# The Deflection and Vibration of Railway Bridges. 2nd Paper.

By

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**1. *Introduction.*** In No. 9 of the *Publications of the Earthquake Investigation Committee in Foreign Languages*, I have given an account of the measurements of the deflection and vibration of eleven railway bridges, with description of the instruments employed. Since then these experiments have been greatly extended, and in the course of 1901 and 1902, the movements of the 24 different girders and trusses on the Government, the Nippon, and the Kwansei Railways have been examined. All the trusses were *through* in construction except the two similar 105′ Pratt trusses of the 5th Aizawa-*gawa* and the Kami Usui-*gawa* bridges which were *deck* in construction. All of these bridges, most of which are constructed according to the Imp. Jap. Gov. Railway Standard, are for single track. In a few cases, the vibration of the bridge piers have also been recorded. The present note gives a tabular statement of the results of these measurements; the full report will be given in a future number of the *Publications*.

**2. *Instruments.*** The measurement of the deflection and vibration of the bridge trusses and girders was done with the same instruments and in exactly the same way as in the preceding series of experiments For taking the direct measurement of the total amount of the deflection, however, a new self recording arrange-

ment was designed, whose mechanical details an given in Pl. XLI. This instrument consists essentially of a strong wooden board ($a$), 5 inches broad and some 3 feet long, which is fixed by means of proper bolts or hooks ($b$) to the girder or the bottom chord of the truss. From the middle of the plate, rises a wooden post ($c$) about 1′ tall, whose top serves as the fulcrum for the lever ($de$). One end of the latter is stretched by three similar powerful spiral springs ($k$) fixed vertically to the plate ($a$); while from the other end, ($e$), a square piece of wood ($f$) is suspended, which is to be tightly stretched by means of a weight ($g$), (not shown in the figure) suspended with a steel wire or tape. To the inner side of the wood piece ($d$) is fixed by a screw a small thin rectangular piece of wood, ($h$), about $1'' \times 5''$ in size, against which presses the point of a pencil ($i$) contained in a guiding tube ($j$) fixed to the base plate. The tube ($j$) contains at its end a small spiral spring which presses the pencil ($i$) forward. Thus, when a train passes over the girder or truss, the latter is deflected and bent down; while the small plate ($h$) remains always in its position, on account of the stretching due to the weight ($g$) and the springs ($k$).

The pencil ($i$) therefore traces in the natural size the amount of the total deflection (i. e. statical deflection and maximum vertical vibration combined) on the plate ($h$). The latter is after each experiment to be substitued by a new one. Except for the case of mountain torrent, this method gave generally satisfactory results, no matter how deep the water was; the weight ($g$) consisting of a cylindrical weight of lead furnished with three small feet, which together weigh about 15 kg. The following are some of the cases, in which the deflection was measured both directly by the above mentioned contrivance, and by the vertical motion seismograph (deflectometer) set up on the bridge itself:—

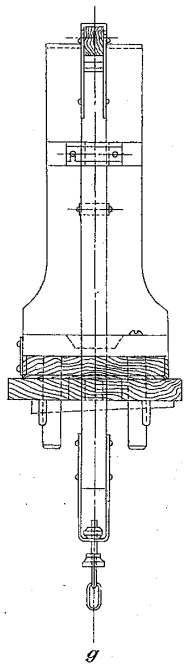
| Bridge. | Deflection measured directly. | Deflection measured by vert. mot. seismograph. | Remarks. |
|---|---|---|---|
| Ōi-*gawa*. (Tokaido Ry.) { 200′ Double Warren Gird. | 24.0 mm | 26.2 mm | { Passenger train, with 2 engines Nos. 608 and 2 at head. |
| Do. | 19.0 | 21.0 | { Mixed train, with 2 engines Nos. 610 and 113 at head. |
| Ibi-*gawa* ,, (Kwansei Ry.) | 18.0 | 17.4 | { Passenger train, Engine No. 44. |
| Do. | 19.0 | 17.5 | { Passenger train, Engine No. 41. |
| *Mean.* | **20.0** | **20.5** | |

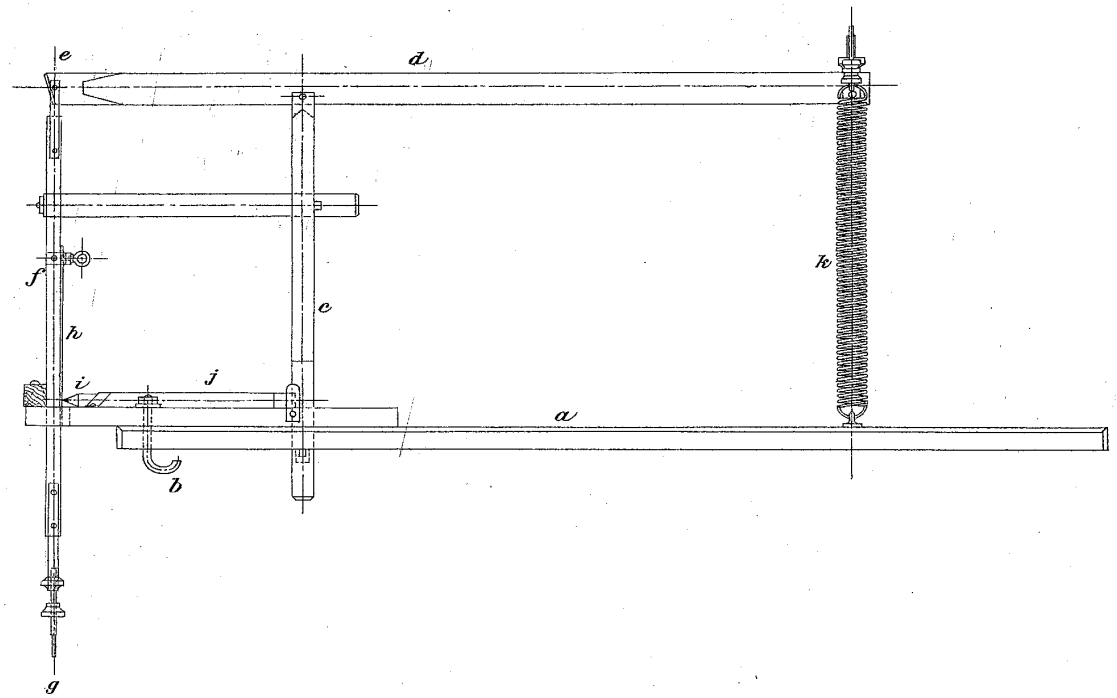
**3. *Deflection and Vibration of the Bridge Girders and Trusses.*** Table II, which embodies the results of the second series of the deflection and vibration measurements, gives for each of the bridge girders and trusses the different elements of the movement; the experiment having been, except in a few cases, repeated 2 to 21 times. Table III gives a general summary of the results of measurements contained in Table II, namely, the absolutely greatest and mean maximum values of the deflection, double amplitude, and period, for each case. Table I gives a list of the locomotives which passed over the different bridges during the experiments. The terms *deflection*, and *vertical*, *transverse* and *longitudinal vibrations*, which are used in the same senses as heretofore and refer to the middle of the bottom side of a girder or truss, are defined as follows:—

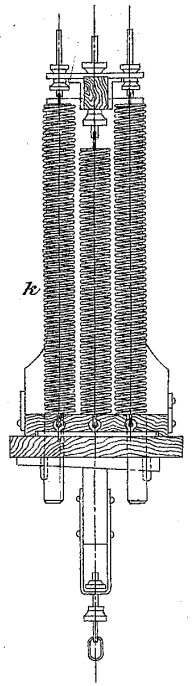
The *deflection* is the total amount of bending, which is equivalent to the sum of the statical bending and the maximum vibration amplitude.

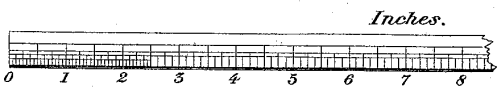
The *vertical vibration* is the up and down quick movement,

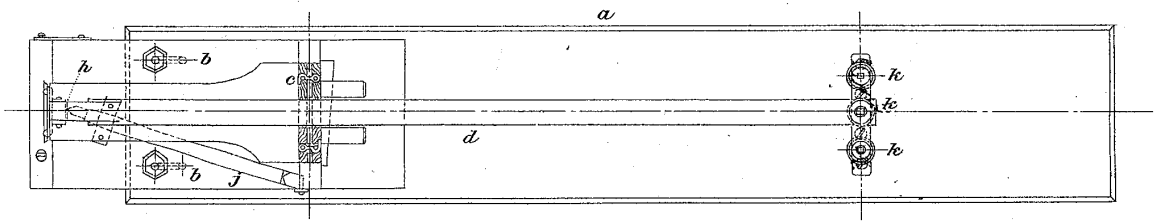
# A Contrivance for measuring the Deflection of a Bridge.



whose period depends on each girder or truss; while the *transverse* and the *longitudinal vibrations* are the movements, which take place in the horizontal plane, and whose directions are respectively perpendicular and parallel to the length of the bridge. For each class of vibrations, the range of motion, or double amplitude, and the period (that is to say, the complete period) are denoted respectively by the symbols 2a and T.

The values of the deflections given in Tables II and III have been obtained as follows:–(1), measured by the deflectometer alone in the cases of a 70′ plate girder of the Tone-*gawa* (Maebashi), the three 100′ Warren girders of the Kuji-*gawa*, the 2nd Sakawa-*gawa* and the 3rd Sakawa-*gawa* bridges, the 120′ Pratt truss of the Ibi-*gawa* bridge, the two similar 105′ Pratt deck trusses (up line) of the 5th Aizawa-*gawa* and the Kami-Usui-*gawa* bridges, and the 200′ Pratt truss of the Kizu-*gawa* bridge; (2), measured directly by the contrivance before described, in the cases of the 20′ plate girder of the Tone-*gawa* bridge (Toride), the 70′ plate girder of the Kizu-*gawa* bridge, the 100′ Warren girder (one nearest the Kasagi end) of the Kizu-*gawa* bridge, the 105′ Pratt truss (down line) of the 5th Aizawa-*gawa* bridge, a 200′ Double Warren girder (Truss No. 14) of the Ōi-*gawa* bridge, the 200′ bow-string truss of the 3rd Aizawa-*gawa* bridge, and a 200′ Double Warren girder (No. 1) of the Tone-*gawa* bridge (Toride); and, (3), measured both by the deflectometer and directly by the same contrivance as in (3), in the remaining 4 cases.

The period of the longitudinal vibration which was generally too quick to be distinctly measured by our instrument, is not given in the tables.

The *asterisks*, affixed in Table III to the names of some of the bridges signify that the values of the deflection and

the vibrations given there are those caused by the passage of the heaviest engine or train which pass over those bridges in the present state of the traffic on the different Japanese railways. In Table III, the absolutely greatest among the different values of a given element of motion in each column are printed in fat letters.

A photographic picture of the contrivance for directly measuring the deflection, described in § 2, is given in Pl. XLII.

# TABLE I.—LIST OF THE LOCOMOTIVES.‡

| No. | Class. | Total Weight | | | Weight of Tender. | | | No. | Class. | Total Weight | | | Weight of Tender. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **NIPPON RAILWAY.*** | | | | | | | | | | | | | | | |
| | | T | C | Q | T | C | Q | | | T | C | lbs | T | C | lbs |
| 38 | Tank Engine | 33. | 8. | 2 | | — | | 513 | Tender Engine | 70. | 16. | 118 | 26. | 13. | 26 |
| 62 | ,, ,, | 44. | 15. | 0 | | — | | 515 | ,, ,, | ,, | ,, | ,, | ,, | ,, | ,, |
| 123 | ,, ,, | 38. | 19. | 3 | | — | | 524 | ,, ,, | ,, | ,, | ,, | ,, | ,, | ,, |
| 209 | Tender ,, | 55. | 16. | 0 | 24. | 10. | 0 | 527 | ,, ,, | ,, | ,, | ,, | ,, | ,, | ,, |
| 211 | ,, ,, | ,, | ,, | ,, lbs | ,, | ,, | ,, lbs | 535 | ,, ,, | 80. | 0. | 122 | 26. | 13. | 26 |
| 508 | ,, ,, | 70. | 16. | 118 | 26. | 13. | 26 | 553 | Tank ,, | 39. | 9. | 12 | | — | |
| 510 | ,, ,, | ,, | ,, | ,, | ,, | ,, | ,, | 555 | ,, ,, | ,, | ,, | ,, | | — | |
| 511 | ,, ,, | ,, | ,, | ,, | ,, | ,, | ,, | | | | | | | | |
| **KWANSAI RAILWAY.** | | | | | | | | | | | | | | | |
| | | T | C | Q | T | C | Q | | | T | C | Q | T | C | Q |
| 24 | Tender Engine | 62. | 17. | 3 | 25. | 17. | 3 | 36 | Tender Engine | 64. | 0. | 0 | 23. | 10. | 0 |
| 27 | Tank ,, | 36. | 2. | 0 | | — | | 38 | ,, ,, | ,, | ,, | ,, | ,, | ,, | ,, |
| 29 | ,, ,, | ,, | ,, | ,, | | — | | 39 | ,, ,, | ,, | ,, | ,, | ,, | ,, | ,, |
| 30 | Tender ,, | 64. | 0. | 0 | 23. | 10. | 0 | 40 | ,, ,, | 54. | 4. | 0 | 18. | 10. | 0 |
| 31 | ,, ,, | ,, | ,, | ,, | ,, | ,, | ,, | 41 | ,, ,, | ,, | ,, | ,, | ,, | ,, | ,, |
| 33 | ,, ,, | ,, | ,, | ,, | ,, | ,, | ,, | 42 | ,, ,, | ,, | ,, | ,, | ,, | ,, | ,, |
| 34 | ,, ,, | ,, | ,, | ,, | ,, | ,, | ,, | 44 | ,, ,, | ,, | ,, | ,, | ,, | ,, | ,, |
| 35 | ,, ,, | ,, | ,, | ,, | ,, | ,, | ,, | | | | | | | | |
| **GOVERNMENT RAILWAYS.** | | | | | | | | | | | | | | | |
| | | T | C | Q | T | C | Q | | | T | C | Q | T | C | Q |
| 2 | Tender Engine | 42. | 14. | 0 | 17. | 6. | 0 | 272 | Tender Engine | 59. | 8. | 0 | 22. | 2. | 0 |
| 74 | Tank ,, | 45. | 9. | 2 | | — | | 278 | ,, ,, | ,, | ,, | ,, | ,, | ,, | ,, |
| 113 | ,, ,, | 33. | 8. | 2 | | — | | 289 | ,, ,, | ,, | ,, | ,, | ,, | ,, | ,, |
| 187 | Tender ,, | 60. | 19. | 0 | 22. | 0. | 0 | 299 | Tank ,, | 48. | 9. | 0 | | — | |
| 188 | ,, ,, | ,, | ,, | ,, | ,, | ,, | ,, | 324 | ,, ,, | ,, | ,, | ,, | | — | |
| 189 | ,, ,, | ,, | ,, | ,, | ,, | ,, | ,, | 325 | ,, ,, | ,, | ,, | ,, | | — | |
| 190 | ,, ,, | ,, | ,, | ,, | ,, | ,, | ,, | 505 | Abt ,, | 53. | 12. | 0 | | — | |
| 191 | ,, ,, | ,, | ,, | ,, | ,, | ,, | ,, | 605 | Tender ,, | 46. | 17. | 0 | 19. | 10. | 0 |
| 193 | ,, ,, | ,, | ,, | ,, | ,, | ,, | ,, | 606 | ,, ,, | ,, | ,, | ,, | ,, | ,, | ,, |
| 194 | ,, ,, | ,, | ,, | ,, | ,, | ,, | ,, | 608 | ,, ,, | ,, | ,, | ,, | ,, | ,, | ,, |
| 197 | ,, ,, | ,, | ,, | ,, | ,, | ,, | ,, | 610 | ,, ,, | ,, | ,, | ,, | ,, | ,, | ,, |
| 199 | ,, ,, | ,, | ,, | ,, | ,, | ,, | ,, | 612 | ,, ,, | ,, | ,, | ,, | ,, | ,, | ,, |
| 200 | ,, ,, | ,, | ,, | ,, | ,, | ,, | ,, | 634 | ,, ,, | ,, | ,, | ,, | ,, | ,, | ,, |
| 203 | ,, ,, | ,, | ,, | ,, | ,, | ,, | ,, | 640 | ,, ,, | ,, | ,, | ,, | ,, | ,, | ,, |

‡ *Total weight* is the weight of the engine and tender.

* The Nippon Railway has recently been nationalized.

# TABLE II. DEFLECTION AND VIBRATION

| River. | Bridge Girder or Truss. | Deflection. | | | Vertical Vibration. | |
|---|---|---|---|---|---|---|
| | | Instrumentally measured. (mm) | Directly measured (mm) | Mean. (mm) | 2a (mm) | T (s) |
| Tone (Toride) (Nippon Ry.) | 20′ Plate Girder | — | 2.1 | — | — | — |
| | | — | 2.9 | — | — | — |
| | 60′ „ „ | 10.8 | — | — | 1.0 | 0.21 |
| | | 8.8 | — | — | 1.2 | 0.24 |
| | | 11.1 | — | — | 1.5 | 0.22 |
| | | 9.1 | 10.3=($\frac{13}{32}$″) | 9.7 | 1.0 | 0.22 |
| | | 8.0 | 10.3=( „ ) | 9.2 | 1.2 | 0.26 |
| | | — | 9.5=($\frac{3}{8}$″) | — | — | — |
| Kuji (Ōmika) (Nippon Ry.) | 60′ „ „ | — | 12.5 | — | — | — |
| | | — | 12.4 | — | — | — |
| | | — | 12.4 | — | — | — |
| Tone (Mayebashi) (Nippon Ry.) | 70′ „ „ | 8.8 | — | — | 2.6 | 0.90 |
| | | 7.5 | — | — | 1.7 | 0.22 |
| | | — | — | — | 1.5 | 0.19 |
| | | 8.8 | — | — | 2.0 | 0.21 |
| | | 9.9 | — | — | 1.8 | 0.21 |
| Kizu (Kasagi) (Kwansai Ry.) | 70′ „ „ | — | 16.3 | — | — | — |
| | | — | 14.5 | — | — | — |
| | | — | 15.5 | — | — | — |
| Kizu (Ōmika) (Nippon Ry.) | 100′ Warren Girder | 14.3 | — | — | 3.5 | 0.35 |
| | | 16.4 | — | — | 5.6 | 0.34 |
| | | — | — | — | 0.9 | 0.34 |
| | | 17.8 | — | — | 5.4 | 0.34 |
| (No. 2) Sakawa (Yamakita) (Gov. Ry.) | 100′ „ | 14.7 | — | — | 3.2 | 0.35 |
| | | 11.6 | — | — | 5.6 | 0.27 |
| | | 13.3 | — | — | 3.2 | 0.32 |
| (No. 3) Sakawa (Yamakita) (Gov. Ry.) | 100′ „ | 15.4 | — | — | 5.1 | 0.29 |

# OF RAILWAY BRIDGES IN JAPAN.

| Transverse Vibration. | | Longitudinal Vibration. | Time taken by Locomotive in passing over the Girder or Truss. | No. of Locomotive. | Train. |
|---|---|---|---|---|---|
| 2a (mm) | T (s) | 2a (mm) | (s) | | |
| — | — | — | — | 209 | Up, Passenger Train. |
| — | — | — | — | 515 | Down, „ „ |
| — | — | — | 3.8 | 553 | Up, Goods „ |
| — | — | — | 3.0 | 123 | Down, „ „ |
| — | — | — | 4.0 | 527 | Up, Mixed „ |
| — | — | — | 3.2 | 62 | Down, Goods „ |
| — | — | — | 4.2 | 555 | „ „ „ |
| — | — | — | — | 513 | „ Mixed „ |
| — | — | — | — | 535 | Up, Goods „ |
| — | — | — | — | 508 | „ Passenger „ |
| — | — | — | — | 524 | Down, „ „ |
| — | — | — | 2.2 | 38 | „ Mixed „ |
| 3.5 | 0.43 | 0.2 | 2.6 | „ | Up, „ „ |
| 2.0 | 0.32 | 1.0 | — | „ | Down, Passenger „ |
| 3.2 | 0.40 | Faint. | 2.6 | „ | Up, Mixed „ |
| 5.0 | 0.37 | 0.4 | 2.6 | „ | Down, „ „ |
| — | — | — | — | 31 | Up, Mixed „ |
| — | — | — | — | 24 | Down, Goods „ |
| — | — | — | — | 36 | „ Express. |
| 8.6 | 0.63 | 0.7 | 2.9 | 511 | Down, Passenger „ |
| 10.0 | 0.99 | 0.9 | 3.2 | 508 | Up, „ „ |
| 6.3 | 1.06 | 0.4 | 6.0 | 535 | „ Goods „ |
| 10.0 | 0.61 | 0.7 | 3.4 | 524 | Down, Passenger „ |
| 6.5 | 0.76 | 1.3 | 4.4 | 194 and 191, in series. | Up, Goods „ |
| 5.9 | Vibration very quick. | 2.7 | 2.3 | 199 | „ Passenger „ |
| 10.2 | 1.09 | — | 3.8 | 193 and 197, in series. | „ Goods „ |
| — | — | — | 4.0 | 190 and 272, in series. | „ Passenger „ |

# TABLE II.

| River. | Bridge Girder or Truss. | Deflection. | | | Vertical Vibration. | |
|---|---|---|---|---|---|---|
| | | Instrumentally measured. (mm) | Directly measured. (mm) | Mean. (mm) | 2a (mm) | T (s) |
| Kizu (Kasagi) (Kwansei Ry.) | 100′ Warren Girder. (on Nagoya side). | 12.0 | — | — | 3.7 | 0.30 |
| | | 10.2 | — | — | 2.7 | 0.28 |
| | | 9.3 | — | — | 2.3 | 0.27 |
| | | 9.8 | — | — | 2.8 | 0.28 |
| | | 11.3 | — | — | 2.1 | 0.25 |
| | | 13.3 | — | — | 4.7 | 0.25 |
| | | — | 11.5 | — | — | — |
| | | — | 10.2 | — | — | — |
| | | — | 10.4 | — | — | — |
| | | — | 10.6 | — | — | — |
| | | — | 9.2 | — | — | — |
| | | — | 9.5 | — | — | — |
| | | — | 14.0 | — | — | — |
| ,, (Do.) | 100′ Warren Girder. (on Kasagi side). | — | 10.2 | — | — | — |
| | | — | 9.8 | — | — | — |
| Ibi (Nagashima) (Do.) | 120′ Pratt Truss. | 7.2 | — | — | 1.6 | 0.25 |
| | | 8.0 | — | — | 1.2 | 0.28 |
| | | 5.3 | — | — | 1.0 | 0.21 |
| No. 5. Aizawa (Oyama) (Gov. Ry.) | 105′ Pratt Truss Deck. | 25.4 | — | — | 5.8 | 0.33 |
| | | 22.4 | — | — | 4.4 | 0.31 |
| ,, (Do.) | 105′ ( ,, ) | — | 17.5 | — | — | — |
| | | — | 15.0 | — | — | — |
| Kami-Usui (Matsuida) (Do.) | 105′ ( ,, ) | 14.7 | — | — | 4.9 | — |
| | | 17.2 | — | — | 6.8 | 0.28 |
| | | 18.2 | — | — | 6.3 | 0.32 |
| | | 17.7 | — | — | 4.3 | 0.28 |
| | | 15.4 | — | — | 4.4 | 0.33 |

*CONT.*

| Transverse Vibration. | | Longitudinal Vibration. | Time taken by Locomotive in passing over the Girder or Truss. | No. of Locomotive. | Train. |
|---|---|---|---|---|---|
| 2a (mm) | T (s) | 2a (mm) | (s) | | |
| — | — | — | 2.3 | 29 | Up, Passenger Train, 11 Carriages |
| — | — | — | 2.8 | 33 | „ , „ „ , 16 „ |
| — | — | — | 3.9 | 38 | Down, Goods „ , 6 Wagons |
| — | — | — | 3.4 | 33 | Up, Passenger „ , 11 Carriages |
| — | — | — | 3.4 | 38 | „ , Goods „ , 11 Wagons |
| — | — | — | 2.5 | 35 | Down, Passenger „ , 10 Carriages |
| — | — | — | — | 39 | Up, „ „ , 11 „ |
| — | — | — | — | 30 | Down, „ „ , 10 „ |
| — | — | — | — | 35 | „ , Goods „ , 11 Wagons |
| — | — | — | — | 33 | „ , Passenger „ , 12 Carriages |
| — | — | — | — | 30 | Up, „ „ , 11 „ |
| — | — | — | — | 35 | „ , Goods „ , 11 Wagons |
| — | — | — | — | 31 | Down, Passenger „ , 10 Carriages |
| — | — | — | — | 34 | Up, Goods „ , 4 Wagons |
| — | — | — | — | 39 | „ , Passenger „ , 10 Carriages |
| — | — | — | 4.4 | 40 | Down, Passenger „ , 10 Carriages |
| — | — | — | 4.6 | 41 | Up, Mixed „ , {Pass., 6 Cars. Goods, 6 Wags. |
| — | — | — | 4.3 | 27 | Down, „ „ , {Pass., 6 Cars. Goods, 6 Wags. |
| — | — | — | 4.6 | {193 and 197, in series. | Up, Goods, „ , 26 Wagons |
| — | — | — | 4.0 | {189 and 289, in series. | „ , Passenger „ , 20 Carriages |
| — | — | — | — | 200 | Down, Passenger „ , 9 Carriages |
| — | — | — | — | 193 | „ , Goods „ , 31 Wagons |
| — | — | — | — | 74 | „ , „ „ , 10 Wagons |
| 7.8 | 1.01 | 0.7 | 3.2 | 299 | Up, „ „ , 12 „ |
| 6.2 | 0.99 | 1.1 | 3.3 | 325 | Down, Mixed „ , {Pass., 7 Cars. Goods, 3 Wags. |
| 7.7 | 1.32 | 0.9 | 3.3 | 74 | Up, „ „ , {Pass., 6 Cars. Goods, 4 Wags. |
| 5.4 | 0.99 | 0.7 | 3.6 | 299 | Down, Goods „ , 13 Wagons |

TABLE II.

| River. | Bridge Girder or Truss. | Deflection. | | | Vertical Vibration. | |
|---|---|---|---|---|---|---|
| | | Instrumentally measured. (mm) | Directly measured. (mm) | Mean. (mm) | 2a (mm) | T (s) |
| Kami-Usui (Matsuida) (Gov. Ry.) | 105′ (Pratt Truss Deck) | 17.4 | — | — | 5.8 | 0.25 |
| | | 16.7 | — | — | 5.7 | 0.28 |
| | | — | — | — | 5.5 | 0.28 |
| | | 14.8 | — | — | 6.1 | 0.32 |
| | | 15.4 | — | — | 4.5 | 0.25 |
| | | 17.0 | — | — | 3.8 | 0.37 |
| | | 18.2 | — | — | 5.6 | 0.28 |
| | | — | — | — | 6.3 | 0.28 |
| | | — | — | — | 5.0 | 0.30 |
| | | — | — | — | 6.8 | 0.31 |
| | | — | — | — | 4.8 | 0.32 |
| | | — | — | — | 5.9 | 0.26 |
| | | — | — | — | 5.3 | 0.33 |
| | | 20.2 | — | — | 9.2 | 0.30 |
| | | 18.2 | — | — | 8.8 | 0.28 |
| | | — | — | — | 4.9 | 0.33 |
| | | — | — | — | 2.2 | 0.32 |
| Ibi (Nagashima) (Kwansai Ry.) | 200′ (Double Warren Girder) | 17.4 | 18.0 | 17.7 | 3.9 | 0.36 |
| | | 17.5 | 19.0 | 18.3 | 8.2 | 0.32 |
| | | — | 18.2 | — | 4.4 | 0.46 |
| | | — | 18.5 | — | 2.7 | 0.59 |
| | | — | 16.5 | — | 5.6 | 0.44 |
| | | — | 13.6 | — | 1.9 | 0.53 |
| Ōi (Kanaya) (Gov. Ry.) | 200′ „ (No. 10 Girder) | — | — | — | — | — |
| | | — | — | — | — | — |
| | | 26.2 | 24.0 | 25.1 | 7.2 | 0.39 |
| | | — | 13.0 | — | 2.5 | 0.35 |
| | | — | 15.8 | — | 3.8 | 0.40 |
| | | 21.0 | 19.0 | 20.0 | 3.4 | 0.38 |
| | | — | — | — | 0.4 | 0.37 |

*CONT.*

| Transverse Vibration. | | Longitudinal Vibration. | Time taken by Locomotive in passing over the Girder or Truss. (s) | No. of Locomotive. | Train. |
|---|---|---|---|---|---|
| 2a (mm) | T (s) | 2a (mm) | | | |
| 11.5 | 0.92 | 1.5 | 2.6 | 325 | Up, Goods Train, 10 Wagons. |
| 2.7 | — | 1.0 | 3.2 | 74 | Down, Mixed „ {Goods, 1 Wags. Pass, 6 Cars. |
| 8.1 | 1.15 | 1.0 | 2.6 | 299 | Up, „ „ {Goods, 6 Wags. Pass, 6 Cars. |
| 6.6 | 0.67 | 1.4 | 3.4 | 325 | Down, Goods „ , 11 Wagons. |
| — | — | — | 3.0 | — | Up, „ „ „ |
| 3.8 | 0.99 | 1.0 | 3.3 | 325 | Down. „ „ , 11 Wagons. |
| — | — | — | 2.6 | 325 | Up, Mixed „ , {Goods, 2 Wags. Pass., 8 Cars. |
| 7.2 | 0.99 | 0.7 | — | 324 | Down, Goods „ , 12 Wagons. |
| 2.9 | 0.28 | 0.7 | — | 74 | „ , Mixed „ , {Pass., 6 Cars. Goods, 4 Wags. |
| 8.9 | 1.25 | 0.8 | — | 324 | Down, Goods, „ , 12 Wagons. |
| 11.5 | 1.21 | — | 4.8 | 505 | Up, „ „ |
| 15.0 | 1.09 | — | 4.0 | „ | Down, „ „ |
| 12.0 | 1.24 | — | 4.8 | „ | Up, „ „ |
| 11.0 | 1.27 | 0.6 | 4.2 | „ | Down „ „ |
| 10.8 | 1.21 | 0.8 | 4.0 | „ | Down „ „ |
| 12.5 | 1.48 | 0.5 | 6.0 | „ | Up „ „ |
| 4.7 | 0.50 | 0.5 | — | 42 | Up, Mixed Train, {Pass., 6 Cars. Goods, 18 Wags. |
| — | — | — | 5.3 | 44 | Up, Passenger „ , 10 Carriages. |
| — | — | — | 5.0 | 41 | Down, „ „ , „ „ |
| — | — | — | 6.0 | 40 | Up, Mixed „ , {Pass., 10 Cars. Goods, 5 Wags. |
| 5.0 | 0.60 | 0.7 | — | 40 | Down, Passenger „ 10 Carriages. |
| 5.4 | 1.12 | 0.7 | — | 41 | Up, Mixed „ , {Pass., 6 Cars. Goods, 6 Wags. |
| 6.5 | 1.12 | 1.3 | — | 27 | Down, „ „ , {Pass., 6 Cars. Goods, 9 Wags. |
| 8.0 | 0.94 | — | — | 606 | Up, Mixed „ , {Pass., 5 Cars. Goods, 10 Wags. |
| 6.0 | 0.66 | — | — | 605 | Down, „ „ , {Pass., 8 Cars. Goods, 8 Wags. |
| 3.8 | 0.81 | — | 7.0 | {608 and 2, in series. | Up, Passenger „ , 18 Carriages. |
| 5.8 | 0.76 | — | — | 634 | Down, Mixed „ , {Pass., 6 Cars. Goods, 20 Wags. |
| 3.4 | 0.79 | — | — | 640 | „ , Passenger „ , 17 Carriages. |
| 12.4 | 0.74 | — | — | {610 and 113, in series. | Up, Mixed „ , {Pass., 6 Cars. Goods, 10 Wags. |
| — | — | — | — | {Two workmen run going and returning. | — |

TABLE II.

| River. | Bridge Girder or Truss. | Deflection. | | | Vertical Vibration. | |
|---|---|---|---|---|---|---|
| | | Instrumentally measured. (mm) | Directly measured (mm) | Mean. (mm) | 2a (mm) | T (s) |
| Ōi (Kanaya) (Gov. Ry.) | 200′ Double Warren Girder (No. 10 Girder) | — | — | — | 4.0 | 0.40 |
| | | — | — | — | 2.4 | 0.42 |
| ,, | 200′ ,, (No. 14 Girder) | — | 15.0 | — | — | — |
| | | — | 14.8 | — | — | — |
| Kizu (Kasagi) (Kwansei Ry.) | 200′ Pratt Truss | 18.2 | — | — | 7.3 | 0.43 |
| | | 15.8 | — | — | 1.7 | — |
| | | — | — | — | 5.3 | 0.37 |
| | | 17.6 | — | — | 4.4 | 0.34 |
| | | 17.4 | — | — | 6.1 | 0.31 |
| | | 19.2 | — | — | 4.8 | — |
| | | 17.0 | — | — | 4.5 | 0.37 |
| ,, | 200′ ,, | — | — | — | 4.5 | 0.37 |
| | | — | — | — | 6.0 | 0.37 |
| | | — | — | — | 5.1 | 0.41 |
| | | — | — | — | 6.9 | 0.43 |
| | | — | — | — | 6.8 | 0.42 |
| | | — | — | — | 2.5 | 0.29 |
| No. 3 Aizawa (Oyama) (Gov. Ry.) | 200′ Bow-string Truss | — | — | — | 2.2 | 0.36 |
| | | — | — | — | 3.5 | 0.26 |
| | | — | — | — | 4.5 | 0.38 |
| ,, | 200′ ,, | — | 10.5 | — | — | — |
| | | — | 13.0 | — | — | — |
| | | — | 11.8 | — | — | — |
| | | — | 11.6 | — | — | — |
| | | — | 11.3 | — | — | — |

*CONT.*

| Transverse Vibration. | | Longitudinal Vibration. | Time taken by Locomotive in passing over the girder or truss. | No. of Locomotive. | Train. |
|---|---|---|---|---|---|
| 2a (mm) | T (s) | 2a (mm) | (s) | | |
| 5.8 | — | — | — | 608 | Up, Goods Train, 24 Wagons |
| 6.8 | 0.88 | — | — | 612 | Down, „ „ , 18 „ |
| — | — | — | — | 608 | Mixed „ , { Pass., 6 Cars. Goods, 4 Wags. |
| — | — | — | — | 612 | Down, Goods „ , 12 Wagons. |
| — | — | — | 6.0 | 35 | „ , „ „ , 11 „ |
| — | — | — | 4.7 | 33 | „ , Passenger „ , 12 Carriages |
| — | — | — | 5.4 | 30 | Up, „ „ , 11 „ |
| — | — | — | 4.7 | 35 | „ , Goods Train, 11 Wagons |
| — | — | — | 5.6 | 31 | Down, Pass. „ , 10 Carriages |
| — | — | — | 4.7 | 36 | „ , „ „ , 10 „ |
| — | — | — | 6.0 | 38 | „ , Mixed „ , { Pass., 1 Cars. Goods, 11 Wags. |
| 2.3 | 0.65 | 1.4 | — | 29 | Up, Passenger „ , 11 Carriages |
| 3.1 | 0.71 | 1.6 | — | 33 | Down, „ „ , 16 „ |
| 1.2 | 0.61 | 1.3 | — | 38 | „ , Goods „ , 6 Wagons |
| 2.3 | 0.26 | 1.3 | — | 33 | Up, Passenger „ , 11 Carriages |
| 2.7 | 0.45 | 1.0 | — | 38 | „ , Goods „ , 8 Wagons |
| 1.9 | 0.77 | 1.5 | — | 35 | Down, Pass. „ , 10 Carriages |
| — | — | — | 5.6 | 272 | Up, Passenger „ , 9 Carriages |
| — | — | — | 5.3 | { 188 and 200, in series. | „ , Goods „ , 28 Wagons |
| — | — | — | 6.6 | { 187 and 191, in series. | „ , Passenger „ , 18 Carriages |
| — | — | — | — | 272 | |
| — | — | — | — | 193 | |
| — | — | — | — | 200 | |
| — | — | — | — | 278 | |
| — | — | — | — | 203 | |

TABLE II.

| River. | Bridge Girder or Truss. | Deflection. | | | Vertical Vibration. | |
|---|---|---|---|---|---|---|
| | | Instrumentally measured. (mm) | Directly measured (mm) | Mean (mm) | 2a (mm) | T (s) |
| Tone (Toride) (Nippon Ry.) | 200′(Double Warren Girder) (1st Girder from Tokyo side) | — | 17.5 | — | — | — |
| | | — | 25.4 | — | — | — |
| | | — | 23.5 | — | — | — |
| ,, ,, | 200′ (Double Warren Girder) (2nd Girder from Tokyo side) | — | — | — | 2.6 | 0.35 |
| | | — | — | — | 4.0 | 0.46 |
| | | — | — | — | 5.6 | 0.43 |
| | | — | — | — | 4.5 | 0.44 |
| ,, ,, | 200′ ( ,, ) ( ,, ) | — | — | — | 8.5 | 0.40 |
| | | — | — | — | 4.5 | 0.50 |
| | | — | — | — | 7.3 | 0.41 |
| No. 3 Sakawa (Yamakita.) (Gov. Ry.) | 200′ (Bow-string Truss) | — | — | — | 4.5 | 0.34 |

*CONT.*

| Transverse Vibration. | | Longitudinal Vibration. | Time taken by Locomotive in passing over the Girder or Truss. (s) | No. of Locomotive. | Train. |
|---|---|---|---|---|---|
| 2a (mm) | T (s) | 2a (mm) | | | |
| — | — | — | — | 123 | Down, Goods Train. |
| — | — | — | — | 527 | Up, Mixed „ |
| — | — | — | — | 211 and 510, in series. | Down, „ „ |
| 3.1 | — | 0.5 | — | 555 | „ , Goods Train. |
| 5.8 | 0.93 | 1.0 | — | 515 | Up, Mixed „ |
| 4.6 | 1.00 | 0.7 | — | 513 | Down, „ „ |
| 4.7 | 0.91<br>0.45 | 0.7 | — | 553 | Up, Goods „ |
| 4.8 | 0.86 | 0.7 | — | 123 | Down, „ „ |
| 5.0 | 0.90 | 1.0 | — | 527 | Up, Mixed „ |
| 6.8 | 1.20 | 0.7 | — | 211 and 510, in series. | Down, „ „ |
| 5.5 | 0.39 | 3.4 | — | 190 and 272, in series. | Up, Passenger „ |

# TABLE III.—SUMMARY OF THE DEFLECTION AND VIBRATION MEASUREMENTS.

| Bridge Girder or Truss. | | | Deflection | | Vertical Vibration | | | | Transverse Vibration | | | | Longitudinal Vibration | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Max. 2a | | T | | Max. 2a | | T | | | |
| | | | 2a | Mean | Absolute | Mean | Longest | Mean | Absolute | Mean | Longest | Mean | Max. 2a | Mean |
| | | | (mm) | (mm) | (mm) | (mm) | (s) | (s) | (mm) | (mm) | (s) | (s) | (mm) | (mm) |
| *Tone (Toride) | 20′ | Plate Girder | 2.9 | 2.5 | — | — | — | — | — | — | — | — | — | — |
| * „ | 60′ | „ „ | 11.1 | 9.9 | 1.5 | 1.2 | 0.26 | 0.23 | — | — | — | — | — | — |
| *Kuji (Ōmika) | 60′ | „ „ | 12.5 | 12.4 | — | — | — | — | — | — | — | — | — | — |
| Tone (Maebashi) | 70′ | „ „ | 9.9 | 8.8 | 2.6 | 1.9 | 0.22 | 0.20 | 5.0 | 3.4 | 0.43 | 0.38 | 1.0 | 0.4 |
| *Kizu (Kasagi) | 70′ | „ „ | 16.3 | 15.4 | — | — | — | — | — | — | — | — | — | — |
| *Kuji (Ōmika) | 100′ | Warren | 17.8 | 16.2 | 5.6 | 4.8 | 0.35 | 0.34 | 10.0 | 9.5 | 1.06 | 0.82 | 0.9 | 0.7 |
| *No. 2. Sakawa (Yamakita) | 100′ | „ | 14.7 | 13.2 | 5.6 | 4.0 | 0.35 | 0.31 | 10.2 | 7.5 | 1.09 | 0.93 | 2.7 | 2.0 |
| *No. 3. „ ( „ ) | 100′ | „ | 15.4 | — | 5.1 | — | 0.29 | — | — | — | — | — | — | — |
| Kizu (Kasagi) | 100′ | „ | 14.0 | 10.9 | 4.7 | 3.1 | 0.30 | 0.27 | — | | | | | |
| „ ( „ ) | 100′ | „ | 10.2 | 10.0 | — | — | — | — | — | — | — | — | — | — |
| Ibi (Nagashima) | 120′ | Pratt | 8.0 | 6.8 | 1.6 | 1.3 | 0.28 | 0.25 | — | — | — | — | — | — |
| *No. 3. Aizawa (Oyama) | 105′ | Pratt Deck | 25.4 | 23.9 | 5.8 | | 0.33 | 0.32 | — | — | — | — | — | — |
| „ ( „ ) | „ | „ „ | 17.5 | 16.3 | — | — | — | — | — | — | — | — | — | — |
| Kami-Usui (Matsuida) | 105′ | „ „ | 20.2 | 17.1 | 9.2 | 5.8 | 0.37 | 0.30 | 15.0 | 8.7 | 1.48 | 1.10 | 1.5 | 0.9 |
| Ibi (Nagashima) | 200′ | Double Warren | 18.5 | 17.1 | 8.2 | 4.1 | 0.59 | 0.43 | 6.5 | 5.6 | 1.12 | 0.95 | 1.3 | 0.9 |
| *Ōi (Kanaya) | 200′ | „ „ | 25.1 | 18.5 | 7.2 | 3.9 | 0.42 | 0.39 | 12.4 | 6.5 | 0.94 | 0.80 | — | — |
| „ „ | „ | „ „ | 15.0 | 14.9 | — | — | — | — | — | — | — | — | — | — |
| *Tone (Toride) | 200′ | „ „ | 29.5 | 24.1 | — | — | — | — | — | — | — | — | — | — |
| * „ ( „ ) | „ | „ „ | — | — | 8.5 | 5.3 | 0.50 | 0.43 | 6.8 | 5.0 | 1.20 | 0.97 | 1.0 | 0.8 |
| Kizu (Kasagi) | 200′ | Pratt Deck | 19.2 | 17.5 | 7.3 | 5.1 | 0.43 | 0.37 | 3.1 | 2.3 | 0.77 | 0.69 | 1.6 | 1.4 |
| *No. 3. Sakawa (Yamakita) | 200′ | Bow String | — | — | — | 4.5 | — | 0.34 | — | 5.5 | — | 0.39 | — | 3.4 |
| *No. 3. Aizawa (Oyama) | 200′ | „ „ | — | — | 4.5 | 3.4 | 0.38 | 0.33 | — | — | — | — | — | — |
| * „ ( „ ) | „ | „ „ | 13.0 | 11.6 | — | — | — | — | — | — | — | — | — | — |
| Hozu (Saga)‡ | 200′ | „ „ | — | — | 3.7 | 3.3 | 0.39 | 0.38 | 2.7 | — | 0.97 | 0.90 | 1.3 | 0.9 |

‡ The Hozu-*gawa* bridge vibrations were measured by Professors S. Tanabe and T. Hibi, of Kyoto Imp. Univ.

From Table III, we see that the absolutely greatest amount of the deflection reached 29.5 mm in the case of one of the 200′ double Warren girders of the Tone-*gawa* (Toride) bridge, and the next greatest amount of 25.4 mm occurred in the case of one of the 105′ Pratt *deck* truss of the No. 5 Aizawa-*gawa* bridge; each having taken place under the passage of two tender engines in series. The greatest vertical vibration of 9.2 mm, which occurred in the case of the Kami-Usui-*gawa* 105′ truss, similar to that of the last-named bridge, was produced by the passage at a velocity of 17 miles / hour of an Abt engine of $53^t$ $12^c$ coupled to a break-van; the maximum vertical motion of a girder or truss of long span generally occurring with a train running at a comparatively slow speed. The next greatest vertical vibration of 8.5 mm occurred in the case of the first-mentioned Tone-*gawa* bridge. From these figures it will be readily understood that the vertical vibration forms an element of the bridge motion of a considerable importance. The period of the vibration varied from about 0.2 sec. for 60′–70′ plate girders to nearly 0.6 sec. for the 200′ double Warren girders.

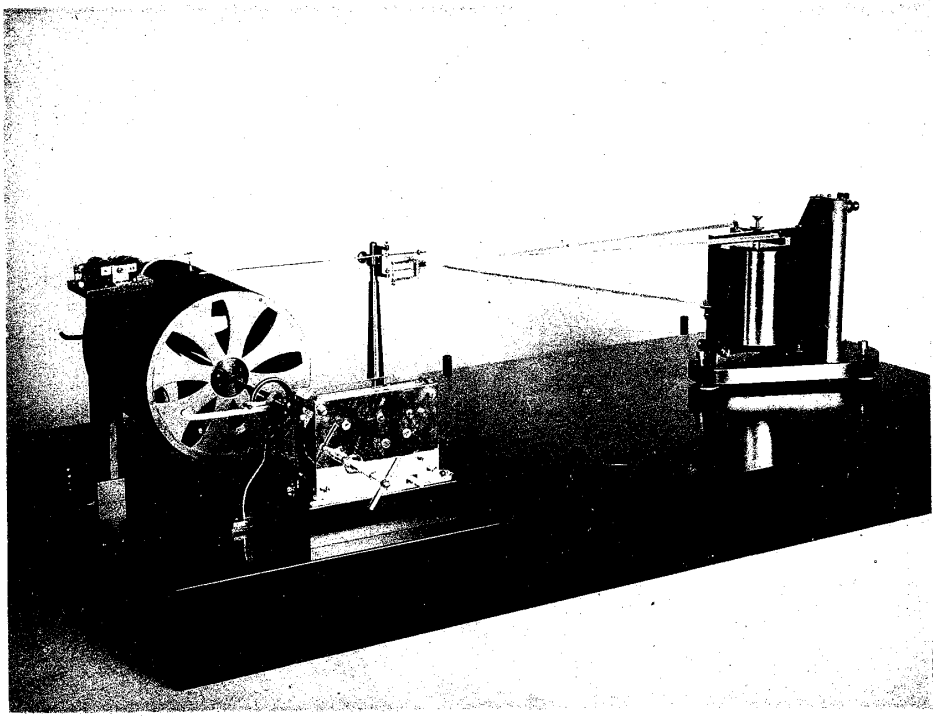
The two greatest transverse vibrations of 15.0 and 12.4 mm occurred respectively in the cases of the Kami-Usui *gawa* 105′ deck Pratt truss and one of the 200′ double Warren girders of the Ōi-*gawa* bridge; the vibration period of former bridge reaching an extraordinary length of nearly $1\frac{1}{2}$ sec. The length of the transverse period was generally more than double the vertical period.

The longitudinal vibrations were always very quick, and I was not able to satisfactorily measure their periods with the instruments then used. The amplitude of these movements was small, varying between 0.9 and 2.7 mm for the different girders and trusses. In virtue of the great intensity or violence, the longi-

tudinal motion, although small, must play an important part in the process of loosening the rivets, or wearing the joints, and its study will prove of great value in connection with the strength of the bridge structures.

A careful study of the results of the measurements given in Tables II and III will disclose many interesting points. Amongst others, it will be observed that a weak bridge has a larger range (double amplitude) as well as a longer period than a strong bridge, the vibration elements being, so to speak, the indices of the strength or quality of a given elastic structure.

A Horizontal Tremor-Recorder.



Deflection Measurer.