SPECIAL ARTICLES, NOTES, AND EXTRACTS.

THE MEXICAN EARTHQUAKE OF APRIL 15, 1907, WITH NOTES ON THE NATURE OF MOVEMENTS INDUCED BY EARTHQUAKES.

By C. F. MARVIN, Professor of Meteorology. Dated April 26, 1907.

A marked period of repose from seismic activity appears to have prevailed, especially thruout the Western Hemisphere, after the Kingston earthquake of January 14, 1907. During an interval of almost exactly three months the Weather Bureau seismographs did not record any movements of noticeable magnitude until the early morning of April 15, when a very complete record was obtained of another great earthquake whose origin is now known to have been within or near the southwestern provinces of Mexico. The towns of Chilpancingo, Chilapa, Ayutla, and doubtless others from which press reports were not received, all near the Pacific coast, suffered very severely or were mostly destroyed.

Judging from the Weather Bureau record the disturbance was of very considerable violence, greatly exceeding the Kingston earthquake, and comparable in intensity with those in California in April and in Chile in August of 1906.

Table 1 gives the times and duration of the several phases usually characteristic of records of great distant earthquakes. The automatic records from which the results have been deduced are partly reproduced on Chart IX.

TABLE 1.—*Times and duration of phases. Mexican earthquake; beginning 1 hr., 14 min., 19 sec. a. m., 75th meridian time, April 15, 1907.*[1]

	N.-S. component.			E.-W. component.		
	h.	*m.*	*s.*	*h.*	*m.*	*s.*
First preliminary tremors began	1	14	19 a. m.	1	14	19 a. m.
Second preliminary tremors began	1	19	28 a. m.	1	19	34 a. m.
Principal portion began	1	26	56 a. m.	1	26	..* a. m.
Principal portion ended	1	43	17 a. m.	1	43	39* a. m.
End of earthquake	2	43	00 a. m.	3	48	00 a. m.
Duration of first preliminary tremors	0	5	9	0	5	15
Duration of second preliminary tremors	0	7	28	0	7	..
Duration of principal portion	0	16	21	0	17	..
Total duration of earthquake	1	28	41	2	33	41
Times of maximum motion	1	27	..	Pen off sheet.		
	1	31 to 33		Pen off sheet.		
Probable amount of actual maximum displacement (double amplitude)	5 mm.			7 mm.		
Period of pendulums	15.5 secs.			20 secs.		
Magnification of record	25 times.			20 times.		

* The beginning and ending of the principal portion in the east-west component are not sharply defined.

Before drawing attention to certain details of the records, it seems desirable to outline certain general characteristics of the movements which seismographs record.

In the first place, the most perfect instruments known at the present time still fail to give us a wholly faithful record of the vibrations of the ground during an earthquake, and, therefore, no exact deductions can be drawn from records thus far obtainable. The ground movements, moreover, are very complex and unfortunately seismographs such as the horizontal pendulum instruments in use at the Weather Bureau, like other forms, are influenced by more than one element of motion. For example, the record ordinarily produced by a horizontal pendulum may represent one or more of at least three possible elementary motions, i. e.: (1) A linear horizontal displacement of a vibratory nature. (2) The passage of undulations of the ground like long, shallow waves on the surface of water where the motion is literally a slight tilting and without translation. (3) The record may even be caused by a certain oscillatory rotation of the ground about a vertical axis. We can not tell, from the record itself, whether one or more than one of these several effects may have been operative.

From other sources of information we are justified in making the following statements concerning the general nature of the motion of the ground at a great distance from the origin of an earthquake:

(1) The motions are essentially vibratory motions, naturally more or less complex and of irregular character. No appreciable permanent dislocations, even of small amounts, appear to be indicated by records, even at relatively moderate distances from the origin.

(2) The period of the main oscillations is relatively slow—scarcely less than ten seconds, and even twenty to thirty seconds and longer. The maximum acceleration is correspondingly small—one millimeter per second per second or less.

(3) The speed of propagation is relatively rapid—several miles per second.

(4) The wave length is accordingly very great—waves of 100 miles in length are plausible.

(5) Under these circumstances, the piers upon which seismographs may be installed, in fact whole buildings, and very considerable horizontal areas, move or vibrate *as a unit* under the influence of the distant earthquake. Consequently, there can not be important differential motions within restricted dimensions.

This explains how it is possible that relatively large ground vibrations, caused by a distant great earthquake, may persist at a place for many minutes, or even hours, and be recorded by suitable seismographs, yet be entirely unfelt by individuals, and be unmarked by creaking of buildings or other tangible evidence of the disturbance.

The case is very different with nearby felt earthquakes even of very feeble intensity. The period of vibration is small, the speed of propagation slower, the wave length accordingly shorter, and the acceleration greater. All such characteristics combine to favor differential motions within limited distances, and the resulting distortion, wrenching, and displacement of structures typical of earthquake effects.

In great destructive earthquakes the intensity as measured by the maximum acceleration of the ground motion may attain to about one-third the acceleration of gravity—that is, to from 3000 to 4000 millimeters per second per second.

We must conclude, from what has already been said, that, at a distance from an origin, the seismograph pier, in fact, the whole material environment, *moves as a unit.* Now, in accordance with well known principles of mechanics, an elementary portion of the motion of the pier during any brief interval of time, may consist of one or both of two separate kinds of motion. (1) The pier may undergo simple linear displacement in some particular direction; or (2), the pier may execute a movement which is an elementary rotation about some particular axis. That is, we may have linear translation along a line, or angular rotation about some axis.

It should always be recognized that these two elementary motions may possibly exist, either separately or simultaneously, but, at the same time, other considerations enable us to see that some motions are more probable than others.

Now it is impossible to so dispose seismographs as to record directly these elementary motions themselves. The best that seismographs are able to do is to pick up one or more resolved components of the primary elemental motions. Since we have two possible elemental movements, and since each elementary motion can have three resolved components, it must therefore follow that six possible resolved components, each separate

[1] When this earthquake was recorded the vibrator device attached to the Weather Bureau seismographs to diminish friction (see Weather Review, May, 1906, pp. 212–217) was, for experimental purposes, temporarily inactive on the north-south component, and, in consequence, this instrument was strongly damped by friction and distinctly less sensitive, as is shown by the damping tests made on the morning after the earthquake. The shorter duration of the earthquake and other features of the record of the north-south motion are also explained by this strong damping.

and distinct from the other, are required to fully represent the two original elemental motions. If we carry this to its logical conclusion, we see that six distinct seismographic records are required to fully represent the true movement executed by a seismograph pier affected by earthquake vibrations.

This requirement is very far from being fully met by any known forms of seismic apparatus, and, in consequence, earthquake records at the present time are, at best, more or less indefinite and incomplete.

The essentially six-fold nature of the motions indicated by seismographs will be more readily recognized under names that more specifically describe them. For example—

(*A*) The three resolved components of the linear displacement of a seismograph pier are, ordinarily—

(1) A horizontal north and south component of motion.

(2) A horizontal east and west component of motion.

(3) A vertical up and down component of motion.

(*B*) The three resolved components of the possible rotatory motion of the pier are conveniently—

(1) A component of rotation about a north and south line. This we may very properly call a tilting of the pier to the east or west.

(2) A component of rotation about an east and west axis. This will logically be called a tilting of the pier northward or southward. Finally—

(3) A component of rotation about a vertical axis. This component may, perhaps, best be called the twisting component of motion.

Entirely erroneous inferences have been drawn concerning the existence of twisting motions during destructive earthquakes, since the twisted displacement of chimneys, monuments, and even buildings is pointed to as evidence of exaggerated amounts of such motions that never really existed. The effects mistakenly attributed to twisting may be fully explained by the action of strictly horizontal displacements upon a tottering or otherwise imperfectly supported mass of considerable inertia.

The popular use of the word "twister", to characterize an earthquake during which rotary motions particularly are imagined to exist, is unquestionably wrong, and should be discouraged by those who write on seismological subjects with some authority and who it may be assumed are prompted by a desire to diffuse sound scientific ideas and teach habits of exact thought.

The foregoing indicates that the exact registration of earthquake phenomena is a very complex problem, and, altho theory calls for six resolved components of motion, yet we are fortunately able to conclude from other considerations that several of the components, if not entirely absent, are of relatively small magnitude and importance, especially at considerable distances from the origin. The horizontal and even the vertical displacements are no doubt of primary magnitude and importance; whereas the tilting and especially the twisting rotations are very small, or utterly inapplicable, except, perhaps, within a limited region near the origin.

Having thus explained, very briefly, the essential details of the ground movements induced by earthquakes, the attention of the reader is invited to a careful examination of the Weather Bureau records of the Mexican disturbance, especially during the initial portions which appear to be so well defined and distinct as to justify some attempt at a synthesis of the component motions recorded, with a view to deducing something concerning the actual motion of the ground at certain phases of the records.

The approximate location of the origin of this earthquake may be placed at latitude 17.5° N. and longitude 99.5° W. A little examination of the geographic relations of this origin to Washington (latitude 38° 54′ N. and longitude 77° 4′ W.) indicates that the direct line of propagation of the wave motion lies almost exactly northeast and southwest. From this circumstance we should expect that the Washington records of the north-south and east-west components of motion should closely resemble each other. This is found to be the case to a certain extent, as is shown by a comparison of the two component records, partly reproduced in the accompanying Chart IX.

If we assume that the records were produced by linear motions of the ground, as distinguished from tilting movements, then they must be interpreted as follows: A displacement toward the *top* of the sheet means that the pier moves to the *east* in the case of the east-west component record, but to the *south*, in case of the north-south component record, and vice versa. This is indicated by the letters on the margins of the records. The reader must understand that both instruments are mounted on one massive pier.

If the effects are due only to tilting motions, then a deflection of the record toward the *top* of the sheet means a tilting of the pier to the *west* in the case of the east-west component, and to the *north* in the case of the north-south component; that is to say, the motion of the ground is such as to cause a vertical line rigid with the pier to deflect toward the west or the north as the case may be.

The time-tick marks on the record sheets represent the beginning of each minute, and are numbered on the margin at intervals, 15, 20, 25, etc. Very perfect time-marking appliances are employed with the Weather Bureau seismographs, and the variation of the errors in the marks thruout the entire day covered by the record does not exceed two or three-tenths of a second. The corresponding tick marks on the two sheets are perfectly simultaneous.

By comparison with the Naval Observatory time signals it has been found that the tick marks on the record sheets are four seconds slow; that is to say four seconds must be *added* to the sheet time to obtain mean time of the seventy-fifth meridian west.

With these explanations of the record in mind we observe that the initial motion of the pier, if a displacement, must have been to the northeast, as if a wave of compression were advancing from the southwest and pushing the pier to the northeast.[2] The amount of the displacement, however, was relatively small (a few hundredths of a millimeter) and was soon succeeded by a much greater movement of the pier to the southwest; followed, in turn, by further oscillations northeastward and southwestward. The crests and hollows of simultaneous, or nearly simultaneous, excursions of the pier have been numbered in the two diagrams, 1, 2, 3, etc. The nominal scale of magnification of the two records is nearly the same, but we can not attach much significance, quantitatively, to the *amplitudes* of the waves. As already stated, the north-south instrument was on this date more strongly damped by friction than its companion instrument, in consequence of which the effect is very much the same as if the scales of magnification were greatly different.

A fair interpretation of the records does not controvert a conclusion that the amplitudes of the east-west and north-south components of motion were about equal, especially thruout the first preliminary tremors.

The times of about sixty-seven wave crests and hollows during the first and second preliminary tremors, representing an interval of about twelve minutes, have been carefully measured off from the records and are tabulated in Table 2.

[2] The vertical component of linear motion was not recorded and is not here considered. If the wave motion was propagated directly along the chord from the origin, the angle of emergence at Washington would be only about 15° whence we should expect only a small vertical component.

TABLE 2.—*Times of crests and hollows of waves of first and second preliminary tremors.*[3]

Wave No.	E.-W.			Difference.	N.-S.			Difference.	Remarks.
	h.	*m.*	*s.*	*Sec.*	*h.*	*m.*	*s.*	*Sec.*	
1	1	14	23	......	1	14	21	......	Crest of first preliminary tremor.
2			34	11			32	11	
3			43	9			41	9	
4			53	10			53	12	
5			62	9			67	14	
6			81	19			79	12	
7			90	9			87	8	
8			99	9			95	8	Ripples begin.
9			117	18			117	22	
10			131	14			131	14	
11			....	......			....	......	Interval of partial rest with ripples.
12	1	18	0	......	1	17	58	......	Waves Nos. 12 to 23 are almost wholly absent in the N.-S. component.
13			11	11	1	18	11	13	
14			21	10			17	6	
15			30	9			31	14	
16			41	11			40	9	
17			51	10			47	7	
18	1	19	2	11	1	19	2	15	
19			11	9			11	9	
20			16	5			17	6	
21			21	5			20	3	
22			24	3			23	3	
23			29	5			28	5	Beginning of second preliminary tremor well defined.
24			39	10			37	9	
25			47	8			42	5	
26	1	20	0	13			56	14	
27			7	7	1	20	7	11	
28			21	14			25	18	
29			27	6			30	5	
30			40	13			34	4	
31			52	12			37	3	
32			57	5			42	5	
33	1	21	3	6			47	5	
34			7	4			50	3	
35			13	6			53	3	
36			24	11			59	6	
37			31	7	1	21	7	8	
38			40	9			20	13	
39			44	4			34	14	
40			51	7			43	9	
41	1	22	3	12			49	6	
42			20	17	1	22	3	14	
43			30	10			12	9	
44			38	8			21	9	
45			45	7			30	9	
46			56	11			40	10	
47	1	23	3	7			50	10	
48			13	10	1	23	0	10	
49			20	7			3	3	
50			30	10			15	12	
51			41	11			22	7	
52			55	14			53	31	
53	1	24	4	9	1	24	9	16	
54			25	21			26	17	
55			35	10			39	13	
56			51	16			52	13	
57	1	25	0	9	1	25	2	10	
58			17	17			15	13	
59			25	8			30	15	
60			42	17			45	15	
61			....	......			49	4	
62			....	......	1	26	0	11	
63			....	......			4	4	
64			....	......			11	7	
65			....	......			19	8	
66			....	......			36	17	
67			....	......			55	19	Beginning of principal portion.

The agreement in times of the wave crests and hollows is noticeably close thruout the first five minutes, as also in the first waves constituting the second preliminary tremors. But discordance soon develops, (at No. 28) and the records can not be said to admit of any very definite interpretation.

There is a noticeable tendency for the wave periods to become longer toward the end of the second preliminary tremors.

From a consideration of all the facts at our command in this connection, we may be warranted in making the following statements in regard to the real nature of the motion of the seismograph pier at the time of registration of the preliminary tremors of the earthquake in question.

1. That all the waves of the first preliminary tremors appear to have produced vibrations of the pier north-east and south-west, and that the first initial motion was a very small motion toward the northeast, followed by a considerably larger displacement to the southwest, and again to the northeast, with a distinct subsidence after one or two complete waves of all motion, except of very small amplitude.

2. That after an interval of about a minute and a half, a series of ripples, or waves of small amplitude and period prevailed for nearly two minutes, followed by much slower waves of small amplitude, just preceding the arrival of the second preliminary tremors.

3. That the second preliminary tremors appear to be exactly the same in character as the first preliminary tremors, except stronger; that is to have caused the pier to move first slightly to the northeast, then much more to the southwest; again to the northeast, and so on. Here, again, the motion distinctly subsides, relatively, but the records indicate more complex motion, and I think we are warranted in assuming that the original longitudinal vibrations northeast and southwest are becoming complicated, possibly with transverse vibrations.

Altho the records are very clearly defined and inscribed, yet the smallness of the time scale, and the inherent defects of seismographic action render it impossible to arrive at any definite further interpretation of the records.

These relatively negative and incomplete conclusions emphasize the necessity for still further development of seismic apparatus. The records in the present case seem practically perfect. In the originals the smallest details are perfectly clear and definite. The difficulty arises from the failure of the steady mass to remain at rest. The relation between its motion and that of the ground is complicated and unknown. Mathematical analysis of the problem enables us to formulate certain analytical relations between the motion of the steady mass and that of the ground, but at the best these necessarily involve certain assumptions as to the ground motion, the damping of the pendulum, etc., that are not justified in nature.

In actual practise it is difficult to realize a sufficiently long period for the steady mass and to render it truly aperiodic under a strictly exponential law.

In the opinion of the writer these are the objects to be striven for in the further development of seismographs.

[3] The times are taken directly from the record sheet. A correction of four seconds must be added to obtain true seventy-fifth meridian time.

NEW JAPANESE SEISMOLOGICAL PUBLICATIONS.

By C. F. MARVIN, Professor of Meteorology. Dated May 22, 1907.

The Imperial Earthquake Investigation Committee of Japan has been a very large contributor to modern seismology and its literature, and the so-called "Publications of the Earthquake Investigation Committee in Foreign Languages" are consulted by all seismologists thruout the world. The committee has very recently issued the first and second numbers of a new series of publications entitled: "Bulletin of the Imperial Earthquake Investigation Committee".

The following quotation from the preface of Vol. I, No. 1, dated January, 1907, explains the object and scope of the Bulletin:

> The object in issuing the Bulletin is to secure quick publication of short notes and preliminary reports on seismological subjects, more especially such contributions as may be of use in connection with the works of the International Seismological Association. The Publications which contain more lengthy papers will be issued from time to time as heretofore.

Numbers 1 and 2 of the Bulletin before us contains a collection of short notes by Doctor Omori treating of individual topics concerning one or more of the recent great earthquakes. In fact, it seems appropriate to give here the titles of the several notes, as follows:

"On the estimation of the time of the occurrence at the origin of a distant earthquake from the duration of the first preliminary tremor observed at any place".

"On the methods of calculating the velocities of earthquake propagation".

"Preliminary note on the cause of the San Francisco earthquake of April 18, 1906".