To Prof. C. G. Cullis

With the Author's compliments.

PRELIMINARY ACCOUNT OF THE EARTHQUAKE OF THE 15TH JANUARY, 1934, IN BIHAR AND NEPAL.

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(With Plates 13 to 21.)

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CONTENTS.

PREFATORY NOTE (BY L. L. FERMOR).

This preliminary account of the earthquake of the 15th January, 1934, is based on the work of four officers in the field and the very numerous replies submitted from all parts of India and Burma to the questionnaire issued by the Geological Survey of India. To Mr. D. N. Wadia was entrusted the duty of examining the affected tracts in Darjeeling and Western Bengal. His report thereon has been supplied to the Government of Bengal. To Dr. J. A. Dunn and Messrs. J. B. Auden and A. M. N. Ghosh was allotted the duty of studying the devastated tracts in Bihar. In addition, it was found possible to arrange for Mr. Auden to visit Nepal and to study the affected areas both near Katmandu and in Eastern Nepal. As a result, Messrs. Dunn, Auden and Ghosh have submitted a preliminary report on the earthquake in North Bihar, which has been submitted to the Government of Bihar and Orissa, and Mr. Auden has prepared a separate report on the earthquake effects in Nepal, which has been submitted to the Government of Nepal.

These reports were not written for publication, but for the purpose of affording advice to the Governments concerned on the suitable time and measures of reconstruction.

For purposes of publication two reports on the earthquake as a whole are necessary, namely a preliminary report in the *Records* of the Geological Survey of India at as early a date as would be compatible with reasonable accuracy: and a full report in the *Memoirs* of the Geological Survey of India to be written at greater leisure, enabling account to be taken of all available data, including seismograph records from observations in distant parts of the world, and aftershocks.

I should have preferred this preliminary report to appear as emanating from the four officers concerned in the field studies; but as Mr. Wadia had to resume field-work in Kashmir, and Dr. Dunn has proceeded on leave, this preliminary report has in fact been written by the two junior officers, making use also of the reports and notes of their senior colleagues.

On account of the public anxiety for early information on the general aspects of this earthquake, and because the cause was a good one, I thought it proper myself to contribute a short article on the geological aspects of this earthquake to the *Statesman* 'Record of the Great Indian Earthquake' in aid of the Viceroy's Earthquake Relief Fund. This article was based on reports received from the officers in the field and on the replies to the departmental questionnaire. It has been reproduced also in *Current Science*, II, pp. 442-445, (May, 1934). The views expressed therein are naturally subject to modification in the light of more detailed knowledge of the earthquake.

This prefatory note gives me the opportunity of mentioning that on account of the interruption of railway facilities and the general destruction, the officers concerned in the field investigation of this earthquake had necessarily to work under conditions of abnormal difficulty and discomfort. It is suitable, therefore, to express here the thanks of the Department to His Highness the Maharaja of Nepal and Their Excellencies the Governors of Bihar and Orissa and Bengal for the interest shown in the work of our officers and for the help provided in the course of their investigations.

The thanks of the Department are also due to all those officials and private persons who have either assisted officers in their investigations in the field or replied to the questionnaires.

I. INTRODUCTION.

Between 14 hours 13 minutes and 14 hours 14 minutes, Indian Standard Time, on the 15th January, 1934, North Bihar and Nepal were visited after the lapse of a century by a severe earthquake. The shock lasted for a period of some five minutes within the central tract. Fortunately it took place at a time in the afternoon when most of the people were awake and many were out of doors so that the number of lives lost was not in proportion to the damage done to property. The death roll, including Nepal, was over 10,000. Loss of life was mainly confined to the crowded towns of Monghyr, Muzaffarpur and the Nepal valley. The buildings involved were mostly built of bad materials and were closely packed on both sides of narrow streets and winding alleys.

Within three minutes Monghyr and Bhatgaon were in ruins, while the towns of Patna, Barh, Jamalpur, Motihari, Muzaffarpur, Darbhanga, Katmandu, and Patan, were strewn with bricks and debris. In Sitamarhi, Madhubani, and Purnea, houses had tilted and sunk into the ground, and sand and water were emitted in great quantities. In addition serious damage was done to Darjeeling in Bengal.

The shock was felt over an approximate area of 1,900,000 square miles, or 4,920,000 square kilometres, in India and Tibet. As far away as England, according to the newspaper reports, the earthquake bell at the West Bromwich Observatory stopped. Shocks were recorded in most of the seismological stations of the world. In India the shock was so strong that none of the seismographs in Calcutta, Agra, or Dehra Dun, was able to make a complete record of the earth waves. At Colaba in Bombay, the earthquake was fully recorded only by the east-west component of the Omori-Ewing instrument. The recording mechanism of the north-south component failed to register after the incidence of the secondary waves. A record from Oorgaum in South India is, however, more complete.

Within the limits of the Indian Empire the shock was felt by persons as far as Peshawar in the north-west, Fort Hertz in the east, Akyab in the south-east, Bezwada and Ongole in the south and Bombay in the south-west. In a northerly direction, beyond Nepal, no reports have been available as to the distance the shock was sensible to man, but pilgrims in Katmandu reported its occurrence at Lhasa.

The shook was not felt by most people in the Bombay Presidency from south of Poona, in Madras Presidency from south of Ongole or in Mysore. A sympathetic shock was, however, felt in the extreme south-west of India, along the Malabar coast, over an area including Mangalore, Ernakulum and Alleppey.[1] A possible sympathetic shook was felt near Moulmein in Lower Burma.

Although the news of the earthquake was received in Calcutta on the same day, especially with reference to Darjeeling, the magnitude of the disaster was not at once fully realised owing to interruptions in the means of communication. Over a large area in North Bihar roads were badly damaged and railway communication was entirely dislocated. The rapidity with which the magnitude of the disaster was brought to the notice of the public is to a large extent due to aerial surveys having been made by the Bihar Government and by private enterprise.

Shortly after the earthquake, Dr. J. A. Dunn and the authors of this paper were deputed to investigate the devastated area in Bihar from the geological point of view. At the same time Mr. D. N. Wadia was asked to visit the affected localities in Northern and Western Bengal. Subsequently it was found possible to arrange for the first author to visit Nepal. A copy of a standard questionnaire was published in the various Indian newspapers calling for public co-operation in reporting the effects of the earthquake, and, in addition, a standard questionnaire was circulated first to the most affected parts of India and subsequently to the more distant parts of India and Burma.

The field-work was not completed until the second week in April, after which Dr. Dunn and the present writers were engaged in preparing from their own field-notes, and Mr. Wadia's report, Preliminary Reports for the Governments of Bihar and Orissa and Nepal. The present report, which may be regarded as a forerunner of a more detailed one to follow in due course, has been compiled from the observations of the officers deputed to make investigations in the affected area and makes no pretensions to finality excepting as regards general descriptions and the effects of the shock. The

[1] Dr. Murray Stuart, in a private letter to Dr. A. M. Heron, Superintendent, Geological Survey of India, has drawn attention to the somewhat similar sympathetic shock which occurred at Madura in South India about six minutes after the Srimangal (Bengal) earthquake of 8th July, 1918. *See* Murray Stuart, *Mem. Geol. Surv. Ind.*, XLVI, Pt. 1, (1920).

results of a brief examination of the answers to the earthquake questionnaire issued by the Department are also embodied in this report, especially in the preparation of the lower isoseismals.

II. DESCRIPTION OF ISOSEISMALS.

Discussion of Scale.

The maps attached to this report represent the delineation of the zones of intensity according to the Mercalli modification of the Rossi-Forel scale. On Plate 20 isoseismals VI to X are shown in the regions of Bihar and Nepal and Bengal that were most affected by the earthquake. These were determined by observation in the field. The isoseismals for the whole of India are shown on Plate 19, and were determined by an examination of the replies to the questionnaires which were sent out by the Geological Survey of India. Isoseismals III and IV are not shown, since they cannot be adequately differentiated.

The Mercalli scale is given on pages 184 and 185, together with certain additions and modifications that the field party of the Geological Survey have suggested.

The extent of emission of sand from vents and fissures north of the Ganges is sufficient to warrant the inclusion of the factor of sanding as one of the criteria. In North Bihar the emission of sand is rare outside isoseismals VIII, and reaches its maximum throughout the slump belt within isoseismals IX and X. Factors, such as a capping of hard clay, tend to inhibit sanding, even in isoseismal X of the slump belt, but in general the criterion of sanding has been found useful in delineating the isoseismals.

Contrary to what is given in the Mercalli scale, it was found in Nepal that landslides occur within VIII-X, and not solely in X as is there given. The formation of landslides is a function of steepness of the mountain slopes and of the nature of the rocks involved. Rocks shattered by tectonic processes in past geological history are more unstable than those not so affected and are, of course, common in the Himalaya. The presence of minerals, such as feldspar, which are readily susceptible to weathering in a monsoon climate, and the absence of cement to the grains in the sand-rock so common in the Siwaliks, are other factors leading to instability. It is clear that shocks of less intensity than required by isoseismal X will be sufficient to disturb the false equilibrium of potentially unstable hill slopes.

TABLE 1.—*Mercalli scale of Isoseismals.*

TABLE 1.—*Mercalli*

Isoseismals.	Additional criteria.	Accelera-tion : in mm. per sec. per sec. McAdie.	Acceleration in Bihar.
I. Instrumental shock, that is, noted by seismic instruments only.	....	10	..
II. Very slight, felt only by a few persons in conditions of perfect quiet, especially on the upper floors of houses, or by many sensitive and nervous persons.			..
III. Slight, felt by several persons, but by few relatively to the number of inhabitants in a given place; said by them to have been hardly felt, without causing any alarm, and in general without their recognising it was an earthquake until it was known that others had felt it.	....	25	..
IV. Sensible or moderate, not felt generally, but felt by many persons indoors, though by few on the ground-floor, without causing any alarm, but with shaking of fastenings, crystals, creaking of floors, and slight oscillation of suspended objects.	....	50	..
V. Rather strong, felt generally indoors, but by few outside, with waking of those asleep, with alarm of some persons, rattling of doors, ringing of bells, rather large oscillation of suspended objects, stopping of clocks.	....	100	..

scale of isoseismals.

Isoseismals.	Additional criteria.	Accelera-tion : in mm. per sec. per sec. McAdie.	Acceleration in Bihar.
VI. Strong, felt by everyone indoors, and by many with alarm and flight into the open air; fall of objects in houses, fall of plaster with some cracks in badly built houses.	..	250	150 (5·9 inches per sec. per sec.) (Calcutta)
VII. Very strong, felt with general alarm and flight from houses, sensible also out-of-doors; ringing of church-bells, fall of chimney pots and tiles; cracks in numerous buildings, but generally slight.	Very rare sand vents	500	
VIII. Ruinous, felt with great alarm, partial ruin of some houses, and frequent and considerable cracks in others; without loss of life, or only with a few isolated cases of personal injury.	Moderate degree of sanding. Fissures in alluvial ground. Landslides. Slight mortality.	1,000	1,500 (4·9 ft. per sec. per sec.)
IX. Disastrous, with complete or nearly complete ruin of some houses and serious cracks in many others, so as to render them uninhabitable; a few lives lost in different parts of populous places.	Sanding intense. Extensive fissuring in alluvial ground. Landslides. Heavy mortality.	2,500	2,000 to 3,050 (6·5-10·1 ft. per sec. per sec.)
X. Very disastrous, with ruin of many buildings and great loss of life, cracks in the ground, landslips from mountains, etc.	Sanding intense. Extensive fissuring in alluvial ground. Landslides. Very heavy mortality.	5,000 10,000	3,270 (10·7 ft. per sec. per sec.)

General Description of the Isoseismals.

A study of the isoseismal lines reveals three tracts where the intensity reached the degree of X. The largest of these, a flattened but regular ellipse, occupies a belt some 20 miles in width striking W.N.W.-E.S.E. for some 80 miles from east of Motihari through Sitamarhi to Madhubani. Buildings within this area were destroyed more by slumping than by actual collapse. Another area of isoseismal X, a slightly irregular ellipse, lies south-east of Katmandu and strikes W.S.W.–E.N.E. for about 10 miles, including the town of Bhatgoan. The third is at Monghyr. The total area included within isoseismal X approximates to 1,300 square miles or 3,400 square kilometres. Within the areas enclosed by isoseismal X in the Nepal Valley and at Monghyr the majority of the buildings were practically razed to the ground.

The area of very severe intensity equal to IX on the scale covers about 14,000 sq. miles or 36,200 square kilometres in Bihar and Nepal. There are three such areas, the largest of which is bounded by an irregular elliptical curve extending 160 miles E.S.E. from west of Motihari to Purnea, and from the Nepal border to the south of Muzaffarpur and Darbhanga. The pronounced embayment of the curve on its eastern side is noteworthy. The next large one is a narrow elongated zone, which extends from Patna to Monghyr, cutting off the northern salients of the Ganges. In the Nepal valley another area within isoseismal IX includes Katmandu and Patan. Buildings within the central isoseismal IX were damaged partly by slumping and partly by actual collapse and tumbling to the ground. All the three areas are separated by wide belts of rather lower intensity in which the damage was equivalent to No. VIII on the Mercalli scale.

Isoseismal VIII encloses an area of some 31,000 square miles, or 80,300 square kilometres in Bihar, Nepal and a portion of Bengal. The most important towns situated near its edge are Bhagalpur, Bihar, Chapra and Bettiah, Darjeeling and Kurseong. A number of old and weak buildings collapsed within this belt and practically every brick-built building bore some stamp of the earthquake. With exception of two places in the Patna district, damage due to slumping and subsidence within this area was practically nil. Nos. VII, VI and V embrace still larger areas respectively. The dotted lines to the north are purely hypothetical.

The elliptical traces of the isoseismals point to the linear nature of the centrum and this dismisses at once the idea of a single point as the focus from which the earthquake impulse originated. Another striking feature of the isoseismals IX-VI is the close proximity to each other of the curves to the north-west, east and south-east of the area affected by the earthquake and their gradual opening out at the western end.

The pronounced indentations and the close similarity of the curves on their eastern sides form a conspicuous feature—although in case of isoseismal V, from the meagre evidence at our disposal, this irregularity could be modified as is shown by dotted lines in the map, Plate 19. It will be seen that in each case the crests of the curves are away from the epicentral tract whereas the troughs point towards it. North of the Ganges the bulge of isoseismal IX near Purnea, the easternmost limit of the slump zone, is repeated in isoseismal VI north-east of Dhubri, suggesting an extension of the fractured zone in this direction. The pronounced U-shaped lobe of isoseismal VI along the western edge of the Garo Hills finds a replica in the westward extension of isoseismals VII and VIII west of Dinajpur and Katihar respectively. The corresponding bulges on the south in isoseismals VIII-VI are found east of Bhagalpur, west of Malda and east of Netrokona respectively.

There is difficulty in determining the boundary of the area over which the shock was felt. Thus, a fairly consistent line runs from just south of Bombay to just south of Ongole, south of which almost all the replies to the questionnaire report that no shock was felt (Satara, Sholapur, Kurnool, Nellore). Yet, the shock was felt very slightly by two people near Madras and by two others at Dharwar. We have drawn isoseismal line II to separate the area over which the shock was felt in general from that over which the great majority of people failed to notice a shock. The estimated area of 1,900,000 square miles, over which the shock was felt iy general, is that enclosed by isoseismal II. On account of the paucity of replies, isoseismals III and IV cannot be properly differentiated.

As will be noticed on Plate 19 a shock was recorded at about the same time as the main earthquake in the south-western coastal region of Peninsular India including South Kanara, Coorg and Travancore where the intensity, in places, reached a degree of six on the Mercalli scale (see footnote, page 181).

Detailed Account of Isoseismals.

Isoseismal No. X.

Within the Sitamarhi-Madhubani area a general subsidence of the ground took place, giving rise to widespread fissuring and to destruction of buildings by tilting and breaking up of the foundations. In large sub-divisional towns such as Sitamarhi and Madhubani, many buildings slumped bodily, or individual walls slumped relatively to adjacent walls. Although the actual collapse of houses, in the sense of tumbling to the ground, was not excessive, not a house of any weight within this area escaped tilting and sinking and few are inhabitable, especially at Sitamarhi. This means entire ruin and leaves no alternative but to rebuild the houses. Fissuring of the ground in this belt is severe and emission of sand reached its maximum, filling up houses, streets and drains in towns and covering the countryside with thick mantles of sand. Wells were choked with sand almost to the brim. Fissures and sand vents threw out sand three to four feet deep, the thickness dying out away from the centres of ejection. Sand and water vents and crater-like depressions lay in profusion in the lowlands. The walls of heavy buildings, such as the Raja of Darbhanga's palace at Rajnagar, were dissected by gaping cracks a foot or more wide. Over considerable sections in this area roads and causeways subsided; embankments originally six feet high were found at ground level, and borrowpits alongside the roads were often filled with sand. The majority of masonry bridges on the various roads had either collapsed or were severely damaged. Screw-pile bridges fared better, although many of them were severely twisted and buckled. As will be seen from Plate 20, the whole of this area lies within the slump belt which extends from the eastern part of the Saran district as far east as Purnea.

Sitamarhi-Madhubani area.

Monghyr is an old town built both on alluvium and on Archæan rocks. This was the worst affected town in Bihar, and here the devastation was most spectacular as far as the collapse of buildings was concerned. The devastation was greatest at the Chauk section of Monghyr bazar where houses collapsed wholesale and scarcely a building or wall was left standing. The remainder of the bazar was, however, much less affected. As a rule buildings on rock outcrops were damaged less than those on alluvium. The north-west corner of the town within

Monghyr.

the Fort suffered but slightly. The main damage to *pucca* buildings occurred along the north wall of the Fort, particularly at the eastern end, that is, on the alluvium at the edge of the high ground, where all the buildings were destroyed. It will be apparent, therefore, that only a portion of Monghyr can be placed in No. X isoseismal. The damage done to buildings at Monghyr was entirely due to the severe shaking which the town received ; neither fissures nor slumping of the ground were noticeable except near the edge of the river on the north. The general direction of collapse throughout Monghyr was mainly to the east.

Nepal valley.

The area in the Nepal valley enclosed by isoseismal X runs E.N.E.–W.S.W. through Bhatgaon, Harisidhi, Khokana and Bagmati. Bhatgaon shows about a 70 per cent. collapse of houses, while at Harisidhi, Khokana and Bagmati there has been total destruction. Destruction in Bhatgaon is not uniform, counts along the streets showing six out of six, seven out of nine, five out of six and two out of five houses destroyed. Temples have suffered less, and houses, built of polished brick, neatly and closely fitting, have generally escaped. The famous Nyatpola temple, five stories high, is surprisingly undamaged. The Vhairaba temple has collapsed. The condition at Harisidhi, Khokana and Bagmati is one of complete ruin. At the time of visit, one month after the earthquake, bodies were still being recovered and it was often impossible to distinguish street from house. In spite of this destruction of houses, there is little in the condition of the ground to suggest a violent earthquake. Even along the edges of the river terraces there has been little slipping. The only observed occurrence of a sand vent in the Nepal valley was near Harisidhi. Subsidence of the ground, and tilting and slumping of the houses are entirely absent. The type of damage is similar to that at Monghyr.

Isoseismal No. IX.

North Bihar.

As in the case of isoseismal No. X, there are three areas enclosed by isoseismal No. IX. The largest area lies in North Bihar and along the Terai and southern ranges of Nepal. The presence of towns along the eastern, southern and western borders of this area enabled a fairly accurate demarcation to be made in these directions. To the north, in Nepal, towns are absent (Udaipur Garhi is only a village) and the boundary there is somewhat hypothetical. Moreover, it was only possible to visit a limited number of places in Nepal, and the local officials who were encountered appeared to know nothing of the condition in neighbouring districts.

The slump belt is completely enclosed by this isoseismal. Within the part of this belt included within isoseismal IX the damage was on the whole similar to, but less intense than that in the more localised region of isoseismal X. Outside the slump belt, in places such as Muzaffarpur and Darbhanga, there was widespread shaking and collapse, but less tilting and subsidence. Prominent fissures and faults in the alluvium were generally confined to the vicinity of such depressions as rivers and lakes. Emission of sand and water was also prominent within parts of isoseismal IX not included within the slump belt, but was more or less independent of slumping.

The phenomenon of slumping is probably exhibited in those areas close to the focal region which at the same time had favourable ground conditions. The belt of regional subsidence believed to exist as a result of the re-levelling operations of the Survey of India is roughly but not exactly coincident with the slump belt. Both regional subsidence and slumping are probably in the first instance functions of distance from the focal region, but the latter is modified by local ground conditions so as to be more localised.

Kutcha-pucca buildings suffered more damage than *pucca* buildings or mud huts. Well built masonry structures, especially if of two or more stories, did not, however, escape, as is witnessed by the destruction of the Agricultural Research Institute at Pusa, and the palaces of the Darbhanga Raj at Darbhanga.

A feature of the damage in the region enclosed by this isoseismal and that of No. X, is the number of earthquake shadows present.

Earthquake shadows.

Between Muzaffarpur and Sitamarhi there are at least two zones along which destruction is small. The damage to buildings in any one town also presents anomalies. A further discussion of this phenomenon must be withheld until the fuller account is written.

It may not be out of place to quote from the report of Mr. J. Williamson, Agent to the Bengal and North-Western Railway, which admirably sums up the damage done to railways within isoseismals X and IX.

'Of the 2,100 miles comprising the Bengal and North-Western and Tirhut system it may be said that on 900 miles traversing North Behar and the eastern United Provinces hardly a mile of track was undisturbed; embankments settled

and even disappeared entirely, the rails remaining suspended; elsewhere they were raised or shifted many feet laterally. The permanent way even where least distorted may be likened to a construction line on a high new bank which has passed through a heavy monsoon without attention. So severe is the distortion in places that a trolly could not be safely taken round the kinks. Not a bridge remains undamaged from minor cracks in arches, wing walls and abutments, displaced piers and girders, to complete destruction. Training works and guide-banks of large bridges have been cracked and shaken. ...... Deeply founded piers and wells of large bridges have been moved many inches either longitudinally to the bridge or laterally.'

Patna to Monghyr.

A narrow zone of high intensity, reaching the degree of IX on the Mercalli scale, extends from Patna eastwards to Monghyr, cutting off the northern saliente of the Ganges. The important towns affected within this zone are Patna, Barh, Monghyr and Jamalpur.

In Patna the worst damage took place along the river front. This is not entirely due to the fact that the oldest structures are located here, as several fine modern buildings were also severely damaged. Similarly, at Barh the effects of the earthquake were more pronounced approaching the river. The destruction at Monghyr was perhaps more severe than in any other large town in Bihar; in the Chauk section of the bazar practically every building within an area of 12 acres was completely razed to the ground. Those buildings erected on the high ground of Archean outcrops were on the whole the least damaged. At Jamalpur the bazar area and railway quarters near the station were most severely damaged, but the newer buildings towards the outskirts of the town on the east and south sides were scarcely affected.

Nepal valley.

The greater part of the low-lying areas in the Nepal valley is included within isoseismal IX. The towns of Katmandu, Patna, Thimi and Thankot were all severely damaged, showing approximately a 25 per cent. collapse of houses. Thankot lies in a small area of isoseismal IX, which is separated from the main area by a continuation of the Kirtipur ridge.

The actual position of isoseismal line IX is determined by the relationship between the soft unconsolidated fluviatile and lacustrine sediments which make up the low-lying portions of the valley, and the older, harder, pre-Tertiary rocks, which form an irregular rim to the valley. The pre-Tertiary rocks are granite, gneiss, quartz-schist, calcareous quartzite, limestone and quartzite

Villages situated on outcrops of these rocks escaped severe damage and frequently have suffered scarcely at all. This is especially evident in the area between Pashupatinath, Boddhanath, Gokarna and Sundarijal. The ridge of Kirtipur and the hill of Swayambunath have also escaped. It was found that damage to property on the recent, loosely-compacted sediments of the valley bears little relationship to the nature of the sediments locally present. Gravels, sands and clays proved equally ineffective in damping the shock.

Fissuring is very rare in the Nepal valley, and has been noticed only on the parade ground at Katmandu and along the flats bordering the *nala* near Nakhandol. No sand vents were seen within the area enclosed between isoseismals IX and X. The disturbance to the ground is clearly less than that within the Gangetic alluvium of North Bihar and the Nepal terai. This may be explained by the fact that water-logged sands are absent from the Nepal valley; any excess of water in the strata flowing out from the edges of the terraces in the alluvium.

The palaces and houses in the bazar are equally affected by damage. Some of the temples of superior construction, and many houses built of neatly-fitting polished brick, escaped. In the palaces, the wings and upper stories suffered the most.

As in Bihar, one of the chief factors responsible for the loss incurred is the poor quality of the materials employed in construction.

Isoseismal No. VIII.

Isoseismal No. VIII encloses an area of 31,000 square miles (80,300 square kilometres) in Bihar, Bengal and Nepal. The line was demarcated with fair certainty in British India. In Nepal it was crossed or approached in three places. The form of the line near Katmandu is influenced by local topographical, and presumably geological, conditions. Chainpur and Taplejung indicate an intensity of about VIII, so that the line near these places is definite. The important towns affected within this zone are Dhankuta, Darjeeling, Bhagalpur, Khagaria, Samastipur, Chapra and Bettiah.

Collapse of old houses is general. Damage is seen also in the upper stories, wings and porches, of newer houses, and in the fall of temple spires and mosque minarets. Many mud houses in the

Begu Sarai subdivision, north of Teghra, were razed to the ground. Destruction was particularly prevalent near the western bank of the Gandak in Saran district, which is close to the western end of the slump belt.

Fissures and sand vents occur sporadically within the area enclosed by isoseismal VIII which lies north of the Ganges, but are considerably less in importance than within the higher isoseismals. Few wells in this area were reported to have been choked with sand.

Railway bridges and permanent ways north of the Ganges suffered considerably, but not to the same extent as those within isoseismals X and IX. Two 200 feet girders of the Inchcape bridge on the Gogra, west of Chapra were thrown down; several piers of the Bur Gandak bridge near Rushera Ghat were fractured and had girders displaced; a pier of the Bur Gandak bridge near Khagaria was sheared and the 100 feet spans of the Bur Gandak bridge near Samastipur had overridden the roller bearings.

A zone of rather high intensity at the S. S. W. corner of the isoseismal stretches for over 50 miles in a W. N. W.-E. S. E. direction from south-west of Arrah to east of Bihar, where many of the buildings were severely fractured. North of this belt, and south of isoseismal IX, the damage is distinctly less. This belt has been separated from the normal isoseismal VIII by dotted lines, and is designated VIII +. Fissures and sand vents were formed at Bikram, south of Hilsa, north of Luckee Sarai and north-east of Sitakhund. At Bikram they were accompanied by subsidence of buildings. In general, fissures and sand vents are absent south of the Ganges.

The eastward continuation of isoseismal VIII includes the hill stations of Darjeeling and Kurseong. Mr. Wadia reports that in Darjeeling several houses have totally collapsed. Others were damaged by the crashing of heavy masonry chimneys through roofs and upper floors. Ground fissures were present at several places in Darjeeling, Tindharia and the Nepal hill villages.

Isoseismal No. VII.

Isoseismal VII has been prepared in the main from the answers to the earthquake questionnaire. The comparatively large area circumscribed is marked by a rapid diminution in apparent intensity as expressed in house damage. Within this isoseismal one is obviously getting away from the epicentral tract to areas where the destructive power of the earthquake becomes visibly less. Within isoseismal VIII, the effects of the earthquake were sufficiently strong to invite general attention, whereas within VII a detailed enquiry had to be made before the violence of the shock could be gauged. In course of his investigations at Gorakhpur the second author would not have noticed any damage wrought by the earthquake but for information from local residents. The outward normal appearance of buildings gave no hint that an earthquake had taken place. Nevertheless, several large towns situated on the banks of the Ganges such as Mirzapur, Benares and Allahabad evinced a certain amount of major damage of the nature of collapsed houses, fallen chimneys, and severe cracking of walls.

The delineation of the southern boundary of this isoseismal is the result of the visit of Dr. Dunn to south Bihar and the Hazaribagh district. Two isolated zones of increased intensity, running approximately W. N. W.–E. S. E., occur within this isoseismal. The more westerly of the two includes Gaya. The other is in the Santhal Parganas between Jasidih and Dumka.

Lower isoseismals.

The description of the lower isoseismals is withheld until the publication of the final account.

III. PHENOMENA.

Fissures, Sand and Water.

General.

One of the most remarkable features of the earthquake is the extent of emission of sand and water from fissures and vents. This is, of course, a common phenomenon in earthquakes in alluvial country, but it may be doubted if any earthquake in historical times can equal that of Bihar in the extent of this phenomenon. Approximately 18,000 square miles (46,000 square kilometres) within isoseismal VIII and higher isoseismals were more or less affected, and 11,000 square miles (28,500 square kilometres) extensively so. Sanding reached its maximum within and close to the slump belt, which has an area of 4,700 square miles (12,200 square kilometres).[1]

It seems to have been a general experience that the uprise of sand and water took place after the main shock had subsided, sometimes as much as several minutes. One observer at Segauli noticed that it began at 14-20 hours and continued for about three hours. Mr. A. Macdonald, of Ryam Sugar Co., Darbhanga, states that fully six or seven minutes elapsed before ejection of water and sand took place. Wells continued overflowing there for 1½ hours.

R. D. Oldham[2] quotes observers caught by the Assam earthquake who noticed the same delay in arrival of the water and sand.

The height reached by the geysers was stated to be as much as 30 feet, a most improbable figure. Reliable observers give the maximum as from six to eight feet. Generally it was less. In many cases a gentle flowing up through fissures was all that was observed.

The experience of Mr. C. H. Gordon, General Manager of the Sursand Raj, may be quoted. He writes :—

'—— a little after two o'clock, I should say, my car began suddenly to rock in a most dangerous fashion ——. Owing to the sound of the engine I noticed no noise, but was told such was heard from the west, a deep terrifying rumble. As the rocking ceased, mud huts in the villages began to fall. To my right a lone dried palm trunk without a top was vigorously shaken, as an irate man might shake his stick, then water spouts, hundreds of them throwing up water and sand were to be observed on the whole face of the country, the sand forming miniature volcanoes, whilst the water spouted out of the craters, some of the spouts were quite six feet high. In a few minutes,—— as far as the eye could see, was vast expanse of sand and water, water and sand. The road spouted water, and wide openings were to be seen across it ahead of me, then under me, and my car sank, while the water and sand, bubbled, and spat, and sucked, till my axles were covered "Abandon ship" was quickly obeyed, and my man and I stepped into knee deep hot water and sand and made for shore. It was a surprisingly cold afternoon, and to step into such temperature was surprising.'

[1]The parts within isoseismals IX and X within the Himalaya are free from sanding.

It is, of course, impossible to give any reliable quantitative estimate of the volume and weight of sand emitted. Some idea, however, of the order of magnitude may be obtained by making the following assumptions, and confining our attention to the slump belt. If we assume a uniform thickness of 5 cm. of sand of specific gravity 2·3 over 5 per cent. of the slump belt, the area of which is 12,200 sq. km., then the volume of sand emitted is 0·03 cubic km. (0·007 cubic mile) and its weight in round numbers is 70,000,000,000 kg. (69,000,000 tons).

These figures are given solely to afford a mental picture of the order of magnitude. A far greater area than that of the slump belt was covered by sand, but outside this belt less than, and generally only a small fraction of 1 per cent. was so affected.

[2] *Mem. Geol. Surv. Ind.*, XXIX, pp. 25, 26, (1899).

The sand came up everywhere; along borrow pits by the sides of roads, into fields, through the floors of houses and factories; and into wells till it overflowed from their tops. Hundreds of wells were left completely choked. About 3,000 cubic feet (85 cubic metres) came up through one portion of the factory floor at Barachakia.

Fissures and lines of sand vents were found generally to follow pronounced surface features such as river banks, lakes, tanks, ditches, road and railway embankments, when these were present. Along the Slump belt sand came up in quantity around the plinths of sunken buildings. Borrow pits alongside road causeways were extensively filled up with sand throughout the country within isoseismals IX and X. In flat country devoid of such features, fissures and sand vents were only occasionally seen to run in any constant direction. More generally they occurred as an irregular network.

Fissures.

The dimensions of the fissures varied greatly. One south of the Agricultural Research Institute at Pusa was 700 yards in length, three inches wide and from five to ten feet in depth. More usually they are less than 100 yards in length. It is doubtful if any extended as open fissures for more than 40 to 50 feet in depth for a period of more than a few seconds.

The fissures varied considerably in character. One type was devoid of sand, and occurred often in the form of step faults. Another type, which grades into lines of closely-spaced sand vents, emitted copious discharges of sand and water. A third type resembles trough faults, in which a portion of the ground sank between two parallel fissures. The maximum width which came to our notice was 26 feet 9 inches. Fissures of this type were usually accompanied by sand and water.

Sand vents.

In places the surface was riddled with sand vents, sometimes so completely that small areas might be compared with boiling porridge (Plate 15, fig. 2). In some places they were found to follow certain directions but they were generally clustered together haphazardly over the area. These vents can be divided into two types as follows:—

The first type simulates miniature volcanic craters, having a low conical, ring-shaped mound with a shallow depression in the centre. The diameter of such vents and cone of extruded sand varied from a few inches to 20 feet. The vents were generally confined to low marshy lands, old river beds, borrow pits on both sides of roads, causeways and railway embankments. In a few instances they were found at the bottom of large fissures.

The second type of sand vent is in the form of a crateriform hollow having a big depression in the centre with the inner walls sloping towards the centre of the hollow forming a large basin. Much sand and water were discharged from vents of this type. The two diameters of an elliptical blow-hole of this type at Muzaffarpur were found to measure 25 feet by 10 feet. Another at Rajnagar was still larger.

Nature of sand.

The sand that came out of fissures and vents was not uniform, either in texture or in composition. This is in accordance with the heterogeneous nature of the alluvial strata from which it was derived. The texture varied from very fine silt to coarse sand. The colour when wet was generally dark ash-grey to grey but became paler as the sands were dessicated. The darker sands owed their colour to finely disseminated particles of carbonaceous matter and to flakes of biotite. North and east of Muzaffarpur, a copper-coloured mica was prevalent in the sand. In Saran district, a rusty yellow sand was common.

Ejectamenta.

In a few places, such as Purnea and Rajaputty, spindle-shaped lumps of semi-compacted mud and silt were ejected. These were often markedly polished and striated as a result of the swirling motion imparted by the water on their upward journey. The largest of these lumps which has come to our notice is one foot in length and 5¾ inches in width. At Chakia, in Champaran, pieces of wood were ejected.

Depth of sand.

The geysers of water and emissions of sand probably formed the most striking of the various impressions formed by those caught in the earthquake. A phenomenon so unique would tend to be explained by recourse to unique conditions. Some, on analogy with geysers in volcanic areas, assumed the influence of vulcanism. With this we are not concerned. It was also suggested that the minimum depth from which the sand came was 250 feet, and that some of it may have risen from depths as great as 600 to 800 feet. The deepest bore-hole, so far as we know, put down in Bihar north of the Ganges is 452 feet. There is no information about the strata at greater depths, and it is impossible, therefore, to assign definite depths of origin lower than that of the deepest bore.

These high figures are not borne out by our investigation. The sand and silt that were emitted often did not differ from that found along present river beds. Mr. Kemp of Pipra, Champaran, states that the sand locally emitted, is similar to that found between about the 40 and 50 feet levels in the deeper wells. Dr. K. S. Caldwell, of the Science College, Patna, suggests a depth of about 20 feet for the sand in the Muzaffarpur district. Water-bearing sands are common at about this depth below ground level and it is very probably the sand down to which the wells penetrated, that was forced up to fill them. By a well at Sagauli Sugar Factory it was noticed that three different types of sand had come up, presumably from three different strata at varying but shallow depths below the well. The casings of two tube wells at Sagauli were both sheared off at 53 feet below ground level, making it impossible to sink rods down after the earthquake. Evidently there was differential movement of the strata, and it is possible that this was accompanied by concomitant loss of sand from this level.

The universality of the sand in some places, and the closeness of the vents, suggest no great depth for its origin, since the greater the depth of the channels leading up to the vents, the more localised and separated would they probably be.

The topmost water-bearing sand is the horizon that would be most under the influence of the larger amplitude and range of vibration exhibited by earthquake waves acting on the free surface of the alluvium, and hence would be freest to escape through fissures and vents. This does not prove, however, that all the sand or water was of shallow origin. It has just been mentioned that three different sands came out of one well at Sagauli. Further, the lumps of clay which came up with the sand at Purnea and other places, are so well rounded that some considerable distance of transport through channels is indicated. Purnea lies on a bed of sand some 80 feet thick, and the clay must have come from some depth greater than this. Water from the deepest affected strata at any one place will carry with it sand from the various overlying water-bearing sands through which it is forced.

It may be pointed out that in sinking *mota* or cavity wells in alluvial ground, water-bearing sands, when first encountered, are often forced up from below in sufficient quantities to fill up the well.[1] Such *mota* wells require an impermeable stratum of clay above the water-bearing sand. Under normal conditions, therefore, in alluvial country, there may often be a considerable head of pressure to the water in alluvial sands. An earthquake causes the fissuring of the overlying beds and the compression of the water-bearing sands, which may in places have already been under hydrostatic pressure.

Dr. Coggin Brown, in a letter to *Nature*[2], states, following Oldham, that the requisite condition for the emission of sand and water is a bed of impermeable clay. The inertia of this is believed to cause a compression of the watery sub-stratum and the expulsion of the water and sand through cracks formed simultaneously above. This does not seem a complete explanation, since sand vents were noticed in Bihar in regions where clay is absent. Often, indeed, a thick bed of clay seemed to form an impermeable cap to the sand, preventing its emission, probably because it was tenacious enough not to fissure and afford avenues of escape.

The fact that sand and water frequently came up after the shock had subsided suggests that the inertia of the overlying stratum is not the main cause of the compression, since differences in inertia would cease to be of importance once the ground movements caused by the shock had ceased. It is possible that water, already under hydrostatic pressure under natural conditions, rose upwards as a result of the breaching of the overlying strata, and continued to flow until the pressure was relieved.

Since the water in the sands tapped by the wells is clearly not under a hydrostatic head, an argument might exist for supposing that the water which did emerge from a depth indicated a similar depth for the sand. The shallow depth of most of the sand is, however, suggested by the arguments given above. The water, on the other hand, probably came both from the higher water-bearing sands and from lower down. Compression caused by earthquake waves was probably responsible for the relatively rapid emission of sand and water from higher horizons, while the water which continued to flow for sometime afterwards may have come

[1] Lacey, 'Hydrology and Ground Water', p. 139, (1926).
[2] *Nature*, Vol. 133, p. 295, (1934).

from lower depths where long-standing hydrostatic pressure too took some time to be relieved.

The depth of this water is unknown. The fact that the water was frequently reported to have been hot is some indication that it may have come from a fair depth. In the field we discounted at once most stories regarding the temperature of the water, as being an attempt to attribute unique properties to what was thought to be an unique phenomenon.[1] Thus, at Mushari the water was said to be so hot that it withered the local cane. Mr. K. L. Khanna, Sugar Cane Research Specialist, who was at Mushari at the time of the earthquake, stated that the temperature of the water was in reality about 21°C (70°F). It was more difficult, however, to discount the evidence of reliable people who stated that in places the water was hot. Mr. Dobson, of Belsund, was positive that the temperature of the water coming up in his compound was that of a hot bath, say 43°C (110°F). Belsund lies in the epicentral tract.

Effect on Rivers.

Himalaya.

There is little information about changes of level in the Himalayan rivers. Mr. Campbell Martin, of Bagaha, noticed that the Gandak river rose at Tribeni Ghat about five feet between 17-30 and 18-00 hours on the 15th January. At Bagaha the rise was recorded between 22-00 and 23-00 hours. Villagers in Nepal along the Trisuli Ganga (a tributary of the Gandak) did not notice anything extraordinary. Again, lower down the Gandak, in Bihar, no such rise was observed. Allowing for a decrease in the rise down the river, it is nevertheless improbable that one of five feet at Tribeni Ghat would not be accompanied by some effect lower down towards the Ganges. Either the observation of five feet at Tribeni Ghat was exaggerated, or the rise that may have occurred lower down the Gandak was not noticed owing to its having occurred during the night.

No difference in level was noticed in the Tawa Khola below Udaipur Garhi.

[1] After submission of our Preliminary Report on the earthquake to the various local authorities, it was pointed out to us by Captain Bomford, of the Survey of India, that on a cold day, such as that of the 15th January was, the hand would have the impression of considerable warmth when placed in water itself of fairly low temperature. Of this, we may say, we were aware, but lack of time and space forbade any discussion in that report of the phenomenon presented by the earthquake.

At Mulghat (26° 56′ : 87° 20′), on the Tamur river, a rise of about two feet was recorded, the water remaining at an abnormal level for two days. A small *nala* flowing into the Arun river one mile south of Legua Ghat (27° 08′ : 87° 16′) flooded strongly just after the earthquake.

In some rivers in Bihar the water level rose soon after the earthquake and continued to be high for some time afterwards. This was especially noticeable in the Balan river north of Teghra, where the level of the water was found to be three or four feet above the normal height for February. In some instances, the river banks closed in on either side causing a considerable restriction of the waterways.

Bihar.

As regards the behaviour of rivers at the moment of shock Mr. Mansfield, Collector of Bhagalpur, quotes evidence that the Balan river, on the border of Darbhanga and Bhagalpur districts, became dry for a few seconds. This locality was along the line of continuation of the epicentre, and temporary uplift of the river bed would fully explain the phenomenon. Mr. J. Williamson, Agent of the Bengal and North-Western Railway, mentions an eye-witness at Monghyr who saw the bed of the Ganges run dry for a few seconds. In some places along the Ganges the water piled up along the south bank and then receded, as would be expected under the impulse of the larger surface undulations. At Luckee Serai one observer remarked that the water receded from mid-stream and sand gushed up from the exposed bed of the river. At Sitamarhi and Raxaul there was considerable silting up of the streams.

Mr. Wadia quotes Captain L. E. Whitehead, Pilot Superintendent of the Lower Ganges section of the India General Navigation and Railway Company, as stating that the water in the Ganges is 2 feet 6 inches deeper over five shoals between Colgong and Goalundo. These shoals, which occasioned difficulty in navigation before the earthquake, are now easily negotiable.

Increased Flow of Water in Mines.

That the superficial layers of the earth's crust received a severe shaking away from the epicentral tract is evident from reports received from numerous collieries in Bengal, Bihar and Orissa, dealing with the disturbance in the underground circulation of water. The mine areas are situated within isoseismal VI. Although a few mines reported no increase of water, in the majority there was a large influx, amounting to a 50 to 400 per cent. increase of flow above normal. The rise continued for some time after the shock, and conditions were not restored to normality even after two months had elapsed. It appears that there was sometimes a decrease of flow in the higher mines, while that in the lower mines showed the greatest increase. In some cases water appeared from old fissures which had been dry for years.

Landslides and Lakes.

Landslides occurred in the mountain areas near Katmandu, Udaipur Garhi, and in Eastern Nepal.

Katmandu.

The falls round Katmandu are confined chiefly to highly weathered granite-pegmatites, which crop out on the south face of the Sheopuri Lekh, the ridge which forms the northern rim of the valley. No loss of life was recorded from them. Other minor falls were seen near Bhimphedi, in phyllites and quartzites.

Udaipur Garhi.

The hill sides in the neighbourhood of Udaipur (26° 55′ : 86° 32′) are everywhere scarred with rock falls (*see* Plate 16, fig. 2). These are most noticeable in gneisses and schists of the Mahabharat range to the north, where vegetation is scanty, but actually such rock falls are as common in the jungle covered Siwalik rocks to the west, south and south-east. No cases of death were reported. The falls in the Siwalik sandstones near Muksar (26° 52′ : 86° 23′) have blocked the local nulla in four places forming lakes. Two of these lakes have since emptied. The larger of the remaining lakes is about 600 feet long with a probable maximum depth of 25 feet. The lake now flows through a small overflow channel across the slip and is rapidly silting up. There is little likelihood of danger to villages lower down from a burst during the monsoon, partly on account of silting and partly due to the fact that there is a broad valley half a mile lower down, over which any water that did burst through would spread out to a negligible depth, thereby dissipating its force.

Dharan, Dhankuta.

A landslide five miles north-west of Dhankuta (26° 59′ : 87° 21′) caused 30 deaths, and another nine miles distant in the same direction caused 13 deaths. The rocks that have slipped here are gneisses and mica-schists. On the north side of the ridge between Dharan and Mulghat, near Dharapani, is a conspicuous landslip which has breached the path. This is in shattered quartzites. It is probable that a large block of quartzite, weighing thousands of tons, will topple over in the near future.

Taplejung.

There are two large areas of landslide near Taplejung (27° 21': 87° 40'). One is about three square miles in extent and lies one mile north of village. It originated in 1927, apparently as a result of the heavy monsoon of that year. The other lies three miles to the E. S. E. of Taplejung and is said to have started in 1924. The slips due to the earthquake are quite unimportant. They are seen sporadically all the way from Taplejung to the Nepal-Darjeeling frontier, interspersed with older slips.

Darjeeling.

No landslides were noticed on the traverse through the Darjeeling district from Nepal. Mr. Wadia reports that the earthquake had no apparent effect on even such unstable areas as the old landslide at Happy Valley.

Slump Belt.

Along a belt of country in North Bihar, enclosed by isoseismal IX, and including the epicentral tract bounded by isoseismal X, there is found to be an intensification of those effects of earthquakes generally manifest in alluvial ground.

This belt was termed the *slump belt* by Dr. Dunn and was meant to indicate the area in which tilting of houses and subsidence of ground were more marked. It encloses an area of 4,700 square miles or 12,200 square kilometres in Bihar. It extends for about 190 miles in a W. N. W.–E. S. E. direction, enclosing wide areas in the Champaran district on the west through Muzaffarpur and Darbhanga district, to as far as Purnea on the east, where it narrows down considerably. On the north it includes, by inference, portions of the Nepal terai.

The chief criterion adopted in the demarcation of this belt is the behaviour of buildings and other structures. These have tilted and slumped bodily into the alluvium, but have seldom tumbled brick from brick. Sinking was often differential, in proportion to the relative pressures of the parts of the buildings per unit areas. Subsidence of road causeways and railway embankments was marked, while fissuring and emission of sand and water reached their maximum development along this belt. The effects of slumping were on the whole more marked along lowlands, marshes and near the edges of rivers, lakes and tanks, but were not confined to such localities.

The damage to buildings along this belt is in contrast to that of the area between Muzaffarpur and Darbhanga, where houses were razed to the ground. The fact that both these belts stretch so far in E. S. E.–W. N. W. direction, crossing rivers and intervening higher land, suggests that their distribution is not primarily associated with the height of the ground water level, for it is improbable that the water table is a uniform height below surface both near the rivers and along the intervening higher land. The explanation of the difference in the type of damage between these two belts is probably to be sought for in their disposition relative to the focal region of propagation of the earthquake. The epicentral tract and the slump belt, lying vertically above the focal region, received vertical shocks rather than oblique. Muzaffarpur and Darbhanga, on the other hand, being further removed from the focal region, received an oblique shock, and suffered less slumping but greater shattering.

Re-levelling by the Survey of India.

Since the earthquake, the Survey of India have re-levelled line No. 71 (1870-72) from Bagaha to Purnea, and line 71A (1920-21), from Darbhanga to Bagaha.

It was assumed by the Survey of India that the level of Bagaha was unaffected by the earthquake, the differences in level elsewhere being deduced from this unchanged level. This assumption is certainly reasonable. The fading in intensity of the shock from Bettiah to Bagaha is very rapid; more rapid probably than along any other section across the isoseismals. Bagaha, though only 32 miles from Bettiah and 93 miles from Sitamarhi, comes within isoseismal VI, and is less damaged than Allahabad, which is in isoseismal VII and is 225 miles from Sitamarhi.

The lines of levelling run in general W. N. W.–E. S. E., and not from north to south, and consequently run parallel to rather than across the main direction of the isoseismal lines, and the greatest extension of the slump belt.

The details, therefore, are scanty or absent for the eastern and southern parts of the area. Two incomplete curves are shown on Plate 20, and represent the boundaries separating areas in which subsidence of bench marks has been less than 0·5 foot (15·24 cm.);

between 0·5 and 1·0 foot (15·24 and 30·48 cm.); and over 1·0 foot. The belt of greatest subsidence (1·0 foot and over) lies between Segauli and Purnea. Subsidence is not uniform, even in a single town. Thus at Purnea it varies from 1 to 2·35 feet. The greatest recorded sinking is at bench mark No. 57 near Darbhanga, where a drop of 4·344 feet (1·3 metres) took place, and at bench mark No. 95, between Bajpatti and Sitamarhi railway stations, where the drop is 4·013 feet (1·2 metres).

Many of the bench marks are on abutments of railway bridges. Such structures are heavy, and are liable to sink into the ground more than the ground itself is likely to have sunk in a regional manner. The surveyors have in many cases estimated the extent to which the bench marks have sunk into the ground. This sinking has naturally to be deducted from the recorded differences in height.

It will be seen from Plate 20 that the area in which subsidence has been one foot or over coincides approximately with the slump belt as determined by Dr. Dunn and ourselves. The question arises as to what extent the subsidence of bench marks represents actual regional sinking of the ground, and to what extent the bench marks may themselves have slumped into the ground, in a manner similar to the houses within the slump belt (Plate 14). The fact that the surveyors have given estimates of the extent to which certain bench marks have slumped suggests that, where no such estimates are given, there has been little or no slumping of the other bench marks. Nevertheless, the Surveyor-General of India, in a letter dated 21st June 1934, addressed to the Director, Geological Survey of India, writes as follows :—

'Bench marks are generally built on or near bridges and houses and such-like heavy structures which have slumped into the ground, and the general ground level has probably changed by lesser amounts : it may not have sunk at all on the average...............The country has a general slope of about one foot per mile from north to south, so that sinkages of a few feet cannot cause any very large areas to be positively surrounded by higher ground on all sides, but the smallest change may divert an unstable river or cause flooding in an area which was previously drained with difficulty.'

In this connection it is of interest to note that although Darbhanga does not come within the slump belt (slumping of houses and marked sanding being absent both at Darbhanga and Laheria Sarai), yet the recorded drop in level of bench marks there are as follows : 4·3, 2·5, 1·9 and 1·3 feet. Except for bench mark No. 58 (line 71A, between Darbhanga and Mohammedpur) there are also no surveyor's reports of slumped bench marks. In this area, therefore, there are neither slumped houses, nor, apparently, slumped bench marks. Yet the figures for bench mark subsidence are considerable. It is perhaps permissible to suppose that here ground subsidence is unmarred by the effects of bench mark slumping. If this be accepted, it is evident that the coincidence between slumping and sinking is not exact. The local nature of the alluvium is probably of importance. A tube well put down by the Bengal and North-Western Railway at Darbhanga shows that clay occurs continuously to a depth of 79 feet. This clay doubtless prevented the usual phenomenon of slumping and excessive sanding, but may itself have succumbed to slight regional subsidence.

In view of the uncertainty which prevails, it is impossible to do more than point out that the area in which bench marks have sunk one foot and over coincides approximately with that of the slump belt, and may mark a belt in which the alluvium has been shaken down by the earthquake to a slightly lower level.

The resurvey operations have not gone as far as the stations at Diwanganj and Forbesganj. Without information from these places, it is difficult to draw the lines of equal apparent subsidence accurately towards the east.

Monsoon Flooding.

In view of the area of apparent subsidence, which corresponds approximately with the slump belt, it is probable that floods will result along the low-lying river tracts which obliquely cross this area. The intervening *rabi* and high *dhan* lands will probably escape, but it may be expected that the low *dhan* lands will suffer to some extent.

The problem of flood waters from the Bagmatti river, north of Muzaffarpur, has concerned the Irrigation Department for some years, and it may be expected to become more serious during the coming monsoon, since the country between the Bagmati and Lakhandai rivers comes within the area of subsidence.

Mr. W. L. Murrell, Executive Engineer of Muzaffarpur district, has made observations on the depth of ground water level in the well in the old sub-jail at Sitamarhi. He states that the fall in ground water level which normally takes place in North Bihar between

February and May is from 12 to 18 feet. In 1934 at Sitamarhi it fell from the three-foot level on the 9th February to the six-foot level on May 14th, a difference of only three feet. Fall when plotted against time gives a straight line, which shows that there has been no improvement in the rate of percolation during the last few months. Mr. Murrell concludes that the coefficient of run-off during the coming (1934) monsoon will be almost 100 per cent.

Earthquake Sounds.

Practically all observers agree that the earthquake was preceded by a rumbling sound, usually heard for a few seconds before the shaking was actually felt. The sound was loudest within isoseismals VIII to X and masked the noise caused by the collapse of buildings, the rattling of doors, windows, furniture, etc. The sound was heard as far as certain places within isoseismal V. Similar sounds were heard during some of the aftershocks that followed in places within isoseismal IX.

In most cases the sound was comparable to that caused by 'several aeroplanes', 'a heavy motor lorry', 'an approaching goods train', 'a passing motor car', or 'a train passing through a tunnel'.

Mention may be made of the brontides, popularly known as the 'Purnea guns', which compare closely with similar ones near Barisal where they are known as 'Barisal guns'. An account by Mr. D. P. Sharma, Officiating Collector of Purnea, about the Purnea guns says that :—

> 'The sound is heard almost all the year round (day and night), but more particularly during the rains. Several loud reports are heard in quick succession for a few minutes. The sound ceases for some time, but is heard again after an interval of half an hour or an hour. Sometimes it is not heard for days or months.
>
> It has been frequently heard after the earthquake also, but for about a month or so it is not being heard (6-4-34). The sound resembles that of a booming of a big gun at some distance. Sometimes one feels, when the sound is louder and nearer, as if an explosion has occurred. . . . . It is heard mostly in Araria and Sadar sub-divisions of this district.'

Similar sounds are heard at Biratnagar (wrongly called 'Gograha,' on the maps) near the Nepal frontier north-west of Araria. The Hakim of Biratnagar states that the sounds have decreased in frequency since the earthquake.

IV. EARTHQUAKE WAVES.

General.

It would scarcely be expected that any consistent picture of the nature of the waves felt in the severely affected area could be obtained. Such moments of emotional and physical crisis are hardly conducive to exact observation of any sustained nature. Horizontal and vertical vibrations are both recorded but not in any definite sequence. In addition, large surface undulations were noticed by the majority of people. Few could stand unsupported even in places as far distant from the epicentre as Dumka. Observers in the same place give very discrepant figures for the number and length of shocks, and their directions of vibration. Two brief quotations may be given to show the nature of the shock within the higher isoseismals. Mr. G. T. Gill, of Japaha Indigo Factory, near Muzaffarpur wrote as follows :—

'At first, mild horizontal shocks occurred of extremely high frequency, rapidly increasing in violence, followed later by enormous vertical undulations during which I had the utmost difficulty in keeping my feet, so much so that I distinctly recollect having once or twice to use my hands.' Length of shock 3½ minutes.

At Ryam, in Darbhanga district, Mr. Macdonald states :—

'The main shock was continuous, and reached its full intensity soon after it started, as I was twice thrown off my feet when outside trying to run in the open not more than 20 seconds after it started.' Length of shock over three minutes.

In Katmandu the evidence was very conflicting, time estimates varying from three to eight minutes for the duration of the shock. In the Singha Durbar Palace north-south movements were followed by east-west, and these in turn by an apparently vorticose motion.

At Betul, in the Central Provinces, which comes within isoseismal V, one observer gives the following approximate figures—

14-20 ; shock for 20 seconds.

14-22 ; shock for 40 seconds.

14-25 ; shock for 30 seconds.

The times are not correct, since the shock was felt by seismographs as far south as Kodaikanal and Mangalore at about 14-17, but the relative duration of shocks and periods of remission are perhaps of the right order.

To the south the shocks do not appear to have been continuous.

Surface undulations.

Mention has been made of the surface undulations. It is well to stress that these were seen by a very great number of people, and there can be no doubt that they occurred. Many seismologists are disinclined to believe that such undulations exist, or at any rate have the dimensions attributed to them by observers. A case is mentioned in the *Bulletin of the Seismological Society of America*, Vol. 23, p. 171, (1933), of a member of the Mount Wilson Observatory staff who thought he saw waves in a concrete floor 10 to 12 feet in length and 4 to 12 inches in height. Yet, on returning after the shock had subsided there were no cracks to be seen in the floor, and unstable objects on shelves and tables had not toppled over. The conclusion drawn was the physiological and psychological conditions had resulted in an exaggerated impression of the dimensions of these waves. The probability of exaggeration, even in the case of trained observers, does not, however, disprove the existence of these waves.

One observer at Muzaffarpur considered the crest to crest distance to be five feet, and the amplitude about six inches. Another at Riga stated that houses seemed to be tilted backwards and forwards on the crests of much larger undulations. The west compound wall of the Belsund Sugar Factory at Riga, running north-south, remains in wave form with two crests and a trough. Crest to crest distance was found to be 240 feet and the amplitude about one foot. A north-south watercourse at the Sugar Cane Research Station at Mushari has also remained in the form of waves, whose crest to crest distance varied. One measured was 240 feet. These two observations were taken in localities where ground subsidence was considerable, and it is difficult to judge to what extent the measured waves are a faithful impress of the surface undulations which may have caused them, and to what extent ground subsidence may have been responsible for their formation. They were noticed only along structures with a north-south alignment in that part of the badly affected region where the fall of objects independently indicated north-south waves. The waves responsible for the overturning of pillars are, however, distinct from the larger and slower surface undulations. Similar undulations were noticed even at Asansol, on thin paddy land lying above Gondwana rocks.

Intensity.

An approximate idea of the horizontal component acceleration is obtained from measurements of fallen objects using West's formula :—

$$f = \frac{g\,x}{y}.$$

It is usually impossible to state whether or not the fallen objects had swayed prior to falling. Eye witnesses frequently noticed the sway of objects and it is certain that some of the pillars and gate posts did so as well. Hence calculated values for acceleration may be sometimes in excess of the actual values. Measurements were taken only of objects that had fallen from their base. The calculated values for acceleration are given below :—

Monghyr	3,270 mm. per sec. per sec.
Sitamarhi	3,000
Muzaffarpur	3,050 to 2,647 mm.
Pipra	2,943
Rampur Hari	2,400
Katmandu	2,048
Pusa	1,500

It is remarkable that the shock in Nepal failed to overturn many of the stone columns supporting images (Plate 16, fig. 1). These columns were cut from single blocks of stone, and were presumably deeply set into the ground. If not deeply set, the centroid of gravity would have been high, and the columns would inevitably have fallen. Some of the overlying capitals did fall, such as that in Hanuman Dhoka at Katmandu, and these were found to have deep tightly-fitting sockets. Good craftmanship, good rock and deep setting were evidently responsible for the frequent escape of these structures.

The amplitude of vibration was determined by the use of the formula :—

$$2a = \frac{4x\,(x^2+y^2)}{3y^2}$$

and gives figures ranging from 30·8 cms. or 12 inches at Muzaffarpur to 13·31 cms. or 5·2 inches at Katmandu. The range, or double amplitude, will be respectively two feet and 10·4 inches.

Railway sleepers along a line oriented north-south near Motihari had pushed the ballast into piles, leaving gaps varying from 8 to 12 inches in width. If these figures are an indication of the true double amplitude, it is possible that the figures obtained by the use of the above formula for amplitudes in the Muzaffarpur-Champaran area may be too large.

Near Udaipur Garhi, in Nepal, a stone was dislodged from its position on soil by nine inches. The amplitude would then be 4½ inches.

The period of vibration was determined by the use of the formula for simple harmonic motion :—

$$f = \frac{4\pi^2 a}{t^2}.$$

This varied from just below two seconds to 1¼ seconds. As the motion was certainly not simple harmonic, the values of these figures are probably not very accurate.

Coming to the lower isoseismals, our colleague Dr. A. L. Coulson has determined the following values for Calcutta (isoseismal VI) from measurement of the displacement of the horizontal pendulum of the seismograph :—

acceleration	150 mm. per sec. per sec.
amplitude	15 mm.
period	3 seconds.

There is unfortunately very little evidence as to the extent of the vertical component of the earthquake waves. The thuds that were felt throughout the badly affected area certainly indicate that this was considerable. One observer at Monghyr stated that he saw a house lifted vertically, and then sink and shatter. In places the vertical acceleration must certainly have exceeded that of gravity.

Directions of Fall.

On Plate 21, is shown the directions of fall of pillars, chimneys, water tanks, etc. An arrow is given where the directions are to one point of the compass ; when to two opposite points, a line is shown.

In contrast to many earthquakes which show a centripetal distribution of directions of fall, in the present earthquake there is a regional east-west direction, except in the west of the epicentral and neighbouring region. Between Hajipur and Sitamarhi the fall is fairly exactly to N. N. E. or S. S. W. It is E. N. E. at Pipra and Udaipur Garhi. At Katmandu it was to east or west and to north or south.

A large proportion of buildings and structures in Bihar and Nepal are oriented north-south. A pillar so oriented will fall to one of the cardinal points, since it would not fall diagonally. A single movement of the ground in, say, a N. W.-S. E. direction would act diagonally, and its forces would be resolved in east-west and north-south directions. This possibility should be allowed for. In the case of round chimneys, there is no such uncertainty. At Katmandu, observers state that distinct shocks in east-west and north-south directions were felt, so that it is probable that the directions of fall do not represent resolved parts, but are a true indication of the movements.

Except for the north front of Patna, near the bank of the Ganges, every place south of the Ganges reported east-west movements. There is no sign anywhere of a centripetal disposition towards a point, or even an area.

Time of Earthquake.

As was the experience in previous earthquakes, no reliance can be had on the majority of time estimates made in the earthquake area. In spite of the fact that railway stations and telegraph offices are supposed to receive Indian Standard time every day, estimates given by the observers varied greatly. In Bettiah, the Postmaster gave the time as 14-05 while the Station Master stated it was 14-15. An accurate clock belonging to Mr. Elms, Manager of the Bettiah Raj, stopped at 14-12. Mr. Kilburne, of Katmandu, gave the same time—14-12. His watch is checked daily by wireless. The clock of the Muzaffarpur Telegraph Office stopped at 14-15. That in the tower of the Secretariat building at Patna stopped at 14-16, evidently sometime after the earthquake began.

Coming to the evidence of seismographs, the only record in India which is of value in determining the time of the shock is that at Colaba, since here alone were S and P waves both recorded. The record at Oorgaum, in South India, is also complete, but it is not known what time correction for the clock is to be allowed in making estimates of the time incidence of the S and P waves.

Confining our attention for the moment to the Colaba record, we have for the time of incidence of the P and S waves respectively 14 hrs. 16 min. 48 secs. and 14 hrs. 19 min. 30 secs. The difference S–P is 2 min. 42 secs. or 162 seconds. Using the table in

Davison's 'Seismology', page 145, (1921), the time of origin of the earthquake is found to be 14 hrs. 13 min. 22 seconds.

The Oorgaum records give a different time of origin of the main shock. The seismographic record for the vertical component gives 14 hrs. 12 min. 53 secs. while that of one of the two horizontal components shows 14 hrs. 12 min. 59 secs. In view of the time of origin deduced from other records, the clock at Oorgaum was probably fast.

Times of incidence of P and S waves at stations.

(Indian Standard time.)

Station.	P wave.	S wave.	Time of origin T_o.	Epicentre.
Alipore (Calcutta) . .	14-14-48			
Agra	14-15-11			
Dehra Dun . . .	14-15-14			
Colaba (Bombay) . .	14-16-48	14-19-30	14-13-22*	
Oorgaum . . .	14-17-04	14-20-17	14-12-59*	
		14-20-24Z	14-12-53*	
Kodaikanal . . .	14-17-36			
Colombo . . .	14-18-05	approx. 14-22-0		
Medan[1] . . .	i 14-19-02			
Chinferg[2] . . .	14-19-11	14-23-58	14-13-08*	25°N. 86°E.
Taikohu[2] . . .	14-19-48	i 14-25-01	14-13-10*	26°N. 86°E.
Manila[2] . . .	i 14-20-09	14-25-33	14-13-03	25°N. 86°E.
Batavia[1] . . .	i 14-20-49			
Malabar[1] . . .	14-21-06	i 14-27-01	14-13-35*	
Amboina[1] . . .	i 14-22-22	i 14-29-35	14-13-14*	
Strasburg[2] . . .	e 14-23-44	i 14-32-14	14-13-11*	27·5°N. 86·5°E.
Perth	14-24-07	14-32-43	14-13-28*	
Kew	e 14-24-20	i 14-33-16	14-13-19*	26·8°N. 86·3°E.
Wellington N. Z. . .	e 14-27-30	i? 14-39-30	14-13-04*	
Florissant[2] . . .	e 14-28-18	i 14-40-52	14-13-16	25·6°N. 85·7°E.

[1] Information supplied by Koninklijk Magnetisch en Meteorologisch Observatorium te Batavia.

[2] Information supplied by University Observatory, Oxford.

* Calculated from Davison's tables. Manila and Florissant supplied by Oxford.

Neglecting Oorgaum, the average of 11 figures gives for the time of origin the following result :—14 hrs. 13 min. 15 secs. I. S. T. or 8 hrs. 43 min. 15 secs., G. M. T. This is the time provisionally adopted, but it is subject to correction after an examination of all the records has been made using the latest tables of wave velocities.

Dr. S. C. Roy[1] believes that the seismograms at Calcutta and Dehra Dun were incorrectly estimated, and that an earlier shock, which he calls *Pm.*, was in reality present on these records.

Depth of Focus.

The difficulty in using Dutton's formula for the calculation of the depth of focus lies in fixing the places between which intensity diminishes with maximum rapidity. Intensity fades rapidly between Sitamarhi and Bagaha, and again, south of Muzaffarpur and Laheria Sarai. But the presence of earthquake shadows, and the variable nature of tho alluvium are factors which must modify the results obtained. The fact that the movements responsible for the shock may have been along inclined fractures makes it improbable that there is any one depth to which the focus could be assigned.

Location of Epicentre.

The position of the epicentre as determined by the interpretation of the seismographic records does not agree exactly with our field work. From the Kew and Colaba seismograms, Kew Observatory calculated that the epicentre lay 26·8°N : 86·3°E. Dr. S. C. Roy fixes it at 26·6°N : 86·2°E. These two locations are in Nepal, the former near Nipania[2], the latter just south of Sirha (Survey of India degree sheet 72J). Both are south of the Siwalik hills, in the Nepal terai, and within our isoseismal IX. The records at Agra and Dehra Dun gave locations of 250 and 100 miles respectively, which are west of the area of maximum damage. There is some doubt, however, about the interpretation of these records. Information supplied by the University Observatory, Oxford, gives the following further results :—

Chinferg and Manila . . .	25°N : 86°E	40 miles south-west of Monghyr.
Florissant	25·6°N : 85·7°E	8 miles north of Barh.
Taikohu	26°N : 86°E	10 miles south-east of Laheria Sarai.
Strasburg	27·5°N : 86·5°E	38 miles north of Udaipur in Nepal.

[1] *Current Science*, Vol. II, p. 419, (1934).
[2] *Gurdham* in sheet 72 J.

V. COMPARISON OF EARTHQUAKES OF 1833 AND 1934.

Records of the Indian earthquakes of the past show that considerable portions of Northern India have from time to time been subject to earthquake shocks. Mallet's Earthquake Catalogue of the British Association mentions of a 'violent earthquake' which took place between 5-30 to 6 P.M. on August 26, 1833, 'all over the centre and east of northern India, especially Nepaul'. The shock was felt in Calcutta, Agra, Lucknow, Tirhoot, Purnea, Patna, Buxar, Allahabad, Monghyr, Katmandu, etc., and also at Lassa (Lhasa). It appears that the shock was fairly violent and lasted from a few seconds up to a minute and that it extended over approximately the same area as the 1934 earthquake. No noteworthy record of any damage in Bihar is given therein but at Tirhoot (probably Muzaffarpur) water was thrown out of tanks, four feet deep, at Chapra, a chasm of considerable size was said to have been formed in the earth and at Monghyr, Rangpur, Muzaffarpur, Mallai, and other places within direct line of influence, many houses were destroyed or injured, and the alarm was great.

An accurate account of the earthquake as it affected Katmandu is given by the Assistant Surgeon, A. Campbell.[1] It is clear that the earthquake of 1833 was not so intense as the recent one. Only 414 people were killed in the Nepal valley, compared with the 3,400 who perished in 1934. The valley was not so populated a century ago, but, allowing for this, the percentage mortality was certainly less.

The important point is that the forms of the isoseismal lines of the two earthquakes in Nepal must have been approximately coincident, even though those of the 1833 earthquake may not have been so high on the Mercalli scale. Bhatgaon suffered the worst damage in 1833, with a loss of 2,000 houses (42 per cent.). Khokana, a small village, was likewise severely damaged, with collapse of 130 houses. Patan and Katmandu were equally affected; in both earthquakes less so than Bhatgaon. Swayambunath, Kirtipur and Gokarna escaped with slight damage.

Aftershocks were recorded during the 15 days that followed. On October 4th of the same year another violent shock, lasting for half minute, was felt at Katmandu, Monghyr and Allahabad. Another shock occurred on October 18th at Katmandu, Goruckpur

[1] *Journ. Asiatic. Soc., Bengal,* Vol. II, pp. 438, 564, 636, (1833).

(Gorakpur) and Allahabad and several were felt at Katmandu on October 26th, November 8th, 16th and 26th, the last one being severe.

The direction of the main shock of 1833 is variously stated. At Tirhoot the motion was said to have been from east to west; at Buxar from north to south; at Patna apparently east to west; at Calcutta, north-east to south-west; at Katmandu apparently east to west. At most of the places, the earth was in almost continuous agitation for 24 hours.

With regard to Monghyr, Lieut. Baird Smith may be quoted[1] :—

'It is a remarkable fact, that Monghyr seems to suffer more from earthquake shocks, from whatever direction these may come, than any other place in its vicinity. This was observed during the shock from the lateral Himalayan tract, of the 26th August 1833, again during that of the 11th November 1842, and I would say from the information before me, that on the present occasion, the shocks were smarter at Monghyr than at any other spot.'

The latter shock was sufficiently strong to overthrow a portion of the fort wall at Monghyr.

There is no doubt that the area in Bihar and Nepal enclosed by isoseismal VIII has been one of seismic activity, although of less frequency than Assam.

VI. GEOLOGY AND CAUSES.

The area affected by the earthquake embraces three distinct geological units :—

(1) The Peninsula of India,
(2) The Gangetic alluvium,
(3) The Himalaya.

The Peninsula of India is a stable region, and formed part of the Gondwana continent up to the end of Mesozoic times. The Himalaya are a new mountain system, containing remnants of the edge of peninsular India caught up by the Tertiary folds, together with the southern portions of the geosynclinal sedimentation belonging to the Tethys, which have no true equivalents in the Peninsula. Some of the thrusts within and bordering the Siwaliks are as recent as Pliocene in age. Between these two units lies the Gangetic

[1] *Op. cit.*, Vol. XII, p. 1039*, (1843).
There are two pages numbered 1039, the second being marked with an asterisk.

trough, a basin of sedimentation containing the products of denudation of the Himalaya and to a less extent of the Peninsula.

The main area of isoseismal X occurs along the alluvium, some 30 to 40 miles south of the Siwalik ranges of the Himalaya. The areas of isoseismal X at Monghyr and in the Nepal valley occur respectively along the northern border of peninsular India, where it sinks under the Gangetic alluvium, and within the palaeozoic and older rocks of the Himalaya.

The Peninsula of India, being a stable block, does not require further description. More attention will be paid to the unstable areas of the Himalaya and the Gangetic alluvium.

Structure of Himalaya.

The structure of the Himalaya in Nepal is scarcely known, whilst that of the Darjeeling neighbourhood was determined 60 years ago, before tectonic geology had progressed far except in Switzerland.

In brief, it may be stated that the structure of the lower Himalaya consists of thrust sheets; older rocks being brought into abnormal juxtaposition by thrust planes upon younger rocks. Most of the thrust planes along the foothills dip northwards, in towards the Himalaya. Until recently, one thrust plane was regarded as of paramount importance—the so-called 'main boundary fault', which, east of about longitude 78°, separates pre-Tertiary rocks from underlying Tertiary rocks. During the last few years it has been found that this thrust is only one of several which occur both in the Tertiary and pre-Tertiary rocks, and its unique importance is open to question.[1]

Three thrusts have been recognised in Nepal. One separates Nahan, or lower Siwalik rocks from underlying upper Siwalik conglomerates. It occurs near Hitaura (27° 26′ : 85° 02′), and again near Nepaltar (26° 54′ : 86° 32′). This thrust cannot be older than Pliocene. The so-called 'main boundary fault' is found just north of Sanotar (27° 28′ : 85° 02′), again on the first col E. N. E. of Udaipur Garhi (26° 57′ : 86° 32′), and probably runs through Dharan Bazar (26° 49′ : 87° 17′), to pass below Tindharia (Darjeeling-Himalayan Railway). A third thrust was seen 1·6

[1] Pilgrim and West, *Mem. Geol. Surv. Ind.*, LIII, (1928).
Wadia, *Rec. Geol. Surv. Ind.*, LXV, pp. 189-220, (1931).
Auden, *Op. cit.*, LXVII, pp. 357-451, (1934).

miles E. N. E. of Udaipur Garhi, and marks the boundary between the garnet-schists of the Darjeeling gneiss and the underlying possibly Krol rocks.

The earthquake of 1905 at Kangra and Dehra Dun was intimately connected with instability along analogous thrusts in the Punjab. It was supposed, therefore, that renewed movement along the thrusts in the Nepal-Darjeeling Himalaya might have been the cause of the recent earthquake of the 15th January. This was tentatively suggested by Dr. Krishnan [1] before the field work of the Bihar-Nepal party had been completed. Dr. Fermor, in his article to *The Statesman Record of the Great Indian Earthquake, 1934*, page 19, also put forward this explanation as one of two alternatives, later [2] accepting the other alternative, adopted by us below.

Earthquake not primarily connected with visible Himalayan Thrusts.

On plate 19, the isoseismal lines are shown in red for the whole of India, while the green line represents the course of the main boundary fault. The area enclosed by isoseismal X lies some 50 miles from the main boundary fault, and 38 miles or so from the nearest outcrop of the Siwalik rocks.

While the damage to Udaipur Garhi and Dharan is certainly great, it cannot be stated that the acuteness at these places bears any definite relationship to the boundary fault or thrust plane. No signs of movement were seen along the thrust plane where it is exposed near Udaipur Garhi. The houses at Udaipur Garhi and Dharan, being of very unstable construction, have naturally collapsed more than the bamboo mud huts of the villages in the plains just below. Rock falls are not confined to the vicinity of the thrust plane, but scar the hill sides around Udaipur Garhi for miles to north and south. Whatever movement may have occurred along this thrust plane below the surface, nothing remarkable happened at its outcrop with the surface. It is more probable that the movements responsible for the earthquake originated further south, along thrust planes that are now concealed by the Gangetic alluvium.

The significance of the slump belt, and of the area of apparent subsidence determined by the Survey of India is almost certainly that

[1] *Current Science*, Vol. II, p. 325, (1934).
[2] *Op. cit.*, p. 443, (1934).

the alluvium there has received a most severe shaking in a vertical direction as a result of lying immediately above the main zone of disturbance.

Zone of Fracture below Alluvium.

It is not known how far the Tertiary rocks extend southwards below the alluvium. The absence of Tertiaries along most of the northern edge of the Peninsula proves that they terminate below the alluvium somewhere between the Peninsula and Himalaya. The Tertiaries of the Siwalik ranges on the northern border of the Gangetic alluvium occur either with northward dips, dipping below older rocks or with southward dips into the alluvium. Southward dips are seen in probable Nahan rocks at Bhorlyani (26° 50′ : 86° 25′). There is no doubt at all that the alluvium does overlap the Tertiaries. This is evident at Dharan, where the Siwalik outcrops of Nepal and south of Tindharia suddenly disappear under a bay of alluvial deposits. The extent of this overlap is, however, not known.[1]

Since the visible thrusts of the Siwaliks appear to have little connection with the earthquake, and since the slump belt indicates a close proximity to the focal region, the cause of the earthquake must be sought for in some line of weakness below the alluvium. Independent evidence for this conclusion is obtained by the location of the epicentre from a study of the seismographic records. Any attempt, however, from such a study, to confine the epicentre to a point or highly localised region results in a distortion of the field evidence. We regard the field evidence as of primary importance. The Indian seismographic records of the recent earthquake appear capable of such variable interpretations that they are of value more when viewed in the light of field evidence than in affording a clue in themselves.

The surface characteristics of the slump belt, while an indication of the location of the focal region, do not afford information concerning the nature of the fracture below the alluvium which was responsible for the earthquake. The earth fissures that were observed were purely superficial effects in the alluvium, a consequence of its incoherent nature. Consequently, conclusions

[1]The width of the Siwalik outcrop in Nepal across the strike is from 12 to 13 miles. At Dehra Dun the width is 16 miles.

drawn as to the underlying fracture or fractures must be hypothetical.

The elliptical nature of the isoseismals strongly suggests the linear nature of the centrum or focal region, and the occurrence of one or more fractures below the Gangetic alluvium between Motihari and Purnea may safely be postulated. Whether or not this fracture zone coincides with the southward termination of the Siwalik rocks against the basement of pre-Tertiaries is impossible to state.

From the parallelism of the major axis of the ellipse of isoseismal X, between Sitamarhi and Madhubani, and of the larger Slump belt between Motihari and Purnea, with the zone of thrusts in the Himalaya, it is possible to infer that the zone of fractures may continue eastwards, still parallel to the Himalaya, as far as Dhubri in Assam. Dhubri, as is well known, is situated in a highly unstable area. Westwards, this fracture zone probably dies out against the north-eastward continuation of the Aravalli range (Delhi ridge) below the Gangetic alluvium, though, from the rapid fading in intensity of the shock to the W. N. W. of Motihari, it is evident that violent movement along this zone was confined during the last earthquake to Bihar.

For the long and narrow area of isoseismal IX between Patna and Monghyr, two explanations may be put forward :—

(1) That the earthquake waves, coming from a more northerly focal zone (below the Motihari-Purnea belt) were reflected off the stable Peninsula along the approximate boundary between the alluvium and older rocks belonging to the Archean and Vindhyan systems. At Monghyr the alluvium is clearly very thin, and the inference is reasonable that westwards also it is shallow, in spite of the southward 'bay' of alluvium between Patna and Gaya.[1]

(2) that along the northern edge of the Peninsula there is a zone of tension induced by the accumulating weight of deposits in the Gangetic valley, and that this tension was relieved by sub-alluvial faulting the moment the force from the seismic focal zone was sufficient to permit its release.

[1] L. L. Fermor, *Current Science*, II, p. 444, (1934).

It is noticeable that the greatest elongation of isoseismals VII and VI towards the west is neither parallel to the system of Himalayan thrusts, nor to the inferred fracture zone between Motihari and Purnea, but coincides more with an extension of the Patna-Monghyr belt.

The disposition of isoseismal lines VI and V in Central India and Rajputana appears to follow to some extent the great curve of Vindhyan rocks round the Bundelkhund gneiss.

The position of isoseismals IX and X in the Nepal valley is more difficult to explain. No geological structures were observed in the Nepal valley to which any particular seismic focus could be attributed. The existence of a flat valley, 15 miles from east to west and 11 miles from north to south, covered by loose fluviatile and lacustrine sediments, is a predisposing reason why the towns situated there should feel an earthquake shock more intensely than if more resistant rocks had cropped out over the whole area. The fact of occurrence of such loose sediments does not explain, however, the initiation of the shock; it only suggests a reason for the greater intensity manifested there by the shock, in whatever manner formed.

The old idea that an earthquake results from a shock at a definite centre or focus has for many years given place to the conception of movement along a fracture, fault or thrust. A further development of this idea, emphasised by our collegue Dr. Dunn, may be that not only a single fracture plane, but a zone of the earth's crust of quite considerable width, including several fractures, parallel or in echelon, is involved in some great earthquake disturbances. Movement throughout this zone may be practically simultaneous.

Relation of Earthquake to Underload.

Dr. J. de Graff Hunter, in an article to *Nature*, Vol. 133, p. 236 (1934), has brought out the relation of the recent earthquake to an area of underload which exists in North Bihar. Dr. Hunter states :—

'The average underloading of this area of about 100,000 square miles is on the average equivalent to a thickness of rock of more than 3,000 feet ; or, put otherwise, the deficiency of pressure in the crust is above 200 tons per square foot. This underloading arises from abnormally low densities in the crust. It is in part accounted for by the low density of the alluvium of the Ganges valley ; but unless this alluvium extends to a greater depth than most geologists would believe, the explanation is not wholly there.'

The rock, upon which the calculations are based, is assumed to have a density of 2·67. The area of maximum underload is an ellipse running E. S. E.–W. N. W., with Motihari above the eastern end of the longer axis.

Dr. Hunter continues :—

'These regions of great loading anomaly must cause very great stress-differences in the earth's crust which supports them. The region of underload and the amount of underloading are very much of the order which has been estimated by Dr. H. Jeffreys to be sufficient to cause fracture in the lithosphere.'

This region of underloading lies along the same line as and overlaps that occupied by the slump belt and isoseismal X. The postulated fracture zone runs, therefore, along the longer axis of the region of underloading.

The thickness of the alluvium in the Ganges valley is unknown. The deepest bore, put down at Ambala, is only 1,612 feet in depth. This did not strike the basement of the alluvium. Realising the immense thickness recorded for the Siwalik rocks (some 18,000 feet), it is probable that the Gangetic alluvium in places also approaches this figure.[1] It seems possible, therefore, that the alluvium is of sufficient thickness largely to account for this underloading.

Not all earthquakes are connected with underload. Assam, which is a region of marked seismic activity, is probably a region of overload.[2] The underload of North Bihar must be due to the downwarping of the sial crust and the filling up of the sunken upper surface with Gangetic alluvium. The postulated fracture zone between Motihari, Purnea and Dhubri, would cross from this area of underload to one of overload. The underload of North Bihar may be not so much a cause as a local symptom of instability there. The downwarping of the Gangetic trough in front of the Himalaya is primarily a tectonic process, accompanied by fracturing, earthquakes and underloading. Tectonic activity in Assam is not accompanied by such extensive downwarping but is nonetheless marked out by seismic activity.

Conclusions.

The slump belt and largest region of isoseismal X occur within the Gangetic alluvium, south of the Siwalik outcrop and zone of visible

[1] *See* Oldham, *Mem. Geol. Surv. Ind.*, XLII, Pt. 2, p. 8, (1917).

[2] Graaf Hunter, *M. N. R. A. S., Geophys. Suppl.*, Vol. 3, Charts, A, C, D, (1932). *See* also Postscript on page 239.

thrusts in the Himalaya, and suggest proximity to the focal region which must have considerable lateral extent.

There are possibly two zones of fracture: one below the Motihari-Purnea zone; the other below the Patna-Monghyr zone.

Accepting that the underload in North Bihar is a symptom of instability occasioned by the uprise of the Himalaya and down-warping of the Gangetic trough, the area of isoseismal X between Sitamarhi and Madhubani may be considered to be the epicentral region. The high intensity isoseismals in Nepal and between Patna and Monghyr are probably secondary, and may be the effect of disturbances, initiated below the epicentral tract, relieving subsidiary zones of strain in these two areas.

The directions of fall of objects are not centripetal, but, except in part of the epicentral region, are regionally east-west. This fact suggests the implication of a wide area of the crust in east-west vibrations, along rather than across the lateral extent of the primary and subsidiary focal regions. Movement along the fractures may have had a pronounced east-west component.

VII. FORESHOCKS AND AFTERSHOCKS.

No evidence is at hand of any foreshocks preceding the earthquake of the 15th January in Bihar. Mention may be made, however, of several shocks which were felt on the 12th and 13th January in the Anaimalai hills, and at Pollachi, Tinnevelly and Sivakasi, in South India. No shock was felt in the last three mentioned places on the 15th January.

Frequent aftershocks have been felt in northern India. Those of the 16th and 19th January were strong, and were well recorded by the seismographs at Alipore and Colaba. Shocks have continued for the last seven months, the last of any severity being on the 2nd June, when several buildings in North Bihar which had been injured in January were brought down[1], and on the 29th August. An account of these shocks will appear at a later date.

[1] It appears probable that this shock was connected with seismic activity in the Shillong plateau. There had, however, been instability on the previous day at Riga, near Sitamarhi. The following extract from a letter dated 2nd June by Mr. Jacobs, Manager of the Belsund Sugar Factory, Riga, addressed to Messrs. Finlay and Co., Ltd., Calcutta, may be quoted :—

'I suppose you will see it in the press that we had two more earthquake shocks during last night or rather 1·30 and 4 o'clock this morning. Yesterday the ground felt all wobbly just as it did after the big earthqauke and subsequent shocks, then last night we got the "bumps".'

VIII. RECOMMENDATIONS.[1]

Belts of Lesser and Greater Disturbance.

It has been stated that the primary epicentral region of the present earthquake is between Sitamarhi and Madhubani, and that there are subsidiary areas of high intensity in the Nepal valley and at Monghyr. Between these higher isoseismals are zones of less destruction. From the imperfect accounts available, it seems that the earthquake of 1833 was felt over approximately the same area as that of the recent earthquake. To assume that there is consequently a *primâ facie* case for supposing identical conditions in the future, with identical belts of lesser disturbance, is to go beyond what the imperfect evidence at hand will permit. All that can be said is that there is probably a fracture zone below the Motihari-Purnea belt, which may continue to the east towards Dhubri, and that there may be a second fracture zone along the Patna-Monghyr line. Monghyr is known to suffer from shocks more than any other place south of the Ganges, but to what extent this is due to the existence of fractures and to what extent to the position of Monghyr at the junction of the alluvium with the Archean basement is difficult to decide. It cannot be asserted, however, that the area between these two zones will necessarily be more immune from shocks in the future until several further violent earthquakes have occurred and some constancy in the position of the isoseismals is established. As far as is now known, another violent earthquake of greater depth and violence might result in this intervening area being included within isoseismal IX. It is safer to accept that the whole region between Patna and the Himalayan foothills is liable to shocks in the future and that no zones in it can be marked as of less liability to damage.

Details of the 1833 earthquake in Bihar are scanty, and accurate comparison cannot be made there between the 1833 and 1934 earthquakes. The problem is different in the case of the small circumscribed area of the Nepal valley, with marked contrasts in ground conditions and with more accurate information with regard to the 1833 earthquake (*see* page 215).

[1] This section has been taken, with slight re-arrangement and omissions, from the Preliminary Report by Dr. Dunn and ourselves to the Government of Bihar and Orissa, and from the Report to the Nepal Government, by the first author.

The coincidence in the valley of the isoseismal lines of the earthquakes of 1833 and 1934 is sufficiently close to suggest that there are areas that are liable to worse shaking than elsewhere, and other areas that are more stable.

The tract between Bhatgaon, Harisidhi, Khokana and Bagmati, included within isoseismal X, may be considered as that which will undergo the worst shaking in future earthquakes. The area between Pashupatinath, Boddhanath and Gokarna, on the other hand, is probably the safest in the valley.

Building Design.

Loss of life and poor building materials.

One of the tragedies of an earthquake is the loss of life and damage to buildings due to unsuitable construction. It is incumbent upon those responsible for future construction to eliminate all weakness which the experience of this earthquake has demonstrated to exist. It may be possible to design safe structures which can be erected at a cost no greater than that of old weak types.

Kutcha-pucca buildings a necessity in India.

It is realised that building conditions in Northern India are different from those in other countries. *Kutcha-pucca* buildings must always form a considerable proportion of town buildings, as the population cannot afford the *pucca* type. It should be possible to design *kutcha-pucca* structures which would occasion the minimum damage and loss of life during earthquakes. Good quality brick-work and whenever possible, mortar, is the best insurance against earthquake damage.

Type of ground.

It is a general experience in earthquakes, that shocks are more severely felt on soft alluvial ground than on harder ground. Consequently, given buildings not specifically designed to withstand earthquake shocks, the damage is greater in alluvial tracts than elsewhere. This was on the whole our experience in the case of the present earthquake, although the extremely poor manner of construction of the buildings has permitted their general collapse even on hills, as at Udaipur Garhi. Freeman[1] mentions that in the San Fransisco earth-

[1] Earthquake Damage and Earthquake Insurance, p. 366, (1932).

quake of 1906 the percentage damage to buildings of non-rigid character was 5-10 times as great on soft ground as on outcrops of older and more consolidated rocks.

When, however, as in many of the buildings put up in Tokyo before 1923, special provision is made to construct rigid buildings with adequate foundations, the damage to such buildings may be less on alluvial ground than on rock. Professor Suyehiro has shown that, by reason of its inertia, the movement of rigid buildings on a massive foundation block, may be much smaller than that of the sand or mud upon which the foundation rests. Soft yielding sand or mud tends to act as a cushion to the shock, and surges to and fro beneath the foundation, without imparting to it vibrations of large amplitude.

Buildings should be of simple design, the parts so well-tied and the whole structure so rigid that it would react as one unit to earthquake waves. The several parts of irregular buildings do not synchronise during a shock, and severe stresses are set up between the individual units. These remarks apply especially to high structures, *e.g.*, a church steeple erected on a tower is frequently destroyed from the base of the steeple; the tower and steeple each having a different vibration period and opposing directions of movement, with the result that the acceleration can be doubled.

Buildings should be kept as low as is conveniently possible, compared with their lateral dimensions. The object should be to keep the amplitude of vibration as low as possible at the highest part of the structure, and so reduce acceleration, for any particular period of vibration.

Acceleration and legislation.

In this report we have mentioned that the maximum acceleration is about 10 feet per sec. per sec. Notwithstanding that the acceleration during earthquakes in other parts of the world frequently approaches this figure, legislation in Japan and New Zealand stipulates that designs must be suitable for an acceleration of 3·2 feet per sec. per sec., *i.e.*, one-tenth g; in other words, the total horizontal force at any horizontal plane must not be greater than one-tenth the total weight of the structure above the plane. For such structure as columns and bridge piers we would suggest the higher figure wherever possible.

Details of Design.

Foundations must receive first consideration in building construction. The amplitude of vibration in soft earth is great, and it is necessary to reduce its effect. For a large heavy structure this can only be done by constructing a strong rigid foundation. The aim of the building engineer should be to reduce as far as possible, the pressure per square foot on the foundations by distributing the total load over as wide an area as possible. In all cases, the different parts of the foundations should be strongly tied together.

Foundations.

In the slump and epicentral zones of North Bihar, the massive reinforced concrete foundations of some of the sugar mills have been tilted and even badly cracked. So far as could be seen, the materials employed were of high quality. It may be doubted if any structures, however well built, if located on soft alluvium containing water-logged sands, and if at the same time in the epicentral region of a severe earthquake, could escape damage. This is no argument for dispensing with good foundations to important buildings. Without such foundations the buildings would suffer much greater damage. No designs and no legislation can be made to apply to the highest zones of damage in alluvial country. The general principles concerning construction in seismic regions have to apply to the type of damage to which the greater part of these regions are likely to be subjected; not to those smaller areas where a combination of factors results in abnormal severity.

Foundations in slump zone.

Buildings of irregular shapes, with wings, protruding verandahs, porches, etc., have invariably suffered. The same applies to buildings to which additions have been made by the abutting of new walls directly, on earlier ones, without dovetailing. The whole building should form one unit. Verandahs and porches should not consist of a series of independent pillars with a roof resting on top, but should be integral parts of the building. If it is impossible to avoid having adjacent structures of different heights and different periods of oscillation, they should be separated beyond the range of collision, and connected by lighter more fragile structures, in which the damage may be safely concentrated.

Shape of buildings.

Excrescences such as towers, turrets, pinnacles, etc., are dangerous both to human beings and to buildings, and should be avoided.

Flimsy parapets, balustrades and similar structures have caused death to many.

Windows are a source of weakness to buildings and a more careful and better spacing should be attempted. Windows should be kept away from outer corners of buildings as far as possible. Wide window areas should be compensated by stronger intervening walls.

Kutcha-pucca buildings.

Kutcha-pucca buildings of more than one storey should not be permitted and their walls should be not less than standard minimum thickness.

The use of timber-frames in *kutcha-pucca* and *kutcha* buildings should be encouraged. Buildings consisting of a platform or sole-plate supporting timber verticals that are well-tied by cross and diagonal beams and firmly attached to the roof are preferable. The weight of the roof would thus be shared both by the walls and the pillars and the tendency of the walls of such building would be to move together as a unit. Timber pillars are greatly to be preferred to brick pillars.

Both for the vertical and horizontal beams palm, *sal, sisu* (seesum) and *kanthal* (jack-fruit) timbers may be used.

With regard to timber buildings, as distinct from brick or reinforced structures, reference may be made to Mr. E. R. Gee's account of the Dhubri earthquake of 3rd July, 1930.[1]

Lightly constructed *kutcha* buildings.

Mr. Gee distinguishes between structures of split bamboo, supported on a wooden frame-work, in which the posts are driven into the masonry plinth or alluvial foundations, and similar structures, in which the framework merely rests untied on the masonry plinth. The former type suffered considerably in the earthquake, the upright wooden posts often being sheared at the base. The latter type was practically undamaged, since the buildings were able to move as a whole upon, and separately from the plinth, with their own natural period of oscillation.

Light roof preferable.

It has been found that heavy roofs were frequently the cause of serious damage to buildings. During big vibrations the inertia of such roofs broke up the walls on which they rested. Flat roofs, therefore, should be made as light as possible, and the junction of wall and roof reinforced in some way. Roofs made of reinforced brickwork are

[1] *Mem. Geol. Surv. Ind.*, LXV, pp. 8, 9, 88, (1934).

lighter, stronger and more graceful than the old type of clumsy and heavy roofs on beams and rafters. The use of flat tiles instead of bricks where beams and rafters are used is advisable for flat roofs. Light tile roofs appear to have caused the least damage where the tiles are securely fastened.

Arches.

We do not recommend the use of arches in doors, windows and verandahs ; during a tremor they are the weakest part of any structure and the first to go. Jack-arches supporting roofs sometimes escaped, but as often were cracked along their centres. If use is made of jack-arches, it is advisable to employ tie-rods to hold together the different spans. Bricks in these arches should be dovetailed and not set in a linear arrangement.

Solid reinforced lintels over doors and windows are preferable. Wherever possible, lintels on each floor should be of the same height and should be carried around the walls as a single band.

Gables.

Sharp gable ends, so characteristic of churches, should be avoided. During an earthquake they sway considerably and aided by the thrust of the roof, collapse easily. Hip roofs are preferable to gables.

Chimneys.

Tall chimneys in factories should not be of brick. Steel or reinforced-concrete chimneys can pass safely through severe earthquake shocks.

High grade building material essential.

Perhaps the best advice we can give is that close attention should be paid to the quality of building material, particularly to mortar. Unfortunately the standard of bricks and mortar used even in public buildings in India is often not as high as it might be. The example of some of the newer railway buildings is well worth following.

We will now outline some general considerations for reconstruction in Bihar and Nepal. Recommendations for north and south of the Ganges and for Nepal will be outlined separately.

Bihar.

NORTH OF THE GANGES.

When to build.

In this belt reconstruction of any heavy buildings should not be undertaken until after the coming rains (1934) and the ensuing dry

Construct next cold weather.

season (1934-35) is well advanced. The alluvium here has received a most severe shaking—it might be compared with a tin of loose sand or flour which, on shaking, settles down into a more compact mass. Irregular subsidence at some places may continue slightly during the next few months. The fact that fissures cannot be actually seen is no criterion of the absence of subsidence. There is, of course, the additional and important fact that tremors may continue for some months and any shock of marked severity is likely to cause obvious weaknesses in partially constructed buildings.

Light inexpensive buildings, such as are erected in the bazaars, can be taken in hand immediately.

Where to build.

One obvious feature of this earthquake is the effect which any shallow depressions, *e.g.*, lakes, *tanks*, rivers and even ditches, have had on neighbouring land. Fissures concentric with or parallel to the edge of such depressions have formed up to several hundred yards from them. This arises from the tendency of all surface features in alluvial country to assume a common level....depressions fill up from the bottom and high ground subsides.

Location of fissures.

We would recommend that no heavy structures should be erected within at least 200 yards of depressions in the slump belt—the heavier the building the greater should be its distance away from depressions. This remark is particularly applicable to such large structures as the Pusa Institute.

Heavy structures kept away from depressions.

What to build.

The recommendations already suggested cover the chief points to be mentioned in this section. The three important factors are :—

(*a*) sound building materials.
(*b*) adequate foundations.
(*c*) safe building construction.

Without adequate foundations even reinforced-concrete buildings may tilt and become uninhabitable. Without proper bracing, a strong horizontal acceleration and a large period of oscillation of the buildings will distort heavy structures, whatever the foundations.

Any further heavy buildings such as the Pusa Institute, that may be constructed in this belt should be erected on rigid reinforced concrete foundation rafts. Where two or more storeys are essential the building should be of steel or reinforced concrete framework with brick or cement concrete panelling.

Heavy buildings to be found on rafts.

In the case of concrete, the panelling should be constructed at the same time as the framework in order to ensure good bonding. Sugar mills should be of steel framework with brick panelling, or covered with corrugated iron or other light material; if possible they should be erected on reinforced concrete rafts.

Houses and similar buildings should be single storied and as light as possible. Along the Motihari-Sitamarhi-Madhubani-Purnea belt we would advise that houses be built of steel or timber framework, all joints being made secure and foundations tied. Structures of this type, carefully designed and conscientiously erected can be as permanent and cool as masonry. In certain places the construction of such light houses could be commenced at once. South of the Motihari-Purnea belt the usual masonry structures with suitable foundations may be erected, but only after the rains.

Houses.

SOUTH OF THE GANGES.

When to build.

South of the Ganges subsidence was rare, but that it took place is sufficient warning to warrant caution in building heavy structures. The danger of further tremors here, except at Monghyr, is not so great as north of the river. In urgent cases, therefore, it may be desirable to accept the risk and erect light structures immediately.

Monghyr is something of a paradox. We have outlined elsewhere probable reasons why it has been affected by this shock so badly. Both Jamalpur and Monghyr always have been more affected than adjacent towns by earthquakes, which have taken place in North East India. Whatever the correct reason may be, this locality will continue to feel earthquakes occurring in the region more severely.

Monghyr.

Although fissuring is absent at Monghyr, except along the river bank, this is no criterion of the absence of subsidence on the alluvial ground. Hence on the low ground at Monghyr we would still commend the next dry weather (1934-35) as the most favourable season for erecting expensive heavy structures. On the high ground reconstruction can be commenced at once, providing urgency demands that the effect of possible tremors during construction should be risked.

Where to build.

Rebuilding of heavy expensive structures along the river front at Patna should be avoided as far as possible. If undertaken, such structures should be restricted to a single storey unless care is taken in the design of foundations. Elsewhere south of the Ganges no particular restriction need be placed on the location of buildings.

What to build.

The damage south of the river has been mainly to older structures, but a few recently-built structures have also suffered. However, well-built single-storied structures have usually escaped and, provided attention is paid to our remarks on arches, verandahs, porches, etc., there is no reason why the usual type of brick structure should not be erected as in the past. Mat or 'floating raft' foundation should here also be constructed under any very heavy buildings that may be erected in the future. Houses should be restricted to a single storey.

Roads.

A minimum standard width for bazaar streets should be insisted upon wherever possible. This will depend upon the height of buildings erected.

No advice can be offered about road construction, but we would remark that the occasional practice of digging deep ditches alongside them is frequently the cause of subsidence of the roads. Ditches preferably should be shallow.

Bridges.

In a severe earthquake in alluvial country, river banks tend to close in and their bottoms to rise up, as a consequence of the general tendency towards the suppression of surface features. No type of structures can withstand such movement, where it is severe, without some damage.

Brick arched culverts and bridges have been damaged most severely and this type should not be built north of the river.

For road bridges screw-piles have proved the most suitable. Piles tend to move up or down during the shock, and movement of the bank tends to bend the piles over. Movement along the stream bed may also displace the piles. After the Bihar earthquake, although pile bridges were acutely distorted they were in almost every case negotiable by traffic. Although easily damaged they can be readily dismantled, straightened and rebuilt.

Frequently it is of course necessary to construct bridges of steel girders resting on masonry piers. The weak points in this type are the piers and abutments. Nothing can prevent their tilting or displacement in a severe shock, but piers should be designed if possible to withstand an acceleration of 10 feet per sec. per sec. from any direction, that is, their width at the base should be one-third of the height of the pier. Girders should also be designed to withstand such an acceleration.

CHANGE OF OFFICIAL HEADQUARTER SITES.

The general question of reconstruction on old sites is one that cannot be discussed lightly, but after careful consideration it seems to us unnecessary that any such drastic steps should be taken as the removal of town sites, except in the case of Madhipura.

At Motihari there is little question that the lake has influenced the destruction of buildings in its neighbourhood. Any heavy costly structures that may be built here in the future should be kept away from the vicinity of the lake.

At Sitamarhi the same remarks apply. Unfortunately the Government buildings, except the P. W. D. Inspection Bungalow, which escaped almost undamaged, are close to the river. If such light structures as are recommended in this report are erected, the old sites can be safely utilised. Otherwise we would recommend construction upon adjacent open ground away from the river.

Madhipura is the one town which might with advantage be abandoned. Forty years ago, before the Kosi river had so treacherously altered its course towards the vicinity of Madhipura the town was an ideal site in every way. The many branches of the river have made movement about the subdivision increasingly difficult, and during the rains the whole of the surrounding country is flooded, with the result that Madhipura can only be approached by boat. In addition, a branch of the Kosi east of the town is gradually working west, it has now breached the bund damaged by the earthquake, and there is every possibility that during the rains the river will be diverted through the town. It is an unequal fight with the river, and the damage done by the earthquake is an additional reason why the site of the subdivisional headquarters should be moved to such a more accessible centre as Saharsa.

The Geological Survey has been approached as to the advisability of moving the headquarters of Purnea district. The advantages of the present site are obvious; it is central and easily accessible from any part of the district by roads and railways radiating from the town; there is also a settled community largely dependant upon the presence of the district headquarters, and much money has obviously been invested in the town by business concerns.

The disadvantages are: the town is within the principal zone of weakness of the earthquake area and may, therefore, be affected by future tremors; the loose sandy nature of the ground is unsuitable for such massive buildings as have been erected. Purnea is at the centre of a tract of country extending from the Nepal border south to the Ganges and from the Kosi river east almost to Kishanganj and which from the data available is formed of a sand bed in places 60 to 80 feet in depth.

The only suitable places for a district headquarters would be between Purnea and Araria, Purnea and Kishanganj or Purnea and Katihar.

Although Purnea is on the zone of weakness it must be remembered that the old town, across the river from the civil lines, was scarcely affected. The main reason for this is that the buildings in the old town are of much lighter construction and accordingly have not suffered subsidence.

From Purnea to Araria damage to the railway line indicates that the intensity here was considerable, so that from the point of view of this earthquake there is nothing to choose between any two localities along this line.

Between Purnea and Kishanganj the damage from six miles east of Purnea was negligible; but there is no reason why a future earthquake, especially one along an easterly continuation of the Motihari-Purnea fracture zone and extending towards the epicentre of the 1897 earthquake, should not be just as severe at Kishanganj as this one was at Purnea.

Between Purnea and Katihar the damage was slight, Katihar is further removed from the likely zone of high intensity in this earthquake belt. If a site away from Purnea were desired, Katihar would be preferable geologically.

The advantages of Purnea, however, easily outweigh the doubtful geological gain in moving to Katihar. It is also doubtful in the immediate vicinity of Purnea any one site is really more reliable than another. Geologically the only point on which there can be certainty is that light structures carefully designed would withstand a future earthquake with the minimum of damage. East of the river at Purnea is as suitable as anywhere.

Darjeeling.[1]

After Bihar, the worst affected area in British India was Darjeeling district in Bengal. The damage to buildings was most extensive in Darjeeling town itself and in some of the tea estates on the neighbouring hillslopes and valleys. Although Darjeeling was free from landslips a number of surface cracks were noticed. As all of them were restricted to the top layers of the sub-soil the best advice is to fill them in with sand, ram in the top part with earth and dress the general slope in order to prevent the entry of rain water.

In the opinion of Mr. Wadia, the causes of the damage to buildings lay in their inherent instability on account of their age, weak construction and poor foundation. The practice of erecting buildings with coarse rubble or undressed stones set in mud or in poor quality mortar should be avoided as far as possible. The importance of well-constructed buildings of brick or dressed stone with high quality mortar or cement cannot be over emphasised. Buildings on hillslopes should be erected in such a way as to behave like monoliths during a shock. For this purpose buildings should be made of ferro-concrete or of good brick and mortar or cement. Height of buildings should be in proportion to the width of their bases. Tall structures without deep foundation and adequate width at the base should not be permitted.

Construction.

Much depends upon the nature of the sub-soil for laying the foundation of a heavy structure. A rocky foundation is most suitable for heavy buildings; where this is absent a compact tough sub-soil should be selected.

Foundation.

[1] Abstracted from Mr. Wadia's report to the Government of Bengal.

Precautionary measures are essential, if it is not possible to avoid disintegrated or decomposed, fissile gneiss for foundation.

'Before commencing re-building the vicinity of cracked ground needs to be kept under observation for some time. Any widening of the cracks as the effects of the aftershocks, or of settlement along one or the other wall of the fissure is an indication of insecure foundation........No immediate building works, however, at such sites are advisable till the stability of the ground is proved by no further subsidence or widening of the crevices taking place. For a hill-station like Darjeeling, which has experienced no less than two earthquakes of high intensity during the last 37 years, safety for the future lies in the selection of moderately compact ground for foundations; in well-revetted ferro-concrete buildings of one or two stories and not too tall for their bases; and in the avoidance of top-heavy ornamental chimneys. The tendency, too frequently noticed, of buildings on "floating foundations" should be checked by Municipal regulation.'

Nepal.

Where to build.

It is obviously impracticable to shift the sites of whole towns to localities which escaped the ravages of the 1833 and 1934 earthquakes. In no other place than Katmandu could sufficient space be found to accommodate the fine palace compounds, the parade grounds and long avenues.

The problem then, as it concerns towns already in existence in parts of the valley that are liable to feel earthquake shock severely, is the construction of buildings according to earthquake-proof principles.

In view, however, of the future development of the Nepal valley, it may be borne in mind that the area to the south-east of the valley should be avoided as far as possible, while that between Pashupatinath, Boddanath and Gokarna may be considered the safest in the valley. This applies in particular to industrial development and the laying down of heavy machinery. The new hydro-electric station above Sundarijal is close to this area of relative immunity, and it will probably be advisable to concentrate industrial concern in this vicinity. There will be the added advantage that the cost of laying down long high tension cables from the power house will be avoided

When to build.

The question of when reconstruction may be taken in hand involves a discussion of two factors :—

(1) the disturbance caused by the earthquake to ground conditions.

(2) the probability of aftershocks.

The conditions in the Nepal valley are not the same as those of the Nepal Terai and the Plains of Bihar. The soft fluviatile and lacustrine sediments of the Nepal valley occur in a small area of approximately 150 square miles, surrounded by hills and underlain by hard older rocks at a small depth. It is doubtful if the greatest depth of the Pliocene and later sediments is as much as 1,000 feet. Over most of the valley it must be much less. Rivers have cut down into these soft rocks, converting the once continuous sheet of sediments into a series of terraces and small valleys. The rain water which falls upon the surfaces of the terraces and seeps in, has a ready outlet along their free edges. There are consequently no water-logged sands in the valley of Nepal.

Contrasted with this small circumscribed area is the approximate 300,000 square miles of the Indo-Gangetic alluvium, which fills the trough or *foredeep* in front of the Himalaya. No bore-hole has struck the bottom of this alluvium along the central tract. The deepest bore is, it is true, not quite 2,000 feet, but it is very probable that the alluvium is in places over 10,000 feet thick. Terraces are absent, and there is no escape for the water that seeps into the alluvium other than a rise of the water table. The sands become water-logged and highly mobile. Under the pressure resulting from an earthquake shock, the sand and water are forced up to the surface to give the extensive extrusions from vents and fissures which have been such a striking feature of the earthquake in Bihar. In the Nepal valley only one sand vent was seen. Fissures are very rare. The disturbance of the ground is clearly less than in Bihar, or the Nepal Terai.

The difference is probably fundamental. The Indo-Gangetic alluvium is made up of a vast pile of sediments, the basement of which must have sunk as the pile grew in thickness. Instability is set up relative to the stable block of Peninsular India and the rising Hima-

[1] The Himalaya are, of course, being denuded, and will eventually wear down to humbler heights. The *rise* referred to may be compared with that of an iceberg as a whole, as the parts above water are in the process of melting.

layan chain both as a result of downwarping and of accumulation of alluvium. The seismic belt of India undoubtedly has some connection with the unstable region of the Indo-Gangetic alluvium. The Nepal valley, on the other hand, is an elevated basin covered by a thin series of sediments, which are being denuded rather than being accumulated, and can have little primary causal connection with the earthquake. The reason for the high intensity of the earthquake in the Nepal valley is not fully understood.

Accepting that ground conditions in the Nepal valley have not been disturbed to the same extent as in Bihar and the Nepal Terai, there remains the question of aftershocks. Aftershocks have continued for over seven months since the initial earthquake. In the earthquake of 1833 aftershocks were recorded for three months after the main earthquake of the 26th August. No shock seems to have occurred in 1833 after the 26th November. At the time of visit of the first author, in February, 1934, several aftershocks had occurred, but none had been severe enough to tear the strips of paper which General Kaiser had placed over cracks in his palace. There is indication, therefore, that the damage occasioned to buildings by these aftershocks is slight. The damage which might be incurred during reconstruction will also in all probability be slight.

For these reasons, it can be stated with confidence that reconstruction may be begun in the Nepal valley at the present time. It may take the Government some months to obtain the materials necessary for the reconstruction of heavy buildings, so that it may not, in any case, be possible to put down such structures until after the monsoon. It would be absolutely unnecessary to wait longer.

Mr. K. K. Sen Gupta, of Calcutta University, has expressed the opinion in the *Statesman* of April 15th, 1934 (town edition), that buildings should not be constructed anywhere in North Bihar until periods varying, according to conditions, of from one to three years have elapsed. It appears to the Geological Survey of India that these periods are unnecessarily long. In any case, they do not concern the valley of Nepal.

The villagers in most places in Nepal have already finished repairing their houses, or building new ones. From the point of view of time, this was legitimate, but it is questionable whether the new houses they have put up show any improvement in design upon those that collapsed so readily during the earthquake.

With regard to the Nepal Terai, the damage by sand and fissuring is not severe along the tracts that were visited. At Jaleswar the condition is probably worse, and more like that at Sitamarhi and Madhubani. There is a greater need for a cautionary period in such cases. Nevertheless, reconstruction may be undertaken in these places with confidence after the monsoon.

EXPLANATION OF PLATES.

PLATE 13, FIG. 1. General view of Chauk Bazar, Monghyr.
FIG. 2. General view of Harisidhi, Nepal valley.
PLATE 14, FIG. 1. Slumping of houses, Sitamarhi.
FIG. 2. Slumping of house, Purnea.
PLATE 15, FIG. 1. Tilting of houses along fault plane in alluvium, Motihari.
FIG. 2. Sand vents near mile 14, Muzaffarpur-Darbhanga road.
PLATE 16, FIG. 1. Durbar Square, Bhatgaon, Nepal.
FIG. 2. Rockfalls near Udaipur Garhi, Nepal.
PLATE 17, FIG. 1. Wood-pile bridge, Kesariya, Champaran.
FIG. 2. Girder bridge near mile 9, Muzaffarpur-Sitamarhi road.
PLATE 18, FIG. 1. Railway line, Sitamarhi.
FIG. 2. Inchcape Bridge, Manjhi, 11 miles west of Chapra.
PLATE 19. Isoseismal map of the earthquake of the 15th January, 1934.
PLATE 20. The higher isoseismals of the earthquake of the 15th January, 1934.
PLATE 21. Directions of fall of objects during earthquake of 15th January, 1934.

POSTSCRIPT.

The section on page 221, relating to underload in North Bihar, was written before the authors were aware of a paper by Major Glennie entitled 'Gravity Anomalies and the Structure of the Earth's Crust' [*Survey of India Professional Paper*, No. 27, (1932)]. Major Glennie's views are summarised on pp. 26 and 27, where he emphasises that a zone of thick deposits, such as that of the Gangetic alluvium, is an effect rather than a cause of instability in the earth's crust.

J. A. Dunn, Photo.

FIG. 1. GENERAL VIEW OF CHAUK BAZAR, MONGHYR.

J. B. Auden, Photo. *G. S. I., Calcutta.*

FIG 2. GENERAL VIEW OF HARISIDHI, NEPAL VALLEY.

FIG. 1. SLUMPING OF HOUSES, SITAMARHI.

J. A. Dunn, Photos. *G. S. I., Calcutta.*

FIG. 2. SLUMPING OF HOUSE, PURNEA.

FIG. 1. TILTING OF HOUSES ON FAULT-PLANE IN ALLUVIUM, MOTIHARI.

J. B. Auden, Photos. *G. S. I., Calcutta.*

FIG. 2. SAND VENTS NEAR MILE 14, MUZAFFARPUR-DARBHANGA ROAD.

FIG. 1. DURBAR SQUARE, BHATGAON, NEPAL.

J. B. Auden, Photos. *G. S. I., Calcutta.*

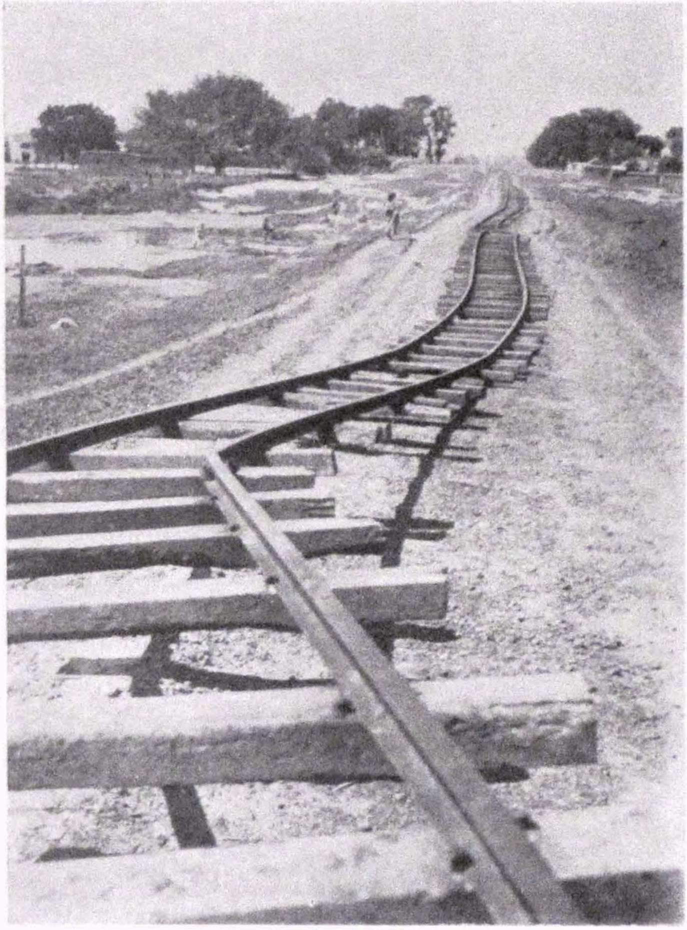
FIG. 2. ROCKFALLS NEAR UDAIPUR GARHI, NEPAL.

J. B. Auden, Photo

FIG. 1. WOOD-PILE BRIDGE, KESARIYA, CHAMPARAN.

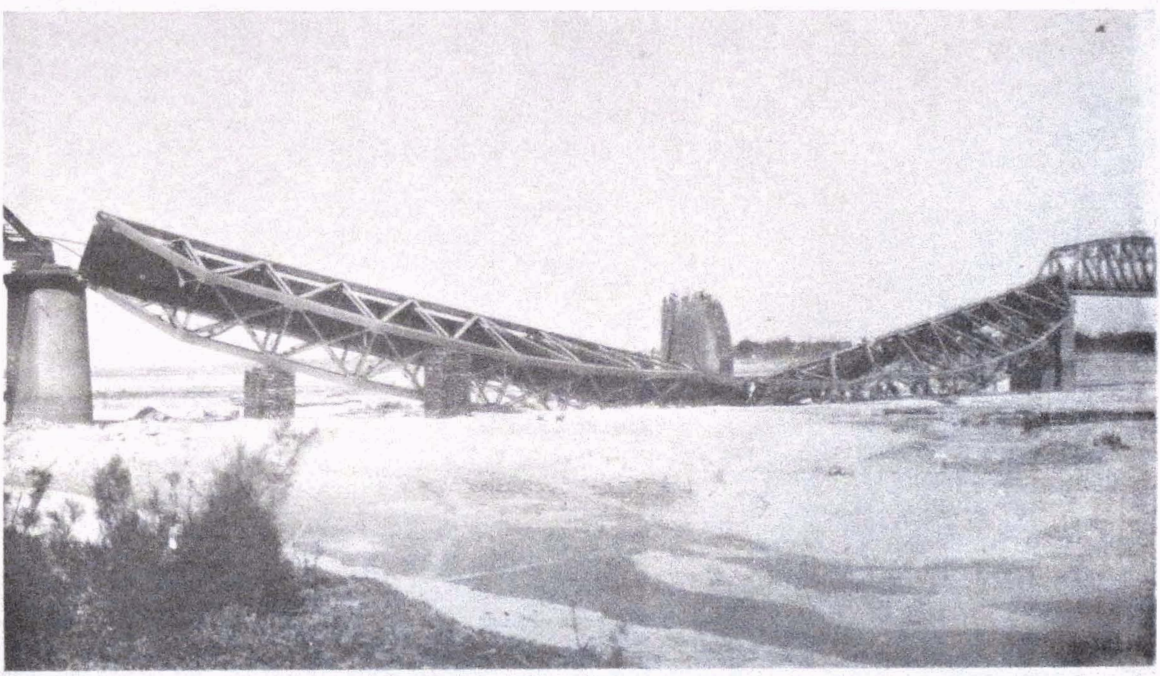
A. M. N. Ghosh, Photo. *G. S. I., Calcutta.*

FIG. 2. GIRDER BRIDGE NEAR MILE 9, MUZAFFARPUR-SITAMARHI ROAD.



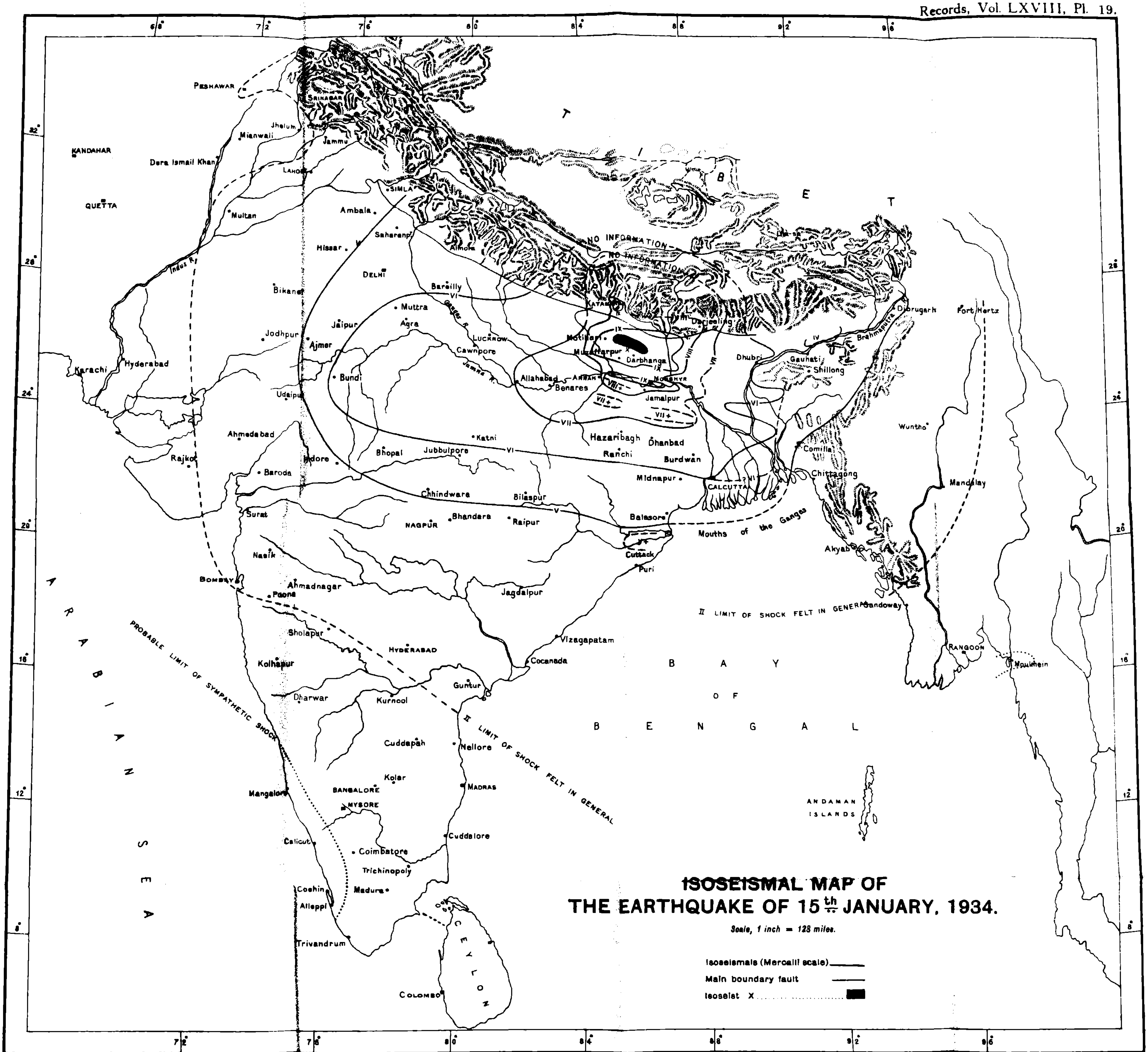
J. A. Dunn, Photo.

FIG. 1. RAILWAY LINE, SITAMARHI.



A. M. N. Ghosh, Photo. *G. S. I. Calcutta.*

FIG. 2. INCHCAPE BRIDGE, MANJHI, 11 MILES WEST OF CHAPRA.



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