30. *The Great Indian Earthquake of January 15, 1934.*

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Having been deputed by the Earthquake Research Institute to proceed to India for the purpose of studying phenomena connected with the great North Bihar earthquake of January 15, 1934, I left Kôbe on April 25, and arrived at Calcutta on May 20. During the ensuing 50 days I travelled through Western Bengal and the United Provinces, where the damage caused by the present earthquake was very serious. In the earlier half of this paper I shall briefly deal with the various phenomena connected with the earthquake and the havoc wrought thereby. Although several opinions have so far appeared in publications regarding the cause of this earthquake, I shall add a few words on the subject in the latter half of this paper. Another subject that calls for careful consideration at this time is the protection of buildings in India from future earthquakes. I shall however deal with the nature of the seismic impulses as observed on the ground and the measurements of the vibrations of buildings, since these are valuable data on which to base our designs for earthquake-proof buildings.

The earthquake that caused such terrible havoc in the northern parts of Bihar and Nepal Valley occurred at about 2 h 13 m p.m. (Indian standard time) on January 15, 1934. The area in which the shocks were acute and great damage to life and property was caused extended from Motihari in Champaran on the west to Purnea on the east — a distance of nearly 200 miles, and from the frontiers of Nepal on the north to Monghyr on the south — a distance of 80 miles. Beyond this, a much wider area, in which the damage was less, extended east into Bengal and Assam and west into the United Provinces. It was felt in the Peninsula as far at least as Bezwada and Bombay. Pilgrims in Khatmandu reported that shocks were felt at Lhasa.

Intensity In the areas most seriously affected by this earthquake the intensity of the shock has been estimated to be VI (*violent*) by the intensity scale in use in Japan or to intensity X by Mercalli's modification of the Rossi-Forel scale.

Three areas are covered by isoseist X (Mercalli), the largest of which runs through North Bihar from Sitamarhi to Madhubani, form-

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1) According to Dr. A. L. Coulson's preliminary examination of seismograms, the time of occurrence by Davison's table came out as 14 h 13 m 22 s (Indian Standard Time).

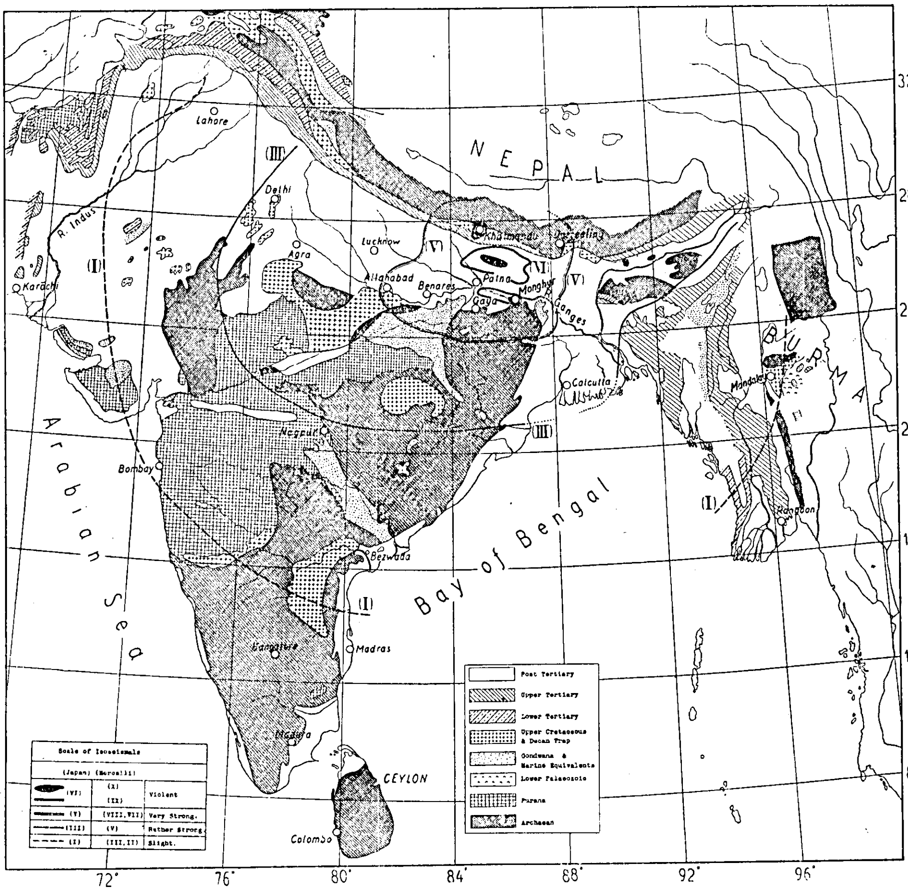

Fig. 1.

ing the main part of the "slump belt",[2] while the remaining two, though small in area, are in the Nepal (Khatmandu) Valley, and at Monghyr. The acceleration of the earthquake motion in these areas as deduced from overturned objects was probably about 3,000 mm/sec^2.

In three other areas the intensity of the shocks was also *violent*, being IX on the Mercalli scale. The largest affected area, approximately 10,000 sq. miles, lies in North Bihar and along the Terai and southern ranges of Nepal. Although in these areas, as well as in those covered by isoseist X, sand vents and ground fissures were observed,

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[2] The term used for regions in which the ground sank through wide-spread fissuring in "The Preliminary Report on the North Bihar Earthquake of the 15th January" by Dr. J. A. Dunn, J. B. Auden, and A. M. N. Ghosh. I am greatly indebted to this report for much of the description of the effects of the earthquake etc., that I have given in this paper.

they were rare or absent in the lesser areas covered by isoseist IX just mentioned.

The earthquake was so severe that even in Calcutta, 400 miles from the epicentre, the walls and facings of several houses were cracked. The tower of St Paul's Cathedral fell to the ground. At Darjeering, the Government House collapsed and many private houses were badly damaged.

The areas covered by isoseists X and IX are shown in Fig. 1 and that in which the earthquake was felt is also shown in the same figure.

Earthquake Phenomena and Destruction.

Earthquake Motion. Judging from reports received from various sections of the devastated area, the shock was most violent for a period of from 2 to 5 seconds. The largest part of the damage occurred early in the principal portion of the earthquake motion, which was so strong that people had difficulty in standing and were forced either to sit or lie on the ground. The period of the earthquake might have been short, say less than 1 or $1\frac{1}{2}$ seconds, as reported from Sitamarhi. There is the possibilty however that vibrations of much quicker period than this were superposed on waves of periods of about one second. It was the latter vibrations that was responsible for the destruction of brick buildings of comparatively small height, the natural oscillation periods of these vibrations being supposed to be a small fractions of a second.

According to reports of Dr. Dunn and others, surface waves or undulations were observed by many people, the waves being propagated with comparatively small velocity, probably of the order of 2~8 miles per minute on soft ground. These waves, which do not radiate from the epicentre, are generated locally by ground vibration. As to the direction in which these waves were propagated, unfortunately uniformity is lacking in the observations reported.

The most noteworthy phenomenon in connection with this great earthquake is the sand and water vents that appeared throughout the central belt of the earthquake area. So much sand and water had spouted out of the earth that it seemed at one time as if large parts of the richest land in North Bihar had turned into permanent a desert. These fears were however dispelled when a survey carried out by the Government showed that though the damage was on a serious scale, it was by no means so disastrous as was at first apprehended. Of the 4,000 sq. miles covered by these sand deposits to serious extent, in only 300 sq. miles is the deposit thicker than 1 ft, the areas in which the deposit exceeded a thickness of two feet being very small indeed.

Dr. K. S. Caldwell of Patna College made a careful study of the manner in which these sand vents were formed. In his interesting report[3] he classifies the various types of sand deposits as follows:

(1) Wide open fissures. The surface opening that appeared near Simraha was 3∼5 ft wide and about 3 ft deep.

(2) At places where the outpouring pressure was not so great the water bearing sand was forced up through small fissures that did not reach the ground surface. These burst out through small isolated craters of sand varying from 1 ft to 3 or 4 ft in diameter. These craters are not the tops of turbular openings going down many feet into the earth.

(3) In the case of wells, deep tanks, or embankments, other conditions arose. Since wells give direct access from the water bearing sand to the ground surface, the water and sand gushed through these ready-made openings often to a height (*according to eye-witnesses*) of 15 ft or more. From such openings the sand is deposited in the form of a flat cone about 100 yards in diameter and varying in thickness from about 1 ft near the centre (sometimes more) to 6 inches at a distance of 15 to 20 yards and gradually thinning out to the edge.

(4) Another type of sand deposit is the basin-like hollow, about 5 ft in diameter and one ft or two ft deep. Hollows of this type were found at places where there had formerly been wells. The site of an old well, now filled in and lying under cultivated land, but whose existence was revealed only through the sand that had gushed out through it, assumes the form just described.

(5) The tanks are mostly 10∼15 ft deep, but as the bottom is within a few feet of the water-bearing sand, in regions of high outpouring pressure the sand had found its earliest means of escape into the tank itself. On all occasions when it was reported that the bottoms of such tanks had risen it was found that the bottom, originally mud, was now sand.

(6) Where the road level of an embanked road had sunk as the result of local effects, large quantities of sand were thrown up at the sides, often filling the nullahs.

(7) The sand and water, which must have found an easy way out into the river beds, poured into it from under the surrounding land. Examples of these are also given in the report of Dr. Dunn previously cited. The Balan river on the border of the Darbhanga and Bhagalpur districts became dry for a few seconds as the result of temporary upheaval of the river bed, the water of the Ganges at Luckee Serai receding from mid-stream and sand gushing out from the exposed bed.

All evidences indicate that the sand which appeared on the ground surface came from within 20∼30 ft of the ground level, and not 300 or 400 ft as has been frequently reported. It might be added here that the water-bearing sand in the neibourhood of Muzaffarpur-Sitamarhi road, where the sand deposits were most typical, is about 20 feet below the ground surface.

As to the distribution of these cracks, through which such vast quantities of sand had been thrown out, the following facts are re-

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[3] Notes on Sand Deposits by Dr. K. S. Caldwell (Mar. 17, 1934).

ported:

The cracks were often double, with short branches, but the general effect was an avenue of sand about 50 yards wide and stretching across the country in an unbroken length for a mile. One walking across the country at right angles to one of these sand avenues would meet with others at a distance of 400~500 yards running roughly in a parallel direction.

These sand avenues were like the crests of waves several hundreds yards apart. (See Figs. 2~5).

Survey of levels During the earthquake the ground rose and sank in a most alarming manner and it was found that many of the rivers had silted up, while some had ceased to flow. Alterations in levels, even on a small scale, are a very serious matter in an alluvial country like North Bihar, where they are likely to cause the rivers to change their courses. After the great earthquake the Geological Survey of India made a check of the levels, the results being given in a paper issued by the Government of Bihar and Orissa on June 10, 1934. The reports contains a good deal of information concerning levelling of country where lines of levels had not been run before. This part of the material will require detailed study by the drainage engineers. There are however two main lines that were surveyed before the earthquake, so that it is possible to gain a general idea as to how the levels have changed.

The longest of these lines is that which runs from Bagaha in the extreme north-

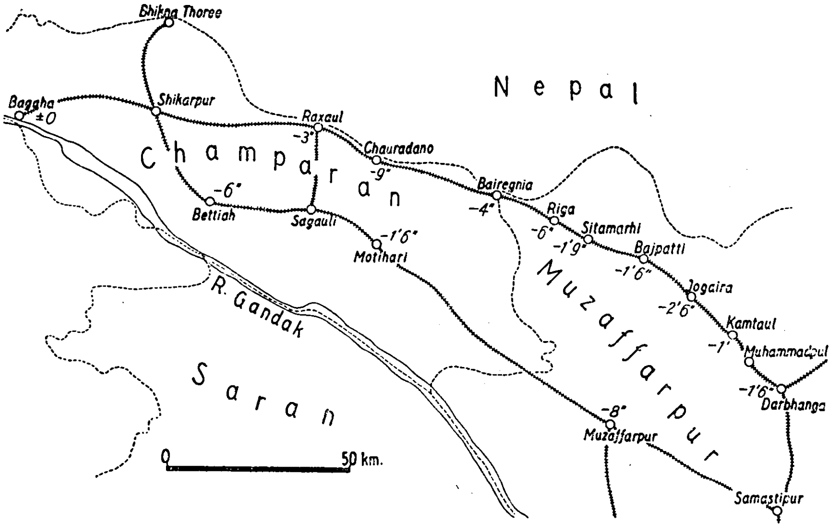

Fig. 6. Levelling routes and the changes in heights of bench-marks in feet ('), inch (").

west of the Champaran district, through Sitamarhi, to Darbhanga, parallel with the railway line. The height of the bench mark at Bagaha was assumed unchanged both before and after the great earthquake. Starting from the west there is no appreciable change as far as Ramnagar. From Ramnagar to Chauradano the levels sank slightly, the depression at Raxaul, for example, being as much as 3 inches, while at Chauradano it was 9 inches; the amount of depression increasing towards the east, but nowhere so much as a foot. Bairegnia sank 4 inches and Riga 6 inches, Sitamarhi railway station 1 foot 9 inches and Bajpatti 1 foot 6 inches. At Jogaira station the drop is 2 feet 6 inches and at Kamtaul 1 foot, while at Darbhanga station the level dropped 1½ feet. East of Darbhanga the falls in level are about one foot.

Another line with which comparisons are possible is that running from Bagaha, through Bettiah and Motihari, to Muzaffarpur. Bettiah sank 6 inches and Motihari 1½ feet. The bench mark at Muzaffarpur showed a subsidence of 8 inches

The measurements that have been quoted are those of what are known as *interred bench marks* or standard bench marks. A large number of bench marks are on railway bridge abutments or on masonry buildings. These showed much greater drops than the interred bench marks, but it is probable that the latter are a truer index to changes in the general level of the country, seeing that a number of heavy buildings have sunk into the surrounding soil, so that lowering of bench marks of fixed to such structures does not necessarily imply sinking of the general surface level.

If the changes along the level lines just mentioned are typical of changes over the surrounding country, it is likely that the present great earthquake caused general sinking of level to a considerable degree, the drop increaseing as one goes south-eastward.

Before the earthquake, Sitamarhi was 201 feet, Muzaffarpur 175 feet, and Darbhanga 155 feet above mean sea level.

Effect on buildings and other structures.

Within the central area in which the intensity of the shocks had been estimated as being No. X on the Mercalli scale, every building was more or less damaged. Houses in this area collapsed by violent shaking rather than ground-sinking. But at places where many large fissures had formed on the ground, the houses sustained serious damage by tilting or through unequal subsidence of the foundations. Number of such houses is by no means negligible. These ground fissures were often formed roughly concentric to buildings or parallel to one of their walls. In some places, houses collapsed as the result of their foundations having been broken up by these large fissures.

Generally speaking, the damage was worst in houses of the *kutcha-pucca* type, while mud huts collapsed in many places, although the substantially built and light *pucca* buildings escaped with only slight damage. Bamboo huts were nowhere damaged.

Railway lines and bridges.

The railways lines over a wide area were severely buckled, the rails being thrown to either side by as much as 3 or 4 feet, while railway embankments sank in many places. The sufferers were the Bengal and North Western, the East Indian, and the Eastern Bengal Railways. Along the B. and N.-W. Railway, the worst damage, which was in the Tirhut section, was found in buildings and bridges which had cracked to almost complete destruction, the severest damage to bridges occurring in their lower parts, both above and below water. Not one bridge in Tirhut remains undamaged. Fortunately, loss of life along this line was very small. On the E. I. Railway, the causalities from the earthquake were very serious at Jamalpur, where more than a hundred houses in the railway colony collapsed. The damage on the E. B. Railway was confined to tracks, bridges, and culverts on the sections between Purnea and Jogbani and between Murliganj and Behariganj. Most of the seriously damaged bridges were of the brick-arch type.

The Devastated Towns.

The earthquake damage was particularly serious within the belt of country extending from Motihari in the extreme northwest to Purnea in the extreme southeast, the belt running nearly parallel with the river Ganges. Within this belt the shock was severest at Sitamarhi, Bajpatti, and Madhubani, the zone along which these towns are situated, about 50 miles long and 20 miles wide, being regarded as the so-called "epicentral tract". In this tract (larger hatched area in Fig. 7), sinking of the ground, on a large scale resulted in numerous fissures and breaking up of foundations, the buildings sometimes subsiding bodily, or individual walls sinking relatively to adjacent walls.

Outside of the Motihari-Purnea belt, another narrow zone of high intensity extends along the southern side of the river Ganges, from Patna to Monghyr. The intensity of the shock in the down-town of Monghyr was no less than in the epicentral tract, it being estimated to have been X on the Mercalli scale.

It must be remembered that there are several isolated spots or regions where the intensity of the shock was much lower than in regions surrounding them. Indeed, we find that side by side with, and

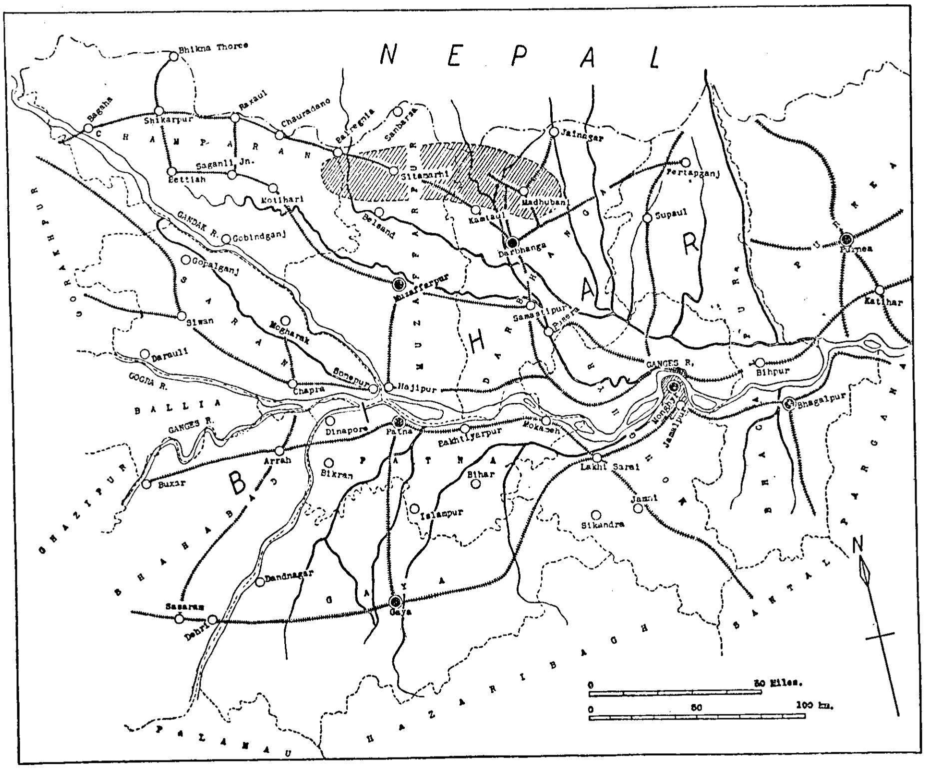

Fig. 7. Map of Bihar.

close to zones of great destruction, are regions along which the intensity was so much less that buildings and bridges escaped damage, while sand vents and fissures were almost absent. For convenience the damage caused to towns lying north of the Ganges will be described, next that to towns south of the same river, and lastly the damage to Nepal.

North of the Ganges.

Bettiah. The earthquake causalities in this town were not great; not more than at Motihari. Although the surrounding country showed ground cracks and fissures, the town itself showed none. The hospital was ruined and the Catholic Church and Bettiah Raj's buildings were all badly damaged. I understand however that twenty per cent of the damaged houses can be repaired. The well water was not fouled so badly as at Muzaffarpur and other places.

Sitamarhi. In Sitamarhi, a town of 10,000 inhabitants in the Muzaffarpur district, nearly every building came down in the earthquake, no house of whatever type escaped tilting or sinking into the ground. This type of damage was best seen in heavy brick buildings. Sand ejection reached maximum intensity here, filling houses, streets, and drains. Large fissures were formed all over the town. Bridges, roads, and railway tracks were either badly damaged or totally destroyed. In places the road sank six to eight feet.

Purnea. It is said that the earthquake here lasted fully three minutes. All the large buildings were seriously affected. The Civil Court, the largest building, was seriously damaged by fissures that formed across the foundation, the building subsiding as much as 2 feet. Many private dwellings, particularly two-storied structures, were destroyed; 50 per cent of the *pucca* buildings were so badly damaged that they will have to be rebuilt. Roads became undulating through local ground sinking, while the wells either dried or silted up. Water spouted out from fissures in many places.

Rajnagar. Rajnagar was badly damaged by fissures and sand vents, many one-storied houses in this town having suffered from these causes. Nearly all the *kutcha* buildings collapsed, while the majority of the *kutcha-pucca* buildings either came down or subsided. In places the sand deposits are from 2 to 3 feet deep.

Madhubani. About 70 per cent of the buildings either totally or partially collapsed. The damage done to buildings was aggravated by ground fissures splitting the walls and foundations. The famous temple of *Hari Sabha,* however, stands uninjured. Sand and water vents were common sights in the surrounding localities.

Motihari. Here faulting, fissuring, and sand ejection occurred on a very large scale. The principal street of the town had altogether changed in appearance. The picturesque town on the bank of the lake of the same name is now a sorrowful picture. Owing to subsidence along the margin of the lake, the houses have taken a strong list towards the lake. The beds of the Gondak and Sikrahna rivers are reported to have risen owing to deposits of sand, while almost all the water channels in the Motihari sub-divison have been filled up with sand.

Muzaffarpur. Although the greater part of the town of Muzaffarpur, north of the railway station, suffered very badly, the damage south of the station is less extensive. In the last mentioned part of the town, the buildings were damaged by sinking and cracking of the ground. Most of the one-storied *pucca* buildings, such as the English Church, the Deputy Inspector-general's residence, and the Circuit House, however, withstood the earthquake, while most Government buildings north of the railway station, such as the Civil Court, the Collectorate, the Commissioner's Court, were badly damaged. Most of the wells at Muzaffarpur were choked up with sand, while the water in the tanks became shallower as their beds were sanded.

Darbhanga. It is stated that damage here on the whole is less than at Muzaffarpur, the destruction of buildings being not so general, although the heart of the town has been completely ruined. The Darbhanga Raj's buildings and the Nargaona Palace have suffered the most. The Post Office buildings, Northbrook School, and Darbhanga Medical School have also been badly damaged. The earthquake caused the worst havoc at the Katki Bazaar, which is densely packed with two-storied *kutcha-pucca* buildings.

Samastipur. In this town, the maximum destruction is confined to the bazaar area, where a number of two-storied *kutcha-pucca* buildings partially collapsed and others were seriously damaged. On both sides of the railway line, sand was ejected from fissures and the buildings of the sugar factory badly damaged, by shock as well as by ground fissures.

South of the Ganges.

Monghyr. Monghyr is a large, flourishing town situated on the right bank of the Ganges. This town is known to the outside world as containing an old fort and, in its environs a hot spring called Sitakund, the objective of Hindu pilgrims. In this town, the Chawk Bazaar fared the worst; the death-roll at this place alone being according to reports (on Jan. 22) about 500. On both sides of the narrow lanes stood a large number of two or three-storied buildings, in which, unfortunately, an unusually large number of people had congregated on this day from the neighbouring villages for shopping in connection with the "Id" festival. As Monday, Jan. 15, happened to be "Amabasya", the Hidus were looking forward to a bathe in the Ganges, while the Muslims were out shopping in connection with the "Id" festival, so that when the houses began to come down Hindus and Muslims were alike crushed to death.

Monghyr is built on both alluvium and archaean rocks. As is usual, houses built on hard rocks suffered less damage than those built on alluvium. The fort wall collapsed in many places, but the buildings inside it (on archaean rocks) escaped destruction with only slight damage. The main damage to *pucca* buildings occurred on the alluvium along the edge of the high ground.

Patna. Here buildings along the river front suffered most. In the bazaar, many buildings collapsed, especially the tall *kutcha-pucca* buildings. The High Court and the Government Houses showed huge cracks in a number of places.

Gaya. At Gaya the damage was considerable, houses in the localities known as Upperdih and Gayawalbigha suffering the most. The great temple *Bishnupada* and other famous Hindu temples escaped damage. Many buildings in the town were cracked, while here and there were porches down. Ground fissures appeared at several places in the river Falgoo (ordinarily a dry sand bed) whence gushed out water and sand in considerable quantities. The famous temple at Budha Gaya sustained no damage.

Towns in Nepal.

All the three important towns of Khatmandu, Bhatgaon, and Patan were severely shaken and almost all the houses either demolished or damaged. The intensity of the shocks at Khatmandu has been estimated to be X on the Mercalli scale. Large cracks appeared on the maidan and several of the roads in Khatmandu. Amid the havoc caused at Khatmandu, however, the temple of Pasupatinath, the Guardian Deity of Nepal, still stands intact, entirely undamaged.

Contrary to what was first feared, no fire accompanied the earthquake, which is extremely fortunate, seeing that wood enters so largely in the construction of houses here.

Cause of the Earthquake.

It is generally accepted that the present Indian earthquake is due to compressional movement or to the push of the Himalayan mass up the faults. It would seem nearer the truth to say that certain sudden change in bulk occurred in the mass underlying the Himalayan mountain range, which would have the effect of displacing the top crust, thus setting up strains that could be relieved only by bending or fracture of the earth's crust causing the jerky movements of the Great Boundary Fault, the immense reversed fault extending along the southern foot of the Himalayas.

The distribution of Indian earthquakes shows that most of the shocks occur in bulging parts of the Himalayan mountain range. On the other hand, according to a map showing the distribution of gravity anomalies,[4] these parts cover an area where the gravity anomalies showed negative values, that is, a region of underload as the result of abnormally low densities in the earth's crust. This underload may perhaps be accounted for by the low density of the alluvium of the Ganges Valley. The alluvium covers, with unknown thickness, a trough or crustal depression that underlies the Ganges valleys.

The depressed condition of the earth's crust in this region is believed to have existed from time immemorial, which with every great earthquake sinks deeper. The lines of level that were run after the present earthquake show that the region most affected had subsided at the time of the earthquake from a few inches to as much as 2½ feet. In 1833, Bihar suffered a similar violent earthquake, when considerable areas were flooded as the result probably of subsidence of the ground caused by the earthquake.

Nature of the Earthquake Motion.

We shall next consider the nature of the earthquake motion on the ground. Damage to houses seems to be caused by earthquake waves of short periods. The greatest damage occurs when the natural oscillation period of the building itself synchronises with the period of the earthquake waves.

According to observations[5] made in Tōkyō and Yokohama, the period of earthquake motion at certain places always had certain definite values, especially in the case of earthquake motions consisting of short-period vibrations, such as those with periods of less than 1 sec. The periods differed with the position where the observations was made— a fact which suggests that the uppermost soil layer is probably an oscillating body capable of executing vibrations of its own period should earthquake waves of similar period come along. Observations[6] covering ten stations in Tôkyô and Yokohama showed that the natural oscillation periods of the ground differed with place. At Hongo and Marunouti, for example, where the former lies on diluvium that forms the up-town and the latter on alluvium down-town, the largest period at Hongo was 0·3 sec, while at Marunouti it was 0·7 sec. The distance between these two points was only 3·0 km. Generally speaking, on diluvium ground, such as Hongo, Aoyama, etc., the natural period of the ground was comparatively short,

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[4] Published by the Geological Survery of India.

[5] M. ISHIMOTO, "Observations accélérométriques des secousses sismiques dans les villes de Tôkyô et Yokohama", *Bull. Earthq. Res. Inst.*, **12** (1934), 234.

[6] M. ISHIMOTO, *ditto.*

the mean value being 0·3 sec, whereas on soft alluvium ground, such as Marunouti and Hukagawa, etc., the period was much longer, with a mean value of 0·4～0·7 sec. An interesting fact[7] noticed at the time of the last Tôkyô earthquake of 1923 is that wooden buildings were affected more by this earthquake down-town than up-town, whereas of heavy construction, such as brick warehouses (go-downs), suffered more serious damage up-towns than down-town. It should be added here that the ordinary Japanese wooden two-storied dwelling houses have periods of natural oscillation of 0·3～0·7 sec., while in the case of low brick buildings they are 0·1～0·4 sec. What has just been stated can therefore be explained by synchronisation of the building with the ground vibration.

Careful studies of earthquake motion revealed that most of the short period waves that were superposed on those of large period were restricted to the superficial soil, rapidly diminishing in amplitude with depth. On comparing the magnitudes of these waves observed on the ground with those under ground, it was found that even a places 10 m below the surface, the amplitude of earthquake motion was far less than that on the ground.[8] Although, the diminishing rate of amplitude varies with the period of the motion, the mean ratio of the amplitudes above and below the surface was 2·5 : 1, the period of oscillation ranging between 0·2 and 0·4 sec. We may thus conclude that the violent motion of the ground which affects houses and other structures are mostly secondary waves produced in the superficial layer.

It has been a common experience that earthquake damage is localised in a certain area or along a certain line. In the present Indian earthquake, damage was most marked over a belt of country some 10 to 20 miles in width extending from Motihari to Purnea. Another zone of high seismic intensity, but slightly less than the former, ran from Muzaffarpur to Darbhanga. Zones of particularly weak formation seem to lie along these regions. This linear distribution of earthquake damage is often due to the existence of zones of particularly soft and weak formation and not to the fact that the seismic origin is of line-form.

In the strong Saitama (Japan) earthquake of 1931, the interesting fact was observed that the damage caused by this earthquake was in the main restricted to a narrow region along the Tone River, whereas the centre of this earthquake as accurately determined by observations was found to lie in the hilly region of Titibu, showing that the earthquake centre and the centre of the affected region do not necessarily lie close to each other. A distance of about 20 km separated the two centres.

As to the most seismic area in India, there is no doubt that the Indo-Gangetic plain and the Assam hills have the strongest claims to this honour. If an earthquake were to originate in the Great Boundary Fault forming the foot hills of the Nepal Himalaya, it is obvious that the greatest damage will occur on the vast Gangetic plain, which unfortunately, is the most densely populated part of India.

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7) T. Saita,

8) W. Inouye, "Comparison of Earth Shakings Above-ground and Underground", *Bull. Earthq. Res. Inst.*, **12** (1934), 712.

Buildings in India.

With respect to buildings in India, especially those in the northern part of the country, the following points with respect construction ought to be taken into consideration in future in order to eliminate such weaknesses in construction as have been demonstrated by the present earthquake.

(1) Use only good quality mortar and bricks: the mortar should have approximately the same strength with respect to compression and tension as the blocks which it binds. The bricks must be of regular shape and laid in a regular uniform manner.

(2) The building must be monolithic, or as near so as possible.

(3) In *kutcha-pucca* buildings, which form a considerable proportion of the town buildings, there should be no loose beams or joists in the upper floors and roofs; the falling of such loose material being a potential danger to life.

(4) The present strength of the walls must be increased: the most suitable form of wall for circumventing the effect of earthquake shocks being those of trapezoidal cross-section or of parabolic cross-section with the vertex downwards as shown in Fig. 8. As to brick buildings, of which the walls are of parabolic cross-section, the following account of experience gained from the Tôkyô earthquake of 1923 might be of interest. In this earthquake, the earthquake-proof brick building of the Seismological Observatory in the compound of the Tôkyô Imperial University sustained no damage, not a fissure having appeared on its walls. On the other hand, a brick column inside this

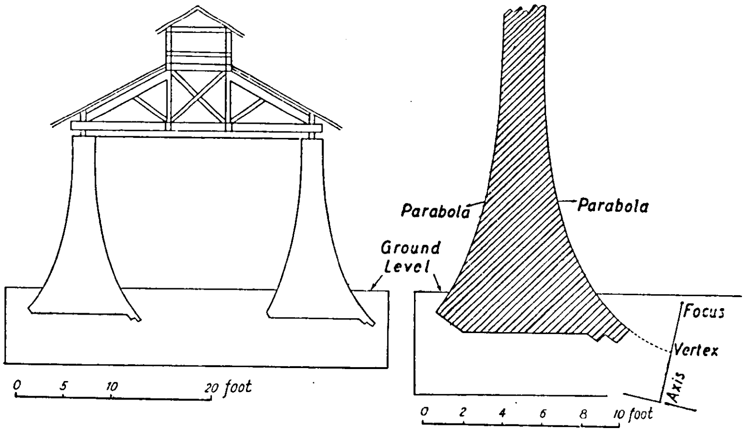

Fig. 8. Walls of parabolic cross-section.

observatory, about 15 feet high and 3×3 feet in cross-section, was fractured, and its upper part twisted at an angle of not less than 30°.

The walls of this brick building were of parabolic section with the vertices downwards, 18 ft high, 8 ft thick at the ground level, and 2·3 ft thick at the top. A tiled roof with skylight rested loosely on the walls; an entrance of about 8·5 ft ×11 ft being the only opening in them.

The walls of parabolic cross-section gave uniform strength throughout the height. The cement and mortar that were used in its construction had beed carefully tested beforehand. This building was designed to withstand any shock that is likely to occur in Tôkyô, as also to serve as a standard with which to compare the effects of shocks on brick buildings of the ordinary type. Walls of this type are recommended for *pucca* buildings, as well as for the *kutcha-pucca* building. I believe that even a *kutcha* building, provided it has walls of parabolic or trapezoidal section, will serve to reduce damage and loss of life during an earthquake to the minimum.

We shall add here the results of studies on the behaviour during an earthquake of ordinary brick walls as they used to be constructed in Japan, which form excellent data for reference in connection with future constructions.

Since damages to brick buildings by an earthquake are usually the result of fracturing of their walls in consequence of the violent horizontal shaking, vibrations of different parts of the wall were measured with seismographs, the example selected being the brick walls of the Engineering College of Tokyo. The instruments were placed near the top of the wall at the middle of its width.

Comparing the motions of the brick wall with those of the ground during earthquakes, it was found that in the case of small earthquakes, the motion consisted of vibrations of comparatively slow period, above 0·5 sec, the motion being virtually the same whether on the upper story or on the ground surface. On the other hand, in earthquakes consisting of a number of quick-period vibrations, the motion at the top of the wall was greater than that of the ground; the average ratio being 2:1. Since the period of vibrations for these two points of observation, were the same, it would seem that in violent shocks, that wall on which the roof rests, behaves like an inverted pendulum, its motion synchronizing with the earthquake motion.

Another series of measurements concerned a two-storied brick building, the walls of which were evidently weak. The seismograph was attached to a 53 feet wall at a height of 31 feet from the ground. In this case the wall was shaken considerably by earthquakes, both the duration and the amplitude of motion being nearly three times those of the ground. The period of natural oscillation of the wall practically constant with a mean value of 0·33 sec., which shows that in an earthquake a weak wall behaves exactly like an elastic spring and executes vibrations of its own period, whatever the period and amplitude of the ground motion.

Another example was a three-storied brick building, which though well designed, stood on the lower ground of Tôkyô. It was found that the motion in the 3rd story did not differ from that in the basement, showing that this brick building behaved as a single mass during an earthquake.

The foregoing examples show that the movements of a brick building during an earthquake differ widely with the quality of the structure.

Lastly, a few remarks will be made regarding the means of minimizing earthquake damage. Obviously the most effective way in which this can be done is to construct the buildings as near earthquake-proof as possible. Although there is little doubt that the reinforced concrete building with iron frame-work easily ranks first in the various kinds of earthquake-proof buildings, owing to the question of cost, to build such structures is not always practicable. During my tour of inspection in connection with the present Indian earthquake, I was strongly impressed with the suitability of the *kutcha-pucca* and *kutcha* style of buildings for India, especially in the districts devasted by the recent earthquake. The unfortunate part of it however is the inability of the average Indian householder to afford to use high grade building materials. Under these circumstances, it is then most important to build a safe structure at no greater cost than one of the old weak type. With special attention to design, it may be possible to build such houses with materials not very much higher in quality than those now in use. For one thing, the heights of *kutcha-pucca* buildings could be restricted to one story, while their walls should not be less than a standard minimum thickness and they should have a parabolic or trapezoidal cross-section.

Acknowledgements.

In conclusion, I take this opportunity of expressing my sympathy with the Government and people of India in the great sorrow and loss caused by the terrible earthquake which forms the subject of this paper.

I wish also to express my heartfelt thanks to Mr. W. E. Brett, who has laid me under obligations by his interest in my mission and placing in my hands valuable data to aid me in my studies. To Commissioner J. E. Scott and Mrs. Scott, at whose delightful home I was privileged to be guest during my stay in Muzaffarpur, I cannot sufficiently express my gratitude for their many personal courtesies which rendered my stay in India so pleasant and enjoyable. I wish sincerely to thank Commissioner Scott, besides, for his innumerable courtesies extended me in his official capacity towards enabling me to prosecute my investigations.

30. 昭和9年1月15日の印度大地震に就いて

地震研究所 那須信治

本論文には印度大地震の踏査報告に加へて本邦最近の地震學より此の地震を見て思ひ浮んだ事を記載した．殊に今回の地震の原因に就いては世上に信じられてゐるヒマラヤ南麓の大斷層の活動さのみ簡單に斷定し得られざるこさを附記した．

又被害分布さ震原の遠近は必ずしも正しき關係を有せず，土地の振動性能に著しく支配されるこさを示し今回の地震に於ける，モンギール市及びネパールの都市の如く甚だ飛び離れた地點に被害のあつたこさも要するにその土地の振動性能に左右された結果であるさし．これ等の地點の眞下に夫々震原を假定するの不自然なるこさを述べた．

各地の被害狀況は概略をのべるに止めて置いた．

本文の後半に於ては印度に多く用ひられてゐる煉瓦及び煉瓦・泥併用建築物の缺點をのぞくに有効さ考へられる事柄を箇條書さしてのべ，印度の一般家庭の現狀より到底良質高價の建築材料を使用し得ざる事を認め現在の材料をそのまゝ用ひて，より耐震力ある家屋を建てるために壁の構造には梯形或は抛物線の斷面を有するものを推賞しておいた．尙ほ煉瓦造りは印度に於ては到底放棄するこさの出來ない建物であるから，これ等の建物が地震の際如何なる振動をするかを本邦に於てなされた實測の結果を擧げ今後の復興建築の參考に供したい希望を有してゐる．

尙ほ今回の地震に於て現はれた土砂の噴出，水準變化等も最も信ずべき資料を引用して記述しておいた．

Fig. 2. Sand-deposits and fissures.

Fig. 3. Craters of ejected sand.

Fig. 4. Craters of ejected sand.

Fig. 5. Two old baked curved tiles and part of wooden cutting edge (Jamo) of the long forgotten well deposited on the surface by the outrash of sand.

(Reproduced from photographs taken by Dr. K. S. Caldwell.)

Fig. 9. *N. Nasu, Photo.*

Fig. 10. *N. Nasu, Photo.*

Fissures in the river banks near Muzaffarpur.

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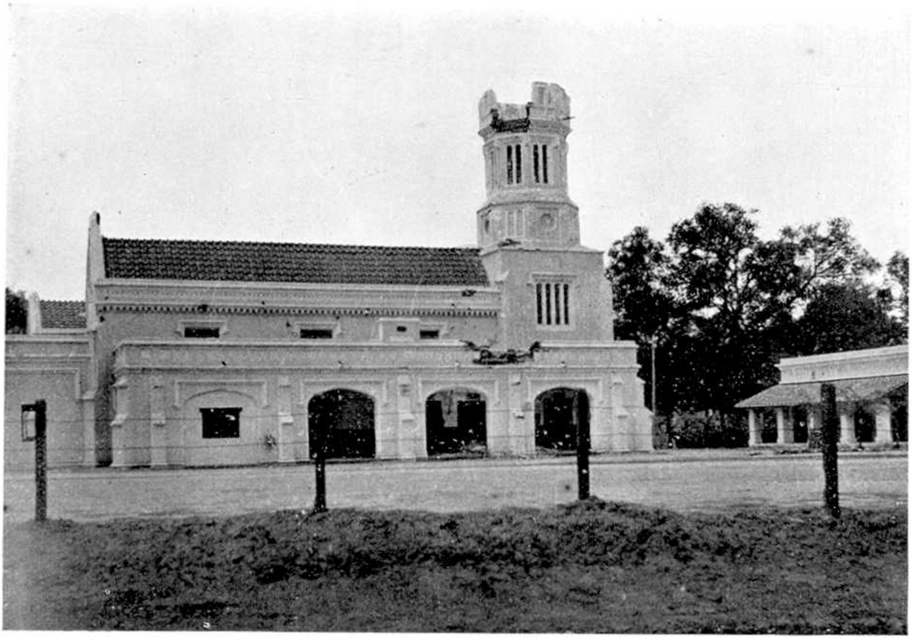

Fig. 11. An office building in Patna. *N. Nasu, Photo.*

Fig. 12. A private residence in Patna. *N. Nasu, Photo.*

Examples of houses that had their upper parts were broken off by the earthquake.

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Fig. 13. Aprivate residence in Patna. *N. Ncsu, Photo.*

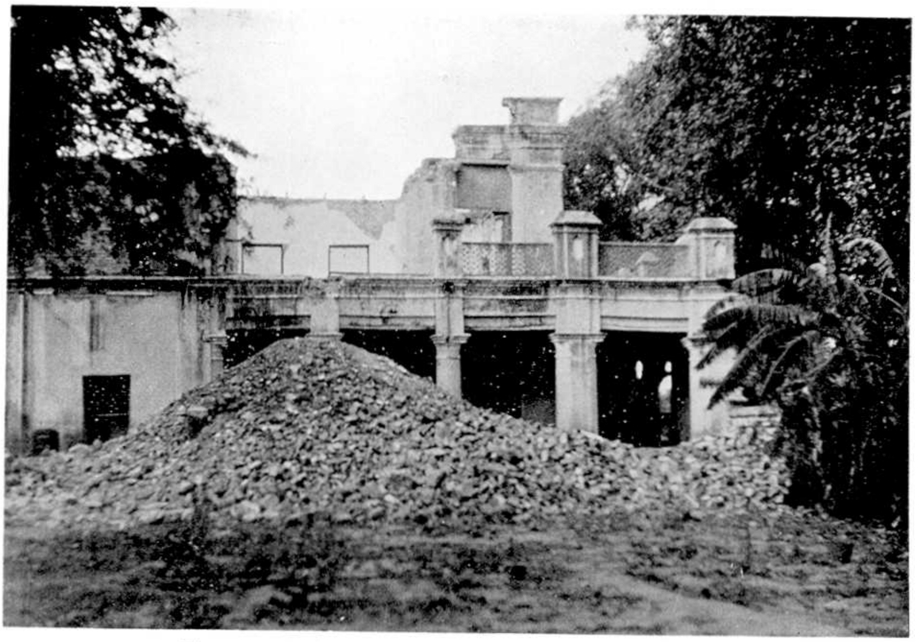
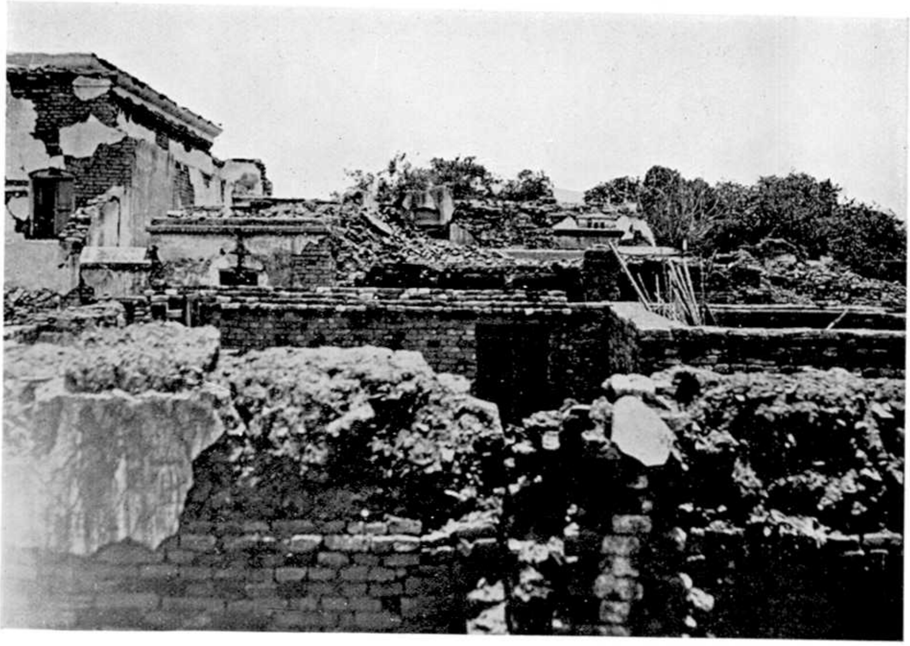


Fig. 14. Aprivate residence in Muzaffarpur. *N. Nasu, Photo.*

Examples of houses whose upper stories were severely damaged.



N. Nasu, Photo.

Fig. 15. Two-storied houses completely ruined near the Monghyr Raj's Palace.

Fig. 16. ditto. *N. Nasu, Photo.*

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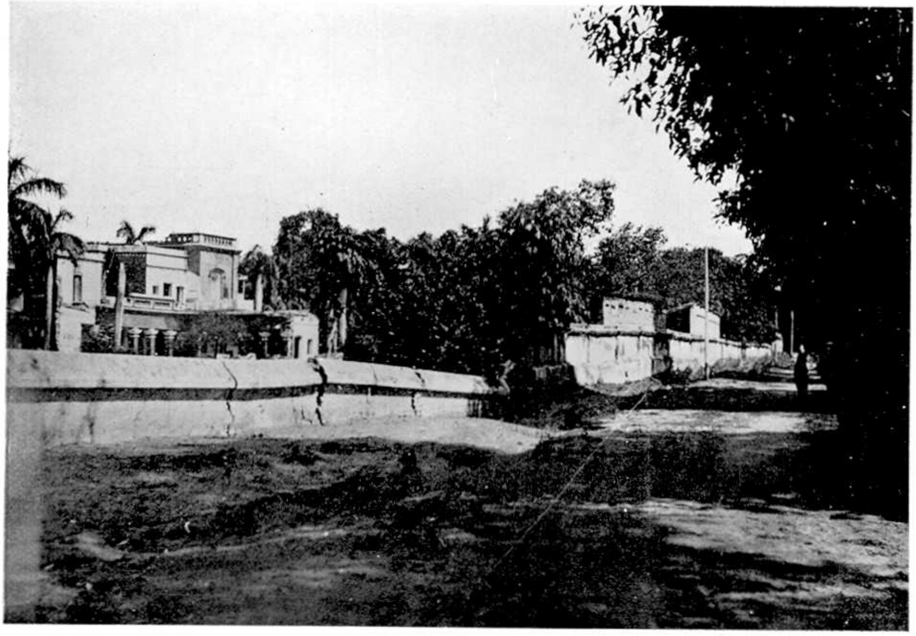
Fig. 17. Ruined town of Monghyr. *N. Nasu, Photo.*

Fig. 18. ditto. *N. Nasu, Photo.*

Fig. 19. Gate of Fort Monghyr damaged by the earthquake. *N. Nasu, Photo.*



N. Nasu, Photo.

Fig. 20. Sand, ejected from fissures (centre), covered the surface of the road. The ground along fissures subsided.