On the Overturning and Sliding of Columns.

By

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With Plates VIII-XI.

1. *Introduction.* The present note is to be regarded as a supplement to my paper, "Seismic experiments on the overturning and fracturing of columns by horizontally applied motion," (the *Publications*, No. 4), and treats of the overturning and sliding of columns caused by the earthquake motion.

A *column* is to be understood as a body of any form resting simply on the ground or on a support fixed to the latter; the earthquake motion being assumed to be horizontal.

OVERTURNING OF COLUMNS.

2. It is very difficult to discuss generally the phenomena of the overturning of columns. The problem is, however, materially simplified by making certain suppositions as to the relative magnitudes of the dimensions of the columns and the range of the earthquake motion,* and by classifying the former into *large* and *small* ones, as follows :—

(*a*) Large columns, or those whose dimensions, (that is to say the height and the thickness), are sufficiently large in comparison to the earthquake motion;

(*b*) Small columns, or those whose dimensions are not very much larger than the earthquake motion.

3. *The earthquake motion.* I give here some of the results of the macro-seismic measurements made in Japan.

(*a*) In the great Mino-Owari earthquake of Oct. 28th, 1891, the maximum horizontal motion at Nagoya was about 233mm, the period being probably about 1.3 sec. (See my "Note on the Mino-Owari earthquake," the *Publications,* No. 4.)

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* The *range* of motion is equivalent to the *double amplitude.*

(*b*) In the great Tokyo earthquake of June 20th, 1894, the strong motion seismograph in the Seismological Institute (Hongo, Tokyo) gave the following results:—

Maximum horizontal motion = 73mm,
Period of max. hor. motion = 1.8sec.,*
Maximum vertical motion = 10mm.

(See Sekiya and Omori's paper "The diagram of the Tokyo earthquake, etc.," the *Publications*, No. 4.)

(*c*) As an example of the measurement of ordinary small earthquakes, I quote here the results obtained by the late Professor S. Sekiya.† During the two years, Sept. 1885 to Aug. 1887, he measured in Tokyo 119 earthquakes with Ewing's seismographs. Of these, 95 measured at Hitotsubashi gave the following average results:—

Maximum horizontal motion = 1.2mm,
Period of max. hor. motion = 1.0sec.

Again, the 18 earthquakes recorded at Hongo gave the following average results:—

Maximum horizontal motion = 0.37mm,
Period of max. hor. motion = 0.76sec.

The vertical component motion was always much smaller than the horizontal. (See Professor S. Sekiya's paper "Earthquake measurement, etc.," Jour. Sc. Coll., Imp. Univ. Tokyo, Vol. II.) With respect to the Tokyo earthquake measurements, it is to be remarked that at Hongo the ground is high and consists of hard loam, while at Hitotsubashi it is low and very soft.

(*d*) As illustrative of the earthquake measurement at a rocky district, I shall summarize the results obtained at the Miyako Meteorological Observatory (in the province of Rikuchu), which is situated on a small promontary of a

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* *Period* means always the *complete period.*

† The reader is referred also to my recently published reports on the Tokyo macroseismic measurements, the *Publications*, Nos. 10 and 11.

palæozoic formation, about 30m in height. During the two years, June 1896 to June 1898, there were observed, with a Gray-Milne seismograph, 31 earthquakes, of which 8 were *strong*, while all the rest were *weak* or *slight*. The period of the maximum horizontal motion* varied in these 31 cases between 0.53 and 1.7 sec., giving a mean value of 1.13sec. Again, the period of the maximum vertical motion varied between 0.56 and 0.90 sec., giving a mean value of 0.71sec. The ratio of the maximum horizontal and vertical movements varied, for the different earthquakes, between 1 : 1.6 and 1 : 10, the mean result being 1 : 5.7. For an example of a *strong* movement, we may take the earthquake of Aug. 31st 1896, 4h 12m 45s p.m., which was one of the fore-shocks of the great Riku-U earthquake, and whose elements of motion were as follows :—

Maximum horizontal motion = 9mm,
Period of max. hor. motion = 0.94sec. ;
Maximum vertical motion = 1.3mm,
Period of max. vert. motion = 0.9sec.

(See Omori and Hirata's paper: "Earthquake Measurement at Miyako," *Jour. Sc. Coll., Imp. Univ. Tokyo, Vol. XI.*)

(*e*) Finally, as an example of earthquake measurement at a sandy district, I take that at Kyoto. During about 5 years, Jan. 1895 to March 1900, there were observed with a Gray-Milne seismograph 48 earthquakes, of which two were *strong* and the rest all *weak* or *slight*. The maximum horizontal motion varied between 0.1mm and 14.0mm, and its period between 0.7 and 1.04sec. ; while the greatest of the maximum vertical motion was 1.0mm, the period varying between 0.22 and 0.55sec. The mean values were as follows :—

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* *Ripples* excepted.

Maximum horizontal motion = 0.51mm (EW component),
" " " = 0.50mm (NS component),
Period of max. hor. motion = 0.88sec.;
Maximum vertical motion = Small

$$\text{Period of max. vert. motion} = \begin{cases} 0.24\text{sec.} \\ 0.46\text{sec.} \end{cases}$$

(See Omori and Tojima's paper, "Earthquake Measurement at Kyoto" [Japanese], *Report of the Earthq. Inv. Comm., Vol. XXXII.*)

From what has been said above, it may be concluded that in ordinary *weak* and *slight* earthquakes, the average maximum range of motion is less than 1mm. When the range approaches 10mm, the motion becomes *strong*; when it is greater than some 50mm, the intensity becomes *violent*, brick buildings and chimneys being seriously damaged. Finally when the range reaches some 200mm, the earthquake will be very destructive. The period of vibration in the *principal*, or most strong, portion of an earthquake is about 1sec. for *weak* and *slight* movements and between 1 and 2sec. for violent and destructive ones In strong and destructive earthquakes, there are, besides the principal or fundamental vibrations, some movements whose period is much shorter and whose amplitude much smaller, than those of the latter. Further, in large earthquakes, there are slow undulations of a long period. These two classes of movements, called *ripples* and pulsations respectively, are to be excluded from our present consideration, as they have but a small effect on the overturning of bodies.

4. *Large column.* The dimensions of the column is supposed to be very large; the height being, for the sake of simplicity, further assumed to be much greater than the thickness. The earthquake motion may then be regarded approximately as acting *impulsively* at the base of the column, that is to say, the latter would be overturned by rotating about its centre of percussion relative to the base.

It is hereby to be remarked that the supposition respecting the magnitude of the dimensions of the column is virtually equivalent to the condition that the period of its rocking should be much longer than that of the earthquake movement. Hence those columns, whose absolute dimensions are not very great, may yet be regarded as *large bodies* with regards to an earthquake motion of a very short period. Further, the deduction of formula (1) given below, which may be applied to these different cases, implies the assumption that the maximum seismic displacement occurs immediately after the termination of the *preliminary tremor* and that this motion is much larger than the succeding movements.

Fig. 1.

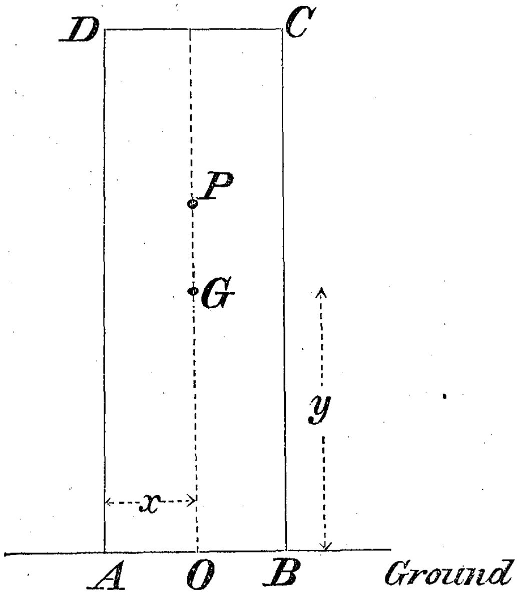
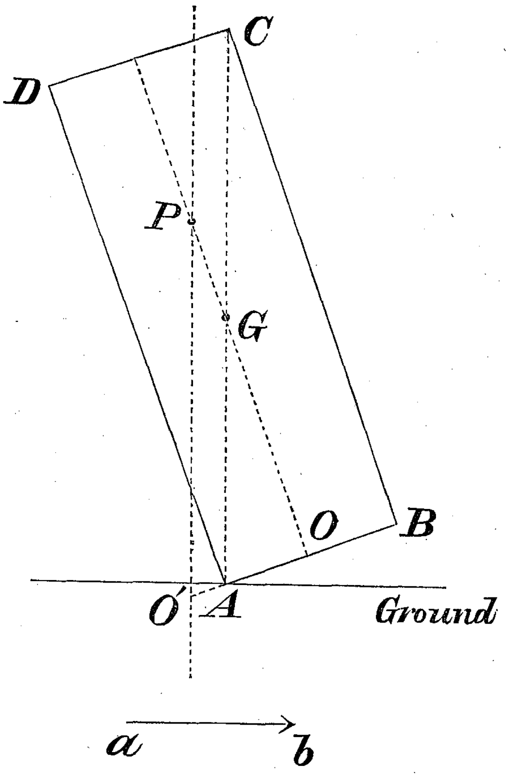


Fig. 2.



Such was actually the case in the great Tokyo earthquake of 1894, which was satisfactorily recorded instrumentally at Hongo. Further, the directions of overturning of various bodies were found to be regular at Nagoya and other places in the meizoseismal area of the Mino-Owari earthquake of Oct. 28th 1891. So it was also the case in the epicentral tract of the Shōnai earthquake of Oct. 22nd, 1894. These facts lead to the conclusion that the character of motion in destructive earthquakes must be comparatively simple, as above supposed.

Let $ABCD$ (Fig. 1) be a rectangular column, resting on the ground, G being its centre of gravity. Let $2y$ and $2x$ be respectively the height and the thickness of the column; y being supposed to be several times greater than x. If P is the centre of percussion of the column with respect to the base AB, its height is given by the following equation:

$$OP=\left(\frac{x^2+y^2}{3}+y^2\right)\div y=\frac{x^2+4y^2}{3y}.$$

If now the ground move suddenly from a to b (Fig. 2), the column $ABCD$ would rotate about the point P as centre, and may be upset when the amount of rotation is so great that the centre of gravity G is brought vertically above the edge A, as shown in the figure. Let O' be the point of intersection of the base AB and the vertical through the point P, then the distance OO' may be taken as representing approximately the range $(=2a)$ of the earthquake motion. We obtain therefore

$$\frac{\overline{GO}}{\overline{OA}}=\frac{\overline{PO}}{\overline{OO'}},$$

or

$$2a=\overline{OO'}=\frac{\overline{OA}\times\overline{OP}}{\overline{OG}}=\frac{x(x^2+4y^2)}{3y^2}, \qquad (1)^*$$

which gives the least value of the range $(2a)$ of the earthquake motion necessary for upsetting a rectangular column of the dimensions $2y\times 2x$.

Equation (1) shows that the value of the $2a$ depends not simply on the ratio $\frac{y}{x}$, but also on x. Hence the earthquake motion necessary for overturning a column, whose height and base are in the ratio of $\frac{y}{x}$, increases with the absolute dimensions of $2x$ and $2y$. As an illustration, I give in the next table a few values of $2a$ corresponding to the ratio $\frac{y}{x}=4$.

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* Equation (1) is a slightly modified but practically identical form of a formula, which I have given in *Seism. Jour. Japan*, Vol. II.

$2x$ (inches)	$2y$ (inches)	$2a$ (inches)
1	4	0.7
2	8	1.4
..	..	..
12	48	8.1
..	..	..

If the column $ABCD$ is not a rectangular prism, as above supposed, but a body of any form with a central axis, we have, instead of (1), the following :—

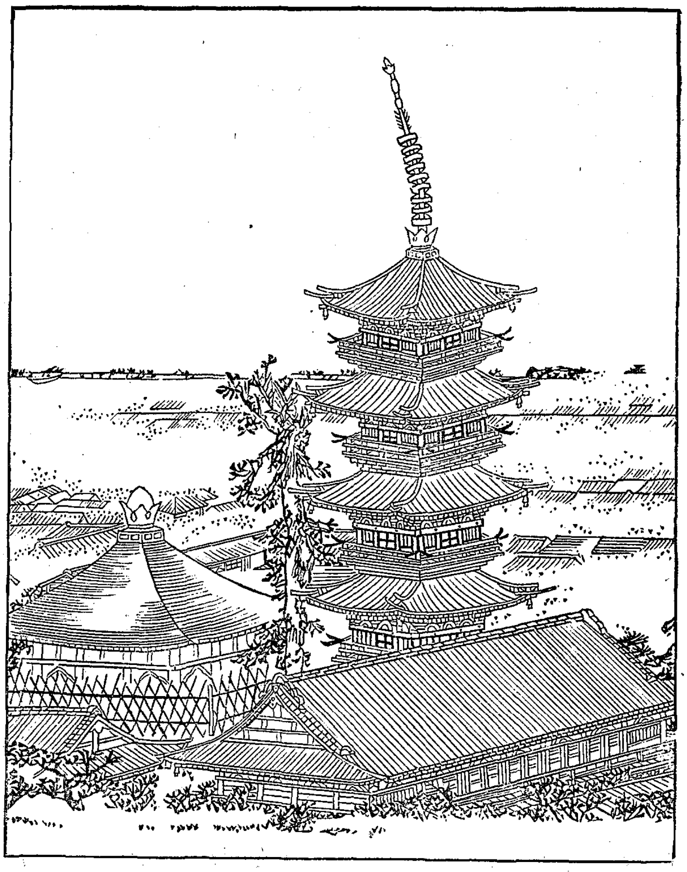
$$2a=\frac{\overline{OA}\times\overline{OP}}{\overline{OG}}=\frac{x}{y}\times h=\frac{xk^2}{y^2}, \tag{2}$$

in which $y=\overline{OG}$; $h=OP$; G and P have the same signification as before; $2x$ is the thickness at the base; and k is the radius of gyration of the column with respect to the base, or what is practically identical, with respect to the point O.

5. *Examples of large bodies.* As an illustration, let us suppose a square uniform column for which $\frac{y}{x}=5$, $2x=20$ft, and $2y=100$ft. Equation (1) then gives $2a=14$ft. This means that such a large column would require for the overturning at least an earthquake motion of some 14ft. Again, if $2x=10$ft and $2y=50$ft, we obtain $2a=6.7$ft. Now even the range of motion at Nagoya on the occasion of the great Mino-Owari earthquake of 1891 was about 233mm or 9 inches; and large movements of 6 or 14ft is not likely to occur even in a very violent destructive earthquake. Hence, according to equation (1), such large columns as here supposed would never be overturned by an earthquake, however violent.

As practical examples of *large columns,* I may mention *gojūnotō* (five-storied pagoda); *sanjūnotō* (three-storied pagoda); *hinomiyagura* (towers for fire bells); bell towers of temples, etc. These buildings are simply put on stone blocks fixed to the ground, but would never be overturned as a whole by an earthquake, except in those cases when their *ishigaki* or masonry foundations give way. Further, they are only little affected by earthquakes, since they are strong in structure and are essentially each a compact single body, being much different from ordinary houses whose construction is so heterogeneous, that is to say, composed of a number of different frame works. Especially, *gojūnotō* suffers so little from earthquakes, that people generally imagine that there must be some mystery in their construction for rendering them earthquake-proof. The principal reason lies, however, merely in the fact that their dimensions are large.

Fig. 3. The Gojūnotō at Asakusa, Tokyo.
(Ansei Earthquake, 1855.)



Brick factory chimneys are usually broken at about $\frac{2}{3}$rd of the height. (See the *Publications,* No. 4.) Now it happens very often that the fractured portions are simply displaced or rotated, but do not fall down. This is probably due to the fact that the dimensions of the chimneys, or of the broken top portions, are much greater than the range of the earthquake motion.

6. *Gojūnotō* (five-storied pagoda). The annexed figure, which is taken from a book entitled "Ansei Kenmonshi," shows the condition of the *gojūnotō* at Asakusa, Tokyo, after the great Ansei earthquake of 1855; the upright metal post at the top was bent into a curve shape, the structure itself, however, remaining undamaged. On the occasion of the great Mino-Owari earthquake of 1891, there were at Nagoya a *sanjūnotō* (three-storied pagoda) and a *gojūnotō,* both not having been damaged; while a very old *sanjūnotō* in the temple ground of Hiyoshi at the town of Gōdo (province of Mino), had its top metal post broken at its base and thrown down to the ground, the building remaining otherwise undamaged.

7. *Bell towers.* Fig. 5, Pl. VII., represents the condition after the great Shōnai earthquake of Oct. 22nd, 1894, of the bell tower in a temple called Anjōji in the city of Sakata. The main temple building itself was greatly damaged by the shock and caused to incline much toward the east, and was four days later crushed to the ground. The bell tower which stood on a platform about 15 ft square and 3 ft high, was not overturned, but rotated about 18° clockwise. (See also Fig. 4.) $a\,b'\,c'\,d'$ represent the original, and $a\,b\,c\,d$ the displaced, positions of the four posts, the column a having remained unshifted. Structures like these, which are top-heavy, are nevertheless not overturned by earthquakes unless their platforms are cracked or the supporting posts give way at the junction with the roof.

8. *Chimneys.* Chimneys* are easily broken by earthquakes. It happens, however, very often that the broken portion remains, either entirely or partly, in its position, suffering only displacement or

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* *Chimney* means here a brick factory chimney.

rotation. Numerous such cases occurred in the Tokyo earthquake of 1894. (See the *Publications*, No. 4, pp. 117–124.). The following two cases relate to the Mino-Owari earthquake.

Chimney of the Cement Factory, Nagoya. The top of the chimney, whose total height was 85 *shaku*† was broken in pieces and thrown down toward W and N. The remainder was fractured at three different heights; the broken portions did not fall down, but rotated each slightly clockwise.

Chimney of the "Kasōjo," Gifu. The chimney, whose total height was 50 *shaku*, had its top portion, about 12 *shaku* in length, broken and thrown down toward WSW to a distance of about 27 *shaku* from the base. The remainder of the chimney was fractured at two different places; but the broken parts did not fall down, each having slightly rotated clockwise.

To determine the range of earthquake motion, necessary to overturn a chimney *as a whole*, which can only occur when the tensile strength of the brick work at the base is *nil*, let us take as an example the chimney of the Ōji Goryōkyoku Factory, near Tokyo.* The section of the chimney, whose height was 100 ft, was circular; the external diameter being 13.4 *shaku* $(=2x)$ at base and 7.2 *shaku* at top. The height (h) of the centre of percussion and the height (y) of the centre of gravity, found by calculations, were 54.4 and 33.9 *shaku* respectively. The earthquake motion $(=2a)$ necessary for overturning the whole structure is therefore

$$2a=\frac{x}{y}\times h=\frac{6.7\times 54.4}{33.9}=10.8 \textit{ shaku},$$

which is much greater than anything likely to occur in actual destructive earthquakes.

The above calculation is of course to be regarded as a gross approximation. Still we see that no earthquake motion, however

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† 1 *shaku* = 0.994 foot.

* For the calculation of the seismic strength of this chimney, the reader is referred to the *Publications*, No. 4, p. 123.

great, would be able to overturn a large chimney as a whole. It is hereby to be noticed that the phenomenon of overturning is totally different from that of fracturing.

9. *Small column.* The column is to be regarded as a small body, when its period of rocking is not much greater than the period of the earthquake motion. These cases have already been discussed in the *Publications,* No. 4, pp. 124–137; the acceleration (a) necessary for overturning a body being, according to the method of Professor C. D. West, given by the formula

$$a = g \times \frac{x}{y}, \qquad (3)$$

where x is half the dimension of the base of the column, supposed to have an upright central axis, and y is the height of the centre of gravity.

Equation (3), which holds good when the earthquake motion is not very small in comparison to the dimension of the base, may be used in the cases of the overturning of the tomb stones,† *ishidoro,** etc., in a destructive earthquake, but not to the overturning of such large bodies as chimneys, *gojūnotō,* etc. The *ripples,* which often exist in *weak* and *strong* earthquakes, have usually very high values of accelerations. These are, however, unable to produce the phenomena of overturning on account of the smallness of amplitude.

10. *Examples of columns overturned by earthquakes.* Figs. 6 and 7, (Pl. VIII), show respectively tomb stones and a *ishidoro,* at Sakata, overturned by the earthquake of Oct. 22nd 1894.

To give an idea respecting the columns overturned, as well as those not overturned, by destructive earthquakes, I shall next mention some of the cases observed at Nagoya and Ōgaki, which were very severely damaged by the great shock of Oct. 28th 1891; the number

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† A Japanese tomb stone consists usually of a square or rectangular post of uniform section put on pedestals.

* *Ishidoro* are Japanese stone lamp posts for gardens, which are found in great number in temples, and consist generally of a cylindrical or square stem, on which chamber for holding light is put, the different parts being usually not cemented together.

Fig. 4. Rotation of the Bell Tower of Anjōji, Sakata.

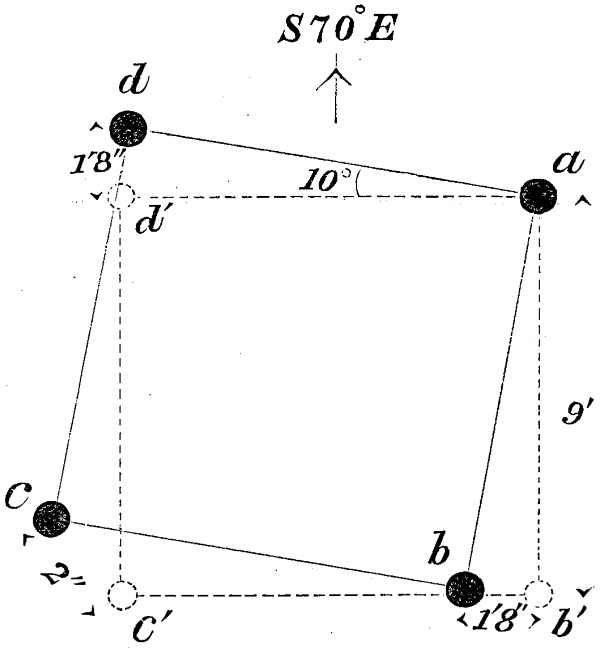


Fig. 5. The Bell Tower of Anjōji, Sakata.

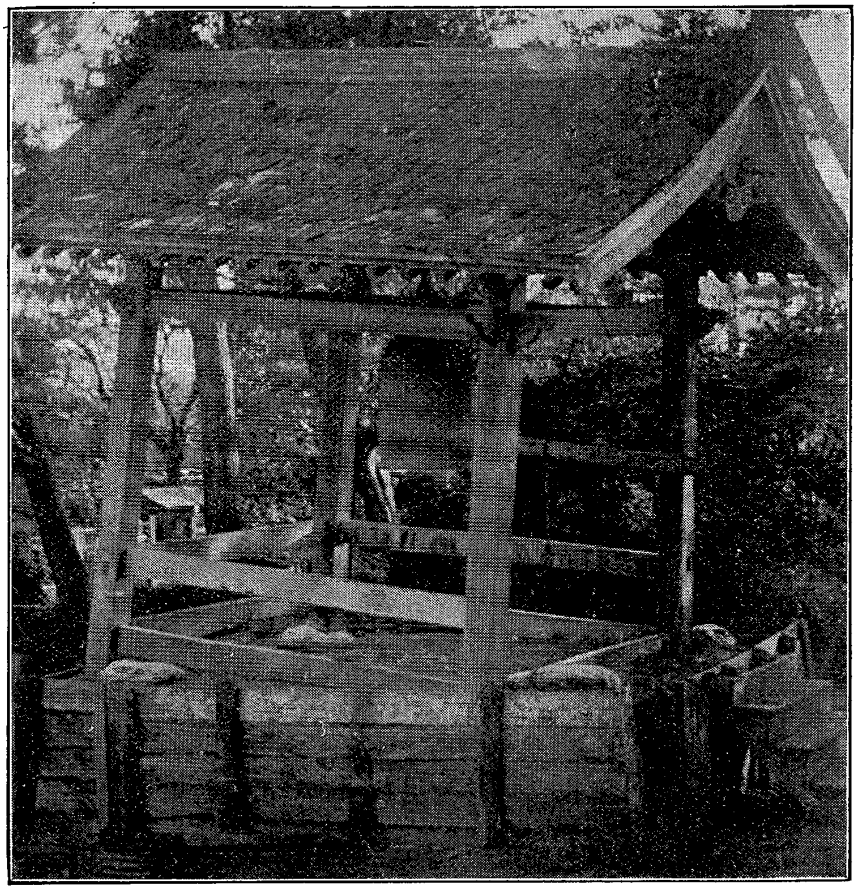


Fig. 6. Overturned tomb stones, Sakata.
Earthquake of Oct. 22nd, 1894.

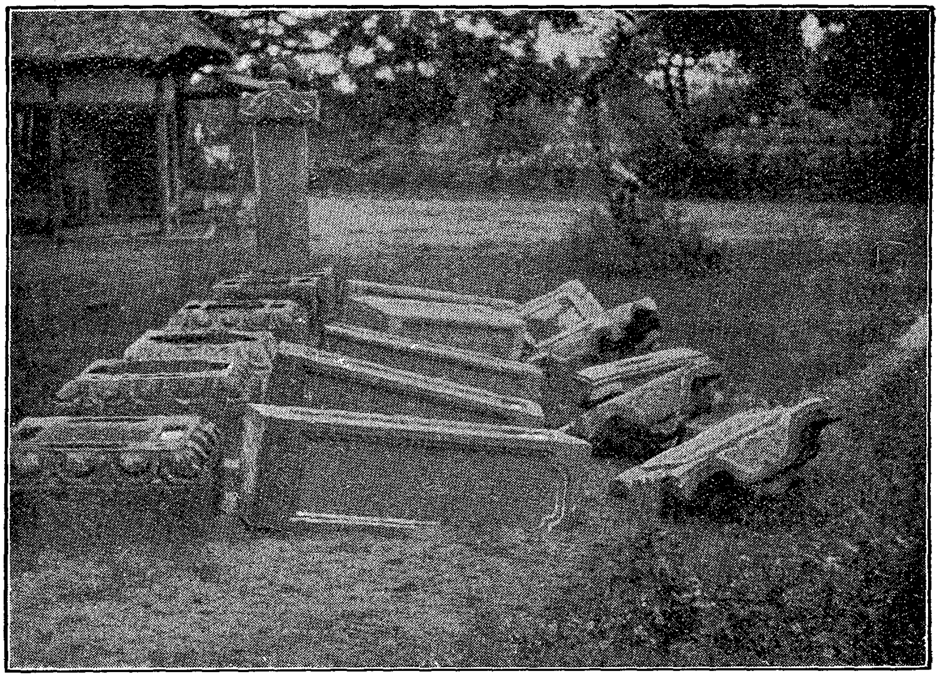
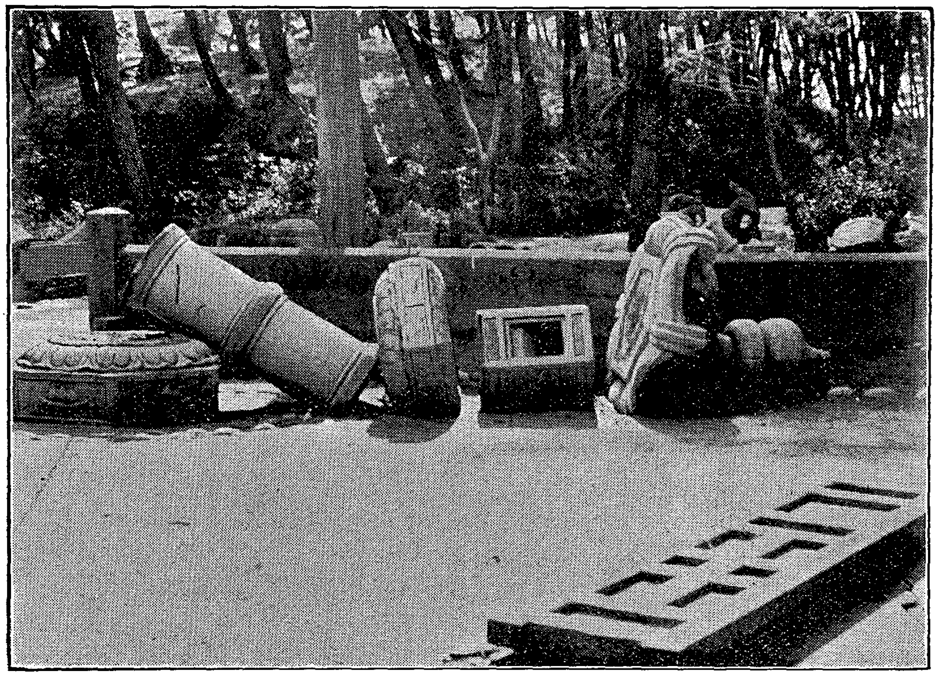


Fig. 7. An overturned *ishidorō,* or stone lantern, (Sakata).
Earthquake of Oct. 22nd, 1894.



of the dwelling houses totally destroyed in these two cities amounting to 3 and 80% respectively. The α's given in the tables have been calculated from equation (3).

Nagoya.

(a) Observations at a temple called Daikōji. The temple, which is in the northern part of the city, was not much damaged, but inclined somewhat toward W. The temple gate, or *sammon*, which suffered only slight damage, such as falling down of plasters, was displaced bodily 45 mm toward W. Some of the tomb stones observed were as follows.

Form of Section.	Sectional Area.	Height.	$\alpha = g \times \frac{x}{y}$ (mm/sec.^{2})	REMARKS.
Square	cm 30 × 30	cm 76	3900	Not overturned.
,,	,,	,,	,,	Not overturned, but rotated together with its pedestal (24 × 47 × 47cm) 5° clockwise.
,,	33 × 33	92	3500	Overturned.
,,	,,	,,	,,	Not overturned, but rotated 30° clockwise.
,,	,,	96	3400	Not overturned, but was displaced 2,5cm toward W.
Rectangle (Longer side parallel N-S.)	30 × 21	75	2700	Overturned toward W.
,,	30 × 19	78	2400	,,
,,	34 × 25	75	3300	,,

(b) Observations at a temple called Kenchūji. The temple, which is in the NE part of the city, was not damaged. There were several hundred well constructed tomb stones and *ishidoro*, which gave an excellent material for the determination of the direction and intensity of the shock; there being no moat, cliff and the like, which could possibly modify the earthquake motion.* Some of the observations at this temple were as follows.

Form of Section.	Sectional Area.	Height.	$a=g\times\frac{x}{y}$ (mm/sec.^{2})	REMARKS.
Square.	24×24 cm	59 cm	4000	Not overturned.
”	”	”	”	”
”	19.5×19.5	92	2100	Overturned toward E.
”	18×18	71	2500	” ” W.
Circle.	(Diameter) 39	92	3300	” ” E 10° S.
Rectangle (Longer sides parallel N-S.)	52×29	108	2600	There were nine similar tomb stones, of which only 1 was overturned, the others not.
Rectangle (Longer sides parallel E-W.)	”	”	2600	Overturned.
Rectangle (Longer sides parallel S20°W -N20°E	21×20	74	2700	There were five similar tomb stones, of which only 2 were overturned and the others not.

(*c*) At Banshōin, a temple in the southern part of the city, there were nine large tomb stones of the form given in Fig. 8, whose height was 190cm and whose thickness at the base was 38cm. Of these one was parallel N-S and was overturned; of the other eight, which were all parallel E-W, six were overturned, while the remaining two were not overturned, but rotated clockwise 25° and 10° respectively. According to equation (3), the acceleration a necessary for overturning the columns would be 2100 $\frac{mm}{sec.^2}$

At the same temple, there were also seven similar tomb stones of the form given in Fig. 9, whose height was 126cm and whose thickness at the base was 31cm. Of these, one was parallel E-W and was overturned toward S; of the other six, which were parallel

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* For the direction observations at Nagoya, the reader is referred to the *Publications*, No. 4, pp. 18–21.

N–S, three were overturned, while the remaining three were not overturned, but rotated clockwise 40°, 50°, and 45° respectively. According to equation (3), the acceleration a necessary for overturning these columns would be $2500\frac{mm}{sec.^2}$.

Fig. 8.

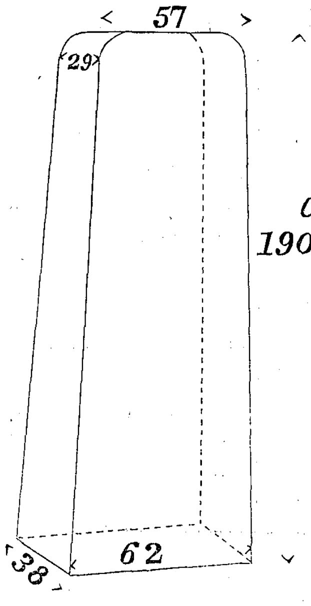
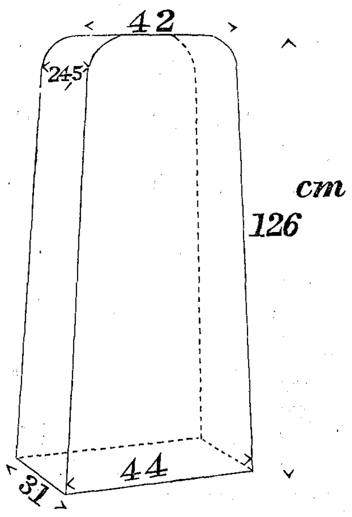


Fig. 9.



The following observations were also made at Banshōin.

Form of Section.	Sectional Area.	Height.	$a=g\times\frac{x}{y}$ (mm/sec.^{2})	REMARKS.
Rectangle (Longer sides parallel E-W.)	48 × 32 cm	135 cm	2300	There were 3 similar columns, of which one was overturned and the others not.
Rectangle (Longer sides parallel N-S.)	44 × 24	116	2000	There were two similar ones; both overturned.
,,	35 × 23½	91*	2500	There were 3 similar ones, all overturned toward W.
Square	34 × 34	94	3600	Not overturned, but rotated 40° counterclockwise.
,,	24 × 24	56	4200	Not overturned, but rotated 15° clockwise.
,,	36 × 36	100	3500	Overturned.

Ōgaki.

The following table gives the observations made at a temple called Entsūji, in Ōgaki.

Form of Section.	Sectional Area.	Height.	$a = g \times \frac{x}{y}$ (mm/sec.^{2})	REMARKS.
Square.	cm 27 × 27	cm 66	4000	Not overturned.
,,	15 × 15	44	3300	,, ,,
,,	23 × 23	60	3800	Not overturned, but was displaced 2cm toward S.
,,	23 × 23	60	3800	Not overturned, but rotated 35° clockwise.
,,	22 × 22	72	3000	Overturned.
,,	25 × 25	65	3800	Overturned toward S.
Rectangle (Longer sides parallel E-W.)	22 × 14	50	2700	Overturned normally to its faces.
Rectangle (Longer sides parallel N-S.)	35 × 22	95	2300	Do.

From the observations above given as well as from many others, I have estimated the intensities at the two cities of Nagoya and Ōgaki to be respectively 2600 and 3000 $\frac{\text{mm}}{\text{sec.}^2}$

11. "*Shaking Table*" *experiments.**

A wooden box, whose height was 484 mm and whose section was 242 × 242 mm, was put on the *shaking table* and tried with the most violent motion which the latter was able to produce. Thus, in one experiment the maximum horizontal motion of the latter was $2a = 119$ mm, $T = 0.51$ sec.,† maximum acceleration $= 9000 \frac{\text{mm}}{\text{sec.}^2}$; while in another experiment, the maximum motion was $2a = 120$ mm,

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* Extracted from my paper "Seismic Experiments, etc.," the *Publications*, No. 4.

† $2a$ denotes the range of motion and T the complete period.

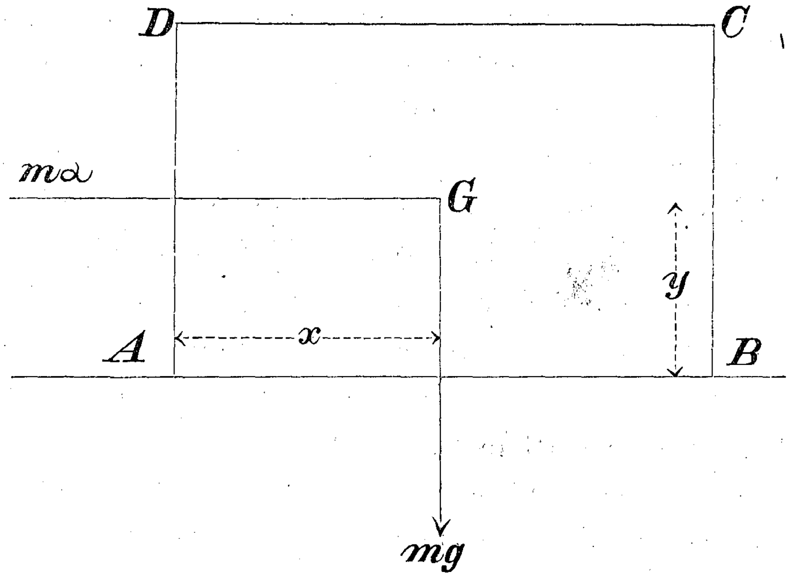
T=0.47 sec., maximum acceleration=10700 $\frac{\text{mm}}{\text{sec.}^2}$. The column was, however, not overturned.

That the acceleration of the shaking necessary for overturning a given column does not depend on the material of the latter has already been shown in the *Publications*, No. 4, p. 137, where brick, iron, and wooden columns were compared with each other.

From these experiments as well as from the examples given in § 10 we can form a fairly good idea respecting the bodies likely to be overturned in destructive earthquakes. Equation (3) is to be used when the basal dimension of a tall column is less than some 30 cm, while equations (1) and (2) are to be used when it is above the latter limit.

SLIDING OF BODIES.

12. A body, resting on the ground, is sometimes never overturned by an earthquake, however strong, but suffers simply a displacement.



Let $ABCD$ be a body, supposed for simplicity's sake, to be a rectangular solid, resting on the frictional surface AB; G being the centre of gravity. Let $2x$ be the dimension of the base and $2y$ the height. If g be the acceleration due to gravity, m the mass of the body, and a the acceleration of the earthquake motion supposed to be horizontal. Then there are two forces mg and ma acting at the point G, the former vertically downwards and the latter horizontally. If now the force ma is about to overturn the body, with the corner point B as centre, we have the following relations among the pressure (P) and the friction (S), which act at the point B downwards and in the direction BA respectively;

$$P=mg\,;$$

$$may=mgx, \text{ or } a=g\times\frac{x}{y}\,;$$

$$S=ma=mg\times\frac{x}{y}. \qquad (4)$$

Now S can not become greater than μmg, μ being the coefficient of friction. Hence, according to equation (4), the the above relations do not hold if the ratio $\frac{x}{y}$ is greater than μ. The body would then be not overturned, but begin to slide. Thus flat bodies, or those for which x is great in comparison to y, are never overturned by an earthquake, but may suffer a sliding when the intensity of motion becomes sufficiently great. It is owing to this reason that in the areas of violent shakings some tomb stones, temple gates, *dozō* (Japanese ware-houses), houses, etc., are displaced from their foundations. When the motion is sufficiently violent, the bodies may be projected. I give next some of the most remarkable examples of the displacement of bodies observed in the great Mino-Owari earthquake of 1891 and the Shōnai earthquake of 1894.

13. Displacement of *ishidoro* (Mino-Owari earthquake).

(*a*) At the village of Kōdokoro, in the Néo-Valley,* province of Mino, there were, in front of a small Kasuga temple by the road

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* The epifocal tract of the great earthquake.

side, two similar *ishidoro* (Fig. 11, *a*) with cylindrical stems, whose condition after the earthquake indicated the great violence of the shock, both columns having been scattered about except their foundation stones fixed to the ground.

One of the *ishidōro* (Fig. 11, *b*) had the stem and the upper parts projected toward N80°W, while the two base plates B and C were together thrown towards NW ; the plate B, whose centre of gravity in the displaced position was 2′ 6″ from the original, having got entirely out of the foundation stone A.

The other *ishidōro* (Fig. 11, *c*) had its stem and the upper parts irregularly projected toward NE, except the top plate which fell toward E. The two base plates were thrown toward opposite directions, namely, the upper plate C′ toward N35°W and the lower plate B′, composed of two halves, toward S40°E. The centre of the latter plate was displaced 40cm. while the displacement of the former plate amounted to more than 38cm.

(b) (Pl. X.) On a hill to the east of the village of Nakamura, also in the Néo-Valley, a small temple was thrown down eastwards. In front of the temple there were two similar *ishidoro* (Fig. 12, *a*) with square stems, which were shattered in a remarkable manner by the shock.

Of the two *ishidoro* (Fig. 12, b), one had its stem thrown toward W and the upper parts toward E. It is hereby to be noted that these directions of overthrowing were not normal to the faces of the foundation plate, whose sides were parallel to N30°W–S30°E and E30°N–W30°S. The base plate B, whose centre of gravity was moved 1′ 3″ from the old position, got nearly out of the foundation plate A fixed in the ground.

The other *ishidoro* (Fig. 12, *c*) had its stem and upper parts thrown toward E. The base plate B was displaced about 9″ toward W on the foundation plate A′.

The directions in which these two *ishidoro* were overturned or displaced were not normal, but parallel, to the contour lines of the hill; so that in this case, the direction of the earthquake motion was not modified by the slope of the ground.

14. *Displacement of "sammon" (temple gate) and ware houses.** (Mino-Owari earthquake).

(a) (Pl. XI.) At Kimbara, in the Néo-Valley, which together with the two villages of Kōdokoro and Nakamura above mentioned was in the most strongly shaken zone, there was produced a fault across the village ground and all the buildings were destroyed with the single exception of the temple gate (Fig. 13, *a*), which essentially consisted of six strong vertical posts, each 12 *shaku* high, supporting a tiled roof. The base of each post rested on a circular disc of stone, which in its turn rested on a small square foundation stone fixed to the ground. The temple gate, which suffered no damage except the shaking down of some tiles from the edges of its roof was displaced 3 *shaku* towards ESE nearly in the direction of one of its diagonals (Fig. 13, *c*). From a close examination of the prints left clearly by the feet of the posts on the ground which was soft, I have ascertained that the displacement was the result, not of a gradual sliding, but of two successive jumpings or projections (Fig. 13, *d*); the first projection having, however, brought the structure near to the final position. The circular base stones suffered also displacements, but were left not far from their initial positions. One of the posts of the gate got after the displacement accidentally on a neighbouring base plate, evidently with a considerable force, as the latter, 6 inches thick, was entirely buried in the ground. This shows that at Kimbara both the horizontal and the vertical movements were very strong indeed.

(b) At the village of Ōi, also in the Néo-Valley, there was, on a flat piece of ground cut in the slope of a hill, a small ware house (Fig. 14), which was 18 *shaku* long and 12 *shaku* wide, and which

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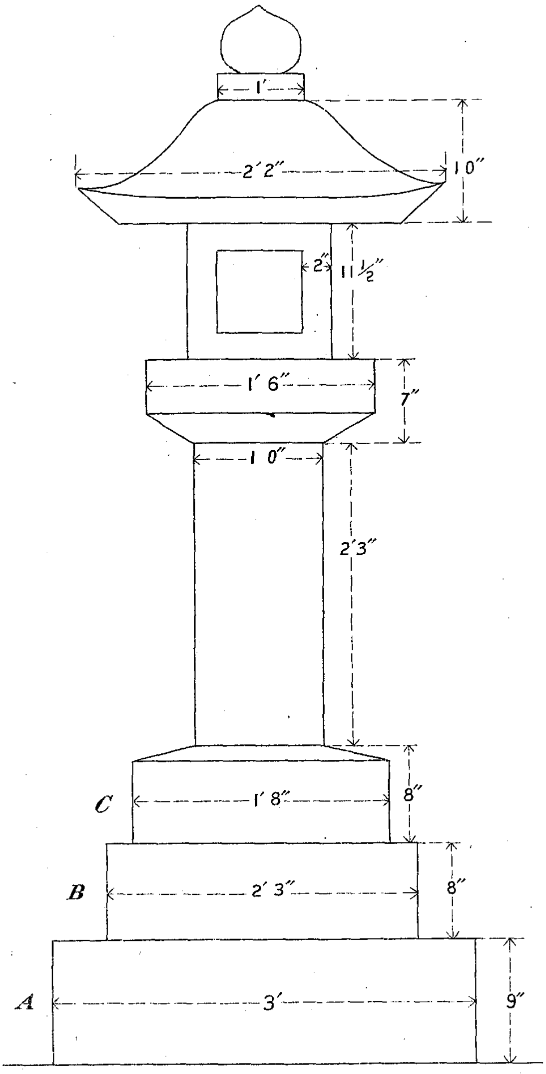
* Japanese wooden buildings consist generally each of a frame of beams simply put on stone foundations fixed to the ground.

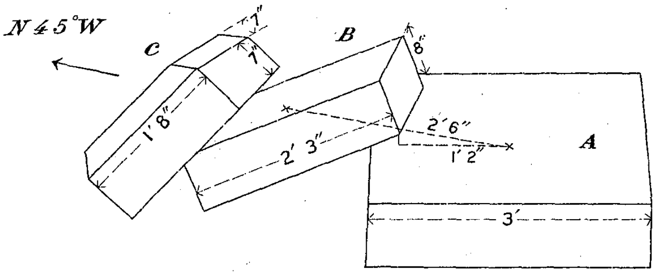
FIG. 11. *ISHIDŌRO* AT KŌDOKORO, NEO-VALLEY, MINO.

Earthquake of Oct. 28th 1891.

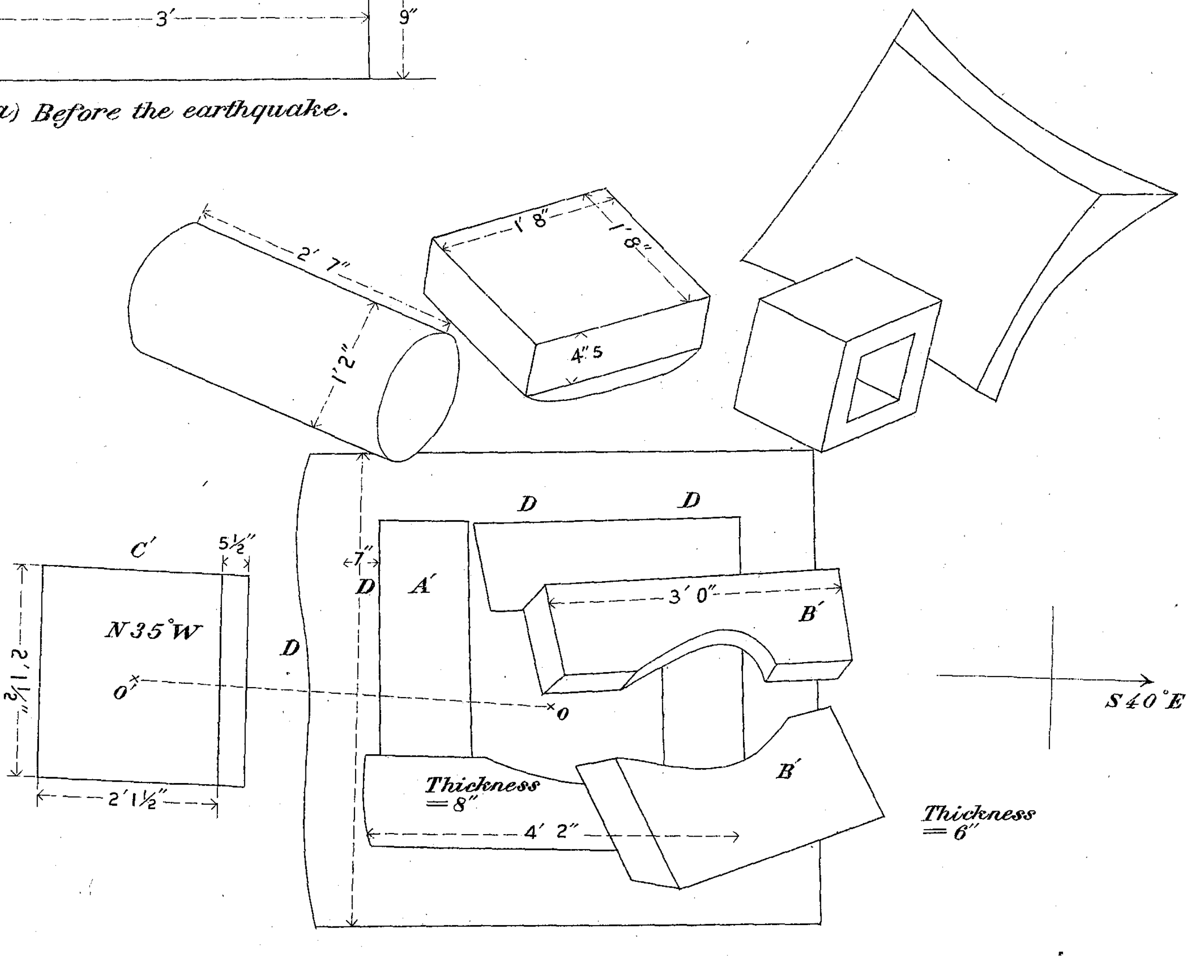
(Dimensions are given in feet and inches.)



(a) Before the earthquake.



(b) Displacement of the base plates of one of the "ishidoros."



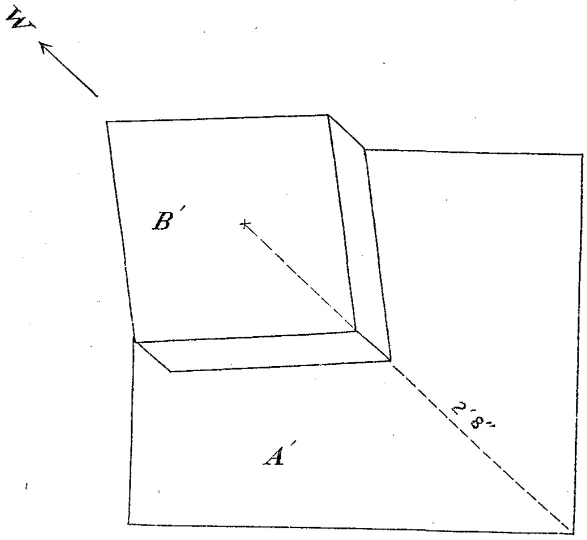
(C) Overturning and displacement of one of the "ishidoros."

Fig. 12.

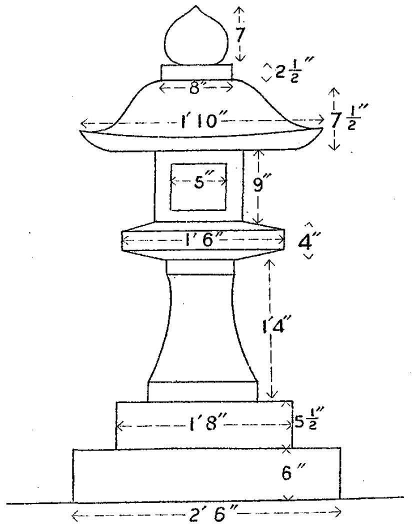
ISHIDŌRO AT NAKAMURA, NEO-VALLEY, MINO.

Earthquake of Oct. 28th 1891.

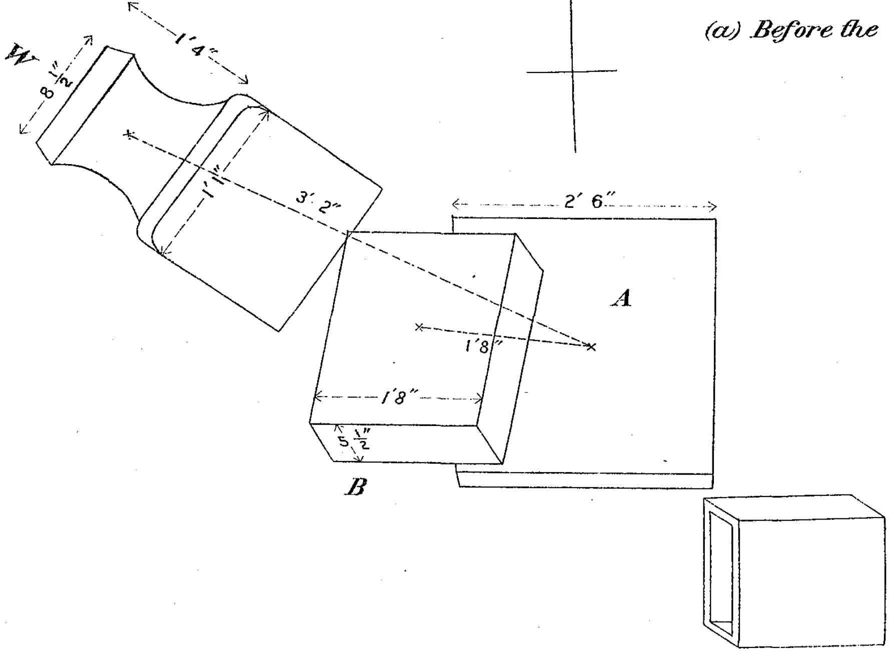
(Dimensions are given in feet and inches.)



(C) Displacement of the base plate of one of the "ishidoro's"



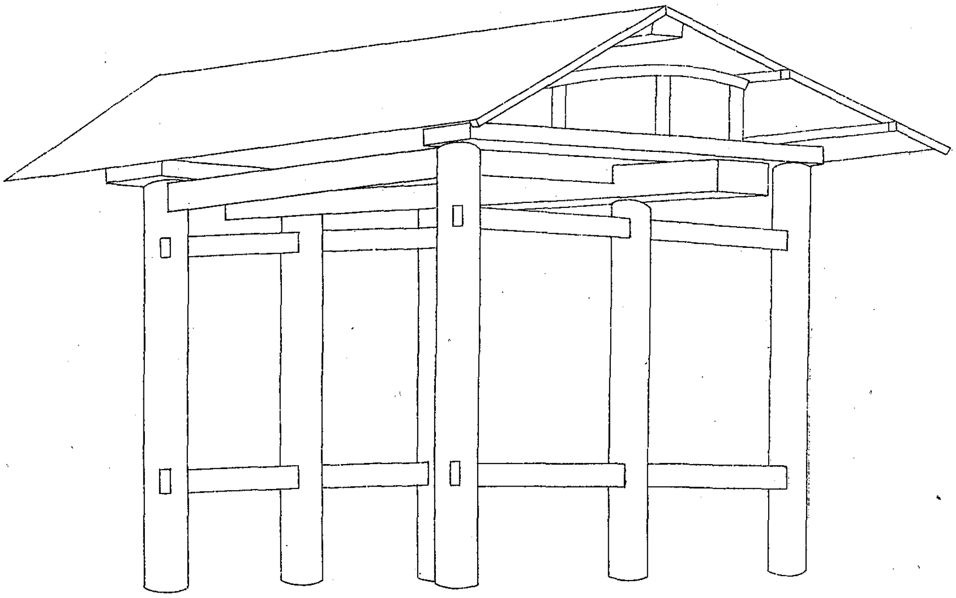
(a) Before the earthquake.



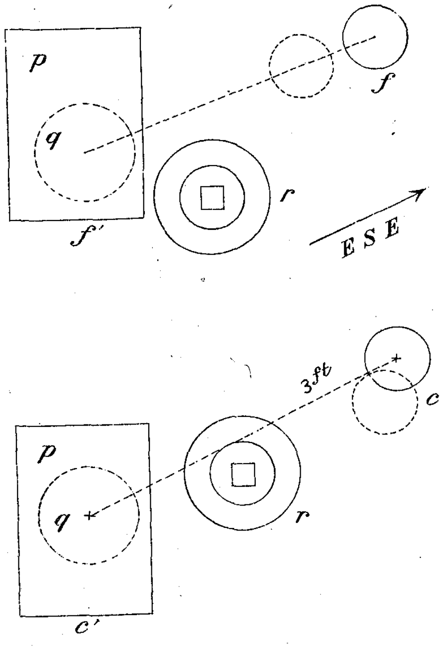
(b) Overturning and displacement of one of the "ishidoro's"

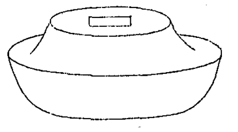
FIG. 13. THE *SAMMON*, OR TEMPLE GATE AT KIMBARA, NEO-VALLEY.

Earthquake of Oct. 28th 1891.

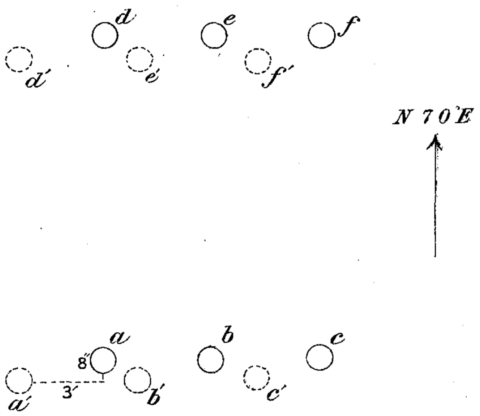


(a) The "sammon" or temple gate.





(b) Base of each post.

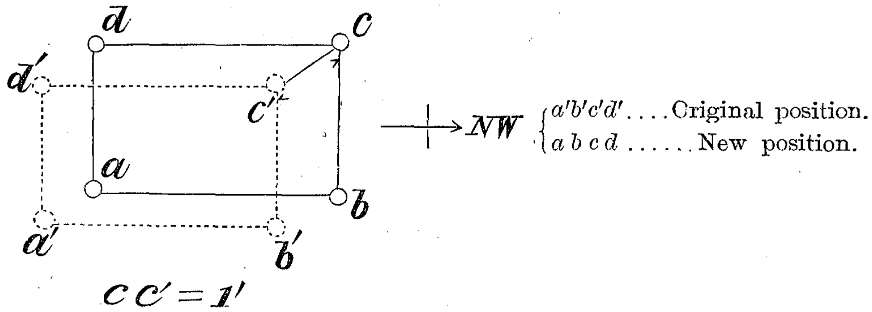


(*d*) Displacement of the two posts *f′* and *c′*. *pp* are the foundation stones and *qq* the positions where the two bases *rr* originally rested; dotted circles near *f* and *c* being the prints left by the posts.

(c) *a′ b′ c′ d′ e′ f′* are the old and *a b c d e f* the displaced positions of the gate posts.

consisted essentially of four vertical corner posts, supporting a thatched roof. The structure suffered no particular damage, but was shifted entirely off the foundation stones about 1 *shaku* toward N60°W.

Fig. 14.



The displacement took place evidently by a single projection, as the feet of the posts were each buried about 1 inch in the ground and there was no sign of a gradual sliding on the surface of the latter.

15. *Displacement of a house.* (Shōnai earthquake). At the village of Asuka, in the province of Uzen, a dwelling house with plastered walls, and 60 × 30 *shaku* in area, whose longer side was parallel S 38° W–N 38° E, was found dislodged from the foundation stones and displaced 1.7 *shaku* toward S 85° W. The village was in the epicentral zone of the Shōnai earthquake.

16. From examples given in §§ 13–15, which are some of extreme cases found in very strongly shaken districts, we can form an idea respecting the displacements of wooden and other structures likely to happen in cases of very great earthquakes.

May 1900. Tokyo.