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Geotechnical Damage Due to Bihar Earthquake of August 1988

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SYNOPSIS: The Bihar-Nepal earthquake of August 21, 1988 (magnitude 6.6) caused significant loss of life and property. Besides the epicentral area, two distant places (Munger in India and Bhaktapur in Nepal) suffered significantly. This was also the case in the 1934 earthquake (magnitude 8.4) and is due to peculiar geology of the area. Geotechnical damage in the affected area includes liquefaction, cracking and subsidence of embankments, and cracks in bridge abutments and wing walls. Besides, in the hilly regions of Sikkim, landslides and rockfalls disrupted road network significantly. Extensive damage took place in the eastern Nepal also. This paper describes the geotechnical damage to the Indian areas only.

INTRODUCTION

On August 21, 1988 an earthquake of magnitude 6.6 (approximately) occurred close to India-Nepal border at 04:39:11 hours (Indian Standard Time). Its epicenter located at a place (26.7°N, 86.6°E) in eastern Nepal between Udaipur and Dharan lies in the vicinity of epicenters of major Bihar-Nepal earthquakes of 1833 (magnitude 7.0-7.5) and 1934 (magnitude 8.4). Preliminary estimates indicate focal depth of about 36 miles (Rastogi, 1988). Fig. 1 shows the location of

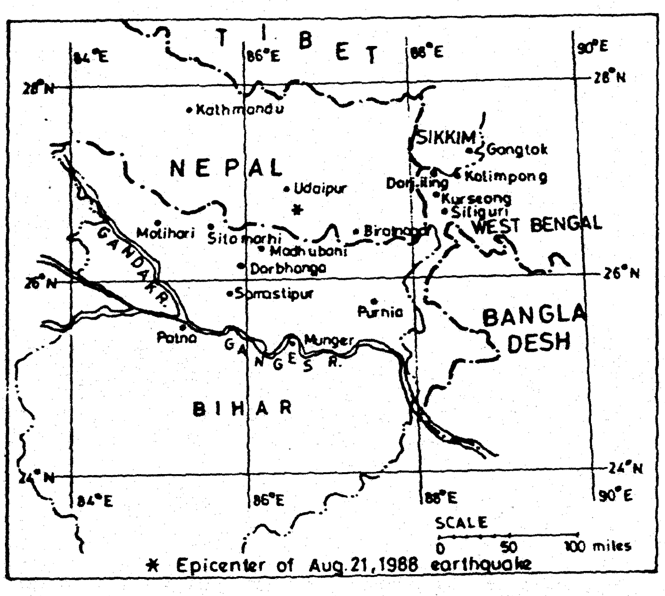

FIG. 1 Affected Areas, August 21, 1988 Earthquake.

epicenter and the affected areas in India and Nepal. Widespread devastation and loss of life was reported. About 1004 people died (282 in India and 722 in Nepal) and more than 16000 received injuries. The affected area consists of mainly the Gangetic alluvial plain of Bihar (India) and Nepal, and the hilly regions of eastern Himalayan ranges.

Fig. 2 (Richter, 1957) shows the affected areas and isoseismals of January 15, 1934 Bihar-Nepal earthquake. An area measuring about 60 miles long and 20 miles wide around the epicenter had an intensity of X. Besides, two more areas about 100 miles away, in opposite directions from the main belt, one at Munger (old Anglicized name Monghyr) and the other at Kathmandu also had intensity of X. Richter (1957) related this peculiarity to geology of the region as, "At Monghyr a ridge of Archean quartzite, an outlier of the peninsular rocks, emerges through the alluvium.... One is led to think that the seismic waves transmitted from a source miles deep under the Ganges alluvium and sediments

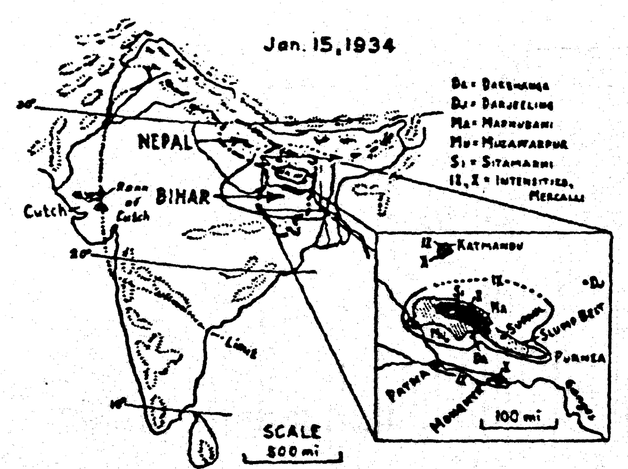

FIG. 2 Affected Areas, Bihar-Nepal Earthquake of 1934 (Richter, 1957).

and, passing through competent rock without appreciable absorption, emerged with considerable violence into the alluvium about Monghyr, which was accordingly more disturbed than the similar ground to the north, where shock waves travelled upward through a greater thickness of absorbing material." Similar explanation was given for the greater damage at Kathmandu. The area enclosed by IX intensity isoseismal around epicenter consists of several thousand feet deep, soft and saturated, alluvium. Large number of buildings tilted and slumped into the soil due to liquefaction in this area (about 190 miles long and of irregular width exceeding 40 miles at places), termed as the 'slump belt' by the investigators. Fissuring of ground and emergence of sandy water at the surface, often in spectacular fountains, was observed at many places. Road causeways and railway embankments subsided by upto 6 feet and depressions like tanks and lakes became shallower. No liquefaction in Munger was observed, although damage to buildings and other structures was comparable to that at places where liquefaction had occurred.

The August 21, 1988 Bihar-Nepal earthquake followed the damage pattern of the 1934 earthquake, although at a much reduced scale. Three distinct areas, one located near epicenter and the other two at Munger and Bhaktapur (near Kathmandu in Nepal), with damages of higher intensity were observed. Fissuring of ground and emission of sandy water was observed during the earthquake at many places in Darbhanga and Madhubani districts of Bihar, while no signs of liquefaction were seen at Munger. Significant damage to embankments, railway bridges, and buildings took place in Bihar. Besides, hilly regions of Sikkim and Darjeeling district of West Bengal, located far away (approximately 125 miles) from the epicenter of the earthquake received extensive damages. These areas are characterized by the presence of unstable mountains with steep hill slopes covered by thin layer of soil and vegetation. The earthquake, preceded and succeeded by heavy rains, caused numerous hill-slope slides and rock-falls in the whole region. A number of roads and highway bridges were damaged due to the combined effect of the earthquake and the rains. Sikkim Public Works Department (SPWD) estimated the total cost of repairs to the roads and bridges in the state of Sikkim alone as approximately Rs.97.74 millions (about US $ 5.5 millions). Extensive damage to buildings, roads and the other structures in plain and hilly regions of Nepal has also been reported (e.g., Gupta, 1988). However this paper includes geotechnical damages in the Indian areas only.

SOIL LIQUEFACTION

As a result of increase in the pore water pressure due to the ground vibration in the saturated granular soil, water comes out in the form of mud sprouts or sand boils as in artesian wells. Several sand boils, in the form of miniature volcanic craters, with diameter ranging from one foot to several feet, were seen in the districts of Darbhanga and Madhubani. A few sand boils measured up to one foot in height. Even larger sand boils were reported in Madhubani district. A covered well, located within the premises of residence of the Superintendent of Police in Darbhanga, was found chocked with sand. A hand pump was mounted on the top cover slab of the well. The upward thrust on the pump punctured the top brick slab and a big heap of sand brought by the springing water was lying all around the well (Fig. 3). A typical sand dune due to liquefaction inside the premises of the Bihar Public Works Department rest house is seen in Fig. 4.

FIG. 3 Sand Boil, Around Hand Pump Inside the Residence of the Superintendent of Police, Darbhanga.

Liquefaction phenomenon was observed along the boundary wall of Darbhanga Jail (about 15 feet high and 27 inches thick brick masonry). Vertical and horizontal cracks were present on the wall due to differential settlement caused by the liquefaction. Tilting of the wall and three watch towers was also noticed. An electric pole and a mango tree situated near the wall tilted significantly away from the wall. Damage to plinth protections and ground floors was evident in many houses in Darbhanga.

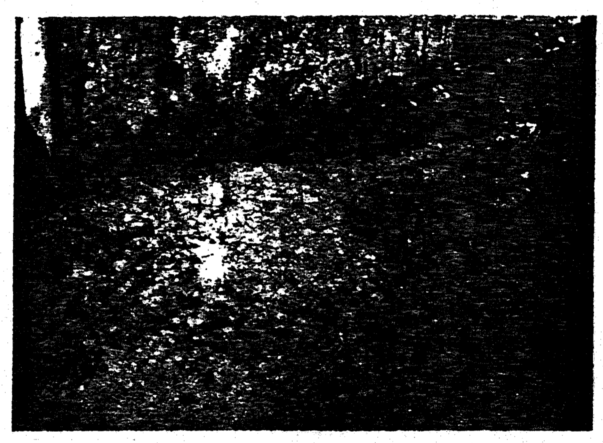

FIG. 4 Sand Boil, Bihar P.W.D. Rest House, Darbhanga.

Damage to railway track and its well compacted embankments in Bihar was limited to minor subsidence of formation and distortion of track at a few places. In Saharsa-Purnea section, between Dhanram Madhepur and Baijnathpur stations, subsidence of approach to the bridge occurred for a length of about 50 feet. This was later set right by packing the subsided portion with cinders. In Saharsa-Forbesganj section damage to railway track was noticed at two places. Between Saraygarh and Tharbitia stations, the sandy formation developed longitudinal cracks and caved-in. At another site located between Pratapganj and Lalitgram stations the formation forming part of the approach to a bridge caved-in.

Northern Bihar is prone to devastating floods. An extensive network of flood control embankments exists along the rivers for flood protection. The quality of construction of these embankments is very poor as no compaction is usually done during the construction. The location of damaged embankments in Flood Control Circle Darbhanga are indicated in Fig. 5. The prominently damaged embankments are as follows.

Embankment on Bhutahi River

Flood protection embankments along the Bhutahi balan (river) were extensively damaged. The worst damaged stretch was in Laukha Block near Phulparas which is about 44 miles east of Darbhanga. The embankment starting from Indo-Nepal

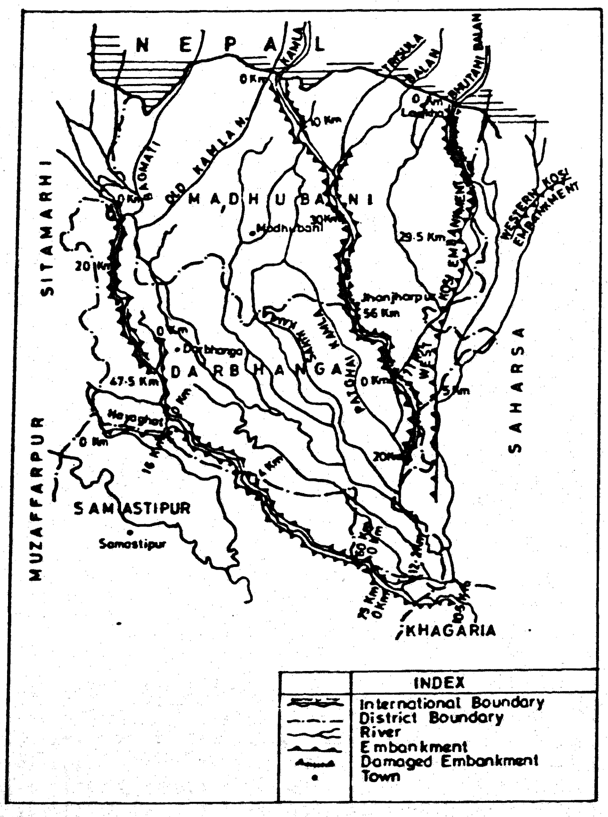

FIG. 5 The Damaged Embankments in Flood Control Circle, Darbhanga.

FIG. 6 Longitudinal Cracks on Top of the Bhutahi River Embankment, Zero Nose Near Laukha, Bihar.

border (Zero Nose, Laukha), is having 1:2 slope on the river side with dry brick pitching over 6 inch filter material. Slope on the other side is 1:3 without pitching. Height of the embankment varies from 10 feet to 12 feet, near Zero Nose (Fig. 5), and its top width is approximately 18 feet. The total length of this embankment is about 31 miles out of which 16 miles was damaged due to the earthquake. Subsidence and series of parallel longitudinal cracks were observed on the embankment (Fig. 6). Sand boils on the river bed were seen all along the embankment. Liquefaction in the ground at either side of the embankment possibly created differential settlement such that the base became convex upwards resulting in the development of longitudinal tension cracks on the top of the embankment.

Embankment on Kamala River

This embankment subsided very significantly at 67.0 km point (Fig. 5) near Jhanjharpur. The damaged site is about 22 miles from Darbhanga. This embankment is 18 feet wide at the top and approximately 18 feet high, having 1:2 slope on the river side and 1:3 slope on the other side with brick pitching on both the slopes. The embankment was reconstructed in August 1987 after a breach and washing away of the earlier embankment. The top of the newly constructed embankment subsided by about 8 feet (Fig. 7). The pitching on the river side slope bulged out, while on the other side it became wavy after subsidence. Longitudinal cracks on top of the embankment and sand boils brought by the liquefaction were also observed. Since construction practice in the area does not include compaction of the embankments, the embankment itself being loose and saturated underwent liquefaction resulting in large slumping.

Other Embankments

Embankments on the Kareh and Khirori rivers were reported to have been damaged at a few places in Darbhanga block. Subsidence over a stretch of 390 feet was reported on the link road connecting

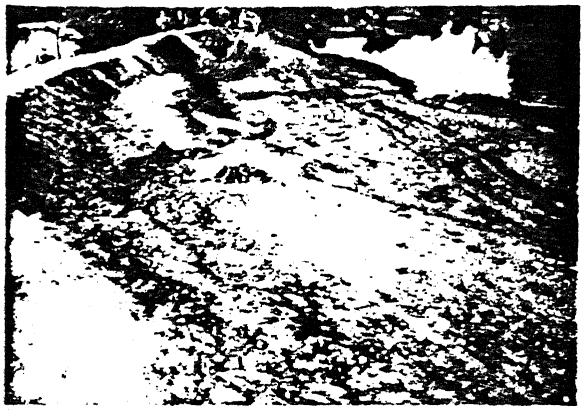

FIG. 7 Subsided Embankment of Kamala River.

FIG. 8 Kumrek Landslide, Sikkim.

Sormarat-Hayaghat embankments on the Kareh river at 16.5 km point (Fig. 5).

DAMAGE TO RAILWAY BRIDGES

Damage to twelve bridges was reported by the railway authorities. Train services in the affected sections had to be suspended for a while for damage assessment and repairs. Wing walls of a bridge, between Naya Nagar and Ruseraghat stations, bulged out. Piers of another bridge, between Janakpur Road and Bajpatti stations, developed cracks. This is a 3 span, each of 20 feet long, steel girder bridge. Six span steel girder bridge, between Kamtaul and Jogiara stations, received severe damages. The bed blocks below the girders cracked and the masonry piers and abutments of the bridge developed wide cracks. The wing walls and the return walls of a steel girder bridge, between Kakarghatti and Trasarai stations, developed cracks. Some portions of the wall masonry cracked and fell down and the abutment masonry bulged out. Parapet wall of approaches of a bridge, between Manigachi and Lohna Road stations, cracked and collapsed. Another bridge, between Dhamaraghat and Koparia stations, having seven span, each being 40 feet long, received damages. The existing cracks in the bed block of two piers widened, requiring immediate epoxy grouting. Pier of a three span, each 40 feet long, bridge in Jhanjharpur-Laukha Bazar section tilted and was found to be out of plumb by two inches, immediately after the earthquake.

LANDSLIDES AND ROCKFALLS

The hill slopes in Sikkim are known for their land-slides. The tremor triggered numerous land slides which was compounded by heavy rains, before and after the earthquake. The slides disrupted communications in many cases and also caused widespread damage to the roads, bridges and the other structures. An initial slip at Kumrek got aggravated due to the earthquake and washed away about 0.6 miles long state highway (Fig. 8). Construction of a new road on a different alignment became necessary in order to restore the traffic. At Narak, initial slope failure occurred due to the earthquake which was aggravated subsequently by rains (Fig. 9). Several other land-slides have been reported to have damaged the road formations in the state. Three major bridges were damaged mainly due to rock-falls and abutting slope failures. Damage also took place to the hilly roads in Darjeeling district of the state of West Bengal.

FIG. 9 Narak Landslide, Sikkim.

Legship Bazar Bridge

This is a newly constructed prestressed concrete bridge of about 200 feet span (Fig. 10), on river Kalej Khola near Legship Bazar town (about 58 miles from Gangtok). Hill slope on the Legship Bazar end failed and soil mass including huge boulders fell on to the bridge deck. Approximately half lane wide deck slab was completely smashed near abutments due to impact of the huge rocks (Fig. 11). The bridge however

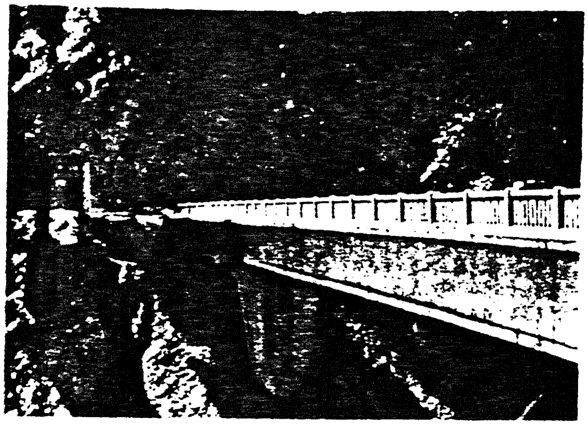

FIG. 10 A View of the Legship Bazar Bridge, Sikkim.

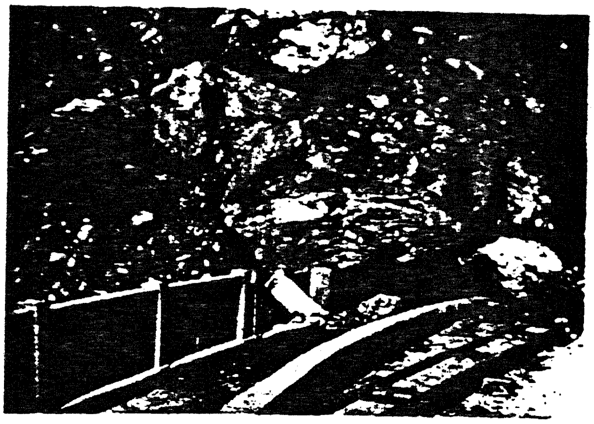

FIG. 12 The Damaged Railings of the Legship Bazar Bridge.

was opened for traffic immediately after removing the debris. The other end did not receive much damage and only some portions of reinforced concrete railing were affected due to the impact of rolling boulders (Fig. 12). There was no apparent damage to piers and abutments.

Tashiding Suspension Bridge

This bridge site is also located on river Kalej Khola at about two miles upstream from the Legship Bazar and is on Legship-Tashiding road. Bridge was under construction and its towers and cable anchors were complete at the time earthquake occurred. Proposed bridge is of suspension type with a span of about 450 feet. Legship end abutment cum suspension tower of reinforced concrete was situated just by the side of a high hill-cliff. During the quake, a huge soil cum boulder mass from the cliff came down and washed away the whole construction on Legship end (Fig. 13). The other end was however intact. An old suspension bridge with wooden decking, which is situated very near to the proposed bridge site, also did not receive any damage (Fig. 14).

Gangtok - Legship State Highway

Damaged site is located about half a mile short of the Legship Bazar township on Gangtok-Legship state highway in the state of Sikkim. At a few places significant subsidence of road, one foot to 10 feet, was observed (Fig. 15).

Retaining Wall on Labong Cart Road

This site is located at 3 miles from Darjeeling (West Bengal) on the Labong Cart road. At this place road is on embankment. A gravity stone-masonry retaining wall supports the embankment on down-hill side. Due to the pressure exerted by the embankment during the earthquake, retaining wall bulged out and some stones came out of the masonry. A longitudinal crack on the road along the length of the retaining wall was also noticed.

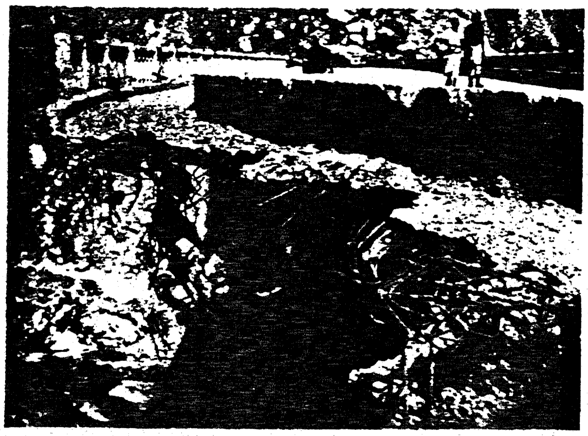

FIG. 11 The Damaged Deck of the Legship Bazar Bridge.

FIG. 13 The Landslide that Damaged the Tashiding Bridge (arrows show pieces of the suspension tower).

FIG. 14 *Old Suspension Bridge Near Tashiding* Bridge, Sikkim (no damage).

DISCUSSION AND CONCLUSION

Apart from the area surrounding the epicenter, two distant places (Munger in India and Bhaktapur in Nepal) experienced higher intensity of damage, as also in 1934 earthquake due to peculiar geology of the region. Extensive geotechnical damage took place in the affected areas; liquefaction, cracking and subsidence of embankments, and damage to bridge piers, abutments and wing walls was evidenced in Gangetic plain near the epicenter. The earthquake along with the heavy rains caused numerous hill slope failures in Sikkim. Widespread damage to roads and bridges occurred due to landslides and rockfalls.

In view of similar but interesting damage pattern, by this and the 1934 Bihar-Nepal earthquake, detailed zoning study of the region is highly desirable. Also extensive geotechnical investigations are required in the Gangetic plain of the region to fully understand the liquefaction potential of the area.

FIG. 15 Subsided Stretch of Gangtok-Legship State Highway (partly repaired).

This moderate size earthquake did considerable damage in Bihar and remotely located areas of Sikkim and West Bengal. A bigger size earthquake, or even a smaller size earthquake occurring in near vicinity, can therefore be devastating. Necessary measures to guard the existing and future constructions against liquefaction related damages in liquefaction prone areas should be taken. The earthen embankments should be properly compacted to avoid risk of disastrous embankment failures. Wherever necessary, change in alignment of bridges and stabilization of existing hill slopes should be considered to minimize the slope instability.

ACKNOWLEDGEMENT

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