

Post earthquake damage studies on the performance of buildings during Bihar (India)-Nepal earthquake on 21st August 1988

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ABSTRACT : The study presents the structural performance of some selected reinforced concrete and brick masonry buildings during August 1988 Bihar - Nepal earthquake. The total collapse of a R.C.C. building has emphasised the importance of ductility detailing. A good building configuration is proved to be the first line of earthquake resistance. The satisfactory performance of two essential facilities buildings is attributed to their good architectural and structural configurations. The participation of the 'non-structural' infills in resisting the earthquake forces was evident. The need to evolve appropriate construction specifications and practices for improving the infill properties and reducing the analytical complexities involved in accounting for the frame-infill interaction is emphasised. Comparative performance of masonry buildings with and without code specified strengthening measures has proved the importance and effectiveness of these measures. As majority of loss of life is due to the collapse of adobe construction in villages, the urgent need is to develop earthquake resistant rural housing techniques.

INTRODUCTION

On August 21st, 1988, a strong earthquake of magnitude 6.6 on Richters scale with its epicentre near Udayapur (Nepal) longitude 86.61 E and latitude 26.78, had occurred causing wide spread damages to lives and properties in the India-Nepal border regions. The worst affected areas were the districts of Darbhanga, Madhubani, Munger in the state of Bihar (India) and Dharan, Mechi, Kosi and Sagarmatha Districts in the eastern region of Nepal. It is reported that, both in India and Nepal, 1000 people were killed, 9000 people were injured and nearly 2,50,000 houses were collapsed or severely damaged. A location map indicating the affected regions are shown in Figure 1.

CHARACTERISTICS OF THE EARTHQUAKE

The maximum intensity of earthquake (on MM scale) observed was VIII + and VIII in the worst affected regions of Nepal and India respectively. The focal depth of the earthquake was 57 Km. This region is known for its high seismicity with the occurrence of two major earthquakes in the past. The first, Bihar Nepal earthquake of August 26, 1833 (magnitude 7.5 and intensity IX) and the second, the major devastating Bihar Nepal earthquake of January 15, 1934 (magnitude 8.4 and intensity IX +) wherein more than 10,000 lives were lost.

As per the seismic code of India (1), the affected regions of Bihar comes under seismic Zone IV, which corresponds to the maximum probable earthquake of magnitude 7 and intensity VIII and zone V which corresponds to the maximum probable earthquake of magnitude above 7 and intensity of above IX. The basic horizontal design seismic acceleration assigned to the zone IV and zone V as per the code are 5% and 8% of g. The gap between the design acceleration and the actual expected ground acceleration is taken care of by suitable ductility provisions of the code.

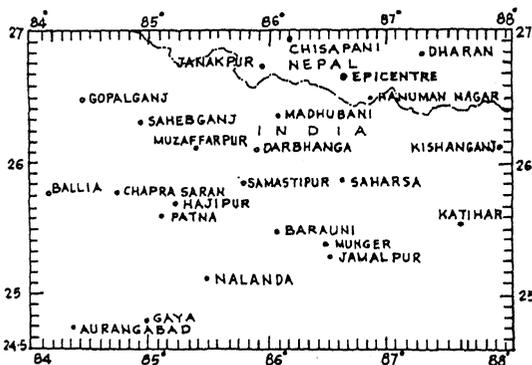


Figure 1. Location map of the affected areas.

BACKGROUND AND SCOPE OF THE STUDY

Central Public Works Department (CPWD), a premier construction agency of the Govt. of India under the Ministry of Urban Development, since its inception in 1930, is engaged in the planning, designing and construction of a variety of civil engineering structures like; mass housing projects, roads and bridges, airports, industrial structures, institutional buildings etc. Central Designs

Organisation (CDO), the planning and design wing of CPWD, is engaged in the seismic design of buildings and also involved in the formulation and updating of the seismic design codes (1,2) of India. With this background, the first author headed a team of engineers of CDO and engineers of the CPWD working in the affected region and conducted a detailed on the spot study of the damages in districts of Darbhanga, Madhubani and Munger in Bihar. The scope and objectives of the study were:

1. To study the seismic performance of different categories of buildings and their mechanism of distress and failure.
2. To study the prevalent construction practices in the region and to identify areas of weakness in the design and construction practices.
3. To document the lessons learnt from the earthquake to minimise losses in the event of future earthquakes and for improved construction practices.
4. To make recommendations to the Government on earthquake mitigation measures.

BUILDINGS STUDIED

The study covered a variety of buildings; old and recent constructions, load bearing brick masonry buildings and reinforced concrete frame buildings and adobe village constructions. This paper deals with the performance of some typical buildings.

Industrial Training Institute, Darbhanga

Observed Damages

This totally collapsed building (Photo 1) was a two storeyed reinforced concrete structure with open bottom storey. The framing system adopted was rigid jointed one bay frames with brick filler walls only in the upper storey Fig.2. The upper storey had collapsed more like a rigid body without its member in an over stressed condition. The ground floor columns had buckling of the reinforcement and crushing failure of the concrete. The ground floor beams apparently were not in a over stressed condition. Observation of beam-column joints indicated inadequate anchorage of the beam bars inside the joints and no column ties were provided within the joint zone. Even in the body of the column, the ties were widely spaced and inadequate to restrain the column bars against buckling. It was seen that the structure had undergone a large sway deflection before collapse.



Photo 1. Collapsed building at ITI, Darbhanga

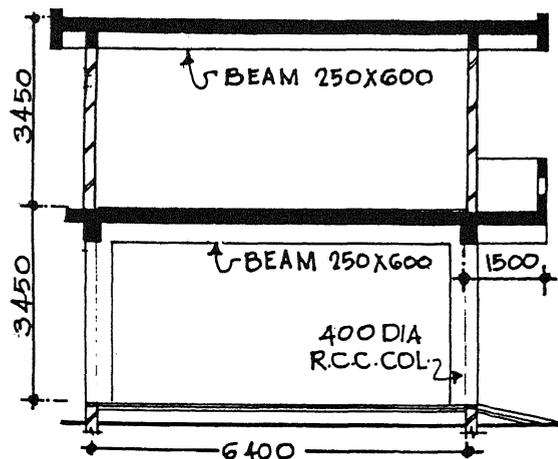


Figure 2. Sectional elevation of building at ITI Darbhanga

Analysis of the damages and inferences

The building with stiff upper storey and flexible lower storey had undergone a heavy stress concentration due to the abrupt change in the storey stiffnesses. Large sway deflection has induced heavy moments and buckling of the columns due to P- Δ effects. The columns did not possess adequate ductility to withstand the large sway deflections and absorb the earthquake energy. This was evident from the absence of ductility detailing in the beams, columns and beam-column joints. Fig 3 indicates the code specified (2) ductility detailing of moment resisting frames.

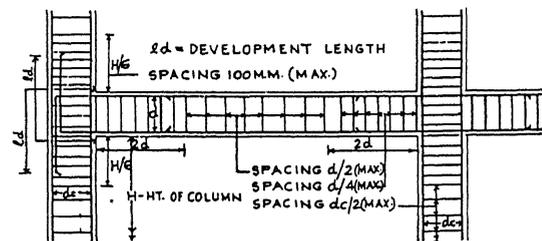


Figure 3. Ductility detailing of moment resisting frames

While the main column reinforcement bars were adequate, closely spaced column ties were not provided to confine the concrete core and to prevent the buckling of the column bars. Due to the total absence of confining ties the vulnerable beam-column joints could not withstand the cyclic stresses induced by the earthquake. It was seen that the beam reinforcement had inadequate anchorage into the beam-column joints, with the result that the beams have not fully participated in resisting the earthquake forces and it could be seen that the beams have simply collapsed like rigid bodies.

The main lesson learnt from this building behaviour is the importance of ductility detailing. Also, the abrupt change in the storey stiffness has caused heavy stress concentration leading to the collapse of the building.

Surgical ward-medical college hospital, Darbhanga

This is a three storeyed reinforced concrete framed building with brick masonry filler walls Fig. 4. The building has a simple rectangular plan configuration and the long length of the building is divided with expansion/separation joints. Being an important hospital in the affected region, it has served to treat the victims of this earthquake.

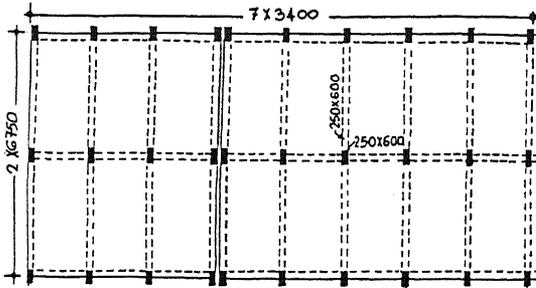


Figure 4. Typical floor plan of surgical ward.

Observed Damages

The main earthquake induced distress in the building was the diagonal cracking of the brick masonry filler walls and their separation from the surrounding frame members. Such separation/cracking was severe in the first storey, less in the second storey and insignificant in the top storey. The pattern of cracking in the filler walls was along the mortar joints of the brick masonry and also at the frame-infill interface. Due to inadequate overall maintenance and seepage/dampness in the toilet areas, some of the RCC columns were in severely corroded condition. These corrosion affected members have further developed cracks during the earthquake shaking.

Analysis of damages and inferences

This hospital building performed reasonably well and remained operational after the earthquake because of its simple and symmetrical plan and elevational configurations. Probably, there had been no significant torsional behaviour because of the symmetry even in the disposition of the non-structural filler walls. It was evident that these non-structural walls had initially acted as shear panel bounded by the frame member. However, due to the absence of the perfect bond with the frame members, these walls have got separated due to the vibratory motion of the earthquake.

The behaviour of this building has demonstrated that good configuration properties is the first line of resistance against earthquake and should be mandatory for such essential buildings which should continue to be operational after such major seismic event. The behaviour of the non-structural walls once again established their structural action and as such they should be given due consideration in the design process and their specifications and construction method should be improved to avoid their brittle failure and to achieve effective composite action with the surrounding frame members. The earthquake codes should provide sufficient guidelines on this important issue for the designers. Another important aspect is the necessity for upkeeping such essential buildings in a good stage of maintenance.

Telecommunication building and International Yogashram building at Munger

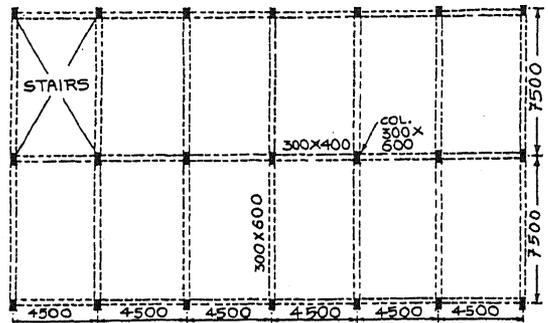


Figure 5. Typical floor plan of telecommunication building at Munger

The Telecommunication building, an essential service building which remained operational after the earthquake, is a three storeyed RCC framed building with moment resisting frames with brick masonry filler walls Fig. 5. The International Yogashram building is a seven storeyed RCC framed building with moment resisting frames with brick masonry filler walls and the tallest building in the affected region Fig.6.

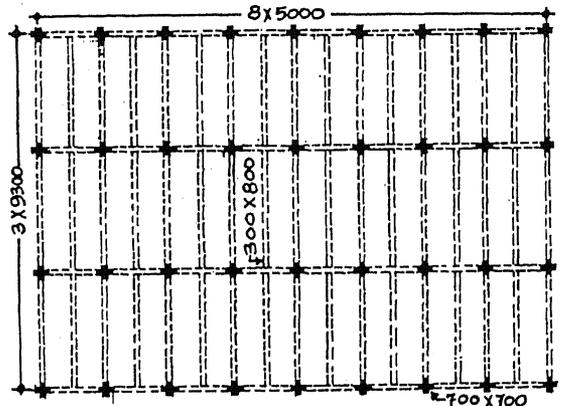


Figure 6. Typical floor plan of International Yogashram building at Munger

Analysis of Damages and inferences

The Telecommunication building had suffered no structural damage except separation and cracking of the non structural filler walls. There was no apparent damage to the RCC structural members. The Yogashram building had suffered practically no damage except few cracking of the brick masonry filler walls in the lower floors. Both the above buildings have shown a good performance under the earthquake primarily due to their regular building configuration and good structural system and arrangement. These are the cases of well designed and detailed buildings, the essential requirements in such high seismic zones.

Industrial Department Building at Darbhanga

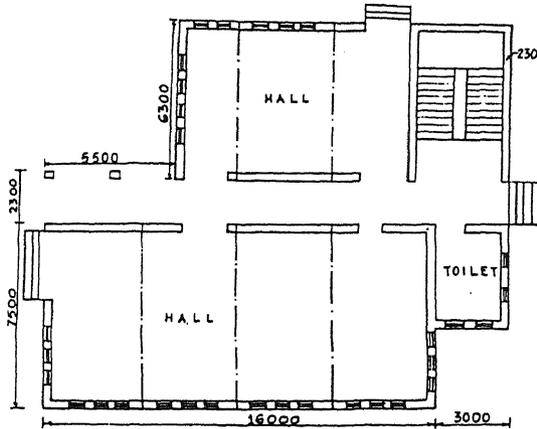


Figure 7. Ground Floor Plan of the Industrial Department building at Darbhanga.

This two storeyed load bearing brick masonry building with a wall thickness of 230mm had RCC beam and slab floor system. The bricks used were of average quality with a crushing strength of about 5N/mm², laid in 1:8 cement sand mortar. The building was of open type with large size halls of size 16m x 7.5m in both the storeys without any cross walls for lateral load resistance Fig. 7. The load bearing external walls had large number of window openings covering almost 70% of the wall area. A stiff staircase core was located at the end of the building providing unsymmetrical stiffening to the building. Although constructed only in 1987, no strengthening measures as per the codal provisions (fig. 8) were adopted.

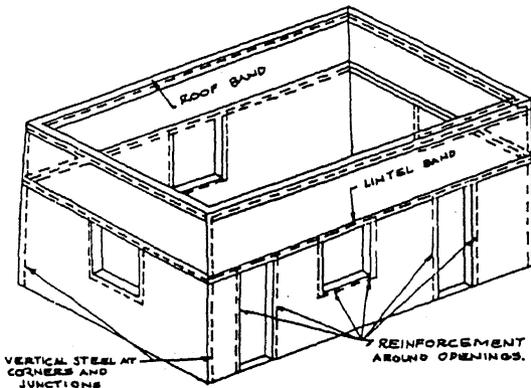


Figure 8. Earthquake strengthening measures for masonry buildings

Observed damages

The brick piers between the window openings had developed extensive shear cracks and particularly the end walls were more damaged (photo 2) and the openings over the doors have developed diagonal cracks upto the RCC floors.

The building had partly tilted. There were no apparent damage to the RCC beams and slabs of the floors. The overall damage was extensive and building was vacated after the earthquake.

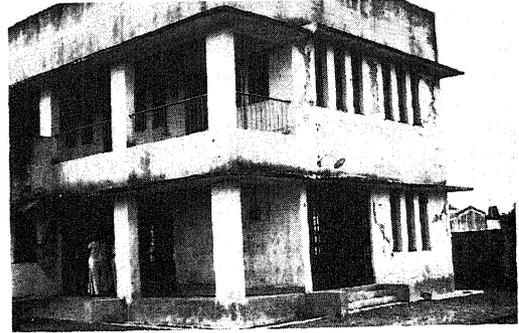


Photo 2. Cracking of brick walls between openings.

Analysis of the behaviour and inferences

The observed behaviour indicate that the building had been subjected to heavy torsion due to unsymmetrical stiffening effect of the stiff staircase portion. Due to this, the end walls were severely cracked and building had tilted. Adoption of such open type of brick masonry structures without any cross walls is undesirable from the earthquake point of view. This structure with large halls and large number of window openings should have been made as R.C.C. framed structure. The low strength of the cement mortar, poor quality construction, improper planning of window openings and non-adoption of strengthening measures were also responsible for the poor performance of this building.

Madrasa (school) building and old hostel building at medical college, Darbhanga

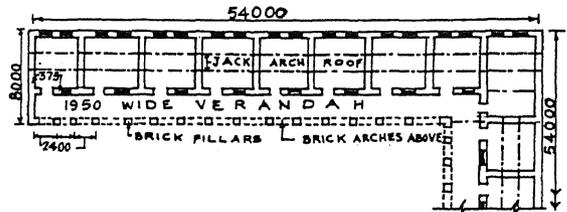


Figure 9. Madrasa building at Darbhanga.

These two buildings built in 1927 were made of 60cm thick brick masonry walls in lime mortar and with brick jack arch roofs with heavy lime concrete filling over the roofs. The Madrasa building at the Darbhanga town was a long L-shaped single storeyed building, each wing 54m long and 8m wide, with a 2m wide front corridor consisting of brick masonry arches supported over brick pillars (fig. 9).

The old hostel building at the medical college complex Fig. 10 is an unduly long (about 120 metres) two storeyed building. Both the buildings had no expansion/separation joints.

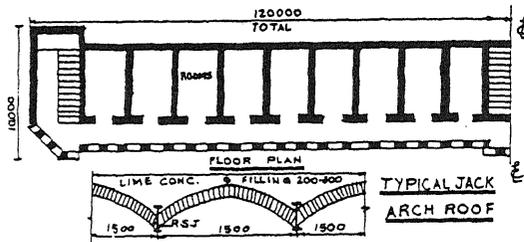


Figure 10. Old hostel building at Darbhanga medical college

Observed damages

The above buildings which had withstood the 1934 earthquake (magnitude 8.4), probably for their being strong and new at that time, are badly damaged due to this earthquake. The long front corridor portion of the Madrasa building in one of its wings had collapsed killing eight persons (Photo 3). The brick jack arch roofs had developed longitudinal cracks at their crown and partially collapsed in many portions of this building. The tie rods provided in the end panels of these arches which were in a corroded condition, had failed due to tension. As regards to old hostel building, one of the end of the building had collapsed (Photo 4) and other end had severely damaged. In the rooms, long and cross walls had developed vertical separation cracks and diagonal shear cracks. The jack arch roof panels had developed longitudinal cracks along their crown and collapsed in several portions.



Photo 3. Madrasa building - collapse of brick arches.

Analysis of damages and inferences

The main reason for the damages of these buildings is their ageing with brick masonry losing their mortar strength due to prolonged weathering actions. The jack arch roofs collapsed as they could not withstand the tensile forces generated during earthquake. The masonry pillars supporting the corridor arches had collapsed due to shear failures. Heavy brick wall thicknesses and very thick lime concrete filling over the roofs had generated large inertial forces and the structure possessed no ductility and had very brittle failure. Another undesirable feature of the hostel building was its unduly long length causing large stresses under the conditions of differential ground vibrations. Similarly, the

Madrasa building might have also been subjected heavy torsional stresses due to its unsymmetric plan configuration.



Photo 4. Old hostel at medical college - collapse of one end.

Residential flats at Munger and Darbhanga and School building at Munger

The Bihar police flats at Munger made of two and three storeyed brick masonry buildings with load bearing single brick walls and RCC floors and roofs were extensively damaged and declared dangerous. Severe cracking of the walls, shearing of brick piers between openings and collapse of free standing parapets were observed. Although constructed only in 1984, these buildings were not provided with code specified earthquake strengthening measures. Absence of these measures combined with the poor quality of construction and maintenance were considered responsible for the poor performance of these buildings.

It was of interest to observe that in a nearby school, a brick masonry building with the code specified strengthening measures had withstood the earthquake only with minor cracking of the walls demonstrating the effectiveness of these provisions. Another example of good design and properly constructed buildings are the residential flats for Kosi irrigation project at Darbhanga which had shown a good performance under the earthquake.

Village Houses

Majority of the loss of lives due to this earthquake was in villages due to the collapse of houses made of walls with mud constructions, sun-dried bricks or stone rubble masonry in mud mortar (adobe construction). The roofs of these houses were mostly clay tiles or stone slabs supported over wooden members, country wood ballies or bamboos. These roofs with no connections with the walls had collapsed, burying the people under the debris. The walls on account of their very brittle nature and heavy mass had cracked extensively and collapsed. However, in some areas

houses made of mud plastered bamboo matting walls and thatched roofs on account of their lightness and flexibility have suffered no damage.



Photo 5. Collapse of a typical adobe house in a village.

It was observed that there is a total lack of awareness among the people on the earthquake resistance measures to be adopted in house constructions. It is necessary to evolve an appropriate low cost rural housing technique taking into consideration the availability of local material, living patterns, climatic and other socio-economic conditions and popularise these constructions among people in such high seismic zones through audio visual media and demonstration houses.

CONCLUSIONS

This study on the analysis of the behaviour of some selected buildings under Bihar-Nepal earthquake has led to the following conclusions.

1. The collapse of the reinforced concrete industrial institute building at Darbhanga has emphasised the importance of ductility detailing of moment resisting frames.
2. A good building configuration with simple and symmetrical plan and elevational shapes with proper structural arrangement is the primary requirement for earthquake resistance and should be made mandatory for essential buildings which should remain operational even after a major earthquake. This is demonstrated by the good performance of hospital and Telecommunication buildings at Darbhanga.
3. In all the R.C.C. framed buildings studied, the participation of brick masonry filler walls in resisting the earthquake load was evident. Past earthquake damage studies have brought out the positive and negative effects (brittle failure, torsional effects) of unaccounted non-structural filler walls. However, common design practices neglect such composite behaviour because of analytical complexities involved arising out of the frame-filler wall interface separation and lack of fit etc. Hence, the need is to evolve appropriate construction techniques and specifications to improve the infill properties and its bond with the frame members and thereby adopt simple design methods.
4. In high seismic zones brick masonry buildings are more susceptible for damages. Hence, the importance of good architectural/structural configurations, proper planning of door/window openings, adoption of code specified strengthening measures is emphasised.

5. The reasons for the failure of old masonry buildings are; ageing, loss of mortar strength due to weathering, heavy thickness of roofs and poor state of repair and maintenance. Long length of buildings subjected to differential ground vibrations, unsymmetrical plans susceptible for torsion are possible reasons of these damages.

6. Most of the human loss due to this earthquake was on account of collapse of mud walls or sundried clay brick (adobe) constructions. Efforts are necessary to evolve appropriate construction techniques for rural masses taking into account local materials, climatic, living pattern and the other socio-economic conditions.

REFERENCES

1. Indian Standard: 1893-1984 Criteria for earthquake resistant design of structures.
2. Indian Standard: 4326-1976 Code of practice for earthquake resistant construction of buildings.