the pardonable repugnance of McClellan to send his young soldiers against works which appeared from day to day more formidable, caused the ardor for battle to be succeeded by a too protracted period of inaction. We no longer heard the distant crackle of musketry, which had made the young aides-de-camp leap in their saddles. The dull voice of cannon, as monotonous as the ticking of a clock, failed to draw the army for one instant out of its torpor; for all knew the inefficacy of "artillery duels" under a heaven on fire and under clouds charged with lightning, and the morale of the soldiers was sadly disturbed by a virgin soil the pestilential emanations of which sent them by thousands to the hospitals.

Kearny, like Achilles, had retired to his tent. It was he who, at the beginning of the battle of Fair Oaks, had been the first to succor and to save the troops of Keyes, surprised and exhausted, after an honorable resistance, by the superiority of numbers and the vigorous offensive attack of Longstreet. At the moment when the Confederate battalions, like an impetuous torrent, were precipitating themselves across the glades which bordered the road, overthrowing all before them, Kearny arrested them with two brigades that, solidly posted on their right flank on the border of the forest, held out against all their assaults. By the promptitude of his attack and the firmness of his resistance he saved the Army of the Potomac from irreparable disaster.

It was Kearny's idea that the army should immediately take a decided step toward Richmond, and his opinion not having prevailed, he suffered with impatience the immobility to which he was condemned — an immobility so much the more painful, as it imposed on his troops a continual vigilance and a most fatiguing service, since they formed the extreme left wing of the Federal army, which rested in the wooded marshes of White Oak Swamp. Without doubt these impenetrable thickets guarded our left, which would otherwise have been absolutely unprotected; but they also concealed the parallel roads descending from Richmond, by which the enemy might fall upon the left, and force or surprise the lower passages of the swamp. Therefore, both these passages, and the tortuous paths formerly traced by Indian hunters and their game across the wall of trunks and foliage which lifted itself before the Federals, needed to be carefully watched. General McClellan had repeatedly desired to inspect these positions in person, and to profit by the occasion to give a proof of his confidence in Kearny, an officer whose rare qualities he greatly appreciated. But every time he had had his horse saddled, a pitiless tyrant, the telegraph, had retained him at headquarters. At last he charged me with his messages for Kearny.

The remembrance of the day passed with this valiant officer, of our ride along his lines, of his technical explanations, interrupted by the exposition of his views on the whole campaign, and by the recital of the various incidents of his military career in the two worlds, has remained deeply engraved upon my mind. Alas! it was our last interview. A few days later we engaged in the terrible struggle known as the "Seven Days' Battle." No one thought of chatting then. Every one concentrated his mind upon the execution of the duty assigned to him. There was time only for a grasp of the hand on meeting, since the safety of the whole army might depend upon an order or a message promptly transmitted. At Glendale and at Malvern Hill Kearny did not belie his splendid reputation. It does not belong to any but an eye-witness to describe the last services he rendered to his country in the dark days of August, 1862.

A sketch of Kearny's military character would be incomplete without the mention of one other trait. A man so ardent, and with so proud a temperament, must have held very decided opinions on all subjects; but he was so penetrated with the sense of duty which impels the soldier to keep himself free from political entanglements, that, notwithstanding our frequent meetings, I never knew to which party he belonged.

Philippe, Comte de Paris.

EARTHQUAKES AND HOW TO MEASURE THEM.

THERE is little or no confusion of meaning produced by the use of the term earthquake in ordinary speaking or writing, but the moment an accurate scientific definition is attempted the term comes to include much more than is ordinarily meant. Any mechanical disturbance whatever, either on or within the surface of the earth, sets up a state of elastic vibration which is propagated to all adjacent parts of the crust by elastic waves which may or may not be evident to human senses. This motion constitutes an earthquake. Scientifically, therefore, an earthquake is the result of any elastic vibrations in the earth's crust, whether they are produced by volcanic eruptions, by the sliding of great strata of rocks over one another, by explosions either natural or artificial, by the fall of a heavy mass, or even by the tread of a foot. In popular language, however, we are in the habit of restricting the use of the word earthquake to comparatively violent motions of short vibration-period which extend over a considerable area, and especially to such motions as are produced by somewhat obscure causes.

It is necessary to our popular use of the term earthquake that the cause, while natural, should be somewhat obscure. It is perfectly well known, for example, that the attraction of the moon, the sun, and the planets produces a stress in the crust of the earth at the point just under the attracting body. This stress travels round the earth, too, like a tide, about once in twenty-four hours; but we do not call the effects of these tidal stresses earthquakes.

Again, a sudden rise of the barometer produces an immense pressure on the region affected; if the barometer rises an inch, for example, every square foot of surface of the earth is loaded with an additional burden of no less than seventy-two pounds. An increase of $\frac{1}{100}$ of an inch in the barometric pressure will increase the load which the suffering earth has to bear by 20,000,000 pounds per square mile. These changes of pressure are known to produce earth movements, but in popular language they are not called earthquakes. And it is so in other cases. Still, it is plain that the difference between a slight disturbance due to a tidal stress and that produced by a terrific catastrophe like the Lisbon earthquake is one of degree only. Every grade of disturbance between the two can be found in nature. It is only the shorter and sharper movements, and especially only those due to relatively obscure causes, that we are in the habit of calling earthquakes.

The explosions of large and small quantities of dynamite have been used to produce artificial shocks which were suitable for study, and the results of this study have lately been applied to the determination of the stability of railway bridges under moving loads. This generation is apt to draw practical lessons wherever and whenever it may find them.

It is necessary to point out that in the study of earthquakes we may take either of two starting-points. We may study the geological or the mechanical aspect of the phenomenon. The geologist is primarily concerned with the cause of shocks. Do they arise from volcanic disturbance, from mechanical slipping and sliding of strata one upon another, or from explosions of steam and gases within subterranean cavities? The mechanician and the physicist, on the other hand, are concerned chiefly with the physical or mechanical phenomenon. How does the earth's crust move during a shock? how can we measure the exact amount and direction of each successive tremor and displacement? how can we determine the velocity and rate of acceleration at every instant while the shaking is going on? and, finally, how can the velocity of the earthquake wave, in its journey from place to place, be measured and recorded? These are problems for the physicist, and it is with these alone that the present paper has to deal.

NOTED EARTHQUAKES.

ALTHOUGH this article deals only with the measurement of earthquake energy, yet it would hardly be complete without giving some notion of what are the most violent manifestations with which the new art has to deal. I regret that lack of space does not allow me to transcribe here some of the accounts of eye-witnesses of the great earthquakes. These stories have more than a scientific interest. They are the direct and simple narratives of persons who have passed through the most awful of human experiences. To them the world, the solid globe, the mother of us all, can never again be the same. They have looked on awful Death face to face, and in an instant have known all the lingering horrors of the Inferno —its hells of sound, of light, of darkness, of cold terror. There is a peculiar quality in such accounts which is singularly striking and pathetic. Perhaps it is not unlike the quality of Dante's poem; for them as for him certain illusions can exist no longer.

In place of narratives into which the human element enters, let me set down in the briefest way some of the statistics of the great earthquakes of recent years only. Whoever recollects what these bald facts mean can readily credit the statement of Robert Mallet, that within historic time not less than thirteen million persons have perished from this cause alone. If we say that whole cities are destroyed in a moment, and mountains leveled, some vague idea can be formed of the forces at work to do this devastation. The Lisbon earthquake of 1755 was felt from Bohemia to Norway, from Africa to the West Indies. More than one third part of the whole globe was sensibly shaken.

EARTHQUAKE OF CHIO, 1881.

IN April, 1881, the island of Chio, or Scio, off the west coast of Asia Minor, was visited by a tremendous earthquake. In a moment nearly all the houses in thirty or forty villages and towns were ruined. Their inhabitants, uncertain where to fly, remained within the streets until a second shock overturned nearly every standing wall. The lives lost in this second shock are counted as five thousand. Other tremendous shocks succeeded at short intervals, and it is computed that in little more than one day nine thousand persons perished. The agitation of the soil continued for nearly a year.

EARTHQUAKE OF ISCHIA, 1883.

FOR over five centuries the volcano Mount San Nicolo on the island of Ischia, off the coast of Italy, near Naples, remained inactive. The neighborhood of this mountain still showed signs of volcanic activity, however, in the thermal springs, etc., about its base. In 1828, again in 1881, and finally in 1883, fearful earthquakes devastated the neighborhood, and especially the beautiful town of Casamicciola. The last catastrophe gave the *coup de grâce*. Scarcely a wall remained standing, and four thousand persons lost their lives.

KRAKATOA, 1883.

LESS than a month after the catastrophe of Ischia, the volcanic island of Krakatoa, in the

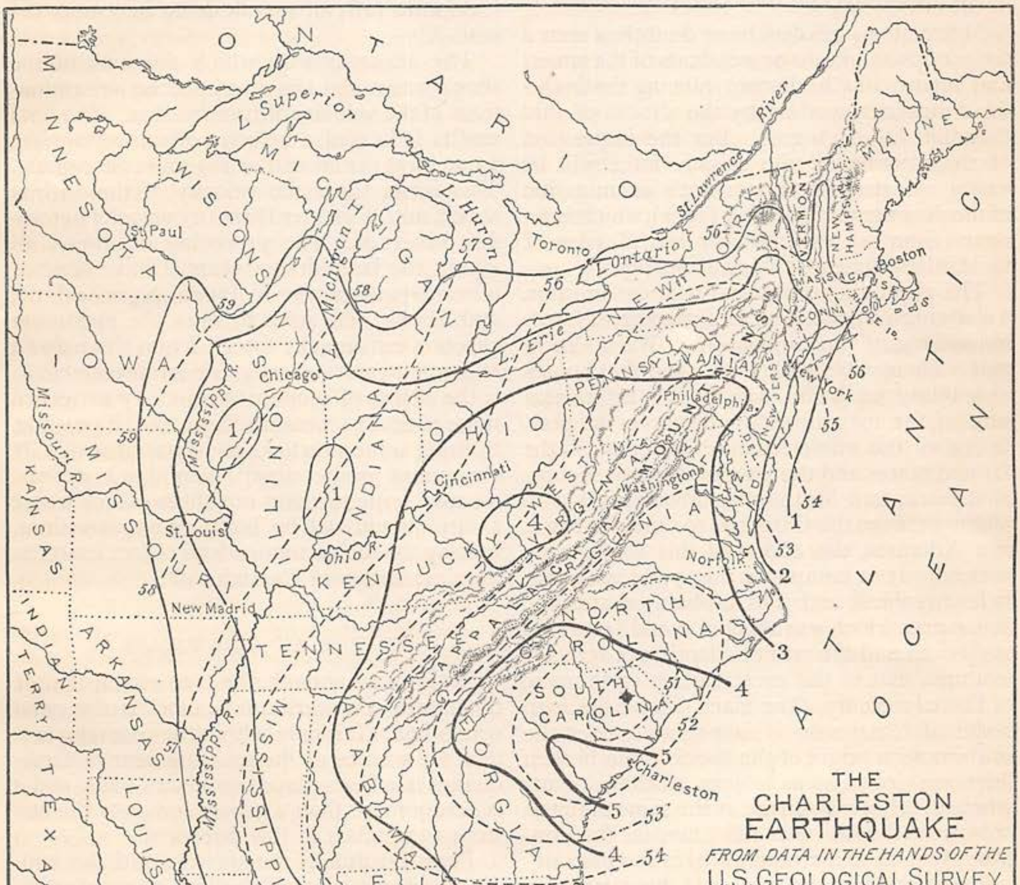

FIG. I.

Strait of Sunda, near Java, was the scene of the most frightful devastation. High mountains were submerged under fathoms of ocean. The whole topography of the group was changed in an instant. It is computed that the solid masses ejected by the volcano would form a cube more than ten miles on each edge. The finer particles, traveling around the globe in both directions, filled our atmosphere with dust that changed the whole aspect of our sunset skies for more than two years. Over 30,000 persons perished from this single eruption.

THE CHARLESTON EARTHQUAKE, 1886.[1]

MOST of my readers have doubtless seen a series of photographs or woodcuts of the streets and squares of Charleston, showing the frightful destruction worked by the shocks of that dreadful day in August. But the impression of the intensity of the seismic force will be vastly increased by a moment's examination of the accompanying map (Fig. 1), which is reduced from one compiled by Mr. Hayden of the United States Geological Survey.

The photographs showed a house in ruins, a wall thrown down, and indicated great forces indeed, but still imaginable ones. We all know that walls may be made to fall, and that houses may be ruined. The map gives a truer measure of the magnitude of the forces at play. It shows the whole Atlantic sea-coast of the United States and the interior as far as Louisiana, Iowa, and Minnesota. From Florida to Vermont, from the Carolinas to Ontario, Iowa, and Arkansas, the effects of this shock were noticed. It is computed that 774,000 square miles trembled, and it is probable that if the ocean-area which was affected could be added we should find the area of disturbance scarcely less than that of the great Lisbon earthquake of dismal memory. The black dot on the map north of Charleston is immediately over the subterranean origin of the shock. The broken lines are drawn so as to join all those points where the shock occurred at the same moment (coseismal lines). The full lines, on the contrary, join all those points where the intensity of the shock was the same. If the earth were homogeneous, these lines would be circles, with the origin as center. Their variation from true circles shows on a grand scale the varying nature of the surface strata of rock, etc.

It would take us too far away from our subject to point out the meaning of some of these inflexions. The reader may see, however, the effect of the great mountain chain of the Appalachians, especially in Vermont and New Hampshire. Here the shock was readily transmitted along the axis of the chain. In the neighborhood of Charleston, however, the chain served to prevent a passage across itself. The circular area at the southern point of Ohio, marked 4, seems to have been caused by a wave deep in the earth; but it may simply be due to the scarcity of observations in the mountain regions. Here was an earthquake on a grand scale. The United States has been visited by few such shocks. Those of New Madrid, Missouri (1811), St. Lawrence Valley (1870), Inyo, California (1872), are alone to be compared with it.

The accuracy with which the time of the shock was noted has given precise determinations of the velocity of transmission. The final results indicated a velocity of something like 17,000 feet per second or 193 miles per minute. This is six times the velocity of the Lisbon shock, and is greater than any velocity heretofore observed. The preceding examples, all within the last thirteen years (I have omitted others equally severe in Japan, New Zealand, and Alaska), will serve to show the maximum effects of earthquake force. From these down to gentle tremors, every grade is represented. It is the object of modern seismology to record these effects, to measure them, and, if possible, to bring some practical good out of it all. If we cannot predict a particular shock, at least we may hope to point out those places where a city should *not* be built, and that without waiting for such a tremendous object lesson as the devastation of Casamicciola.

WHAT IS AN EARTHQUAKE?

STRANGELY enough, the true conception of the nature of an earthquake shock is of very recent origin. It is only within the past ten years that the science of the measurement of earthquakes has been placed on a sure basis, and it is hardly more than a generation since the first steps were taken in this direction.

From the time of the ancients until the middle of our own century the phenomena of earthquakes had been observed and described on countless occasions. But if any one will look over the pages of Humboldt's "Cosmos" (published in 1844) which summarize the then existing knowledge on this subject, he will find almost no sign that earthquakes are to be studied like other mechanical motions. The effects of the great Neapolitan earthquake of 1857 were so studied by Mr. Robert Mallet, a distinguished engineer, and his most interesting work, in two profusely illustrated volumes, is, perhaps, the first in which an attempt is made

---

[1] Since this article was in type, an elaborate memoir on the Charleston Earthquake, written by Captain Dutton, has been issued. It is printed in the Ninth Annual Report of the United States Geological Survey, and is worthy of general attention.

to attack the problem from its mechanical side. His study of the destruction due to the earthquake was intended to lead to the knowledge of the intensity of the individual blows or impulses. But in fact an earthquake is not made up of blows at all. It is a continuous series of intricate twistings and oscillations in all possible directions, up and down, east and west, north and south, of the greatest irregularity both in intensity and direction. Frequently it is quite impossible to find among these any single impulse at all adequate to do the damage which is actually observed. This damage is not done by a blow; it is done by the combination of many small motions and twistings taking place in many directions. On account of this fundamental misconception of the nature of an earthquake, most of the conclusions arrived at by Mr. Mallet are not valid, and his methods generally do not lead to correct results. But, nevertheless, the spirit in which the question was approached was the true one, and he is one of the founders of the modern science of earthquake measurement.

This science had its birth in the city of Tokio only a few years ago. Within the last dozen years the University of Tokio has brought together a great number of foreigners of ambition and learning to constitute its faculty. I shrewdly suspect that in many cases they had few prescribed duties, and that the instruments and laboratories for research were often lacking, at least in the earlier years. This band of learned and active men could not fail to be incited to the study of the very frequent earthquakes in Tokio and the vicinity (when we take all Japan into account, there are on an average two shocks daily), and it is chiefly to the members of the Seismological Society of Japan that we owe the science of earthquake measurement.

The most assiduous writer and experimenter is Professor Milne, the head of the society, and the chief improvements in instrumental methods have been due to Professors Gray and Ewing. The work of the last named on "Earthquake Measurement" (1883) is indeed the Principia of this subject, and, unless I am much in error he was the first to grasp the fundamental notions of the new science, and the first to measure the magnitude and direction of earth movements in connection with their period.

Italy has long possessed earthquake instruments and even observatories, but, so far as I know, the mechanical principles which underlie earthquake measurement were first clearly apprehended by the band of experimenters in Japan.

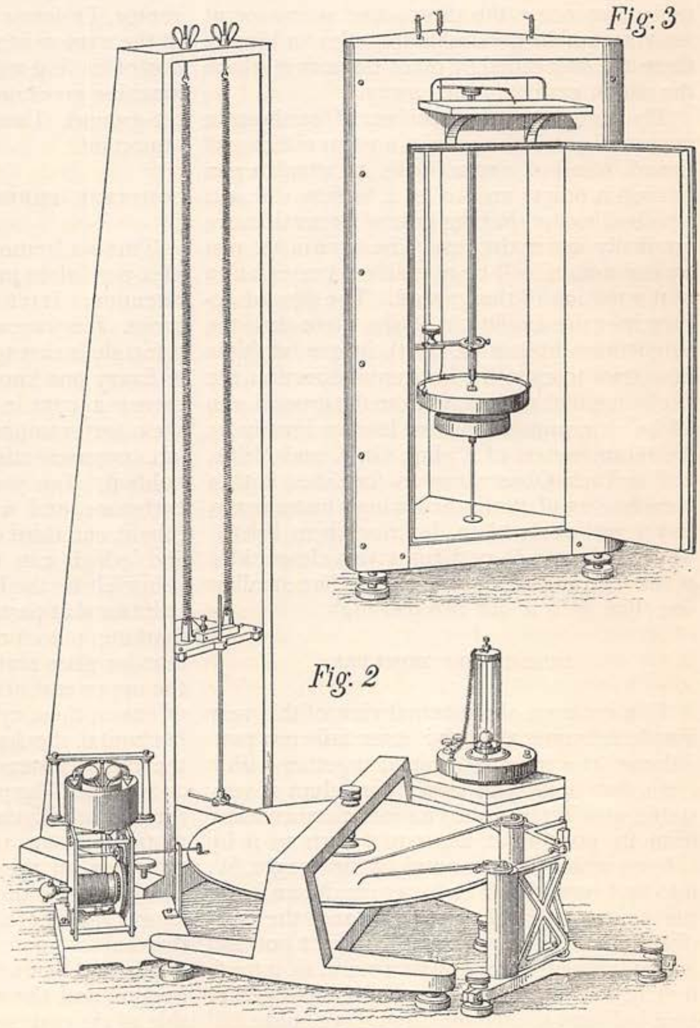

Fig: 3

Fig. 2

SEISMOMETERS.

Fig. 2. Ewing's Seismometer. The three pens remain steady during a shock while the smoked-glass plate moves with the earth, and traces the record of motions in the direction up and down, east and west, north and south.

Fig. 3. Ewing's Duplex Seismometer. The single pen traces the earth's horizontal motions only.

SEISMOMETERS, OR SEISMOGRAPHS.

A MERE pendulum freely suspended is a rough earthquake-indicator. It will not do to measure earthquake intensity, because it has a period—an idiosyncrasy—of its own which may or may not agree with the period of the earthquake wave. A set of such pendulums of various lengths (and periods) has some value as a measuring instrument. Little cylinders set on end have been used for the same purpose. The shock (supposed to be a definite impulse) overturned them, and recorded its direction, etc. But these and many similar devices are now obsolete, as they presuppose the shock to be an impulse. It is far from that. First there arrives a tremor of greater or less duration; then come the destructive waves, or at least those of the greatest amplitude; and finally these are succeeded by other tremors in which the shock gradually dies away.

The essence of the problem of earthquake measurement is to contrive a point *which will remain steady during a shock;* to attach a pen to such a point; and to let a surface which is attached to the shaking ground beneath move gradually under the pen. The trace of the pen on the surface will be a visible representation of the motion of the ground. The time of occurrence, the amplitude of the wave (half the height from hollow to crest), its period (time from crest to crest), its horizontal direction, the angle at which it emerges from the ground, can all be determined more or less accurately by the seismometers of Ewing, Gray, and Milne.

The Lick Observatory is furnished with a complete set of Professor Ewing's instruments, and I will proceed to describe them briefly. The woodcuts will, perhaps, give a clearer idea of their arrangement and size. The smallest one (Fig. 3) is about two feet high.

DUPLEX SEISMOMETER.

THE cut gives the external view of this very simple instrument, which is essentially two pendulums (one inverted) joined together within a wooden box. The upper pendulum is very stable, and if it is moved a short distance away from its position it tends to return to it by a force which is measured by its weight, W, into its length, L. The lower pendulum is, on the contrary, highly unstable, and the least disturbance makes it leave its upright position with a force measured by its weight, w, into its length, l. If we join the two pendulums together by a ball-and-socket joint, and if we make Wl equal to wL, we have created a system in neutral equilibrium. A slight motion in any direction will carry the system to a new point from which it will have no tendency to move. The motions of these two heavy pendulums of lead have, so long as they are joined, an analogy to those of a viscous fluid-like tar. Within certain limits, then, the point of junction of these pendulums is a steady-point. A jointed rod is attached to this steady-point, and ends in a pen which rests over a horizontal plate of smoked glass (on the little shelf at the top of the box in the cut). The pen is necessarily steady during a shock; the glass moves under it as the ground is shaken, and the pen describes on the moving plate an accurate (and magnified) trace of the motions of the area on which the machine stands.

Nothing could be more simple and, within limits, more satisfactory. The limits permit the measurement of ordinary earthquakes, and this little machine has lately been applied by its inventor, Professor Ewing, to the measurement of the tremors of railway bridges under the action of moving trains. It will be noticed that this machine gives only the horizontal motions of the ground. Usually these are by far the more important.

COMPLETE THREE-COMPONENT SEISMOMETER.

THIS is a far more elaborate affair than the duplex-pendulum machine, and requires constant attention. It is fit for use only in fixed observatories. It is somewhat complex, but its essential principle is easy to comprehend (see Fig. 2).

Every one knows, or can easily know, that there is a point in every solid body, a walking-stick, for example, which may be struck without communicating a shock to the hand which holds it. Tap your walking-stick against the curbstone, and a little trial will find a point (about one third of the length from the ferule end) which can be struck without the blow being felt by the hand. The hand is a steady-point for that particular blow. Each of the two marking pens (on the right of the horizontal circular glass plate in the figure) is fastened to the upper end of a metal cylinder. The axis of one of these cylinders is a steady-line for all horizontal shocks east and west. The axis of the other is steady for all such shocks north and south. The pen suspended by two springs (on the left of the cut) registers only vertical motions, in an analogous way, by horizontal scratches on the glass plate. The little ball pendulum (on the upper right hand side of the figure) is part of a telegraph line. The instant this ball is moved by an earthquake by so much as a hair's breadth, the telegraph line is broken, and the machinery (on the left hand side of the cut), sets the smoked circular glass plate to revolving. So long as the plate is not moved to and fro by shocks the (steady) pens will mark three concentric smooth circles on the revolving glass plate. A clock (not shown in the cut) marks lines at the edge of the disk every second.

If, for example, the earth makes a sudden lurch east and west, the corresponding pen leaves its perfect circle, and shows a bend in the curve it is tracing. As the plate moves hither and thither, up and down, east and west, north and south, every one of its motions is faithfully traced by the proper pen in a permanent record. The seconds marked on the edge of the plate fix the time of each one of these separate shocks, and finally we have a complete picture of the earthquake from its chief motions down to the minute tremors with which it usually begins and dies away.

JAPAN EARTHQUAKE OF JANUARY 15, 1887.

In order to illustrate the operation of these earthquake instruments, I have copied the diagram given by Professor Sekiya relating to the severe Japan earthquake of January 15, 1887. This record is more suitable for my purpose than that of any of the comparatively light earthquakes which have been registered in California. The diagram (Fig. 4) is an exact copy of a portion of the earthquake record on the revolving glass plate of one of the larger Ewing seismographs. The arrow shows the direction in which the plate revolved. The waves marked on the two inner circles correspond to the horizontal components of the disturbance (east and west, north and south, as marked). The actual motions of the earth are magnified. The outer circle registers the vertical motion of the earth also magnified. The radial lines divide the plate into seconds of time. It is easy to see then what the earth was doing at each instant. For example, at the fourth second the earth had just completed a strong movement (up) and was in the midst of a horizontal motion toward the south and east; and so with other cases. The height of the curves corresponds to the amplitude of the motions.

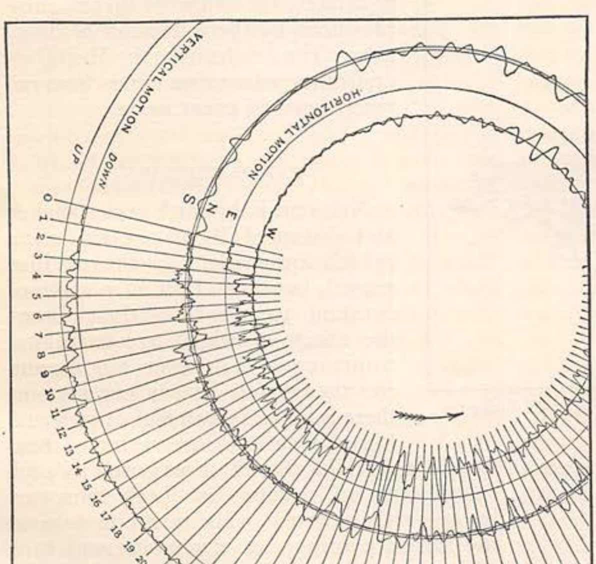

Fig. 4. Diagram of horizontal and vertical motions observed at Tokio, January 15, 1887. The horizontal motion is magnified five times; the vertical motion, eight times. The radial lines indicate the successive seconds after the instant of beginning.

MODEL SHOWING THE MOTION OF AN EARTH-PARTICLE.

The diagrams on the revolving plate show the three components of earth motion at each instant. But they are separately recorded, and it is not easy to form a conception of the actual motion of the earth-particle directly beneath the machine. Professor Sekiya has had the happy idea of making a model out of copper wire twisted in such a way as to represent the path which this earth-particle actually traveled during the disturbance. This model is represented in Fig. 5. To avoid confusion, the model was made in three parts; the first showing the motion from the beginning to the end of the twentieth second, the second from the latter instant to the end of the fortieth second, and the third from the forty-first second to the end of the shock.

Each model is mounted on a separate stand, which shows in the cut. The little tags attached to the wire indicate the seconds of time (each bears a number on it). By carefully tracing out the convolutions of the wire, an idea of the great complexity of these motions is obtained, and it is readily seen how different the phenomenon is from the current notions regarding earthquake movements.

The shock begins, as is usual, with short-period tremors. During the third second we have the first vigorous horizontal motion; the ninth second gives the maximum vertical motion, and so on.

CHARACTERISTICS OF EARTHQUAKE MOTIONS.

Professor Ewing has summarized the characteristics of earthquake motions as he has observed them in the plain of Yedo. The results

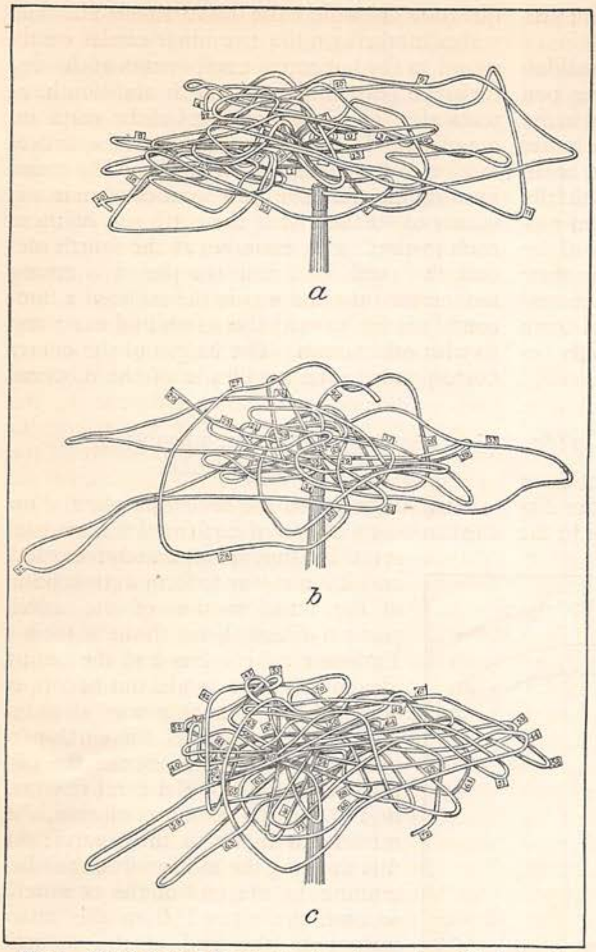

Fig. 5. Model showing the actual motion of an earth-particle during the Japan earthquake of January 15, 1887.

which have been so far obtained in California entirely agree with his conclusions. These are, briefly:

I. The motion of the ground usually begins with small tremors, and the maximum does not occur for some seconds. (This makes it impossible to fix the time of the beginning of a shock with precision.)

II. There are usually several maximums, with intervals of comparative rest between them.

III. The disturbance usually dies away even more gradually than it begins.

IV. The range, the period, and the direction of movement are exceedingly and irregularly variable during an earthquake.

V. The whole duration is rarely less than one minute.

VI. Even in destructive shocks the greatest displacement of the soil is only a few millimeters.

VII. The period of the principal movement is usually from half a second to a second.

VIII. The vertical motion is usually far less than the horizontal. At the Lick Observatory the vertical motions approach the horizontal in magnitude by reason of the situation of the instruments on the top of a mountain, and also on account of the disposition of the rock strata. It would be out of place to discuss here the importance of these conclusions in directing our future experiments in the study of earthquakes. If they are general conclusions of universal validity, they seem to me to show that many pieces of apparatus now in use are of little practical value, and also that the direction in which some present experiments are being made must be modified if useful results are to follow.

It is of great importance that a series of trials should be made and registered on *artificial* disturbances produced by the explosion of dynamite. The results from the Hell Gate and other submarine mines have already been of great value.

EARTH-TREMORS.

NOT only is the earth's crust shaken and disturbed by true earthquakes (which are evident to the unaided senses), but it is kept in a state of constant tremor by various forces, the effects of which are small but continuous. Whenever the barometer rises or falls over a certain area there is increase or relief of pressure. If the barometer rises one inch, for example, it is a sign that the load borne by each square mile of country has been increased by one million tons. The incoming tide on the seashore brings an enormous load to a shelving beach, and this load is periodically removed with the ebb. The long swell of the ocean, breaking against cliffs or surrounding reefs, keeps the adjacent land in perpetual movement.

One of the small coral atolls of the South Pacific, surrounded as it is by very deep water, and exposed to the incessant beating of a tremendous surf always coming from one direction, must be looked upon as a huge inverted pendulum a mile or more long, continually in vibration. The force of wind on an exposed mountain side, the varying pressure of a frozen lake against its own shore, the continual slipping of one inclined stratum of rock over the one beneath it, and a thousand other causes, are perpetually active in producing tremors in the crust of the earth.

In the deep mines of the Comstock Lode there are abandoned galleries which were once ample passages, the roofs, sides, and floors of which were solidly timbered with huge sticks a foot square. The pressures of the surrounding rocks (which are as often up or sidewise as down) have reduced these galleries to mere holes and compressed the huge timbers into mere sticks. Every part of the upper crust of the earth is in a state of constant change.

These changes were first discovered by their effects on the position of astronomical instruments. The meridian line marked out by the instrument had a diurnal, and an annual, change due to the regular variations of temperature. Besides these periodic changes, others could be detected by the altered readings of their sensitive levels. The earthquake of Iquique, a seaport town of South America, in 1877, was shown at the Imperial Observatory near St. Petersburg an hour and fourteen minutes later by its effects on the delicate levels of an astronomical instrument. I myself have watched the changes in a hill (100 feet above a frozen lake which was 700 feet distant) as the ice bent and buckled and changed the pressure on the adjacent shore. The level would faithfully indicate every movement. The most sensitive instrument for such observations is perhaps a basin of quicksilver in which the image of a fixed spider-line can be viewed by a telescope of high magnifying power. The least change in the level of the mercury surface is visible in the telescope. Such an instrument as this has been set up by M. d'Abbadie at his home in France (near the seashore), and continuous records show continual changes, which are too irregular, however, to bring out any law. In Italy and in Japan microphones deeply buried in the earth make the earth-tremors audible in the observatory telephones.

The difficulty in all these methods of observing is not that it is difficult to prove the existence of such tremors, but rather that too many are recorded. They come from all kinds of sources, and their complexity masks the regular laws, if there are any such. In earthquake regions near active volcanoes, as in Hawaii, Chile, and Italy, it is possible that the microphone may one day serve to predict earthquake phenomena, and the same may be possible in regions where the shocks are caused not by volcanic causes, but by the slipping of rock strata over one another.

THE ROSSI-FOREL SCALE OF EARTHQUAKE INTENSITY.

FIXED observatories and amateurs in science can afford to own instruments for registering the occurrence or the intensity of earthquakes, but the number of such seismometers must necessarily be very limited, while the areas within which earthquakes are likely to occur are very large. It is obviously desirable, then, to have some tests of the intensity of shocks which do not depend upon the indications of specially constructed seismometers, but refer to the damage done to ordinary structures, or even to the sensations of an individual. By one of those coincidences in science which are often described as curious, while the real strangeness is that they do not happen even oftener, Signor Rossi of Italy and M. Forel of the Swiss Earthquake Commission each independently devised such a scale. This is reprinted below, and its purpose is at once evident. In the investigation of the effects of any particular earthquake it is of prime importance to escape as soon as possible from the exaggerated accounts of special correspondents or of the inhabitants who wish to magnify the importance of their neighborhood or of themselves, and to obtain a numerical and quantitative basis for computation. The Rossi-Forel scale gives such a basis. Its degrees are from I to X; from the lightest to the severest shock; from a mere tremor to a fearful catastrophe. It is necessarily imperfect. The first three degrees of the scale depend chiefly on the sensations of the observer, the others relate to the damage or destruction of artificial or natural objects. But in spite of its necessary imperfections, it serves a really useful purpose, and it is reprinted here not only as a part of the history of the subject, but in the hope of making it more widely known and used.

THE ROSSI-FOREL SCALE.

I. MICROSEISMIC shock; recorded by a single seismograph or by seismographs of the same model, but not putting in motion seismographs of different patterns; reported by experienced observers only.

II. Shock recorded by several seismographs of different patterns; reported by a small number of persons at rest.

III. Shock reported by a number of persons at rest; duration or direction noted.

IV. Shock reported by persons in motion; shaking of movable objects, doors and windows, cracking of ceilings.

V. Shock felt generally by every one; furniture shaken; some bells rung.

VI. General awakening of sleepers; general ringing of bells; swinging of chandeliers; stopping of clocks; visible swaying of trees; some persons run out of buildings.

VII. Overturning of loose objects; fall of plaster; striking of church bells; general fright, without damage to buildings.

VIII. Fall of chimneys; cracks in the walls of buildings.

IX. Partial or total destruction of some buildings.

X. Great disasters; overturning of rocks; fissures in the surface of the earth; mountain slides.

I have reprinted it in the final form given to it by its joint authors. It appears to me to need three slight additions as follows: To V there should be added, "Some clocks stopped" (those critically placed with reference to the direction of the earthquake wave); "some sleepers waked" (to cover the cases of highly nervous American women). To VI there should be added, "window-glass broken"; and finally to VII, "Nausea produced in some cases." These additions are all based on my examination of many thousand separate accounts of earthquake shocks in California and elsewhere, and they serve to make the scale rather more definite just in that portion of it where definiteness is best attainable. The two ends of the scale, I, II and IX, X, are necessarily indefinite, more especially the latter. We are obliged to call the Inyo earthquake, and the great shocks of Lisbon and Riobamba, X, and yet the actual intensity of these must have been enormously different.

With this scale in hand, the various intensities of an earthquake may be pretty accurately assigned by an acute observer who visits the scene of the shock and questions the intelligent eye-witnesses. From his notes he can construct a map of the shaken district, placing the intensities I–X at their proper positions. By joining all the places which have felt the shock with the same intensity, something like an accurate picture of the progress of the shock can be made out, in much the same way that the Signal Service curves serve to show the progress of a storm-center. Such a map has already been given for the Charleston earthquake.

EARTHQUAKES IN CALIFORNIA.

ONE of the objects which I have constantly kept in view in placing earthquake instruments in California has been to obtain the means of making the Rossi-Forel scale even more definite and useful than it is. If we know the mechanical measure of the force required to break window-glass, for example, we have a mechanical measure of the value of VI on the scale; and so with other cases.

There are now a number of shocks for which the mechanical effects have been measured by seismometers. Their intensity of acceleration is measured in millimeters per second.[1] At the same time the popular accounts of these shocks give the damage done to buildings, chimneys, etc. I have combined the information from all cases of this kind known to me, and have obtained a little table like the following, which is at least a first attempt to give something like mathematical precision to merely popular accounts. I find that (approximately, at least)

I	corresponds	to	$\frac{1}{490}$	of the acceleration	due to gravity,	20 units.
II	"	"	$\frac{1}{245}$	"	"	40 units.
III	"	"	$\frac{1}{163}$	"	"	60 units.
IV	"	"	$\frac{1}{123}$	"	"	80 units.
V	"	"	$\frac{1}{89}$	"	"	110 units.
VI	"	"	$\frac{1}{65}$	"	"	150 units.
VII	"	"	$\frac{1}{33}$	"	"	300 units.
VIII	"	"	$\frac{1}{19}$	"	"	500 units.
IX	"	"	$\frac{1}{8}$	"	"	1200 units.

These intensities seem very small when we compare in our minds a fearful event like an earthquake with the quiet operation of gravity which is so familiar and matter of course. But let us conceive for one moment that the operation of gravity were discontinuous. That at one instant a pound weight would not fall when it was released, while at the next moment the usual state of affairs might suddenly return. The beneficent and quiet force of gravity would become a wanton fiend of destruction, and the small fractions of the last table would seem quite large enough to account for any possible experiences. Coming down an ordinary flight of stairs under these abnormal conditions would be a feat before which a strong man might shrink with terror. It would be worse than the India voyage in Shakspere's day.

By and by the observations now being made at the Lick Observatory, in Japan, and in many places in California will give us a far more accurate table than that last printed. But even now some very interesting results can be derived from it. During the years 1808–1888 there were 417 shocks recorded in San Francisco. For 200 of these shocks (which were mostly very light), an intensity can be assigned on the Rossi-Forel scale by means of newspaper and other accounts. This has been done, and the result is that there were 8 shocks of intensity I, 55 of intensity III, 12 of intensity VI, 4 of intensity VII, and so on. But the mechanical equivalent of a single shock of intensity I, III, VI, VII, etc., has just been given in the table; so that it is a matter of simple arithmetic to compute the total intensity of all shocks. Thus:

8 shocks of intensity I correspond to 8 times 20 units of acceleration = 160 units.

55 shocks of intensity III correspond to 55 times 60 units of acceleration = 3300 units.

---

[1] We may call an acceleration of one millimeter per second a unit, and we can get an idea of its amount by recollecting that the acceleration due to gravity is 9810 units (32 English feet).

And so with the other cases. Finally, all the shocks felt in San Francisco in the years from 1808 to 1888 (417 in all) were evaluated in this way, and the sum total of their accelerations was 33,360 units of intensity. The details of the computation are dry enough, but the results which we can now draw are of interest. The average intensity of the 417 shocks of these 80 years results as IV, and this is $\frac{1}{123}$ part of gravity. The total intensity for the whole period is $3\frac{4}{10}$ times the acceleration of gravity; that is, if all the earthquake force which has been expended in San Francisco during these 80 years were concentrated so as to act at a single instant, it would be capable of producing an acceleration almost $3\frac{1}{2}$ times that of gravity. At the end of one second a body would be moving at the rate of 109 feet per second instead of the 32 feet which gravity impresses on a freely falling mass.

The severest earthquake felt within the city of San Francisco itself was that of 1868 (intensity VIII). This shock threw down chimneys, broke glass along miles of streets, and put a whole population in terror. The total earthquake force of eighty years was capable of producing nearly thirty separate shocks each one as severe as that of 1868; but it has been doled out so gently and gradually that earthquakes are scarcely thought of by the people, and are hardly considered at all by architects and builders.

In the foregoing article I have endeavored to state the main outlines of an entirely new department of physical or mechanical science. It has been necessary, of course, to omit many details. At the same time the essence of the important methods is given, and enough of the results to show their application. I have great hopes that the United States Geological Survey may conclude to add the registration of earthquakes to its other duties. The field is also open to occasional observers, whose records may be of the greatest value. We are apt to think that the opportunities for such work are very few except in certain limited portions of the country. In fact, this is not so. Even in New England and New York earthquake shocks of intensity sufficient to record themselves on the duplex seismometer (Fig. 3) are by no means infrequent.

The instrument is extraordinarily simple and inexpensive, and requires next to no attention. It will give me pleasure to advise with any one who may feel willing to undertake observations of this kind. We have already in California a considerable number of these seismometers installed and in working order. It is much to be desired that others should be established throughout the whole country.

Edward S. Holden.

The Courting of Jufrow van Loo

I.

IN the outskirts of Kitwyk stood the castle of Ten Brinck, an old ruin built on three sides of a quadrangle, and surrounded by a moat covered with a bright green scum and lily-pads, and agitated by nothing more warlike than a family of ducks floating about, while bullfrogs, like a hidden orchestra, kept up a lively bass. Ruin and blight had fallen on Ten Brinck; its stone steps were sunken and crumbling, grass grew between the cracks,