Comparison of Earthquake Measurements made in a Pit and on the Surface Ground.

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In certain earthquake reports it is stated that there has been comparatively little or no movement felt at the bottom of a deep pit or excavation, while great damage was done on the surface of the ground,* and it seems to be generally believed that shocks are felt less intensely in mines. It is not easy to make instrumental measurements in a mine, and, in fact, we have very little exact knowledge of underground shakings. From a practical point of view, however, with reference to the building of houses, it is more interesting to investigate the shakings in pits or excavations such as might be made for foundations. The only instance of such actual measurements as yet published, as far as we are aware, is that described by Prof. John Milne in a paper entitled "On a Seismic Survey made in Tokio in 1884 and 1885" (Trans. Seis. Soc. Vol. X.) He made observations in a pit 10 feet in depth, whose bottom was dry and consisted of hard natural earth. Comparing the maximum amplitudes, maximum velocities and maximum accelerations obtained in the pit during the tolerably severe earthquake of

* For instance, see Trans Seis. Soc. Vol. VIII. page 98. "The Earthquakes of Ischia."

March 20th, 1885, with those obtained on the surface ground about 30 feet distant he found that they were in the ratios of 1 : 34, 1 : 52 and 1 : 82 respectively. But for small disturbances, the records in the pit did not differ much from those on the surface. The observations we have made are really a continuation of Prof. Milne's, the same method being adopted in both cases. The results contained in the present paper also show in certain cases some difference of movement on the free surface and in the pit.

The observations were made in the Imperial University at Hongo, Tokyo, where the soil is hardened alluvium. The pit is 4 feet square and 18 feet deep, and is situated only a few yards distant from the instruments in the Seismological Observatory. Its bottom is paved with bricks to a thickness of about 2 feet. The soil appears here to be very homogeneous, so that there will be little difference in earth-shakings arising from the heterogeneity of ground between the surface and the bottom of the pit.

Comparison of the Instruments used on the Surface and in the Pit.

The comparison in the present paper is restricted to the horizontal components of earth movements. The instruments employed were Prof. J. A. Ewing's Horizontal Pendulum Seismographs. For earthquakes which are not too great these instruments give diagrams which represent practically absolute motions of the ground.*

The instruments used in the pit and on the surface were made as much alike as possible. To compare their action, they were placed on a shaky table, and their diagrams for the same motion were

* See Memoirs of the Science Dep., Univ., Tokyo: No. 9, and the Jour. Science Coll., Imp. University, Vol. I.

taken. Specimens of such comparison diagrams are given in Pl. XXXV. The multiplying ratio of both sets of instruments was intended to be five. If we go through the diagrams, we see that for moderate motions both give waves of almost exactly the same amplitudes and periods. Even small and irregular ripples are faithfully recorded. Fig. 1 is for the East-West component instruments, and Fig. 2 is for the North-South component instruments. In the following tables is given the numerical comparison of the amplitudes of some of the corresponding waves as recorded by the pit and surface seismographs.

For E.W. Component Instruments.

Amplitudes in mm. given by		Ratio.	Amplitudes in mm. given by		Ratio.
The Surface Instrument s.	The Pit Instrument p.	$\frac{s}{p}$	The Surface Instrument s.	The Pit Instrument p.	$\frac{s}{p}$
1.3	1.4	.9	1.3	1.45	.9
.92	.92	1.0	.9	.9	1.0
.6	.75	.8	1.2	1.2	1.0
.85	.9	.9	2.5	2.45	1.0
1.2	1.2	1.0	2.1	2.6	.8
1.65	1.55	1.1	.67	.67	1.0
.4	.4	1.0	1.3	1.3	1.0
.3	.3	1.0	1.05	1.2	.9
.15	.15	1.0	.9	.9	1.0
.4	.35	1.1	1.45	1.45	1.0
1.4	1.4	1.0	1.5	1.55	1.0
2.1	2.3	.9	1.45	1.6	.9
2.9	2.6	1.1	1.5	1.5	1.0
1.2	1.05	1.1	.26	.26	1.0
.23	.20	1.2	1.3	1.25	1.0
.15	.15	1.0	1.03	1.2	.9

For E.W. Component Instruments. *(Continued.)*

Amplitudes in mm. given by		Ratio.	Amplitudes in mm. given by		Ratio.
The Surface Instrument s.	The Pit Instrument p.	$\frac{s}{p}$	The Surface Instrument s.	The Pit Instrument p.	$\frac{s}{p}$
.1	.1	1.0	1.1	1.05	1.0
.2	.22	.9	.4	.48	.8
2.65	2.85	.9	.1	.1	1.0
2.5	2.35	1.1	.25	.13	1.9
2.2	2.0	1.1	.12	.10	1.2
.65	.85	.8	.2	.2	1.0
.82	.7	1.2	.27	.30	.9
2.7	2.55	1.1	.36	.4	.9
3.05	2.8	1.1	.4	.4	1.0
1.75	1.6	1.1	.55	.55	1.0
1.85	2.0	.9	1.9	1.8	1.1
1.1	1.1	1.0	.9	1.0	.9
.18	.17	1.1	1.8	1.8	1.0
1.4	1.35	1.0	2.1	2.0	1.1
1.55	1.55	1.0	1.82	1.9	1.0
1.9	1.9	1.0	.9	.9	1.0
Average of all the ratios...					1.01

For N.S. Component Instruments.

Amplitudes in mm. given by		Ratio.	Amplitudes in mm. given by		Ratio.
The Surface Instrument s.	The Pit Instrument p.	$\frac{s}{p}$	The Surface Instrument s.	The Pit Instrument p.	$\frac{s}{p}$
1.9	1.7	1.1	2.9	2.75	1.1
2.1	1.9	1.1	1.35	1.4	1.0
1.8	1.7	1.1	1.3	1.25	1.0

For N.S. Component Instruments. *(Continued.)*

Amplitudes in mm. given by		Ratio.	Amplitudes in mm. given by		Ratio.
The Surface Instrument s.	The Pit Instrument p.	$\frac{s}{p}$	The Surface Instrument s.	The Pit Instrument p.	$\frac{s}{p}$
1.4	1.3	1.1	1.1	1.15	1.0
1.15	1.15	1.0	.58	.55	1.1
1.4	1.45	1.0	.7	.66	1.1
1.15	1.2	1.0	.92	.89	1.0
1.2	1.4	.9	.9	.8	1.1
2.5	2.4	1.1	.2	.2	1.0
1.7	2.0	.9	.65	.61	1.1
2.1	2.4	.9	.18	.13	1.4
1.2	1.6	.8	.74	.74	1.0
1.5	1.4	1.1	.71	.69	1.0
1.8	2.2	.8	.3	.3	1.0
2.15	1.65	1.3	.65	.65	1.0
1.3	1.15	1.1	.42	.42	1.0
2.1	1.8	1.2	.4	.4	1.0
1.5	1.7	.9	.31	.31	1.0
2.0	2.1	1.0	.21	.20	1.1
1.9	1.8	1.1	.16	.15	1.1
1.7	1.7	1.0	.1	.08	1.3
1.9	1.9	1.0	.76	.76	1.0
2.85	2.6	1.1			
Average of all the ratios...					1.04

In the above tables, the numbers are the actual semi-ranges of motion as recorded by the instruments each divided by 5. These shew that the two sets of instruments give on the whole results which are practically identical, so that their records are at once comparable.

It should be stated that the surface-ground and the pit instruments were interchanged with each other in June, 1888.

The quantities calculated for the different earthquakes are :—

(1). The number of waves in 10 seconds, marked n.

(2). Amplitude, (r), or semi-range of motion in mm.

(3). Complete Period, (T), or the time taken to make a complete for-and-back motion of the ground in sec.

(4). Maximum Velocity in mm. per sec., (V), or $\frac{2\pi r}{T}$.

(5). Maximum Acceleration in mm. per sec. per sec., (A) or $\frac{V^2}{r}$.

In (4) and (5), it is assumed as usual that the motion of the ground is simple-harmonic. It is rare, however, that any complete wave presents a very good simple-harmonic character during the whole of its course, but usually differs in extent of motion and in the corresponding time of describing it in the first and second semi-phases of the motion, and so in some cases we have calculated V and A for the two different semi-phases of a wave. Sometimes also we give the maximum period during the 10 seconds interval.

The East-West and North-South components of the horizontal motion are not compounded, but the same components in the pit and on the surface are compared separately. It is a well known fact that motions of very quick periods and of small amplitudes generally occur at the beginning of earthquakes, and in the diagrams appear superposed on the principal undulations. In severe earthquakes, such as those of January 15th, 1887, and of February 18th, 1889, these ripples are very prominent; and, being very quick in period, though small in amplitude, they have maximum accelerations very much greater than those of the principal waves, which are longer in period though greater in amplitude. We have also made calculations on some of these ripples, which can sometimes be identified in the two sets of diagrams. As may be imagined their calculation is very difficult, especially in the estimation of their periods, so that any great exactness is not to be obtained. The calculation will, however, give some approximate idea as to the state of things. Hence, for some of the earthquakes, "large waves" and "ripples" are separately calculated. "Large waves" are those principal undulations for which calculation is usually made in earthquake reports, and "ripples" are the irregular wavelets superimposed on them. In doubtful cases the amplitudes only are given. With respect to n, the number of waves in 10 seconds, there is no difference to be found between the large waves of earthquakes observed on the surface and those observed in the pit; but, for ripples, the number is often very much less in the pit diagram, because of the reduction of amplitude and the consequent unification of some of them amongst themselves. The quantity n is therefore given only for ripples and not for large waves. The distinction between large waves and ripples is often very doubtful and does not exist for small earthquakes.

We may here remark that the maximum acceleration, A, is a quantity which approximately measures the overturning and fracturing effect of the shocks. In the case of a ripple, whose period is very short, this effect might probably be also measured by the total amount of impulse communicated to a body during a semi-phase of the wave, which is found to be proportional to the maximum velocity.

Records.

For the materials of the present paper we examined the records of thirty actual earthquakes. Of these, three interesting shocks have their diagrams shewn in Pl. XXXVI. and Pl. XXXVII., and their peculiarities are discussed. The other twenty-seven shocks were comparatively small and the different quantities, measured and deduced from the actual diagrams, are arranged in tabular form. Notwithstanding the frequent occurrence of earthquakes in Tokyo, simultaneous records of the pit and the surface instruments have been obtained for a comparatively small number of earthquakes. This was owing to the difficulty of managing the underground instrument.

(1.)—January 15th, 1887.—This was an earthquake of unusual severity a full account of which has already been given.* The beginning portions of the surface and pit diagrams are given in Pl. XXXVI.,† and these for the convenience of comparison are placed side by side. Fig. 3 is for the E.W. component, and Fig. 4 is for the N.S. component. The glass plate which received the record of the surface instrument made one revolution in 128 sec., and that of the pit instrument in 68 sec., so that the latter moved nearly twice as quick as the former. Such a difference of the rate of revolution would however cause no material difference in the diagram. In these, as well as in the following diagrams, the corresponding parts are marked with the same *alphabets*, and the short radial lines mark the successive seconds counted from the beginnings of shocks.

The earthquake begins as usual with tremors. After a few seconds, the motion becomes suddenly great. The character of the motion is striking. The ripples are very prominent, and these are superimposed on slower undulations, whose period is about 2 sec. in the E.W. component, and about 3 sec. in the N.S. component. After a short time the ripples become less evident but the amplitude of the motion continues to be great, and the maximum displacement occurs at a point marked *o* in the E.W. component. Comparing now the surface and pit diagrams, we see that the latter is much smoother

* See the Journal of the College of Science, Imperial University, Japan, Vol. I., Part III. or Transactions of the Seismological Society of Japan, Vol. XI.

† The complete diagram of the surface instrument is given in the same volumes as cited above.

than the former, especially near their beginnings. The numbers, 1, 2, 3, etc., in the first column in this and other tables are merely given for convenience.

(I.) Large Waves. E.W. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf/Pit	Surf.	Pit	Surf./Pit
1	mm. 1.6	1.35	1.2	...	...	...	...	...	...	...	...	...
2	1.1	1.26	0.9	...	...	...	...	...	...	...	...	...
3	1.58	1.45	1.1	...	...	...	...	...	...	...	...	...
4	2.05	1.93	1.1	...	...	...	...	...	...	...	...	...
5	1.75	1.54	1.1	...	...	...	...	...	...	...	...	...
6	1.7	1.25	1.4	...	...	...	...	...	...	...	...	...
7	.95	.93	1.0	.86	1.1	0.8	7.0	5.3	1.3	50.	30.	1.7
8	1.05	.8	1.3	.89	.93	1.0	7.4	5.4	1.4	52.	36.	1.4
9	2.4	1.75	1.4	2.0	2.2	0.9	7.6	5.	1.5	24.	14.	1.7
10	3.53	2.65	1.4	2.8	2.0	1.4	7.9	8.3	0.9	22.	26.	0.9
11	2.2	1.25	1.8	1.3	1.7	0.8	11.	4.6	2.4	52.	17.	3.0
12	1.35	.95	1.4	1.5	1.4	1.1	5.7	4.3	1.3	24.	19.	1.3
13	2.75	2.55	1.1	1.8	1.7	1.1	9.6	9.4	1.0	34.	35.	1.0
14	1.8	1.65	1.1	1.6	1.2	1.3	7.1	8.6	0.8	28.	45.	0.6
15	1.4	.65	2.2	.93	1.4	0.7	9.5	2.9	3.5	65.	13.	5.0
16	2.15	1.8	1.2	2.8	1.9	1.5	4.8	6.	0.8	11.	20.	0.6
17	.74	.1	7.4	1.1	.6	1.9	4.2	1.0	4.2	24.	10.	2.4
18	1.7	2.25	0.8	.97	2.7	0.4	11.	5.3	2.1	72.	12.	6.0
19	1.8	1.8	1.0	3.2	2.7	1.2	3.5	4.2	0.8	7.	9.8	0.7
20	1.3	.55	2.4	2.5	1.4	1.8	3.3	2.5	1.3	8.	11.	0.7
21	.7	.1	7.0	1.3	.9	1.4	3.4	0.7	5.0	17.	5.	3.5
22	1.6	.38	4.2	1.0	1.0	1.0	10.	2.4	4.1	63.	15.	4.2
23	1.3	.14	9.0	1.8	.9	2.0	4.6	1.0	4.7	16.	7.	2.4
24	1.65	.44	3.7	2.1	1.3	1.6	5.	2.1	2.4	15.	10.	1.5
25	1.6	1.5	1.1	1.9	1.5	1.3	5.3	6.3	0.9	18.	26.	0.7
26	1.83	.9	2.0	1.7	1.3	1.3	6.8	4.4	1.6	25.	22.	1.1
27	1.65	.85	1.9	3.1	3.2	1.0	3.4	1.7	2.0	7.	3.4	2.0
28	1.7	.55	3.1	1.5	1.5	1.0	7.1	2.3	3.1	30.	10.	3.0
Average.			2.3			1.2			2.1			2.1

(II.) Large Waves. N.S. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	1.42	.85	1.7	...	...	...	...	...	...	...	...	...
2	1.65	1.25	1.3	...	...	...	...	...	...	...	...	...
3	1.65	1.3	1.3	...	...	...	...	...	...	...	...	...
4	1.85	2.1	0.9	...	...	...	...	...	...	...	...	...
5	1.85	2.4	0.8	...	...	...	...	...	...	...	...	...
6	1.5	1.8	0.8	1.5	1.7	0.9	6.3	6.7	1.0	26.	25.	1.0
Average.			1.1									

(III.) Ripples. E.W. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	.95	.75	1.3	...	...	...	...	...	...	...	...	...
2	1.05	.94	1.1	.54	.73	0.7	12.	8.1	1.5	140.	70.	2.0
3	.6	.34	1.8	.39	.46	0.6	9.7	4.7	2.1	160.	65.	2.5
4	.6	.16	3.8	.29	.66	0.4	13.	1.5	9.3	280.	14.	25.0
5	.56			.25			14.			350.		
6	.5	.19	2.6	.25	.6	0.4	13.	2.	6.5	320.	21.	15.0
7	1.24	.78	1.6	.34	.6	0.6	23.	8.2	2.8	130.	86.	5.0
8	.51		...	.45	...	...	7.	...	...	100.	...	...
9	.92	not existing.	...	.4	...	...	15.	...	...	230.	...	...
10	.75		...	.4	...	...	12.	...	...	190.	...	...
11	1.2	.82	1.5	.75	.9	0.8	10.	5.7	1.8	83.	40.	2.1
12	.98	.90	1.1	.4	.7	0.6	15.	8.	1.8	240.	73.	3.3
Average.			1.9			0.6			3.7			7.8

(IV.) Ripples. N.S. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	.56	.25	2.2	.2	.28	0.7	18.	5.4	3.3	550.	120.	4.6
2	.7	.64	1.1	.28	.55	0.5	16.	7.3	2.2	370.	83.	4.4
3	.32	.29	1.1	.4	.31	1.3	5.	6.	0.8	78.	120.	0.6
4	.59	.37	1.6	.32	.38	0.8	12.	6.1	2.0	230.	100.	2.3
5	1.05	.87	1.2	.5	.55	0.9	13.	10.	1.3	170.	120.	1.4
6	.41	.31	1.3	.25	.36	0.7	10.	5.4	1.9	260.	94.	2.8
7	.59	.65	0.9	.53	.8	0.7	7.	5.1	1.4	83.	40.	2.1
Average.			1.3			.8			1.8			2.7

In (III.), the two ripples marked 4 and 5 in the surface-ground diagram have united into one in the pit diagram, and those marked 8, 9, 10 in the former do not exist separately in the latter.

If these calculations be correct, or at least approximate, it would appear that the maximum velocities and maximum accelerations are considerably greater for ripples than for large undulations. Such a difference will be found also to be the case with other severe earthquakes.

(2.)—April 16th, 1887.—A very small earthquake.

	Max. Ampl.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
E. W. Comp.	.1	.13	0.8	...	...	...	...	...	...	...	...	...
N. S. Comp.	.1	.15	0.7	.6	1.2	.5	1.1	.8	1.4	12.	4.	3.

(3.)—May 2nd, 1887.—This is a good example of a small earthquake. The motion indicated by the pit record appears to be smaller than that indicated by the surface record.

N. S. Component.

n.			Aver. Period.			Max. Period.		
Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
21.	21.	1.	.5	.5	1.	.7	.9	.8

Max. Ampl.			Period.			Max. Vel.			Max. Acc.		
Surf.	Pit.	Surf./Pit.	Surf.	Pit.	Surf./Pit.	Surf.	Pit.	Surf./Pit.	Surf.	Pit.	Surf./Pit.
.1	.06	1.7	.5	.6	.8	1.3	.6	2.	16.	6.	3.

E. W. Component.—Maximum amplitude is not greater than 0.1 mm. both in the surface and pit diagrams. The waves are too flat to be counted definitely.

(4.)—May 7th, 1887.—A small earthquake whose extent of motion appears to be rather greater in the pit than on the surface.

	n.			Aver. Period.			Max. Period.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
E. W. Comp.	22.	19.	1.2	.46	.53	.9	.7	...	...
N. S. Comp.	19.	18.	1.	.5	.56	.9	.7	1.	.7

	Max. Ampl.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
E. W. Comp.	.1	.1	1.	.6	.4	1.5	1.	1.6	.6	11.	25.	.44
N. S. Comp.	.15	.13	1.2	.7	1.0	.7	1.4	.9	1.6	13.	6.	2.2

(5.)—June 20th, 1887.—A small earthquake.

	Max. Ampl.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
E. W. Comp.	.1	.07	1.4	.9	1.	.9	.7	.4	1.6	5.	2.8	1.8
N. S. Comp.	.1	.1	1.	.5	1.1	·5	1.3	.58	2.3	16.	3.4	5.

(6.)—June 30th, 1887.—A very small earthquake.

E. W. Component :—Almost insignificant, the maximum amplitude being not greater than .05 mm. in the surface diagram, and obscure in the pit one.

N. S. Component :—in the surface diagram, the maximum amplitude is .06 mm., and in the pit diagram probably not greater than .05 mm.

(7.).—July 2nd, 1887.—A small earthquake.

	Max. Ampl.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf	Pit	Surf./Pit
E. W. Comp.	.16	.16	1.	.5	.5	1.	2.1	2.1	1.	28.	27.	1.
N. S. Comp.	.25	.22	1.1	.6	.7	.9	2.6	2.1	1.2	27.	22.	1.2

(8.)—July 22nd, 1887.—An earthquake of average extent of motion, but of slow period. The character of this earthquake is interesting. Unlike most earthquakes, which begin with quick vibrations, this begins very gently, with waves of small amplitude and of long period. After about 10 seconds from the start, the motion becomes larger and irregular, and ripples appear superimposed on principal undulations. All the irregular wavelets are tabulated.

	n.			Aver. Period.			Max. Period.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
E. W. Comp.	36.	14.	2.6	.3	.7	.4	1.	1.6	.6
N. S. Comp.	28.	20.	1.4	.36	.5	.7	.7	1.7	.4

E. W. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	.15	.15	1.0	.5	.8	0.6	1.9	1.2	1.6	24.	9.4	2.6
2	.25	.21	1.2	1.1	1.0	1.1	1.4	1.3	1.1	8.5	8.	1.1
3	.11	.14	0.8	.64	.65	1.0	1.1	1.4	0.8	11.	14.	0.8
4	.21	.2	1.1	.95	.94	1.0	1.3	1.4	0.9	8.	10.	0.8
5	.15	.15	1.0	.7	.7	1.0	1.4	1.4	1.0	12.	13.	0.9
6	.18	.24	0.8	1.2	1.3	0.9	1.	1.2	0.8	5.	6.	0.8
7	.18	.11	1.6	1.2	1.1	1.1	1.	.6	1.7	5.	3.6	1.4
8	.14	.14	1.0	1.1	1.0	1.1	.8	.9	.9	4.6	5.5	0.8
9	.14	.09	1.6	.93	.9	1.0	.9	.6	1.5	6.5	4.4	1.5
10	.13	.11	1.2	.83	.75	1.1	1.	.9	1.1	7.4	7.7	1.0
11	.12	.12	1.0	.83	.94	0.9	.9	.8	1.1	7.	5.	1.4
12	.14	.15	.9	1.1	1.0	1.1	.8	.9	.9	4.6	6.	0.8
13	.15	.15	1.0	.83	.94	.9	1.1	1.	1.1	8.7	7.	1.2
14	.08	.05	1.6	.74	.8	0.9	.7	.4	1.8	6.	3.	2.0
15	.15	.12	1.2	1.0	.9	1.1	.9	.8	1.1	6.	6.	1.0
16	.08	.05	1.6	.7	.64	1.1	.7	.5	1.4	6.	5.	1.2
17	.20	.19	1.0	1.3	1.5	0.9	1.	.8	1.3	4.7	3.4	1.4
18	.21	.15	1.4	1.1	1.4	0.8	1.2	.7	1.7	7.	3.1	2.2
19	.16	.23	0.7	1.3	1.4	0.9	.8	1.0	0.8	3.8	4.4	0.9
20	.21	.25	0.8	1.3	1.6	0.8	1.	1.0	1.0	5.	3.8	1.3
21	.34	.31	1.1	1.5	2.0	0.8	1.4	1.0	1.4	6.	3.1	2.0
Average.			1.1			1.0			1.2			1.3

N. S. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	.37	.35	1.0	.7	.9	.8	3.3	2.5	1.3	29.	18.	1.6
2	.13	.2	.7	.6	1.5	.4	1.3	.8	1.6	13.	3.5	3.7
Average.			.9			.6			1.5			2.7

In the latter part of the motion, the amplitude seems to be larger in the pit diagram than in the surface diagram. But the period was much longer in the former than in the latter.

(9.)—September 25th, 1887.—A moderate earthquake, like the preceding one. The extent of motion appears to be larger in the pit than on the surface, and consequently also the duration of motion is longer in the former than on the latter.

	n.			Aver. Period.			Max. Period.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf/Pit	Surf.	Pit	Surf./Pit
E. W. Comp.	28.	10.	2.8	.35	1.	.4	1.1	1.8	.6
N. S. Comp.	30.	17.	1.	.33	.6	.6	1.	1.	1.

E. W. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	.25	.46	0.5	1.5	1.5	1.0	1.1	1.9	0.6	4.4	8.	0.6
2	.08	.1	0.8	.6	.7	0.9	.8	.9	0.9	8.8	8.1	1.1
3	.09	.22	0.4	1.4	1.5	0.9	.4	.9	0.4	1.8	3.9	0.5
4	.09	.15	0.6	1.2	1.3	0.9	.47	.73	0.6	2.5	3.6	0.7
5	.12	.21	0.6	.73	.76	1.0	1.	1.8	0.6	9.	15.	0.6
6	.05	.07	0.7	.5	.57	0.9	.6	.8	0.8	7.4	8.5	0.9
Average.			0.6			.9			0.7			0.7

N. S. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	.17	.19	0.9	.56	.69	0.8	1.9	1.7	1.1	21.	15.	1.4
2	.2	.25	0.8	.51	.42	1.2	2.5	3.8	0.7	31.	58.	0.5
3	.1	.15	0.7	.46	1.0	.5	1.4	.95	1.5	19.	6.	3.2
4	.08	.1	0.8	.54	.6	.9	.9	1.	0.9	11.	11.	1.0
5	.13	.15	0.9	.7	.66	1.1	1.2	1.4	0.9	11.	13.	0.8
6	.1	.14	0.7	.6	.66	0.9	1.0	1.3	0.8	11.	12.	0.9
7	.11	.15	0.7	.8	1.0	0.8	.9	.95	1.0	6.9	6.	1.2
8	.05	.1	0.5	.44	.53	0.8	.7	1.2	0.6	10.	14.	0.7
9	.17	.2	0.9	.66	.6	1.1	1.7	2.1	0.8	17.	22.	0.8
10	.1	.15	0.7	.6	.6	1.0	1.0	1.6	0.6	11.	17.	0.6
11	.19	.18	1.0	.5	.48	1.0	2.4	2.4	1.0	30.	32.	0.9
12	.06	.08	0.8	·5	.57	0.9	.8	.9	0.9	10.	9.7	1.0
13	.06	.06	1.0	.45	.43	1.0	.8	.9	0.9	12.	13.	0.9
14	.09	.16	0.6	.6	.71	0.9	.9	1.4	0.6	10.	12.	0.8
15	.07	almost nul.	...	.45	.44	1.0	1.	...	...	13.	...	...
Average.			.8			0.9			0.9			1.1

(10.)—December 16th, 1887.—An earthquake of moderate intensity. At a glance, the motion on the surface appears to be larger and more irregular than that in the pit.

	n.			Aver. Period.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
E. W. Comp	41.	20.	2.	.24	.5	.5
N. S. Comp.	41.	18.	2.	.24	.67	.4

E. W. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf/Pit	Surf.	Pit	Surf./Pit
1	.77	.7	1.1	.9	.9	1.0	5.4	4.9	1.1	38.	34.	1.1
2	.2	.25	0.8	.5	.8	0.6	2.5	2.0	1.2	31.	16.	2.0
3	.25	.22	1.1	.65	.8	0.8	2.4	1.6	1.5	23.	22.	1 0
4	.07	no.	...	.2	...	...	2.2	...	...	70.	...	...
5	.1	.14	0.7	.5	.7	0.7	1.3	1.3	1.0	16.	12.	1.3
6	.14	.14	1.0	.7	.7	1.0	1.3	1.3	1.0	12.	12.	1.0
7	.15	.18	0.8	.6	1.2	0.5	1.6	.9	1.8	17.	5.	3.4
Average.			.9			0.8			1.3			1.6

N. S. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	.55	.53	1.0	.53	.53	1.0	6.5	6.3	1.0	77.	75.	1.0
2	.3	.24	1.2	.55	.72	0.8	3.4	2.1	1.6	38.	18.	2.1
3	.33	.05	6.6	.4	.42	1.0	5.2	.75	7.	82.	11.	7.5
4	.25	.25	1.0	.5	.54	1.0	3.2	2.9	1.1	41.	34.	1.2
5	.25	.15	1.7	.55	.8	0.7	2.9	1.2	2.4	34.	10.	3.4
6	.24	.1	2.4	.8	.67	1.2	1.9	.95	2.0	15.	9.	1.7
7	.16	.03	5.3	.25	.26	1.0	4.0	.73	5.5	100.	18.	5.5
8	.2	.11	1.8	.42	.83	0.5	3.	.84	3.6	45.	6.4	7.0
Average.			2.6			0.9			3.0			3.7

(11.)—January 11th, 1888.—A very small earthquake. In each component on the surface, the maximum amplitude is 0.1 mm.; while for the motion in the pit, it is not greater them .06 mm. The motion seems here to be much more pronounced on the surface than in the pit.

(12.)—April 5th, 1888.—A tolerably severe earthquake, in which the amplitude is not very large, but the vibrations are very quick.

The difference of appearance between the surface and the pit diagrams is striking, the small sharp waves which exist in the former being mostly flattened in the latter.

	n.			Aver. Period.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
E. W. Comp.	57.	25.	2.3	.18	.4	.5
N. S. Comp.	54.	25.	2.2	.19	.4	.5

E. W. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	.4	.35	1.1	.7	.8	0.9	3.6	2.7	1.3	32.	22.	1.5
2	.65	.37	1.7	.52	.65	0.8	7.8	3.6	2.2	95.	34.	2.8
3	.3	.1	3.0	.2	.3	0.7	9.4	2.2	4.3	300.	50.	6.0
4	.35	...	...	.33	...	...	6 7	...	...	120.	...	...
5	.35	.25	1.4	.24	.42	0.6	9.	3.8	2.3	240.	60.	4.0
Average.			1.8			0.8			2.5			3.6

N. S. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	.4	.38	1.1	.43	.53	0.8	6.	4.5	1.3	90.	53.	1.7
2	.3	.1	3.0	.21	.27	0.8	9.	2.3	4.0	270.	53.	5.1
3	.22	.08	2.8	.2	.3	0.7	7.	1.7	4.1	220.	35.	6.3
4	.65	.35	1.9	.71	.7	1.0	5.7	3.2	1.8	50.	29.	1.7
5	.5	.26	1.9	.47	.7	0.7	6.7	2.3	3.0	90.	21.	4.3
6	.2	.26	0.8	.27	.56	0.5	4.7	2.9	1.6	110.	32.	3.4
7	.15	.15	1.0	.24	.35	0.7	3.9	2.7	1.5	100.	49.	2.0
8	.24	.15	1.6	.24	.44	0.5	6.3	2.2	2.9	165.	32.	5.2
9	.18	.23	0.8	.24	.45	0.5	4.7	3.2	1.4	120.	45.	2.7
10	.3	.16	1.9	...	...	...	...	...	...	...	...	...
11	.31	.2	1.6	.7	.75	0.9	2.8	1.7	1.7	25.	14.	1.8
12	.2	.2	1.0	.24	.56	0.4	5.3	2.3	2.3	140.	25.	5.6
13	.25	.15	1.7	.47	.8	0.6	3.4	1.2	2.8	46.	9.	5.1
14	.4	.18	2.2	...	...	...	...	...	...	...	...	...
15	.34	.2	1.7	...	...	...	...	...	...	...	...	...
16	.22	.25	0.9	...	...	...	...	...	...	...	...	...
17	.3	.18	1.7	.73	.7	1.0	2.6	1.6	1.6	22.	15.	1.5
Average.			1.6			0.7			2.3			3.6

(13.)—April 29th, 1888.—A severe earthquake. This is very like the preceding one, but much more intense. The beginning portions of both sets of diagrams are given in Pl. XXXVII, Fig. 5. and Fig. 6. The glass plate of the surface-ground instrument made one revolution in 88 sec., and that of the pit instrument in 70 sec. In the early part of the shock, the vibrations are very quick, and with the exception of the wave marked A in the E. W. component there is no prominently large wave, though the ripples are distributed more or less in groups. Here again the pit diagram appears much smoother than the surface one ; compare, for instance, the portions marked a, b, c, d, e, f, g, in the E. W. component. Towards the end, the motion becomes slow.

E. W. Component.

n.			Aver. Period.		
Surf.	Pit	Surf./Pit	Surf.	Pit	Surf/Pit
49.	30.	1.6	.2	.33	.6

(I.)—Ripples.—E. W. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	.55	.21	2.2	.23	.22	1.0	15.	6.	2.5	410.	170.	2.4
2	.3	.04	7.5	.2	.19	1.0	9.5	1.3	7.3	300.	40.	7.5
3	.27			.2			8.5			270.		
4	.4			.2			13.			400.		
5	.35	.55		.25	.8		8.8	4.3	3.0	220.	34.	12.0
6	.25			.22			7.2			210.		
7	.5	.35	1.4	.17	.47	0.4	19.	4.7	3.9	690.	63.	11.0
8	.4	.25	1.6	.3	.23	1.3	8.4	6.9	1.2	180.	190.	1.0
9	.3	.28	1.1	.44	.43	1.0	4.3	4.1	1.1	62.	60.	1.0
10	.5	.4	1.2	.25	.8	0.3	13.	3.2	4.0	320.	25.	15.0
11	.55	.48	1.2	.27	.47	0.6	13.	6.2	2.1	300.	80.	3.7
Average.			2.3			0.8			3.2			6.7

(II.) Large Waves. E. W. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	2.	1.65	1.2	1.	.8	1.3	13.	13.	1.0	80.	94.	0.9
2	.42	.35	1.2	.5	.5	1.0	5.3	4.4	1.2	66.	55.	1.2
3	.57	.7	0.8	.93	.9	1.0	4.	5.	0.8	26.	34.	0.8
4	.63	.85	.7	1.	1.	1.0	4.	5.3	0.8	25.	33.	0.8
5	.53	.58	.9	1.2	1.1	1.1	2.8	3.3	0.9	15.	19.	0.8
Average.			1.0			1.1			0.9			0.9

(III.) Ripples. N. S. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf,	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	.27	.18	1.5	.22	.23	1.0	7.7	4.9	1.5	220.	130.	1.7
2	.6	.55	1.1	.32	.43	0.7	12.	8.	1.5	240.	120.	2.0
3	.55	.31	1.8	.3	.35	0.8	12.	5.6	2.1	240.	100.	2.4
4	.37	.2	1.9	.25	.35	0.7	9.3	3.6	2.6	230.	65.	3.9
5	.54	.04	14.	.4	.3	1.3	8.5	0.8	11.	130.	16.	8.0
6	.58	.15	3.9	.24	.3	0.8	15.	3.2	4.9	400.	68.	6.0
Average.			4.0			0.9			3.9			4.0

(IV.) Large Waves. N. S. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	.75	.55	1.4	.6	.58	1.0	7.9	6.	1.3	82.	65.	1.2
2	.78	.53	1.5	1.3	1.2	1.1	3.5	2.8	1.2	16.	15.	1.1
3	.8	.6	1.3	1.4	1.2	1.2	3.6	3.1	1.2	16.	16.	1.0
4	1.05	.85	1.2	1.2	1.0	1.2	5.5	5.3	1.0	29.	34.	.9
5	.45	.45	1.0	1.1	1.1	1.0	2.6	2.6	1.0	15.	15.	1.0
6	.75	.75	1.0	1.7	1.6	1.1	2.8	3.	.9	10.	11.	.9
7	.52	.45	1.2	1.1	1.0	1.1	3.0	2.8	1.1	17.	18.	.9
8	.55	.53	1.0	1.3	1.0	1.3	2.6	3.3	.8	12.	21.	.6
9	.75	1.0	.8	2.	2.	1.0	2.3	3.1	.8	7.4	9.6	.8
Average.			1.2			1.1			1.0			0.9

In (I), the ripples numbered 3, 4, 5, 6 which are distinct on the surface have united into one wave in the pit. In taking the ratios of maximum velocities and maximum accelerations, this single wave is compared with the greatest of the corresponding ripples.

(14.)—June 3rd, 1888—An earthquake of moderate amplitude.

N. S. Component.

n			Aver. Period.		
Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
35.	17.	2.	.3	.6	.5

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	.3	.4	0.8	1.2	1.2	1.0	1.6	2.1	0.8	8.5	11.	0.8
2	.5	.45	1.1	1.5	1.	1.5	2.1	2.8	0.8	8.8	17.	0.5
3	.46	.32	1.4	1.	1.	1.0	2.9	2.0	1.5	18.	13.	1.4
Average.			1.1			1.2			1.0			0.9

E. W. Component.

Max. Ampl.		
Surf.	Pit	Surf./Pit
1.1	.95	1.1

(15.)—October 20th, 1888.—A small earthquake. In this case the amplitude seems to be much greater in the pit than on the surface.

	n			Aver. Period.			Max. Period.		
	Surf.	Pit	Surf./Pit	Surf	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
E. W. Comp.	31.	20.	1.6	.33	.5	0.7	.6	.9	0.7
N. S. Comp.	28.	21.	1.3	.45	.5	0.9	.5	.6	0.8

E. W. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surt.	Pit	Surf./Pit
1	.12	.2	0.6	.7	.9	0.8	1.1	1.4	0.8	10.	10.	10.
2	.1	.2	0.5	.5	.7	0.7	1.3	1.8	0.7	16.	16.	10.
3	.06	.21	0.3	...	...	...	...	...	...	...	...	...
4	.18	.26	0.7	...	...	...	...	...	...	...	...	...
5	.11	.21	0.5	...	...	...	...	...	...	...	...	...
6	.14	.21	0.7	...	...	...	...	...	...	...	...	...
Average.			0.6			0.8			0.8			1.0

N. S. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	.16	.15	1.1	.4	.5	0.8	2.5	1.9	1.3	39.	24.	1.6
2	.1	.2	0.5	.4	.6	0.7	1.6	2.1	.8	26.	22.	1.2
3	.1	.2	0.5	.7	.5	1.4	0.9	2.5	0.4	8.	31.	0.3
4	.1	.16	0.6	.4	.5	0.8	1.6	2.0	0.8	26.	25.	1.0
5	.1	.16	0.6	.5	.5	1.0	1.3	2.0	0.7	16.	25.	0.6
6	.1	.21	0.5	.5	.5	1.0	1.3	2.6	0.5	16.	32.	0.5
7	.3	.4	0.8	...	...	...	...	...	...	...	...	...
8	.11	.28	0.4	...	...	...	...	...	...	...	...	...
9	.1	.27	0.4	...	...	...	...	...	...	...	...	...
10	.1	.25	0.4	...	...	...	...	...	...	...	...	...
Average.			0.6			1.0			0.8			0.9

(16.)—November 2nd, 1888.—A small earthquake. The pit diagram is much smoother than the surface one.

	Max. Ampl.		
	Surf.	Pit	Surf./Pit
E. W. Comp.	.19	.16	1.2
N. S. Comp.	.15	.14	1.1

(17.)—January 1st, 1889.—A small earthquake.

	Max. Ampl.		
	Surf.	Pit	Surf./Pit
N. S. Comp.	.04	.05	1.

(18.)—February 18th, 1889.—A severe earthquake, in which there was a considerable amount of vertical motion. The earlier portions of the diagrams of the E. W. component are given in Pl. XXXVII, Fig. 7. The glass plates of the surface and pit instruments made revolutions in 108 sec. and 95 sec. respectively. The periods of the vibration are very short and the motion on the surface seems to be much sharper than in the pit.

	E. W. Comp.			N. S. Comp.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
n_1	46.	28.	1.5	50.	30.	1.7
n_2	35.	21.	1.7	49.	23.	2.1
n_3	20.	15.	1.3	39.	14.	2.8
n_4	19.	19.	1.0	26.	20.	1.3
n_5	12.	11.	1.1	15.	16.	.9

In this table n_1 n_2 .... are the number of irregular wavelets in the successive 10 sec. intervals.

(I.) Ripples. E. W. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	.24	.23	1.0	.28	.27	1.0	5.4	5.4	1.0	120.	130.	1.0
2	1.05	.8	1.3	.7	.66	1.1	9.4	7.7	1.2	84.	74.	1.1
3	1.35	1.3	1.0	...	...	...	...	...	...	...	...	...
4	2.4	2.17	1.1	...	...	...	...	...	...	...	...	...
5	.73	.4	1.8	...	...	...	...	...	...	...	...	...
6	.95	1.05	0.9	...	...	...	...	...	...	...	...	...
7	.3	.06	5.0	...	...	...	...	...	...	...	...	...
8	.82	.52	1.6	...	...	...	...	...	...	...	...	...
9	.8	.32	2.5	...	...	...	...	...	...	...	...	...
10	1.3	.8	1.6	...	...	...	...	...	...	...	...	...
11	.7	.35	2.0	.24	.25	1.0	18.	9.	2.0	480.	220.	2.2
12	.65	.25	2.6	.32	.23	1.4	13.	7.	1.9	250.	190.	1.3
13	1.05	.8	1.3	.35	.73	.5	19.	7.	2.8	340.	60.	5.7
14	.31	.2	1.6	.27	.29	0.9	7.2	4.4	1.6	170.	100.	1.7
15	1.15	.72	1.6	.55	.54	1.0	13.	8.4	1.6	150.	100.	1.5
16	.8	nul	...	.5	...	...	10.	...	...	130.	...	...
17	1.2	.7	1.7	.33	.3	1.1	23.	15.	1.6	440.	320.	1.4
18	.4	nul	...	.18	...	...	14.	...	...	490.	...	...
19	.85	nul	...	...	...	...	...	...	...	...	...	...
20	1.73	1.5	1.1	...	...	...	...	...	...	...	...	...
21	.78	.6	1.3	.26	.64	0.4	19.	6.	3.2	460.	60.	8.0
22	.75	.45	1.7	.36	.6	0.6	13.	4.7	2.8	230.	50.	4.7
23	.3	.06	5.0	.2	.2	1.0	9.	1.9	4.7	280.	60.	4.4
24	.87	.75	1.2	...	...	...	...	...	...	...	...	...
25	.71	.6	1.2	.3	.7	0.4	15.	5.4	2.8	320.	50.	6.5
26	.95	.79	1.2	.6	.8	0.8	10.	6.2	1.6	100.	50.	2.0
27	.88	.75	1.1	.55	.58	1.0	10.	8.2	1.2	110.	90.	1.3
28	.5	.55	0.9	.3	.58	0.5	11.	6.0	1.8	220.	66.	3.3
29	.47	.3	1.6	.5	.32	1.5	6.	6.	1.0	80.	120.	0.6
30	.84	.56	1.3	.6	.8	0.8	8.8	4.4	2.0	92.	35.	2.6
31	.32	.23	1.4	.4	.5	1.0	5.	3.6	1.4	78.	56.	1.4
Average.			1.7			.9			2.0			2.8

(II.) Large Waves. E. W. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	4.1	2.	2.1	...	...	...	...	...	...	...	...	...
2	1.7	1.4	1.2	1.5	1.7	0.9	7.1	5.2	1.4	30.	19.	1.6
3	1.75	1.5	1.2	.72	.79	0.9	15.	12.	1.3	130.	96.	1.3
4	2.	1.6	1.2	2.	2.	1.0	6.3	5.	1.3	20.	16.	1.2
5	1.4	1.	1.4	2.5	2.4	1.0	3.5	2.6	1.3	9.	6.8	1.3
6	.92	.95	1.0	1.0	1.0	1.0	5.8	6.0	1.0	37.	38.	1.0
7	.8	.92	.9	1.4	1.3	1.1	3.6	4.5	0.8	16.	22.	.7
8	1.4	1.1	1.3	1.4	1.3	1.1	6.3	5.3	1.2	28.	26.	1.1
9	1.8	1.35	1.3	2.	1.9	1.0	5.7	4.5	1.3	18.	15.	1.2
10	2.05	1.75	1.2	3.9	3.7	1.0	3.3	3.	1.1	5.3	5.1	1.0
11	1.45	.9	1.6	2.	1.9	1.0	4.6	3.	1.5	15.	10.	1.5
12	1.2	.8	1.5	1.7	1.7	1.0	4.5	3.	1.5	17.	11.	1.5
13	1.4	1.3	1.1	2.7	3.	0.9	3.3	2.7	1.2	8.	5.6	1.4
14	1.65	1.	1.7	3.	3.	1.0	3.7	2.1	1.8	8.3	4.4	1.9
15	2.2	1.25	1.8	2.4	2.6	0.9	5.8	3.2	1.8	15.	8.2	1.8
Average.			1.4			1.0			1.3			1.3

(III.) Ripples. N. S. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	.85	.7	1.2	.43	.52	0.8	12.5	8.5	1.5	180.	100.	1.8
2	1.65	1.2	1.4	.6	.56	1.1	17.	14.	1.3	500.	150.	3.3
3	.4	.09	4.4	.2	.23	0.9	13.	2.5	5.0	400.	70.	5.7
4	.72	.65	1.1	.3	.3	1.0	15.	14.	1.1	320.	290.	1.1
5	.4	nul	...	.15	...	...	17.	...	...	700.	...	...

Ripples. N. S. Component. *(Continued).*

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
6	.85	.78	1.1	...	...	...	...	...	...	...	...	...
7	.75	.85	0.9	.33	1.0	.3	14.	5.	2.8	270.	34.	8.0
8	.3	.1	3.	.14	.25	0.6	14.	3.	4.7	600.	60.	10.
9	.4	.6	0.7	.17	.6	0.3	15.	6.3	2.4	550.	66.	8.3
10	.65	.55	1.2	.3	.5	0.6	14.	7.	2.0	290.	87.	3.3
11	.4	.12	3.3	.14	.25	0.6	18.	3.	6.0	800.	80.	10.
12	.5	.56	0.9	.46	.4	1.2	7.	9.	0.8	93.	140.	0.8
13	.6	.4	1.5	.46	.45	1.0	8.	6.	1.3	110.	80.	1.4
14	.6	.5	1.2	.4	.4	1.0	9.	8.	1.1	150.	120.	1.3
15	.5	.3	1.7	.44	.4	1.1	7.	5.	1.4	100.	74.	1.4
16	.65	.45	1.4	.73	.7	1.0	6.	4.	1.5	48.	46.	1.0
17	.94	.74	1.3	...	...	...	...	...	...	...	...	...
18	.66	.33	2.0	...	...	...	...	...	...	...	...	...
19	.28	nul	...	.24	...	...	7.	...	...	190.	...	...
20	.99	.89	1.1	.53	.58	.9	12.	9.7	1.2	140.	110.	1.3
21	.65	.59	1.1	.24	.4	.6	17.	9.	1.9	450.	150.	3.0
22	.67	.42	1.6	.24	.3	.8	18.	8.8	2.0	460.	180.	2.5
Average.			1.6			.8			2.2			3.8

(IV.) Large Waves. N. S. Component.

No.	Amplitude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	2.75	2.3	1.2	1.6	1.6	1.0	11.	9.	1.2	44.	35.	1.3
2	2.9	3.3	.9	2.0	1.9	1.0	9.1	11.	0.8	29.	37.	0.8
3	.8	7.	1.1	.6	.42	1.4	8.4	11.	0.8	88.	170.	0.5
4	.5	.25	2.0	.6	.7	0.9	5.3	2.3	2.3	56.	21.	2.7

(IV.) Large Waves. N. S. Component. *(Continued.)*

No.	Ampritude.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
5	.85	.63	1.4	.74	.66	1.1	7.2	6.	1.2	61.	57.	1.1
6	.85	.8	1.1	.6	.8	0.8	8.9	6.3	1.4	93.	50.	1.9
7	1.4	1.25	1.2	.8	.8	1.0	11.	9.1	1.2	87.	72.	1.2
8	1.4	.7	2.0	1.1	1.2	0.9	8.	3.7	2.2	46.	19.	2.3
9	1.65	1.4	1.2	.77	.8	1.0	14.	11.	1.3	110.	87.	1.3
10	1.45	1.1	1.3	...	...	...	...	...	...	...	...	...
Average.			1.3			1.0			1.2			1.3

The ripples numbered 16, 18, 19 in (I) and those numbered 5, 19 in (III), which are distinct on the surface, do not exist in the pit.

(19)—May 6th, 1889.—A small earthquake, on whose undulations are superposed minute irregularities. Here the motion appears to be rather greater and of longer duration on the surface than in the pit.

	n.			Aver. Period.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
E. W. Comp.	43.	33.	1.3	.23	.3	0.8
N. S. Comp.	50.	22.	2.3	.2	.4	0.5

E. W. Component.

No.	Amplitude.			Period.			Max. Acc.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
1	.1	.1	1.0	1.	.7	1.4	.6	.9	0.7	4.	8.	0.5
2	.05	.05	1.0	1.3	1.7	0.8	.2	.2	1.0	1.	.7	1.4
3	.07	.07	1.0	1.6	1.4	1.2	.3	.3	1.0	1.	1.5	0.7
4	.08	.09	0.9	1.3	1.4	0.9	.4	.4	1.0	2.	2.	1.0
5	.05	.07	0.7	1.3	1.4	0.9	.24	.32	0.8	1.	1.5	0.7
6	.05	.06	0.8	1.	1.2	0·8	.3	.3	1.0	2.	2.	1.0
Average.			0.9			1.0			0.9			0.9

N. S. Component.

Max. Ampl.			Period.			Max. Vel.			Max. Acc.		
Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
.13	.09	1.4	.8	.5	1.6	1.	1.1	0.9	8.	14.	0.6

(20.)—May 30th, 1889.—A small earthquake.

	n.			Aver. Period.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
N. S. Comp.	32.	21.	1.5	.3	.5	0.6

	Max. Ampl.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
E. W. Comp.	0.8	.1	0.8	.33	.46	0.7	1.5	1.4	1.1	28.	20.	1.4
N. S. Comp.	.3	.15	2.0	.9	.4	2.3	2.1	2.4	0.9	15.	38.	0.4

(21.)—June 1st, 1889.—A very small earthquake.

In the E. W. and N. S. Components of both the surface and pit diagrams, the maximum amplitudes are about .03 mm. and .02 mm respectively.

(22.)—June 3rd, 1889.—A very small earthquake.

In the E. W. Component of the both the surface and pit diagrams, the maximum amplitude is about .03 mm.

N. S. Component.

Max. Ampl.			Period.			Max. Vel.			Max. Acc.		
Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
.1	.05	2.	1.	.7	1.4	.6	.5	1.	4.	4.	1.

(23.)—June 15th, 1889.—A small earthquake.

	Max. Ampl.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
E. W. Comp.	.07	.07	1.0	.8	.8	1.0	.55	.55	1.0	4.3	4.3	1.0
N. S. Comp.	.07	.05	1.4	1.0	.6	1.6	.44	.53	0.8	2.8	5.6	0.5

(24.)—June 16th, 1889.—A small earthquake.

E. W. Component. On the surface, the maximum amplitude is not greater than .02 mm., and in the pit it is about .05 mm.

N. S. Component. On the surface, the maximum amplitude is about .07 mm., and in the pit it is about 0.1 mm.

(25.)—June 20th, 1889.—A small earthquake. In this case, the amplitude seems to be rather greater in the pit than on the surface.

	n.			Aver. Period.			Max. Period.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
E. W. Comp.	35.	25.	1.4	.3	.4	.8	...	...	...
N. S. Comp.	48.	21.	2.3	.2	.5	.4	.6	.7	.9

	Max. Ampl.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
E. W. Comp.	.08	.14	0.6	.5	.7	.7	1.	1.	1.	13.	12.	1.
N. S. Comp.	.07	.11	0.6	.4	.5	.8	1.1	1.4	.8	17.	18.	1.

(26.)—June 27th, 1889.—A small earthquake.

	Max. Ampl.			Period.			Max. Vel.			Max. Acc.		
	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit	Surf.	Pit	Surf./Pit
E. W. Comp.	.1	.05	2.	1.4	1.2	1.2	.5	.3	1.7	2.	1.3	1.5
N. S. Comp.	.1	.03	3.	1.2	.5	2.4	.5	.4	1.3	2.7	4.8	0.6

(27.)—July 3rd, 1889.—A small earthquake.

In the E. W. Component, the maximum amplitude is .13 mm. on the surface, and .1 mm. in the pit.

(28.)—February 13th, 1890.—A very small earthquake.

E. W. Component. Both on the surface and in the pit the maximum amplitude is not greater than .05 mm.

N. S. Component. Both on the surface and in the pit, the maximum amplitude is about 0.1 mm.

(29.)—April 11th, 1890.—A small earthquake.

	Max. Ampl.		
	Surf.	Pit	Surf./Pit
E. W. Comp.	.13	.15	0.9
N. S. Comp.	.1	.06	1.7

(30.)—April 18th, 1889.—A very small earthquake.

	Max. Ampl.		
	Surf.	Pit	Surf./Pit
E. W. Comp.	.07	.04	2.
N. S. Comp.	.06	very small.	...

Summary of Results.

It is generally believed that the earthquake motion is considerably less in a pit than on the surface. From the foregoing calculations it seems probable that this is true for some earthquakes and not true for others. Among the thirty earthquakes we examined, there are three which were especially severe. These are (1), (13), and (18). The rest are small earthquakes of the kind that daily occur in Japan. The ratios of the amplitudes, periods, maximum velocities and maximum accelerations for some of these latter earthquakes as observed on the free surface ground to those observed in the pit are collected in the following table, average values being used when a number of waves have been calculated for a single earthquake.

(No.)	Ratio of Amplitudes		Ratio of Periods		Ratio of Max. Vel.		Ratio of Max. Acc.	
	E. W.	N. S.	E. W.	N. S.	E. W.	N. S.	E. W.	N. S.
(2)	0.8	0.7	...	.5	...	1.4	...	3.
(3)	...	1.7	...	.8	...	2.0	...	3.
(4)	1.0	1.2	1.5	.7	.6	1.6	.44	2.2
(5)	1.4	1.0	0.9	0.5	1.6	2.3	1.8	5.0
(7)	1.0	1.1	1.0	0.9	1.0	1.2	1.0	1.2
(8)	1.1	0.9	1.0	0.6	1.2	1.5	1.3	2.7
(9)	0.6	0.8	0.9	0.9	0.7	0.9	0.7	1.1
(10)	0.9	2.6	0.8	0.9	1.3	3.0	1.6	3.7
(12)	1.8	1.6	0.8	0.7	2.5	2.3	3.6	3.6
(14)	1.1	1.1	...	1.2	...	1.0	...	0.9
(15)	0.6	0.6	0.8	1.0	0.8	0.8	1.0	0.9
(16)	1.2	1.1	...	...	...	...	...	...
(19)	0.9	1.4	1.0	1.6	0.9	0.9	0.9	0.6
(20)	0.8	2.0	0.7	2.3	1.1	0.9	1.4	0.4
(22)	...	2.0	...	1.4	...	1.0	...	1.0
(23)	1.0	1.4	1.0	1.6	1.0	0.8	1.0	0.5
(25)	0.6	0.6	0.7	0.8	1.0	0.8	1.0	1.0
(26)	2.0	3.0	1.2	2.4	1.7	1.3	1.5	0.6
(27)	1.3	...	...	...	...	...	...	...
(29)	0.9	1.7	...	...	...	...	...	...
Average. ...	1.06	1.4	0.9	1.1	1.2	1.4	1.3	1.9
Average for both Components.	1.2		1.0		1.3		1.6	

This table seems to shew that for small earthquakes the amplitude and the period are on the whole nearly the same on the free surface and in the pit, there being a slightly greater motion on the surface. This confirms the result which Prof. Milne previously obtained. In the above are not included those very small earthquakes, whose measurements are difficult; these however shew that the motion in the pit is also small when the motion observed on the surface ground is small.

It must be noticed that the diagram taken in the pit appears always to be smoother than that obtained on the surface, and n, or the number of irregular wavelets occurring in 10 seconds, is found in every case to be greater for the latter, being often twice as many as for the former. This is very remarkably shown in the three severe earthquakes mentioned above, for which calculations have been made separately as regards large undulations and small superposed ripples. The ratios of the amplitudes, periods, maximum velocities, and maximum accelerations for the surface and pit motion of these three earthquakes are given in the following tables.

(I.) Large undulations.

(No.)	Ratio of Amplitudes		Ratio of Periods		Ratio of Max. Vel.		Ratio of Max. Acc.	
	E. W.	N. S.	E. W.	N. S.	E. W.	N. S.	E. W.	N. S.
(1)	2.3	1.1	1.2	...	2.1	...	2.1	...
(13)	1.0	1.2	1.1	1.1	0.9	1.0	0.9	0.9
(18)	1.4	1.3	1.0	1.0	1.3	1.2	1.3	1.3
Average. ...	1.6	1.2	1.1	1.1	1.4	1.2	1.4	1.1
Average for both Components.	1.4		1.1		1.3		1.3	

(II.) Ripples.

(No.)	Ratio of Amplitudes		Ratio of Periods		Ratio of Max. Vel.		Ratio of Max. Acc.	
	E. W.	N. S.	E. W.	N. S.	E. W.	N. S.	E. W.	N. S.
(1)	1.9	1.3	0.6	0.8	3.7	1.8	7.8	2.7
(13)	2.3	4.0	0.8	0.9	3.2	3.9	6.7	4.0
(18)	1.7	1.6	0.9	0.8	2.0	2.2	2.8	3.8
Average. ...	2.0	2.3	0.8	0.8	3.0	2.6	5.8	3.5
Average for both Components.	2.2		0.8		2.8		4.7	

It will be thus observed that for principal undulations of severe earthquakes the range of motion is somewhat greater on the surface than in the pit, but there is no great difference of maximum velocities and maximum accelerations between the two sets of observations. This seems to be due to the fact that for the larger undulations the period will somewhat increase with the amplitude. In fact, table (I.) would appear to indicate some slight increase of period on the surface. The case is different with ripples, for which the results are more uniform and the difference of surface and underground effects more decided. From Table (II.) the average extent of horizontal motion in the pit is only half that on the surface ground, and the period for the former seems rather greater than for the latter, which arises from the fact that very many of the ripples disappear in the pit. The maximum velocities and maximum accelerations on the surface are respectively about three and five times those in the pit.

Our conclusion then is that for small earthquakes there is no practical difference between the surface and underground observations; for the principal undulations of severe earthquakes this difference may exist, but not to any marked degree; but for the small quick vibrations the difference is considerable. Now, though only approximate the calculation for the ripples may be, their maximum velocities and maximum accebrations are found to be very great, and, in fact, many times greater than those for the principal undulations. And thus, if these ripples are really in great part smoothed away in the pit, it is very likely that in times of such severe earthquakes as discussed above, there might be less destructive action in deep pits than on the free surface.

We shall not venture here to discuss what these ripples may be. They exist only in the early part of the shocks and seem to be the continuation of the tremors which occur at the beginning of earthquakes. The appearance of the diagrams of the severe earthquakes is very much like that of the disturbances in the sea where minute ripples are superposed on large undulations. If the ripples be regarded as waves travelling on the surface, then the whole thing will admit of an easy explanation.

We must state however that these observations were made at Hongo, where the ground is hard, and it is needless to say that the character of the earthquake motion depends in a great measure on the nature of the soil. Hence it is quite possible that observations in different places may lead to somewhat different results than those obtained here. Thus, for instance, at Hitotsubashi, where the soil is soft, the range of motion is two or three times greater than that at Hongo, and yet the earthquake diagrams obtained there seem to be comparatively free of superposed wavelets.

In the above the observations were confined to the horizontal component motion alone. The usual argument for the supposed smallness of the motion at a subterranean point is derived from the behaviour of a row of ivory balls in contact with each other when one at the end is sharply struck. This argument appears to apply rather to the vertical component than to the horizontal. It is our intention to continue these observations we have been making and in addition to investigate the nature of the vertical motion in the pit.

Fig. 1.—Comparison Diagrams of the East-West Component Instruments.

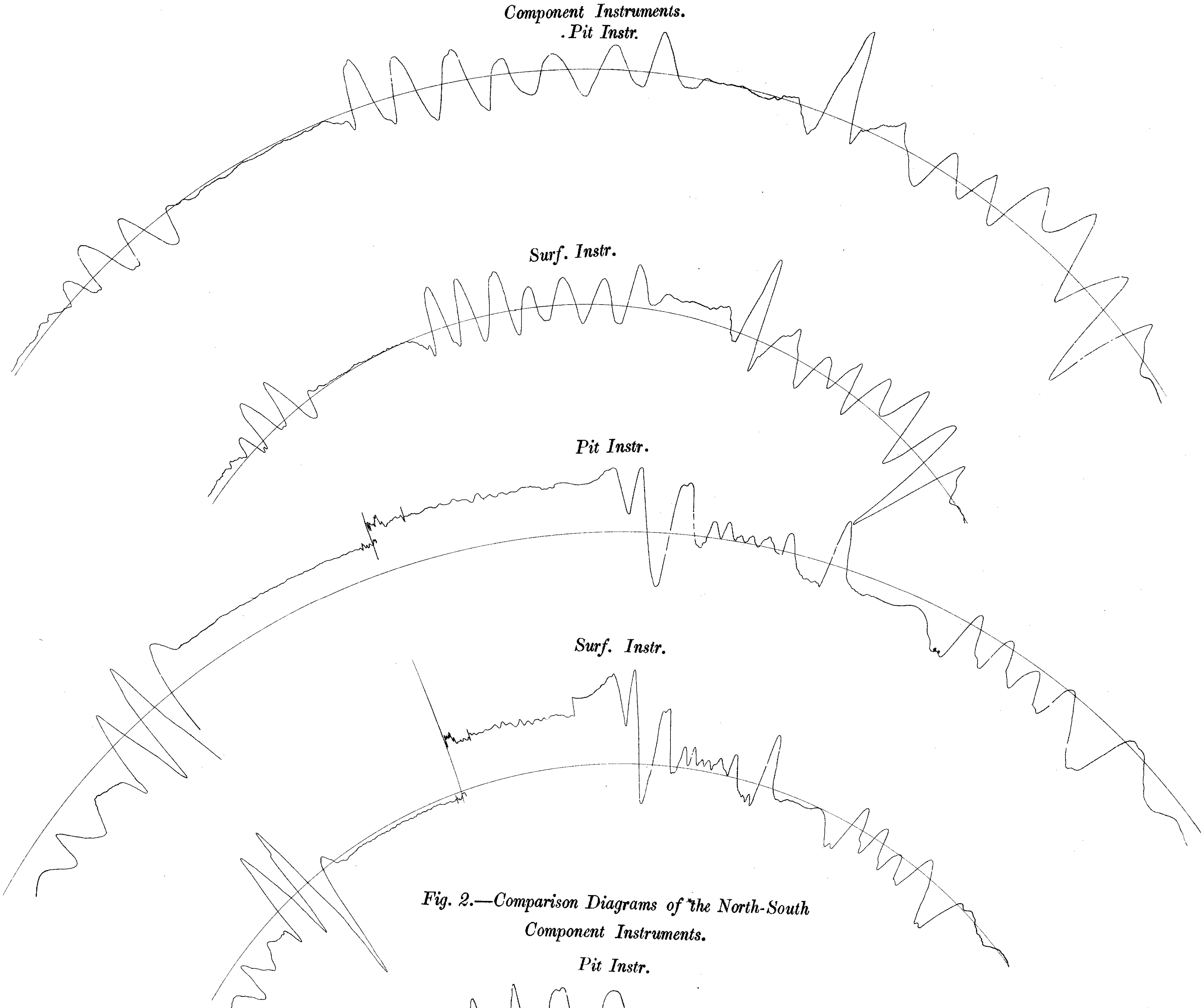

Fig. 2.—Comparison Diagrams of the North-South Component Instruments.

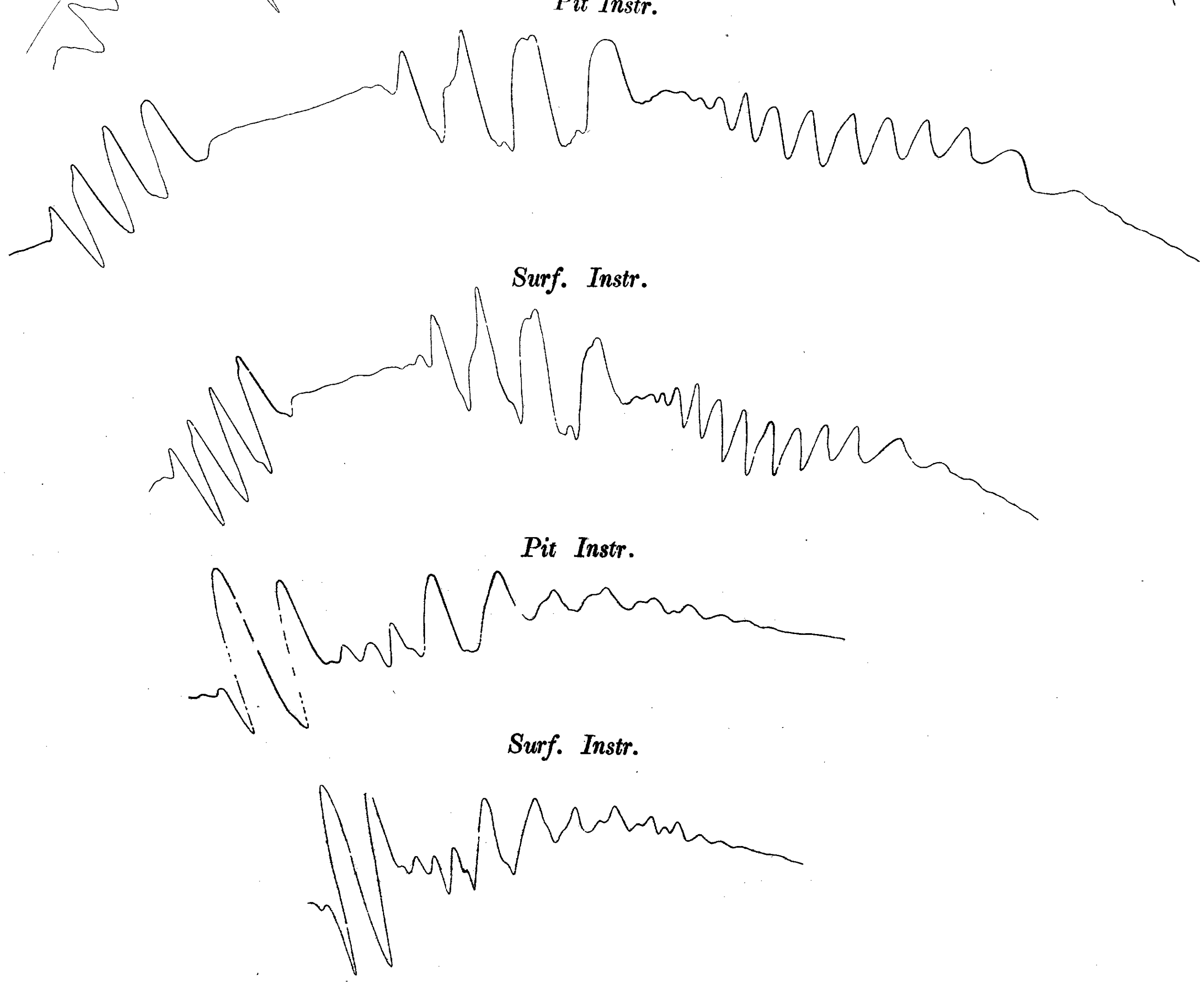

Fig. 3.—Earthquake of January 15th, 1887.
East-West Component.

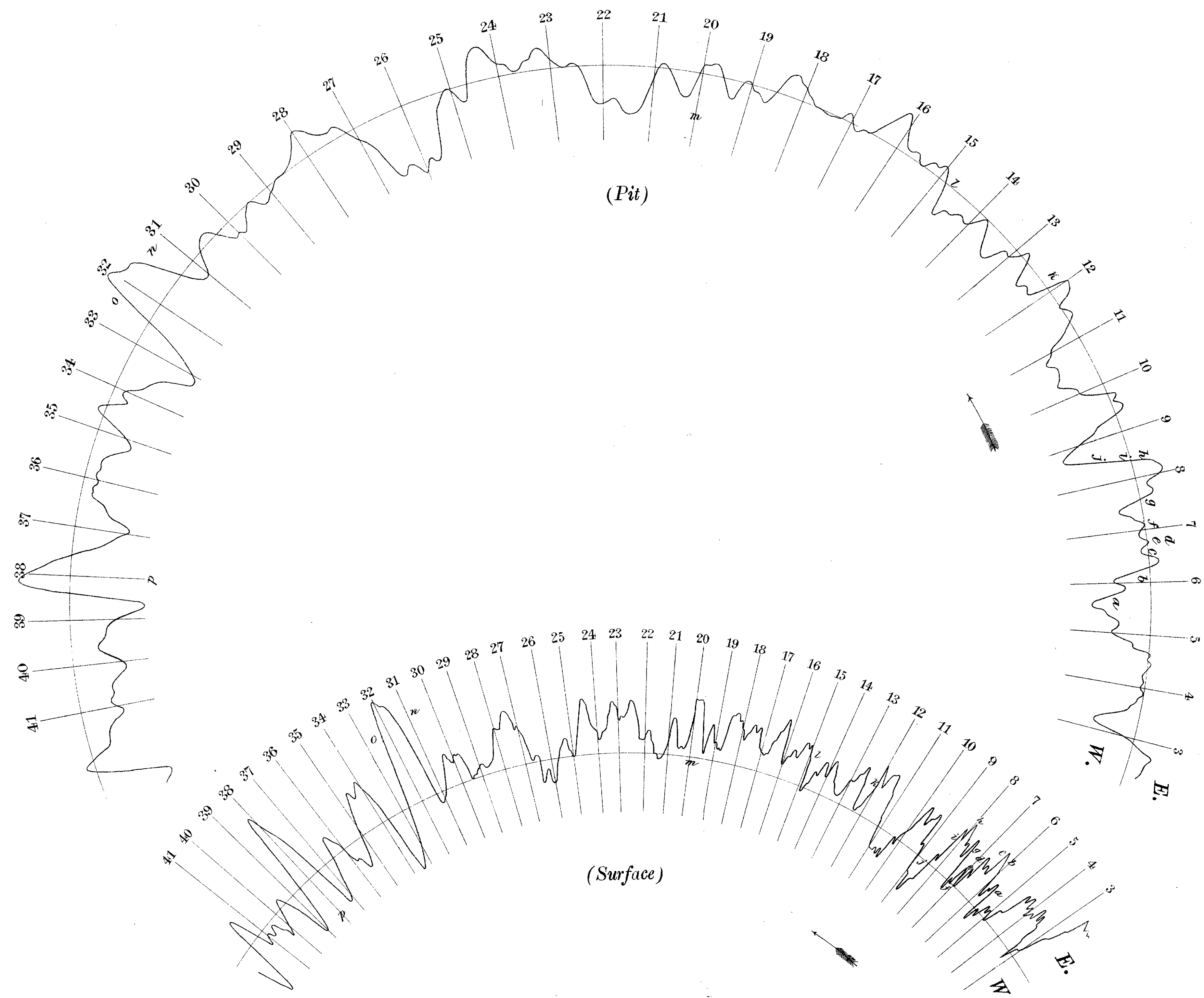

Fig. 4.—North-South Component.

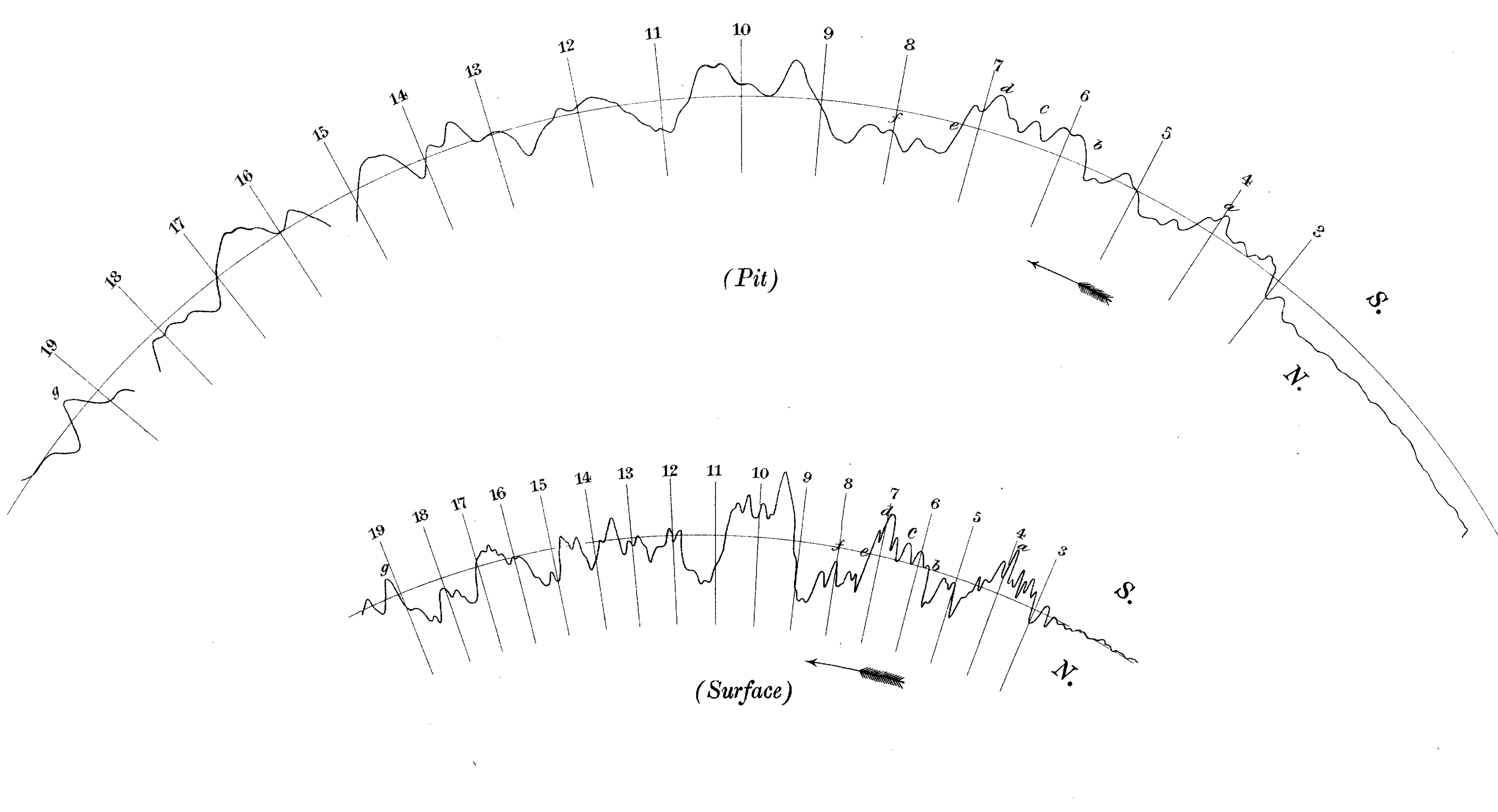

Fig. 5.—Earthquake of April 29th, 1888.
East-West Component.

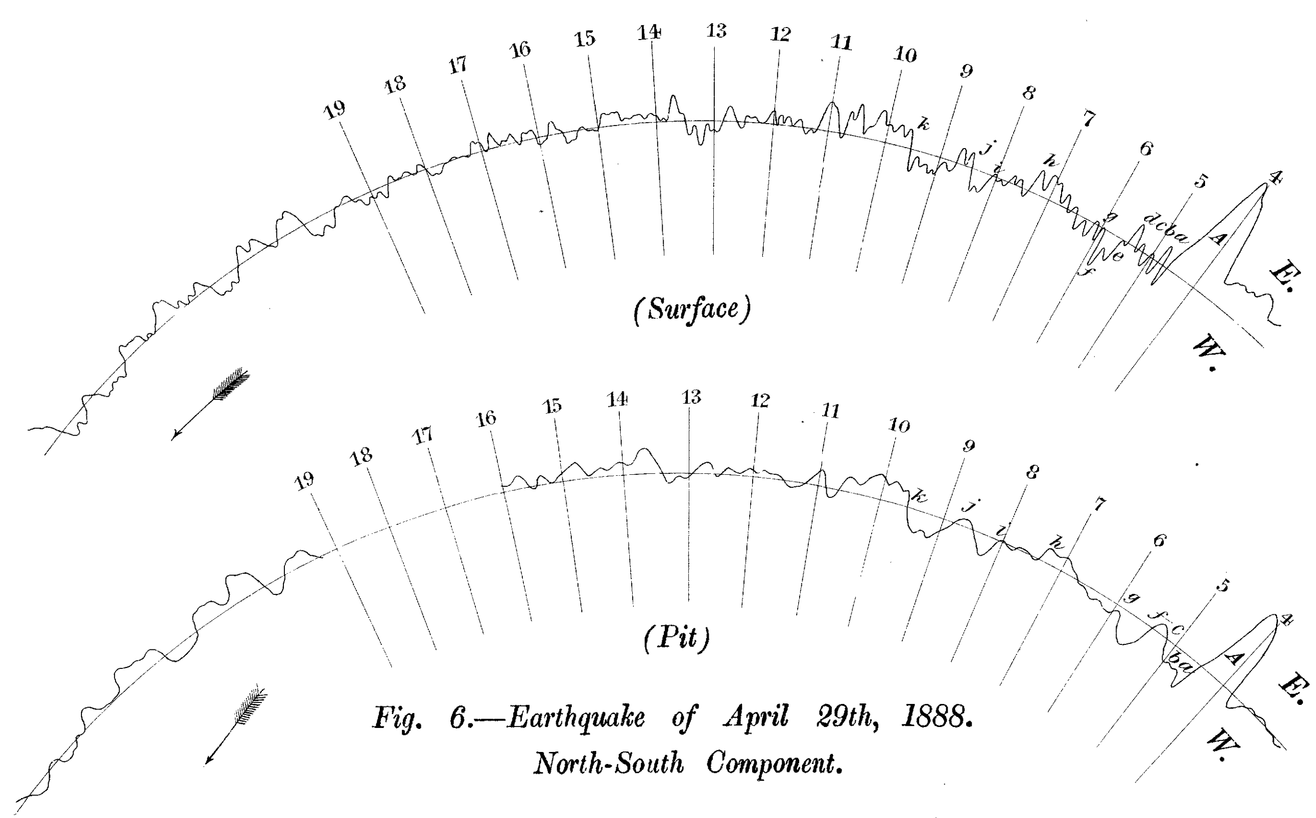

Fig. 6.—Earthquake of April 29th, 1888.
North-South Component.

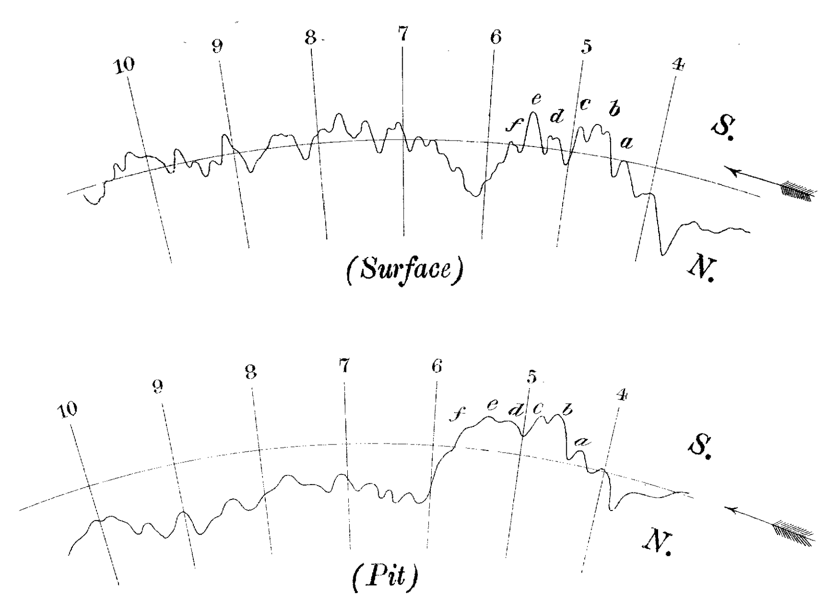

Fig. 7.—Earthquake of February 18th, 1889.
East-West Component.