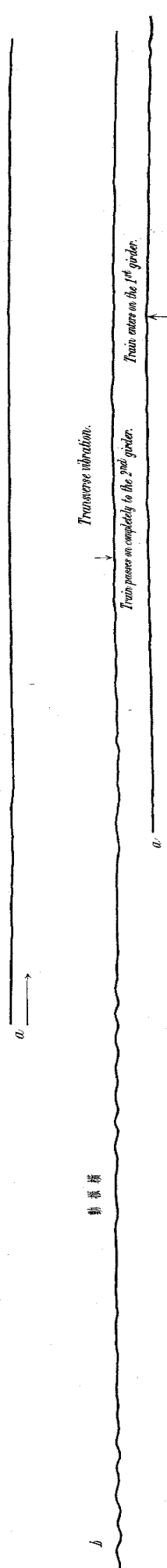
EXPT. 2.

Vertical vibration.



動振橋

Transverse vibration.



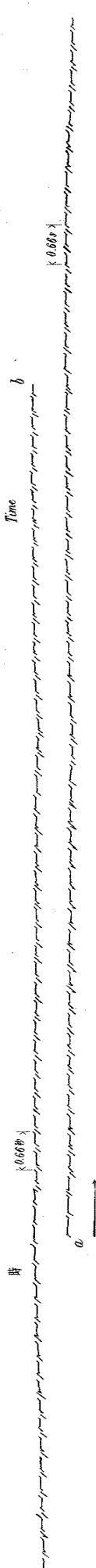
動振縱

Longitudinal vibration.



時

Time



脚橋号四第橋川斐揖道鐵西關

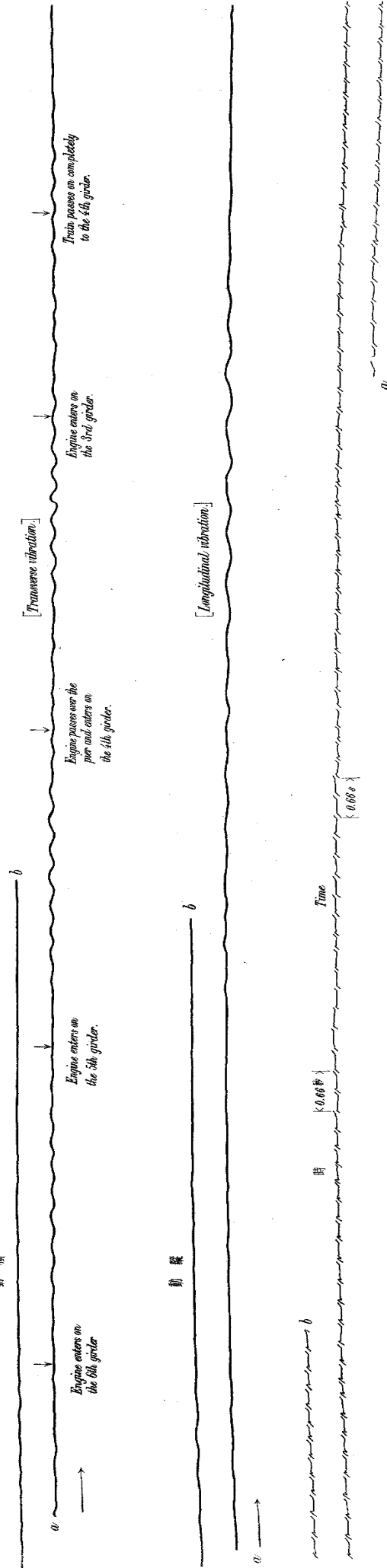
動振ノ縦ビ及横

TRANSVERSE AND LONGITUDINAL VIBRATIONS OF PIER NO. 4,

IBI-GAWA BRIDGE, KANSEI RAILWAY.

動横 繪實圖一第

EXPT. 1.



動横 繪實圖二第

EXPT. 2.

