# A NOTE ON THE GREAT EARTHQUAKE OF OCTOBER 28TH, 1891.

(SEE REPORT TO THE BRITISH ASSOCIATION 1892.)

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If we may judge from the contortions produced along lines of railway, the fissuring of the ground, the destruction of hundreds of miles of huge embankments which guard the plains from river floods, the utter ruin of structures of all descriptions, the sliding down of mountain sides and the toppling over of their peaks, the compression of valleys, and other bewildering phenomena, we may confidently say that last year, on the morning of October 28, Central Japan received as terrible a shaking as has ever been recorded in the history of seismology. It is a subject that might be written about at interminable length, and therefore in the following few pages no attempt is made to give detailed descriptions of all that happened.

Mr. F. Omori, who works with me in the Seismological Laboratory, has made several visits to the shaken district, and ever since has been busily engaged in analysing the materials he collected. Professor Tanakadate, with a staff of assistants, devoted himself to observations relating to the velocity of propagation of earth-waves, the curious sound phenomena, and, lastly, to a redetermination of magnetic elements in the devastated district. Dr. B. Koto has studied the phenomena from a geological standpoint.

Under the title of "The Great Earthquake in Japan," in conjunction with Professor W. K. Burton, I have published a popular account of the more striking phenomena which were observed, illustrating the same by a series of photographs. The questions to which greatest attention has been given are those of importance to engineers and builders, but inquiries and investigations have been made relating to everything which was thought to be of interest. A few days after the disaster, at the request of Professor D. Kikuchi, I drew up a circular containing some fifty queries. Ten thousand of these documents were issued, and we are now surrounded by boxes filled with newspaper cuttings and replies. Five per cent. of the whole may be of value, but yet it has all to be patiently examined. In addition to this material, there is that of our own collecting, which, in addition to what has already been mentioned, includes some hundreds of diagrams taken by seismographs of what seemed to be at one time an unending series of shocks which followed the great disaster. This chaotic mass of material is gradually being sifted, and assuming a form suitable for systematic investigation. Although many of the results may be more marked by the magnitude of the phenomena they represent rather than by their novelty, we have already gone sufficiently far to see that certain observations can hardly fail in widening the circle of our present knowledge.

The first notice that I received of the earthquake was at 6h. 39m. 11s. on the morning of October 28, whilst I was in bed. From the manner in which my house was creaking and the pictures swinging and flapping on the wall I knew the motion was large. My first thoughts were to see the seismographs at work; so I went to the earthquake-room, where to steady myself I leaned against the side of the stone table, and for about two minutes watched the movements of the instruments. It was clear that the heavy masses suspended as horizontal pendulums were not behaving as steady points, but that they were being tilted, first to the right, and then to the left. Horizontal displacements of the ground were not being recorded, but angles of tilting were being measured. That whenever vertical motion is recorded there must be tilting, and therefore no form of horizontal pendulum is likely to record horizontal motion, is a view I have often expressed. What I then saw convinced me that such views were correct. Next I ran to a water-tank which is 80 feet long, 28 feet wide, and 25 feet deep. Its sides are practically vertical. At the time it was holding about 17 feet of water, which was running across its breadth, rising first on one side and then on the other to a height of about 2 feet. It splashed to a height of 4 feet. It seemed clear that the tank was being tilted, first on one side, and then on the other. Whilst this was going on, trees were swinging about, telegraph-wires were clattering together, the brickwork of the tank was cracked, and the college workshop a two storied brick building, a few yards away, was so far shattered that it has had to be partially rebuilt. The effect of the motion upon myself was to make me feel giddy and slightly sea-sick. The chimney of a paper-mill in Tokio fell, and also a chimney at the electric-light works in Yokohama. The constructor of the latter derived some satisfaction from the fact that it fell as a heap of loose brick round its base, for had it been made of better materials, it might have toppled over in large masses, and destroyed neighbouring buildings. Many structures were slightly fractured. During the day twenty-one other shocks were recorded, but nearly all of them were so slight that they failed to give a diagram sufficiently large for analysis. From the slow and easy swinging nature of the motion, it was known that the shock was not of local origin, but that it had originated at a distance. As disturbances of this character had often reached us from an area beneath the Pacific Ocean about 400 miles to the north-east, it was from the northern parts that we expected to receive further information. The surmise that the origin was at a distance proved correct, but instead of being beneath the ocean to the north-east, it was beneath the land in an exactly contrary direction. The first news was that in Kobe, which is about 400 miles towards the south, many chimneys had fallen, earthquake shocks continued, and all were in alarm; whilst at Osaka, which is 356 miles from Tokio, a cotton-mill had collapsed and many people had lost their lives. Little by little news of destruction arrived from many towns, and as it came it grew more terrible. The scene of greatest disaster was the Nagoya-Gifu Plain, which lies about 140 miles W.S.W. of Tokio, and 80 miles N.E. of Kobe. In this district destruction had been total. Cities and villages had been shaken down, the ruins were burning, bridges had fallen, river embankments had been destroyed, the ground was fissured in all directions, and mountain sides had slipped down to dam the valleys. More accurate estimates of certain damages are now before us. The killed numbered 9,960, the wounded 19,994, and the houses which were *totally* destroyed were 128,750. In addition to these there were many temples, factories, and other buildings. In an area of 4,176 square miles, which embraces one of the most fertile plains of Japan, and where there is a population of perhaps 1,000 to the square mile, all the buildings which had not been reduced to a heap of rubbish had been badly shattered. To rebuild the railway, reconstruct bridges, roads, and embankments, and to relieve immediate distress, about five million *yen* were poured into the district, a large portion of which came from the Imperial treasury. This sum, however, only measured a fraction of the total destruction. One hundred thousand houses had to be rebuilt, irrigation works had to be repaired; a value had to be given to land which had been buried by landslides or lost by what appears to be a permanent compression of valleys; there had been a six months interruption of traffic and of industries, and nearly 10,000 people had lost their lives—all of which are factors which cannot be overlooked when measuring the effect of an earthquake by the sum it takes to replace the damage it has occasioned. Independent of the lives which were lost, the total cost of the earthquake may be recorded as thirty million *yen*.

The immediate cause of this great disburbance was apparently the formation of a fault which, according to Dr. B. Koto, can be traced on the surface of the earth for a distance of between forty and fifty miles. There are also many minor faults. In the Neo Valley, where it runs nearly N. and S., it looks like one side of a railway embankment about 20 or 30 feet in height. The fields at the bottom of this ridge were formerly level with the fields which are now on the top of it. In Mino, where it strikes towards the east, it is represented by subsidences and mound-like ridges, suggesting the idea that they might have been produced by the burrowing of a gigantic mole. Although there is only 20 feet of displacement on the surface, from what we know of surface disturbances resulting from the caving in of subterranean excavations, the maximum throw of this fault is in all probability very much greater than that which is accessible for measurement. Not only have the rice-fields been lowered, but, according to the peasants, the mountain peaks on the western side of the valley have decreased in height.

In addition to the evidence of subsidence along this line, there are many evidences of horizontal displacements. Lines of roads have been broken, and one part of them thrown to the right or left of their original direction ; whilst fields which were rectangular have been cut in two, and one-half relative to the other half has been shifted as much as 18 feet up or down the valley. One result of this, is, that landowners find there has been a partial alteration in the position of their neighbours. A more serious change has been the permanent compression of ground, plots which were 48 feet in length now measuring only 30 feet in length. It appears as if the whole Neo Valley had become narrower. A similar effect is noticeable in the river-beds, where the piers of bridges are left closer together than they were at the time of their construction.

Since the big shock about 3,000 minor shakings have been recorded. At Gifu and Nagoya, where most of these were felt, their distribution with regard to time was as follows, the numbers representing the number of shocks which were recorded during successive intervals of ten days :—

| Month. | Day. | Month. | Day. | Nagoya. | Gifu. |
|---|---|---|---|---|---|
| 1891 : X | 29 | 1891 : XI | 7 | 559 | 1,132 |
| XI | 8 | XI | 17 | 123 | 341 |
| XI | 18 | XI | 27 | 76 | 116 |
| XI | 28 | XII | 7 | 48 | 139 |
| XII | 8 | XII | 17 | 40 | 190 |
| XII | 18 | XII | 27 | 27 | 75 |
| XII | 28 | 1892 : I | 6 | 36 | 87 |
| 1892 : I | 7 | I | 16 | 9 | 60 |
| I | 17 | I | 26 | 6 | 36 |
| I | 27 | II | 5 | 9 | 45 |
| II | 6 | II | 15 | 7 | 37 |
| II | 16 | II | 25 | 11 | 39 |
| II | 26 | III | 6 | 9 | 40 |
| III | 7 | III | 16 | 3 | 28 |
| III | 17 | III | 26 | 3 | 13 |
| III | 27 | IV | 5 | 9 | 42 |
| IV | 6 | IV | 15 | 1 | 26 |
| IV | 16 | IV | 25 | 4 | 28 |
| | | Total | — | 980 | 2,474 |

The most violent shakings took place high up in the Neo Valley, on the line of the great fault, and again in a district to the west of Nagoya, about 25 miles farther south, in the middle of the Owari Plain. This second area of great disturbance may indicate the proximity of a second line of fracture not visible on the surface, or it may be an area where waves from various sides of the plane coalesced.

With the first of these shakings, great landslips took place, and long lines of mountains which were green with forest now look as if they had been painted yellowish white. The valleys in these districts have been filled with débris, and behind one of the dams which has been formed there is now a lake six miles in circumference. In one district on the eastern side of the plain we are told that mountain peaks fell in and depressions were formed. Depressions also occurred in some of the valleys, and the houses of farmers suddenly sank up to their eaves, burying their inmates in a sea of earth and mud beneath the floor on which once they lived.

In the plains, river embankments which on the top are from 20 to 30 feet in width, and have slopes of 3 to 1 and 2 to 1, were very much cracked and fissured. Usually these cracks were 2 or 3 feet in width, but in places they had so far united that openings 10 or 15 feet wide and about the same in depth had been formed. In all cases the fissures were parallel to the river bank, and it was in villages near these banks where destruction had been most complete. It might be expected that these fissures would occur at distances of half wave-lengths from the river bank, and at similar distances from each other, but no such rule was observable. The general appearance of the ground was as if gigantic ploughs, each cutting a trench from 3 to 12 feet deep, had been dragged up and down the river banks.

Fissures, out of which sand and water had been poured, sometimes to form small craters, were also to be seen on the open plains. These fissures, which seldom exceeded a foot in width, and which may have been formed by the compression of watery strata beneath, may possibly give approximate measures of maximum horizontal displacement, it being assumed that the direction of motion was at right angles to the direction of the fissure.

Along the railway-line many curious appearances were presented. It was almost everywhere more or less disturbed, the exceptions being where it passed through small cuttings. Along these cuttings, although they might not be more than 20 or 50 feet in depth, the rails and sleepers were unmoved; from which it may be inferred that the movement on the free surface of the plain had been much greater than the movement at a comparatively shallow depth. Measurements of the motion experienced on the surface and that recorded in pits 10 to 20 feet in depth have already been given in former papers. The results of these experiments have been practically applied to several buildings in Tokio, by giving them basements and a free area. The Imperial College of Engineering is such a building. It does not show the slightest trace of damage after the last earthquake, whilst at a distance of 20 yards the workshop, which is also a strong brick building, but rising from the surface, as already stated, has been rebuilt. This is the third time the Engineering College has escaped damage, whilst neighbouring brick buildings have been cracked in almost every room.

Where the line was on the open plain, and only separated from it by a narrow ditch on either side, it appeared as if the ground had been piled up into bolster-like ridges between the sleepers. This indicated a longitudinal motion, but in many places it was noticeable that the sleepers, relatively to the ground, had also been moved endways. Neither of these movements greatly exceeded 6 inches. Wherever the line crossed a small depression in the general level of the plain, even if it did not exceed 2 or 3 feet, at such places the whole of the track was bent from its straight course into a bow-like form, suggesting the idea that along these depressions, which are probably filled with softer material than that composing the plain, a greater quantity of motion had been transmitted, which, striking the line like a flood, had caused a permanent deflection. The more reasonable explanation is that these lines of soft material, like the valleys and river-beds, had been permanently compressed, and the amount of compression was measured by the amount of bending. Effects of compression were most marked on some of the embankments, which gradually raise the line to the level of the bridges. On some of these, the track was bent in and out until it resembled a serpent wriggling up a slope. Not only were there these horizontal foldings, but by subsidence or compression there were vertical folds, which in places gave the line the appearance of a switchback. Close to the bridges the embankments had generally disappeared, and the rails and sleepers were hanging in the air in huge catenaries.

At the bridges, one of which, over the Kisogawa, made up of 200-feet spans, is 1,800 feet in length, the destruction was various. In nearly all cases wing walls had given way. At one brick bridge the abutments had been forced backwards, and the arch had fallen bodily between them down upon the roadway, where it lay in two big segments, looking like a gigantic toggle-joint. At the Nagara Bridge the piers, each of which consisted of five large iron columns filled with concrete and braced together, had in several instances not simply been broken at their bases, but they were snapped in pieces and thrown out upon the shingle beach of the river, where they lay like bits of broken carrot. The bridge was thrown 19 feet out of a straight line, and one of the foundations near the centre of the river had been moved 5 feet 2 inches up-stream. Where the greatest deflections occurred the foundations could not be positively recognised.

Mr. C. A. W. Pownall, who constructed these bridges, and who gave me the above measurements, estimates the deflection on the line where it approaches the bridges at 1 foot 6 inches in a distance of 90 feet. The distance through which the foundations of the Kiso Bridge have permanently approached each other is 2 feet in a span of 200 feet—that is to say, the contraction across the river-bed is 1 per cent. When all the piers of a bridge had not been broken, it was observed that those which escaped were the shorter ones, near the river banks. The longer piers of the Kisogawa Bridge had a cross-section of 22·5 feet by 10 feet, and a height of 29 feet above the plane of fracture, which was 4 or 5 feet above their foundations. They carried girders weighing about 200 tons. The shorter piers, which also had a cross-section of 22·5 feet by 10 feet, had heights of about 21 feet above their planes of fracture. They carried girders weighing about 22 tons.

The tensile strength of the brick and cement work of these piers was, as shown by tests made by the writer, unusually high, often reaching 100lb. to the square inch. When making these tests, it was seldom that the cement gave way, fracture taking place either by the breaking of the brick or by *separation* between the cement and brick,

The tensile strength of brick and mortar work from cotton-factories and other private buildings seldom exceeded 5lb. to the square inch.

Professor Tanabe, of the Imperial College of Engineering, has very kindly applied the fracturing formula to the Kisogawa and other structures, with the following results:—

The tall piers at the Kisogawa Bridge, which were broken, were capable of resisting an acceleration of 5.05 feet per sec., whilst the shorter piers, which were also broken, could have resisted a force involving an acceleration of 10.8 per sec. per sec.

The acceleration in the neighbourhood of this bridge was therefore greater than the higher of these two numbers. Because there is no necessity that one set of piers out of a series should only have half the strength of another group in the same series, or that any given structure should be weaker at its base than it is in its upper parts, so far as resistance to stresses consequent on horizontal movement is concerned, the writer ventures to express the opinion that when constructing in an earthquake country, ordinary engineering practice requires modification. Such modifications are being made by Mr. C. A. W. Pownall in the design of a series of bridges now being built up the Usui Pass, in this country.

For the Nagara Bridge, where cast-iron piers have snapped in two, the accelerations experienced have not yet been calculated.

Leaving the railway works, and examining the various brick-and mortar structures, like public buildings and mills, which existed at many towns upon the plain, we meet with hardly anything but absolute ruin. Two conspicuous brick-and-mortar ruins in Nagoya were the Post Office and a cotton-mill. Walls like these, even if not weakened by openings near their base, assuming them to have been 40 feet high and 1½ foot thick, and with a tensile strength for their brickwork of 5lb.

per square inch—which is not an underestimate—might have resisted a suddenness of motion of a few inches per sec. per sec. From overturning phenomena and diagrams we know the acceleration impressed upon buildings in this area may have been as much as 15 feet per sec. per sec.

One curious form of destruction was that which was observed with many mill chimneys, which, with the exception of one in Yokohama, instead of breaking at their bases, gave way at about two-thirds their height. The conclusion is, that sections near the bases of these chimneys were apparently sufficiently strong to resist the stresses due to the inertia of the upper parts, while sections at about two-thirds the height were so weak that they failed to resist the inertia effect of the upper one-third of the chimney. Calculations respecting these structures have not yet been made.

The ruins of ordinary Japanese buildings existed along all the roads in never-ending lines. In some streets it appeared as if the houses had been pushed down from the end, and they had fallen like a row of cards. Where a row of buildings had only been partially pushed over, it was noticeable that those at the end had suffered more than their neighbours. Sometimes you passed a mass of heaped-up rubbish, where sticks and earth and tiles were so thoroughly mixed that traces of streets or indications of building had been entirely lost.

Many of the ruined towns, like Kasamatsu and Gifu, caught fire, and all that remained was a sea of reddish earth and broken tiles. At several places people were caught in the fallen ruins, and subsequently burnt to death. The chief causes which led to the destruction of Japanese buildings were:—

1. The heavy roofs, which are usually made of a heavy framework carrying a layer of heavy tiles bedded in a thick layer of mud. The roofs of the farmers' houses are covered with a heavy thatch. These latter fell intact, and even now the country is covered with these saddle-shaped masses, which have served as temporary tent-like shelters.

2. The want of cross-bracing and the thinness of the vertical supports, the strength of which, as pointed out by Mr. W. Silver Hall, is reduced to perhaps an eighth of what it might be, by a variety of tenons, mortices, and other cuts, made for the reception of cross-timbers.

Both of these faults in the construction of an ordinary Japanese dwelling might be easily overcome, but from the buildings which are now being erected it is clear that the survivors prefer that to which they have been accustomed and can easily obtain. Buildings to resist earthquake motion are outside the experience of ordinary carpenters in Japan, and any novelty in construction would be expensive. For these reasons, and perhaps with the idea that severe earthquakes only recur at long intervals, the inhabitants of the Nagoya district are giving another trial to the old forms of construction.

Among the buildings which were only shattered, but which did not fall, are two castles and several heavy-roofed temples.

The castles stood, partly perhaps, because they were well built, partly because they were surrounded by deep moats, but chiefly on account of their pyramidal form, their bases being sufficiently wide and strong to withstand effects due to the inertia of their upper parts.

The temples undoubtedly resisted the severe movements partly because they were well built, but chiefly, perhaps, on account of the multiplicity of jointed corbel-work, which comes between the upper parts of the supporting pillars and the heavy roof. If this had not existed and acted as a yielding medium between the roof and its supports, it seems impossible that the latter could have resisted the inertia of the load above them.

A class of buildings which here and there escaped entire destruction were structures like some of the school-houses, which were built of wood, and framed according to foreign methods.

The movements which caused all this terrible destruction throughout the Gifu and Nagoya Plain do not appear to have been waves which were entirely those of elastic compression and distortion. On the coast-line to the north of the devastated district we are told that the shore-line rose and fell, and with this rising and falling the waters receded and advanced. In the district itself many eye-witnesses tell us that they saw the ground in waves.

Mr. Kildoyle, an engineer, who at the time of the disaster was in Akasaka, says that the waves came down the street in lines. Their height may have been 1 foot, and the distance from crest to crest anything between 10 and 30 feet; but he very naturally added that he could not be sure of any measurements, as he was expecting that the houses on one side or the other of the street might at any moment fall in upon him. It may here be remarked that because on the street side of the houses in a town there are many openings, which make this side of the buildings weaker than they are at the back, the tendency is to fall forwards from two sides into the street. For the safety of the inhabitants of a town, special attention ought to be given to the construction of shop and other frontages, and the streets be made wide.

Another indication of wave movement is the statement of people who say that after they had been thrown upon the ground the movements of the earth rolled them from side to side. A station-master, who tumbled on the ground as the station-house fell close behind him, showed the writer the manner in which he seized one of the rails whilst lying on the ground, the rail passing between his legs. While in this position he was tumbled from side to side, first striking the ground with one shoulder, and then with the other.

Reasons for believing that in Tokio the ground was thrown into long undulations have already been given. First, there was the evidence of our sensations; secondly, the observation of the manner in which water moved in ponds; and, thirdly, the observations on the movements of bracket seismographs, which were tipped from side to side. The most certain evidence about the tilting is, however, that which is furnished by the diagrams of many seismographs, which, rather than showing a series of irregular waves with superimposed irregularities, in almost all cases show a series of clean-cut curves. In one instrument which was tested, the periodicity of these curves did not agree with the period of the instrument, from which we may conclude that they had not been formed by swinging. Further, the periods of a consecutive series of waves are not constant. For example, one set of east and west tiltings followed each other, with periods measured in seconds of 3·4, 2·0, 2·7, 1·7, 4·1, 3·1, 3·1, 2·7. On another instrument another set of waves, taken at random, followed each other at intervals of 1·9, 2·5, 1.3, and 2·6 seconds. These observations also preclude the idea that the records were obtained by swinging. The most interesting observation, however, is that a pair of conical pendulums, the bobs of which, supposed to be steady points, and which had no pointers for multiplication, gave diagrams about twice as large as similar, but smaller, conical pendulums which carried pointers to multiply any motion relative to their bobs six times.

The actual records are as follows :—

| | N.S. Motion. in. | E.W. Motion. in. |
|---|---|---|
| Large pendulums with booms 18 inches long... | 8 | 13 |
| Small pendulums with booms and *pointers* 9.5 inches long ........................................ | 4 | 8 |

On the assumption that the bobs of these machines had acted as steady points, we should come to the conclusion that the range of north and south motion had been 8 inches, as given by one instrument, whilst it was only ·66 inch as given by another, both instruments being in the same building. It is clear that these two instruments had not behaved as modern seismographs are supposed to behave at the time of an earthquake, but because the displacements indicated are practically proportional to length of boom, or the length of boom and pointers it may be concluded that the instruments had been tilted, and the extent of the displacement measures maximum slopes of earth-waves.

To interpret these measurements, it is necessary to place a level on the stand of the seismograph, and determine by experiment the angular values of tilting corresponding to measured movements of the writing-pointers, the latter quantities varying with the amount of stability given to the horizontal pendulums. Immediately after the earthquake, Mr. F. Omori very kindly made such determinations from a seismograph in the laboratory of the Imperial University, with the result that the maximum slopes which this seismograph had recorded were about one-third of a degree. Waves with such slopes, as shown on the diagram, succeeded each other at intervals of about 2·2 seconds. The vertical motion which was recorded was about 10 mm.; but as ordinary lever spring instruments, when the levers are not parallel to the wave-fronts, are as sensitive to tilting as horizontal bracket or conical pendulum seismographs, these measurements must be regarded as maximum rather than actual values. Combining the maximum wave slopes with these records of vertical motion, we obtain certain values for the lengths of the waves, which may be taken at 18 or 20 feet; and as we know their period, we may determine their velocity of propagation, which appears to have been about 10 feet per second. This is exceedingly slow, but notwithstanding the errors in the observation of vertical motion, I do not think the velocity exceeded double this amount. The velocity of propagation of more truly elastic vibrations will be referred to later.

From these observations, which I think are made for the first time, rather than concluding that modern seismographs are useless whenever vertical motion occurs, we see that on such occasions they must be regarded as angle-measurers. The action of any bracket seismograph when recording horizontal motions depends greatly upon its inertia, but to obtain the best measurements of tilting, any cause likely to produce swinging should be minimised. To obtain a true measurement of vertical motion, the method which first suggests itself is to have a number of spring lever arrangements in different azimuths, the one which happened to have its arm at right angles to the direction in which the wave advanced being the one which would give the best results.

Independently of any new instruments which may be devised to measure tilting, we now know that the instruments we already possess have a double function, not only measuring horizontal displacements, but also measuring angles of tilting. In order to take advantage of this second function, it is necessary that when a bracket or conical pendulum instrument is once set up, experiments should be made to determine the effects of tilting, otherwise, should it be tilted by an earthquake, its records will not be measurable.

An investigation of considerable importance in connection with the intensity and direction of motion, which has been carried out by Mr. F. Omori, relates to the overturning of bodies of various dimensions. At all temples, which are as thickly distributed as the towns and hamlets, there are stone lanterns, standing on circular or square pedestals, whilst in the vicinity there are hundreds of gravestones, which are square or rectangular in section, and stand freely on their end. Applying the overturning formula to some thousands of these which were overturned in the Nagoya-Gifu Plain, average minima and maxima values for the accelerations experienced at different points within the earthquake area have been determined. Inasmuch as the results given by the formula, which is due to Professor C. D. West, conform with the results obtained by experiment, we have every confidence in the figures given in the following table :—

## Average overturning acceleration and mean direction of Shock as experienced at various Places in the Shaken Area.

### Calculated by Mr. F. Omori.

| Place, District, and Province. | Intensity in Millimetres per sec. per sec. | Direction. |
|---|---|---|
| Tsu, Ano, Ise | <2,000 | S. 70° E.-N. 70° W. |
| Yokkaichi, Miye, Ise | <1,900 | S.E.E.-N.W.W. |
| Kuwana, Kuwana, Ise | 2,000 | E. 10° N.-W. 10° S. |
| Tokonabe, Chita, Owari | <2,400 | E.-W. |
| Handa, Chita, Owari | 2,000-2,700 | S.E.-N.W. |
| Toyohashi, Atsumi, Mikawa | 1,700-1,800 | S. 75° E.-N. 75° W. |
| Okazaki, Nukada, Mikawa | <900 | |
| Atsuta, Aichi, Owari | 2,300-3,500 | E.N.E.-W.S.W. |
| Northern part of Nagoya (Toshogoo) | 2,600 | S. 80° W.-N. 80° E. |
| North-eastern corner of Nagoya (Kenchiuji) | 2,600 | S. 60° W.-N. 60° E. |
| Central part of Nagoya | 2,500 | |
| Mean for Nagoya | 2,600 | S. 65° W.-N. 65° E. |
| Bamba, Kaito, Owari | >4,100 | E.N.E.-W.S.W. |
| Tsushima, Kaito, Owari | | E.-W. |
| Jimmokuji, Kaito, Owari | | E.-W. |
| Shimo-Otai, Nishi Kasugai, Owari | | Nearly N. and S. |
| Komaki, Higashi-Kasugai, Owari | >4,000 | Chiefly E. and W. say W.S.W.-E.N.E. |
| Iwakura, Niwa, Owari | >4,300 | Chiefly N. and S. say S.S.W. N.N.E. |
| Koōri, Niwa, Owari | >2,100 | S.W.-N.E. |
| Imaichiba, Niwa, Owari | >2,600 | |
| Inaghi, Niwa, Owari | 2,300-4,000 | S. 15° W.-N. 15° E. |
| Ichinomiya, Nakajima, Owari | 2,500-3,500 | W.N.W.-E.S.E. |
| Kasamatsu, Haguri, Mino | 4,000 | W.N.W.-E.S.E. |
| Gifu, Atsumi, Mino | 3,000 | W.S.W.-E.N.E. |
| Ogaki, Ampachi, Mino | 3,000 | N.N.E.-S.S.W. |
| Kitagata, Motosu, Mino | | Nearly N.-W. |
| Beppu, Motosu, Mino | >3,900 | |
| Kurono, Katagata, Mino | | S. 50° W.-N. 50° E. |
| Monju, Motosu, Mino | | S. 60° W.-N. 60° E. |
| Kochibara, Motosu, Mino | <1,900 | N. 20° W. |
| Kami, Motosu, Mino | >2,000 | S. 60° W. |
| Higashi-Katabira, Kani, Mino | >2,400 | N.-S. |
| Dota, Kani, Mino | <2,200 | S. 20° W.-N. 20° E. |
| Imawatari, Kani, Mino | | N.-S. |
| Mitake, Kani, Mino | About 1,600 | W.N.W. |
| Takayama, Toki, Mino | >1,800 | |
| Tokiguchi, Toki, Mino | >2,000 | N. and S. |

| Place, District, and Province. | Intensity in Millimetres per sec per sec. | Direction. |
|---|---|---|
| Tajimi, Toki, Mino .............. | | S.S.W.-N.N.E. |
| Ikeda-Machiya, Toki, Mino ... | | S. 20° W.-N. 20° E. |
| Utsutsu, Higashi - Kasugai, Owari .............................. | 2,000 | S. 35° W.-N. 35° E. |
| Akechi, Higashi - Kasugai, Owari .............................. | >2,000 | |
| Ono, Ono, Echizen ............... | >1,200 | E.-W. |
| Katsuyama, Ono, Echizen...... | About 1,200 | Nearly N.-S. |
| Fujishima, Yoshida, Echizen... | >1,300 | Nearly N.-S. |
| Fukui, Asuwa, Echizen .. ...... | 2,500 | N.N.E.-S.S.W. |
| Asozu, Asuwa, Echizen ......... | <1,100 | S. 30° W. |
| Midochi, Imadate, Echizen ... | About 2,000 | |
| Sabai, Imadate, Echizen ...... | About 1,800 | |
| Takefu, Imadate, Echizen...... | About 1,200 | N.-S. |
| Higashiura, Tsuruga, Echizen. | About 1,300 | |
| Tsuruga, Tsuruga, Echizen ... | About 1,200 | N.N.W.-S.S.E. |
| Nagahama, Sakata, Omi ...... | About 2,400 | Nearly N.-S. |
| Hikone, Inukami, Omi ......... | About 2,700 | N.N.W.-S.S.E. |
| Kioto, Yamashiro ............... | <1,200 | S.S.W.-N.N.E. |
| Inari, Kii, Yamashiro........... | About 1,000 | N. 10° W.-S. 10° E. |
| Fukakusa, Kii, Yamashiro...... | >1,000 | N.-S. |
| Fushimi, Kii, Yamashiro ..... | | S.S.E.-N.N.W. |
| Nara, Yamato ........... ......... | | S.S.W.-N.N.E. |
| Horiuji, Yamato .................. | About 1,300 | S.S.E.-N.N.W. |
| Osaka, Settsu ...................... | About 1,000 | |

The principal measurements obtainable from the records of seismographs are as follows :—

1. Tokio. Central Meteorological Station.

Maximum horizontal motion, N. and S., about 28 mm. Period, 1.4 sec.

Maximum horizontal motion, E. and W.>about 32 mm. Period, 2.5-4.0 secs.

Maximum vertical motion, 3.1 mm., with period .84 sec., and 4.4 mm. with period 2.3 secs.

2. Tokio. Imperial University.

Maximum horizontal motion, >35 mm. Period, 2.0 sec.
Maximum vertical motion, 9.5 mm. Period, 2.4 sec.

3. Osaka.

Maximum horizontal motion, 30 mm. Period, 1.0 sec.
Maximum vertical motion, 8 mm. Period, 1.0 sec.

4. NAGOYA.

Maximum horizontal motion, >26 mm. Period, 1.3 sec.
Maximum vertical motion, 6.2 mm. Period, 1.5 sec.

5. GIFU.

Maximum horizontal motion, 18 mm. Period, 2.0 secs.
Maximum vertical motion, >11.3 mm. Period, 0.9 sec.

At the two latter places the records only showed the first half-dozen vibrations of the disturbance, after which the buildings fell, and the instruments were buried.

At several places in the Neo Valley objects like gateposts have apparently shifted their positions by jumping, each leap being from 1 to 4 feet.

Another observation, also due to Mr. Omori, is that the greater number of columns in one district fell in one direction, whilst those in another district fell in some other direction. Thus, in the southern part of the Nagoya-Gifu Plain, on its eastern side, columns fell towards the west, whilst at towns on the western side of the plain they fell towards the east—an observation which suggests that the movements causing overturning had advanced eastwards and westwards, from a line or tract running north and south down the centre of the plain. In the northern part of the plain the direction of motion, similarly determined, must have been more north and south.

From the measurements of maximum acceleration, and from the records of seismographs which at Nagoya and Gifu gave for the commencement of the disturbance the period of the back and forth motions, we may approximately determine the amplitude and maximum range of motion. The following are a few of such determinations, which it will be observed do not materially differ from the width of fissures found in the open country. The period taken is one and a half second :—

| Place. | Acceleration mm. per sec. | Range of Motion. |
|---|---|---|
| West of Nagoya ............ | 4,500 ...... | 495 mm.=19½ inches |
| Komaki and Kasamatsu ... | 4,000 ...... | 440 mm.=17⅓ inches |
| Gifu and Ogaki ............ | 3,000 ...... | 330 mm.=13 inches |

It must be remembered that all the numbers given referring to acceleration and range of motion only apply to the open plain, and not to free surfaces like river banks or lines of soft material like river-beds. A phenomenon which seemed to accompany most, if not all, of the Nagoya-Gifu shocks was a hollow, booming sound. These sounds, which accompany all great earthquakes, and even small ones, if they occur in rocky regions, have been discussed at considerable length in the "Transactions of the Seismological Society" (*see* vol. xii. p. 53, and p. 115). They are evidently the result of vibrations conveyed through the earth, and may be continuous with the large vibrations which constitute the earthquake. Professor Tanakadate endeavoured to determine the intervals in time between the sound and the subsequent shakings. Sometimes there was an interval of one or two seconds, whilst at other times the two phenomena were synchronous. The distance of the point of observation from the origin of these disturbances was in all probability at least 10 or 12 miles. While the writer was at Nagoya, which may have been from 25 to 45 miles distant from the earthquake's origin, the sounds never preceded a shaking by more than two seconds. Sometimes they were synchronous, and often there were sounds without any subsequent shaking.

Very many observations were made in Tokio, on the Gifu Plain, and in other places, to determine the velocity of propagation. These have not yet been computed, but the disturbance appears to have reached Tokio at rates of about 8,000 feet per second.

From observations made at the Zikawei Observatory, near Shanghai, which is, roughly, 1,000 miles distant, the velocity with which the movement was transmitted was about 5,104 feet per second. As stated in newspapers, the time taken to reach the Berlin Astronomical Observatory, in round numbers, was forty-nine minutes, the velocity of transmission being about 9,840 feet per second. The disturbance apears also to have been noted at the Magnetical Observatory in Potsdam.

Although numerous experiments and observations have been made to determine the velocity with which motion is conveyed through the earth, we have not as yet any satisfactory explanation of the great differences which have been observed.

From a long series of experiments, extending over several years, which were made in Tokio, where earth disturbances were caused by exploding charges of dynamite, velocities were obtained varying from 200 to 630 feet per second. All these experiments were made in alluvium. Amongst other results the following were of importance:—

1. The velocity of transit decreases as a disturbance radiates.

2. The velocity of transit varies with the intensity of the initial disturbance.

3. The motions transmitted most rapidly are vertical free-surface vibrations; normal motions come next, whilst the lowest records obtained were for transverse motions (*see* "Trans. Seis. Soc.," vol. viii. p. 50, &c.).

Mr. Mallet determined a velocity in sand of 824·915 feet, and in granite, of 1664·576 feet per second. General Abbott, at the destruction of Flood Rock, noted velocities as high as 20,526 feet per second. Professor S. Newcomb and Captain C. Dutton determined velocities for the Charleston earthquake of 17,072 feet per second. The highest velocity for a sound-wave through piano steel of density 7·7 is given by Tomlinson at 5,198 metres (17,049 feet) per second.

Although elastic vibrations may have been transmitted from the earthquake district 150 miles to the Tokio Plain at the rate of several thousand feet per second, the resultant gravity-waves in the Tokio Plain itself do not seem to have been propagated at a greater rate than a few feet per second. With these results before us, all we can say, is, that earthquakes have caused motions in the ground, which apparently have been transmitted at rates varying between 20 feet per second and 20,000 feet per second, the latter being a rate which is higher than that at which sound waves are propagated through hard steel. Attention has often been called to these facts, but any explanation for them has not yet been formulated.

The result of Professor Tanakadate's magnetic survey shows that there is a slight irregularity in the isomagnetic curves, showing the daily change in declination, which does not appear to have been noticed before the earthquake.

A curious observation, made by Dr. Julius Scriba and other medical men, was that many of the troubles amongst the wounded, like tetanus and erysipelas, were in great measure due to the result of nervous excitement. From my own observations at a time when all were camped in the midst of ruin, and every few minutes a shock was heralded by a booming sound, the only effect that the great catastrophe had produced upon the people was, when they heard one of these unaccountable noises, to cause them to act with unusual quickness in seeking safety. Amongst the Japanese, so far as I could learn, there was no hysteria, fainting, or nervous prostration like that which was observed amongst European women. Although they were surrounded by ruin, the dead, and the dying, all that happened when a hollow thundering announced a coming shock was that they ran quickly for the open, shortly afterwards coming back laughing and talking about the terrible effects of earthquakes. Notwithstanding this, it is not unlikely that this disaster will have produced an impression sufficiently great that for many a year to come it will be commemorated by a religious ceremony, when services will be performed in honour of the dead.

The Nagoya-Gifu Plain is a flat expanse of rich alluvium, covering an area of about 600 square miles. On its east and west sides it is fringed by low hills made out of tertiary tuffs lying at the feet of palæozoic mountains which rise to heights of from 2,000 to 4,000 feet. These latter, which stand up in serrated ridges and overlook the plain, are composed of slates, schists, and other metamorphic rocks. Here and there beds of limestone are found, and rising from the midst of these hills are several large granite bosses. Volcanic rocks do not exist in this part of Japan. From ancient maps and historical accounts we know that the southern portion of this plain has rapidly been encroaching on the sea. This, no doubt, is largely due to sedimentation; but because evidences of elevation exist at so many places along the eastern coast of Japan, it is reasonable to infer that the growth of land may in part be attributable to this cause. A certain number of earthquakes are every year recorded in the Nagoya Gifu Plain, but it is by no means so often shaken as many other parts of the Empire. A somewhat remarkable observation connected with the seismological history of this portion of Japan is the fact that, although written records of natural phenomena are usually fewer the further we go back in time, yet, from what has been chronicled, great earthquakes were more frequent in the district between Nagoya and Osaka in bygone times than they have been during more recent times. The last severe shakings at and near Gifu took place in 1826, 1827, and in 1859. Many ordinary buildings and even mountains suffered, people and animals were killed, rivers stopped up, and floods occasioned. The shocks lasted for several days. A rather severe shock was felt on May 12, 1889. In 1880 there were shocks and sounds came from the north-west. From 1885 to 1890 the number of shocks annually recorded in that district were respectively 9, 4, 10, 12, 15, and 36. In 1888, in one locality near to the centre of the late disturbance, 19 shocks were recorded; in 1889 the number was 15; in 1890 there were 20 shocks; and between January and October 1891, that is, up to the time of the great disturbance, 26 shocks were noted. These figures suggest the idea that for four years before the Great Earthquake there was a marked increase in seismic activity, and that an unusual number of small disturbances had heralded the great collapse.

Even if it is only sometimes true that small shakings warn us of larger ones to follow, because the latter are so terrible in their effects, it would seem well to carefully study districts in which from time to time there are definite indications of an increase in underground activity.

Earthquakes generally occur in mountainous countries where the mountains are geologically young, or in countries where there is evidence of slow secular movements like elevation. These latter movements are usually well marked in volcanic countries, and it is not unlikely that the majority of earthquakes, even in volcanic countries, are the result of the sudden yielding of rocky masses which have been bent until they have reached a limit of elasticity. The after-shocks are suggestive of the setting of disjointed strata.

In Japan, the majority of the earthquakes which we experience do not come from the volcanoes, nor do they seem to have any direct connection with them. Assuming that the greater number of earthquakes represent interruptions in the general process of rock crumpling, it would appear that light might be thrown upon the time of their occurrence by careful observation on the change of level in a district where seimic disturbances were frequent. To accomplish this it is suggested that several miles of water-pipes be laid at right angles to a known axis of elevation, and that continuous photographic record be kept showing the height of the water in standards at each end of the line. A more complete arrangement would be to have two lines of piping, placed at right angles. The cost of the installation would be about 500*l.* or 3,500 *yen.*

Possibly self recording tromometers such as are described in this number might at much less expense throw light upon the questions relating to change of level. Arrangements for these investigations are now being made.

In conclusion, it must not be overlooked that these remarks on the Great Earthquake only aim at giving an outline of phenomena which have been observed, and the general character of the results to which they lead. The complete account of this great disaster to be issued under the auspices of the Imperial University of Japan will not be ready for publication for several months.