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SYNOPSIS A moderate size earthquake rocked Bihar-Nepal border at 4.40 hrs. on August 21, 1988 causing wide spread devastation leading to loss of many lives and economic loss to the people of that region. The paper describes the study of damages occurred in masonry buildings, reinforced concrete buildings and liquefaction of the soil. The weakness of construction, causes of damage and lessons learnt from the performance of structures are highlighted. The traditional and old structures without any earthquake resistance measures has suffered greater damage. The new reconstruction and strengthening measures must take into consideration the experience of failure of structures.

INTRODUCTION

In early hours on August 21, 1988 an earthquake with MB = 6.4 occurred in Bihar-Nepal border region. The earthquake shook northern Bihar and caused damage in towns such as Madhubani, Darbhanga, Muzaffarpur, Munghyer, Barauni, Bhagalpur, Bihar Sherif, Nalanda, Saharsa and Patna. The Northern Bihar lies in Seismic Zone IV of India. The damages were reported from several towns of Nepal, such as Dharan, Biratnagar, Dhankuta, Sunsari district, Panchthar, Therathum, Ilam and towns close to Bihar border. Figure 1 shows the area affected during this earthquake. The reported earthquake location falls to the south of the Main Boundary Thrust (MBT) and is about 50 Km east northeast of the location of great Bihar-Nepal earthquake of January 15, 1934. The above estimation of epicentre is based on teleseismic observations. However, determination of epicentre using near station data falls to the north of the MBT near the Eastern Himalaya between Udaipur and Dharan. The focal depth was estimated to be 57 Km. In the epicentral track the earthquake was accompanied by rumbling noise and felt in two waves of 10 to 15 seconds duration. Those persons who witnessed the earthquake of 1934 and 1988 are of the view that the intensity of 1988 earthquake was no less than the 1934 one but lasted for much shorter duration which was one of the reasons for less damage. The main shock was followed by number of after shocks. This paper presents a brief account of damages in masonry and reinforced concrete buildings. The reasons of damages, lessons learnt and study of evidence of liquifaction of soil in some regions is also discussed.

EARTHQUAKE DAMAGES IN MASONRY BUILDINGS

The detailed report on damage survey by Thakkar et.al., (1988) gives an account of damage to various buildings in the earthquake affected region. Herein, the highlights of damage in some selected buildings are described.

Old Brick Masonry Buildings :

The old masonry brick buildings were constructed in lime mortar. The roofs consist of inclined tile roof on rafter. The arch construction in door openings, window openings and verandah are very common. The building heights range from one to three storeys. Typical damages are described below.

High Court Building, Patna (Photo 1) : This is a massive two storeyed structure constructed in 1917-1918 having 50 cm thick brick wall in lime mortar. The cracking occurred on the outer surface of dome, inner and outer walls. The separation of walls at corner was also observed.

Governer's Residence, Raj Bhawan, Patna (Photo 2) : The massive three storeyed structure was constructed during 1915-1918. It consists of several load bearing arches. This structure withstood the 1934 Bihar-Earthquake which had cracked the dining hall on the first floor in N-S direction. Nearly, all the verandah arches about 10 m span on all floors oriented in approximately E-W direction suffered damage in this earthquake. The damage was in the form of fine cracks. The 15 m span arch in the western side of the building developed a large horizontal shear crack on one side just above the crown.

Land Mortgage Building, Darbhanga (Photo 3) : This is about a 100 year old building with arches constructed in lime mortar. The front arches failed and as a consequence the building was severely damaged.

Civil Surgeons House, Darbhanga (Photo 4) : This is an old building in lime mortar. This was severely damaged and the building was abandoned. The masonry arch at the entrance developed severe diagonal cracks. The roof was also badly damaged and in one of the rooms, the roof collapsed because it was supporting a water tank over it.

Madarsa Hamedia, Qila Ghat, Darbhanga (Photo 5) : This is an old single storey building of L shape constructed in 1927. There were fourteen class rooms in either wing of 6.5m x 6.5m size, approximately. The main walls of buildings were load bearing, made up of brick masonry in lime mortar. There was verandah corridor consisting of brick masonry arches resting on brick pillars in the front of the class room. The roof of class room consists of four small arches resting over iron girders. The 3.0m span arches of a verandah got damaged completely in one wing and the rooms were damaged beyond repair. The longitudinal and cross walls got separated at the corners. The reasons for damage were : (i) failure of verandah arch due to release of lateral thrust; (ii) additional shears induced due to torsion of L-shape

buildings, (iii) deterioration of strength due to age and (iv) absence of earthquake resistant measures.

New Brick Masonry Buildings

The newly constructed brick masonry building in cement mortar also suffered cracking at many places. The two room single storeyed building of Jail employee in Darbhanga was severely damaged. There are several load bearing two storey blocks constructed of conventional type in brick with cement mortar. The mortar mix of 1:8 and less was used in construction. There were severe horizontal shear cracks developed in the walls.

Collectorate Building, Samastipur (Photo 6) : The three storeyed building constructed in 1974 showed heavy cracks in the cross walls in E-W direction. The three storeyed collectorate building of same design existing in Madhubani relatively did not show much damage. In this building, the cracks occurred in one of the extreme blocks possibly due to torsion. The difference in behaviour of building of same design at two different places in the same earthquake is attributed to difference in intensity, quality of construction and variation of local soil condition.

Reasons of Damage of Brick buildings : The following causes of damage of brick buildings are identified :

(i) In old buildings, there was a deterioration of strength.

(ii) No earthquake resistance measures were provided.

(iii) The mortar mix in new construction is weak and inadequate from seismic consideration.

(iv) The quality of new construction is poor.

EARTHQUAKE DAMAGES IN REINFORCED CONCRETE BUILDINGS

The reinforced concrete buildings are relatively few in number in the affected area and most of them are recently constructed. The damage to reinforced concrete buildings has been less as compared to brick masonry buildings. The common type of failure in such buildings was the heavy cracking of partition walls, much less damage occurred to the frame as such. Typical damages are described below :

Cycle stand cum Canteen structure (Photo 7) : This is a two storey reinforced concrete structure. The bottom storey consisting of several columns framed with the beam was open and used as a cycle stand, the upper storey housed a canteen. The structure of the same design was constructed at Darbhanga and Munghyer. The structure at Darbhanga completely collapsed while the structure at Munghyer survived with the cracking of columns near the top. The structure at Munghyer received relatively less severe ground motion because of its greater distance from the epicentre as compared to Darbhanga. The soil at Munghyer was relatively firm than at Darbhanga. The lack of continuity of steel in beams and inadequate stirrup spacing seemed to be the reason of collapse of this structure at Darbhanga. No measures were taken to incorporate ductility provision in the structure.

Surgical Ward building of DCHS, Darbhanga (Photo 8): This is a three storeyed concrete structure constructed in early 70's. The following types of damages were observed :

(i) The reinforced concrete columns developed diagonal cracks in the ground floor. In one of the columns, the rusted reinforcement was exposed due to spalling of concrete. The spacing of ties was quite apart. One of the columns had significant vertical crack in the lower portion.

(ii) Cracks were also observed in concrete on the face of the column concealing the pipe.

(iii) There were horizontal and diagonal cracks on the cross wall in the first and second floor.

The reasons for damage of this building were (i) poor quality of construction and poor maintenance; (ii) dampness in the building causing corrosion in reinforcement; (iii) lack of detailing of reinforcement.

Telegraph Office, Munghyer (Photo 9) : This is a three storeyed reinforced concrete frame building constructed in 1984. The ground floor was damaged much more than the first and second floors. The walls got cracked badly between lintel and plinth. There was practically no damage to beams and columns of frame. The twelve and half centi meter thick partition walls were cracked badly. The reasons for damage was the inadequate connection detail between partition wall and the frame.

The International Yogashram Building Munghyer : This is a seven storeyed reinforced concrete framed building constructed in 1985 having large rooms. This building is well designed and has good quality of construction. The building did not suffer any damage which is attributed to its good quality of design and construction.

LIQUEFACTION OF SOIL

Extensive evidence of liquefaction was reported from areas near Darbhanga, Laheriasari, Madhubani and Jhanjharpur. In this belt, sand water geysers rising to a height of about 1m were reported. Sand and water vents were seen in open areas and floors of buildings cracked with water and sand oozing out of the cracks, building foundations and long boundary walls sank and cracked. The boundary walls of the Darbhanga Raj complex developed cracks at many places and so did the thick walls of the Darbhanga Jail complex. In both, Darbhanga and Laheriasarai, roads are reported to have cracked at many places with sand and water gushing out (Photo 10). In the nearby villages of Taralahi, Bishanpur and Keoragach a layer of sand was reported to have been deposited following the earthquake. Much of the tell tale evidence of liquefaction of these areas were lost due to the floods which followed the earthquake.

As in the previous earthquakes of 1897 and 1934, it was observed that the spewing of sand and water took place after the earthquake shock and continued for hours afterwards. Sand was reported to have oozed out in the Fulwara distribution system and silted upto a length of about 30m to 40m. Most of the wells at Rajbiraj, Nepal were reported to have dried up due to choking caused by sand. Following the earthquake of August 1988, it was reported that the hot water coming out of the hot springs at Rajgir turned blood red. This red coloured water oozed out for about 10 to 12 hours after the earthquake. No red coloured sediment was observed in the tanks at the springs after this behaviour.

LESSONS LEARNT FROM EARTHQUAKE DAMAGES

The following lessons are learnt from the observation of damages in Bihar-Nepal Earthquake :

(i) The old brick masonry buildings using traditional methods of construction are highly vulnerable to damage in earthquakes. The strengthening measures for future protection of these buildings in earthquakes should be worked out.

(ii) The masonry arch construction has been found to be weak under seismic conditions. Such construction should not be used to span the openings in new construction.

(iii) Poor quality of construction and poor maintenance has been cause of failure in many cases. The rich mortar mix should be used in new construction.

(iv) Absence of horizontal band in the mud and brick houses caused most of the damages. The use of building codes for incorporating earthquake resistance in the construction should be mandatory.

(v) The inadequate detailing and continuity of reinforcement has been responsible for the damage of reinforced concrete buildings. The poor drainage led to the corrosion of reinforcement.

(vi) The traditional method of constructing brick partition walls in the reinforced concrete frame is found to be defective, this has caused enormous cracking in infill walls. Properly designed connection and detail between frame and infill needs to be developed and incorporated in practice. There can be substantial saving in post earthquake repairs if such a detail is used.

(vii) Some damages of structures were associated with the liquefaction of soil. The proper design of foundation is very important to safeguard failures caused by liquefaction.

CONCLUSIONS

The paper describes the salient features of damages in certain brick masonry and reinforced concrete buildings in Bihar-Nepal earthquake of August 21, 1988. The possible reasons for damage are highlighted. The lessons learnt from this earthquake indicates the need to follow earthquake resistant measures more rigorously in planning and executing new construction. Study of liquefiable soil of the region is necessary in order to bring improvements in foundation design.

REFERENCES

Thakkar, S.K., Paul, D.K., Mukerjee, S., Bandyopadhyay, S., Kumar, A. and Lavania, B.V.K. (1988), Damage Survey Report on Bihar-Nepal Earthquake of August 21, 1988, Department of Earthquake Engineering, University of Roorkee, Roorkee.

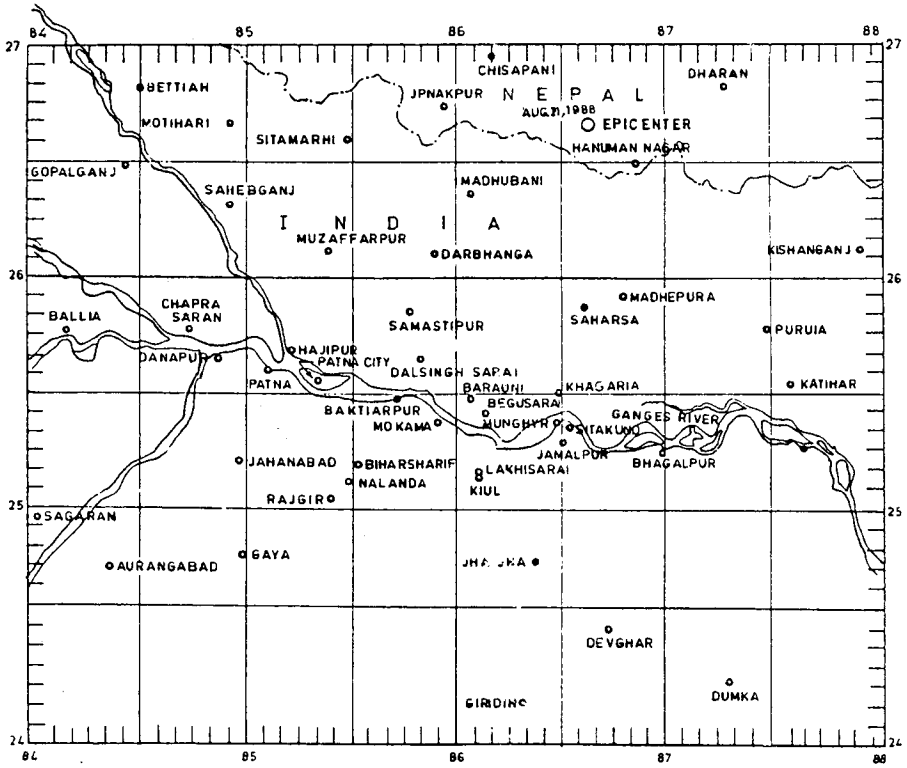

FIG. 1 - AFFECTED AREA DURING BIHAR-NEPAL EARTHQUAKE OF AUGUST 21, 1988

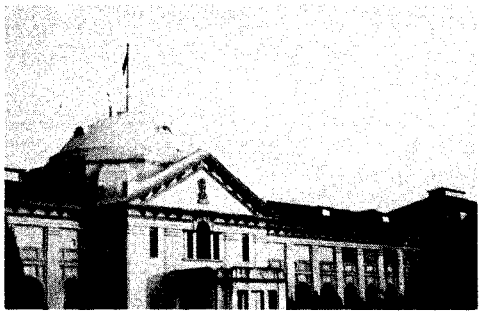

Photo 1(a) High Court Building, Patna
(Cracking of dome, walls, roof)

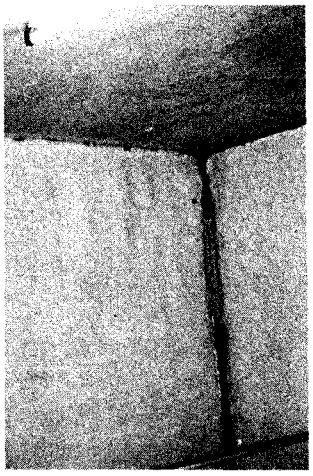

Photo 1(b) High Court Building, Patna
(separation of walls at corner)

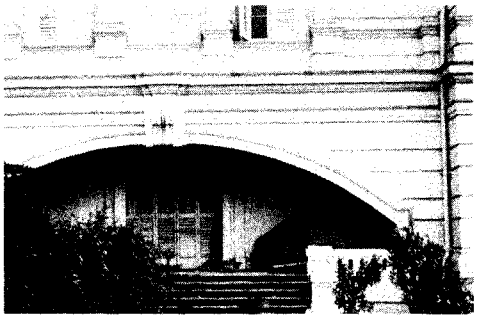

Photo 2 Raj Bhawan, Patna (Horizontal Crack over the arch in right half)

Photo 3 Land Mortgage Building, Darbhanga
(Failure of front arches, walls and roof)

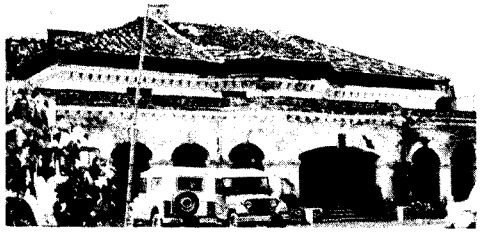

Photo 4 Civil Surgeons House, Darbhanga
(Severely damaged, building abandoned)

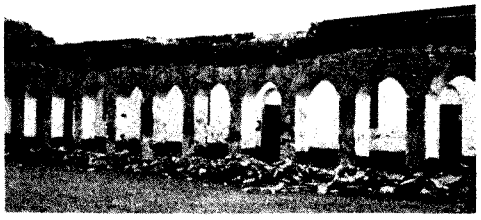

Photo 5 Madarsa Building, Darbhanga
(failure of arches)

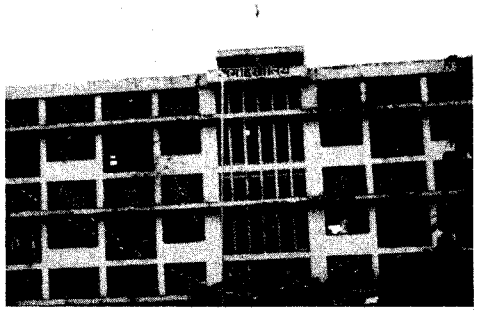

Photo 6 Collectorate Building, Samastipur
(Walls showed heavy cracks)

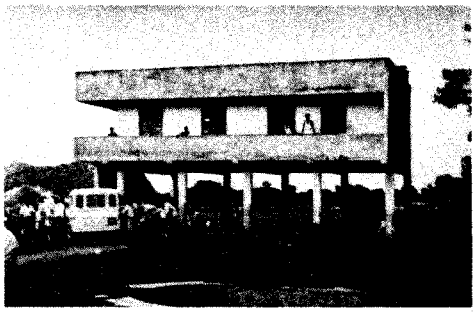

Photo 7 Cycle stand cum canteen R.C.
structure, Munghyer.

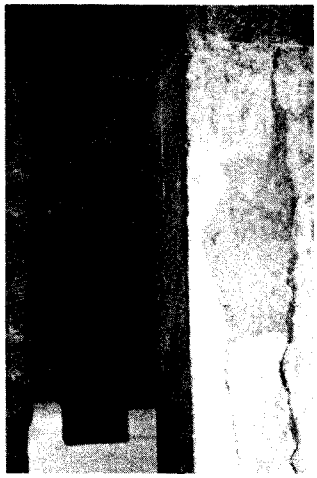

Photo 3 Surgical ward, Darbhanga
(Cracks in r.c. column)

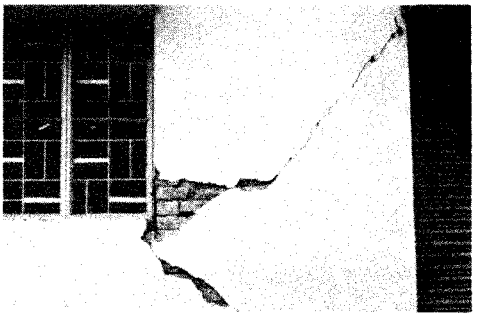

Photo 9 Telegraph Office, Munghyer
(wide spread cracks in inner walls)

Photo 10 Jail Building, Darbhanga
(Circular patch of sand left over after
liquefaction)