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IMPACT OF KUTCH EARTHQUAKE ON NON-STRUCTURAL ELEMENTS AND APPENDAGES OF BUILDINGS

Amit BOSE[1], Pratima R. BOSE[2], Amita SINVHAL[3], Alok VERMA[4], Amir A. KHAN[5]

SUMMARY

Last decade (1991-2001) had been very severe for India, which was subjected to 5 damaging earthquakes. Important feature was that most of them, particularly the last one, had hit the urban settlements. Professional community of India, engaged in the business of earthquake engineering, was shocked and realized for the first time, the hollowness of their reach and depth. International community utilized this tragedy to further sharpen their tools for equipping themselves for ensuing fight to make the habitats safe against earthquake disaster, especially in the developing world. Focus of most of the studies and strategies, after Kutch earthquake, related to earthquake safe habitats in India has been biased towards structural engineering components of the built form. All our codes also have the same inclination. We tend to forget that damage to non-structural components also causes casualties and even collapse of the building, due to its adverse behavior on the structural members. The problem gets compounded because, even if the structural components of the building remain unaffected, non-structural damage may cause loss of critical function of the building for a long period, thereby hampering the economics of the existence of the building. This study focuses on the behavior of non-structural components in building due to Kutch earthquake, and how they have been responsible in inducing damage to the functioning of the building and the structural system. The study will be useful for disaster mitigation, particularly the damage to buildings inflicted by non-structural components. It recommends future course of action in the fields related research needed and development of new codes and guidelines..

INTRODUCTION

India has experienced five major earthquakes in the decade from 1991 to 2001. The location and reach of these earthquakes were as varied as their damaging impact. (See Table-1). October 20, 1991, Uttarkashi and March 29, 1999, Chamoli earthquakes were located in the hilly Himalayan region of northern India. September 30, 1993 Latur, followed by May 22, 1997, Jabalpur earthquakes were located in central India,

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1- Architect and Director, Designers' & Planners' Combine, 501,B-9, ITL Twin Towers, Pitampura, Delhi-110054, INDIA
2 - Professor, Department of Civil engineering, Delhi College of Engineering, Delhi – 110042, INDIA
3- Associate Professor, Department of Earthquake engineering, I.I.T Roorkee, Roorkee-247667, INDIA
4-Lecturer, Department of Civil engineering, Delhi College of Engineering, Delhi – 110042, INDIA
5-Senior Research Officer, National Institute of Disaster Management, IP State, Ring Road, Delhi-110001, INDIA

whereas January 26, 2001 Kutch earthquake was located in the western part of the country. Out of all these recent damaging earthquakes, Kutch earthquake literally shook the nation, especially the professional community, who were involved in the building industry. This was the first earthquake, which had affected predominantly the urban areas. So many modern RC buildings, besides masonry and traditional buildings were damaged or collapsed, affecting 21 of 25 districts and more than 7600 urban and rural settlements of Gujarat. It was a new and shocking experience for the Indians, particularly those who were involved in design and construction of buildings.

Table 1: Damaging Earthquakes in India During 1991 to 2001

Earthquake and location	Date and time	Magnitude & MM Intensity	Focal depth (km)	Lives lost and injured	House damaged
Uttarkashi 30.75N, 78.68E	October 20, 1991 2.53 hrs. (IST)	6.6 IX	12	770 (d) 5000 (i)	80000 (t+p)
Latur 18.22N, 76.356E	September 30, 1993 3.56 hrs. (IST)	6.4 VIII+ 0.2g	5-15	9000 (d) 20000 (i)	28700 (t) 170000 (p)
Jabalpur 23.08N, 80.06E	May 22, 1997	6.0		40 (d)	
Chamoli 30.4N, 79.23E	March 29, 1999 00.35 hrs. (IST)	6.8 VIII 0.36g	15-20	103 (d) 400 (i)	4500 (t) 25000 (p)
Kutch 23.45N, 70.34E	January 26, 2001 08.47 hrs. (IST)	6.9 IX+	23	13811 (d) 166836(i)	233660 (t) 971538 (p)

d – death, i– injured, t – total damage/collapse, p – partial damage

Damage Scenario After Kutch Earthquake

According to the seismic zoning map of India (IS: 1893-1984), Kutch district of Gujarat is classified in the most severe seismic zone, zone V, where MSK Intensity IX and above is considered a probability. Parts of the most affected districts, like Patan, Surendernagar, Rajkot and Jamnagar are in zone IV, with probable maximum MSK VIII and other districts, including the capital of the state, Ahmedabad lie in zone III, with maximum MSK Intensity VII. Therefore, the occurence of January 26, 2001 earthquake in this region was not a surprise, unlike Jabalpur or Latur.

The Kutch earthquake affected 21 of the 25 districts of Gujarat state, and out of more than 18000 small and big urban and rural settlements, almost 8000 got affected. In terms of population, 16.04 million were affected. The economic loss was enormous and the estimates are to the tune of US$ 4.5 billion, including both direct and indirect. Most of the loss was caused by collapse or damage to built form and infrastructure. [1]

Lot of attention has been given, and analysis has been done for the RC framed buildings, load bearing masonry structures and traditional construction of Kutch region, to find out the causes of failure, damage or collapse. The focus has been mostly on the structural components of the building. This Study focuses on the role of non-structural elements, and how these elements have behaved and contributed to the behavior of structural members of the building, or damage/collapse of the non-structural components themselves.

NON-STRUCTURAL ELEMENTS OF BUILDING

Non-structural elements of any building are those components which are, as the nomenclature indicates, not part of the structural system, like vertical support components (columns, piers, walls, etc.), horizontal components (beams, slabs, etc.) or any other structural elements used for buildings' basic dead, live and dynamic loads. [2] Non-structural elements in a building may be broadly categorized as:

a) Architectural components, consisting of non-load bearing external and internal walls, vertical and horizontal features on the façade of the buildings, vertical projections on the roof top, means of vertical access in the form of stairways, interior works like false ceiling, etc.
b) Mechanical and electrical components, consisting of HVAC equipments, elevators, escalators, piping, fire fighting system, pumps, electric panel boards, etc.
c) Plumbing components, consisting of supply and disposal piping network, pumping system, etc.
d) Contents in the building, consisting of electronic equipments, data processing facilities, medical supplies, high tech equipments, hazardous and toxic materials, life support equipments, etc. [3]

This study covers the damage to non-structural elements for the first category, i.e. architectural components. Following five different components have been discussed:

i) Non load bearing walls
ii) Vertical and Horizontal features and appendages
iii) Vertical projection on the roof
iv) Roof top water storage tanks
v) Additions and alterations in the building

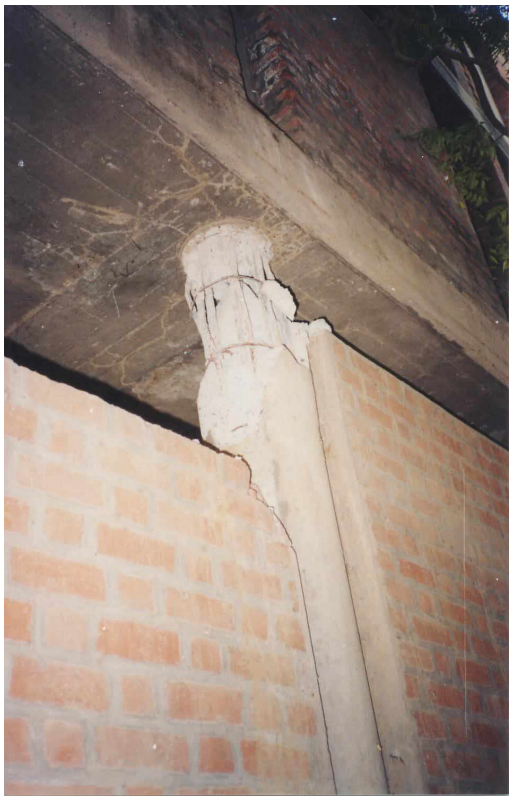

Fig. 1: In IIM Building presence of partitions wall converted the column into short column leading to the sever structural damage of column

Fig. 2: Non-structural wall of first floor over turned and fell on the ground, as it was not properly connected to the main structural system

NON-LOAD BEARING WALLS

Non-load bearing walls, both external and internal, are inevitable components of any building. The flexibility available to the user by RC frame structures have shaped the evolution of building forms and increased the use efficiency of the building functions. Problem arises when these non-structural walls are positioned in places of torsion and/or stress concentration, without taking these factors into consideration. Placement of these walls in-between columns may apparently look safe and innocuously harmless, but during an earthquake, these harmless partition walls becomes responsible for inducing short column effect. Figure 1 show one such example, where the partition walls lead to the failure of column Figure 2 shows the failure of non-structural exterior wall of a school building at Gangarampar in Gujarat. The cause of the collapse of the wall may be attributed to the fact that during earthquake the wall was subjected to a distortion and was not in a position to adjust to loads caused by the deflections of the core structure.[2] This phenomenon, along with the practice of not tying the wall appropriately with the main structural frame of the building, is very common in India, and Kutch earthquake has demonstrated the high vulnerability of these buildings.

VERTICAL AND HORIZONTAL FEATURES AND APPENDAGES

Vertical and horizontal features are the tools in the hands of architects, which they use to write a statement on the face of the building. Besides serving the utilitarian aspect of their existence, these features bestow identity to the buildings. These elements, if not handled properly, may cause severe damage to the building. The authors of this paper, during their post disaster survey, observed many buildings in urban areas where these non-structural elevation features played havoc and caused heavy damage and/or collapse of buildings. Two examples, a residential school building near Bhuj and a multistory residential complex in Ahemdabad have been discussed in this paper.

Haritpawan Gurukul of Swaminarayan (Residential School) at Gangarampar, near Bhuj

The residential school building had a simple rectangular architectural shape with single loaded wide corridor, having three wings in C formation. This three-story building was made of RC frame. Non-load bearing partition walls were used to create classrooms and other usable spaces as per the needs of the school. The finishing specifications of the building were very rich and non-structural architectural detailing of corridor railing and arched façade were exquisite Figure 3.

Fig. 3: School building with long corridor having rich and non-structural architecture detailing of corridor railing and arched facade.

Fig. 4: Sever damage to columns due to non-structural elements in the form of heavy railing and arched façade.

On January 26, 2001, when the earthquake hit the region, it did not differentiate between structural and non-structural elements of the building.[2] Architectural features of the building in the form of corridor arches and railing modified the response of the structural system (columns), which proved to be detrimental to the safety of the building. Columns, in between the floors, were stiffened at top and bottom at almost 1/3rd distance due to arches on the upper part and railing on the lower part. This led to failure of the column due shortening effect and associated concentration of stresses Figure 4.

Residential Apartment Building Complex

A complex consisting of multi-story residential apartments were located in Ahmedabad. The complex consisted of different towers, with similar architectural plan and structural system, but oriented at right angle or parallel to each other. The buildings were of RC frame structure, with stilts on ground floor for parking and housing other services. Façade of the buildings had lot of mass and heavy projections to serve as, besides architectural feature, shade from rain and sun Figure 5. These heavy features, having weight more than the wall itself on which they are stuck, added additional weight to the wall. The loads due to these features, on the outer face of the building, have not been considered while designing the structure. Moreover, these appendages were not tied with the main structure of the building. During the earthquake, these non-structural features behaved independently and not in consonance with the structure of the building, thereby contributing its share in damaging itself and the building beyond repairs.

Fig. 5: Heavy appendage in the form of architectural façade, not tied with the main structural system of the building.

ROOFTOP WATER STORAGE TANKS

Roof top water storage tanks, besides serving the primary purpose for which they are required, are also an effective tool available to architects to manipulate upper profile and shape of the building. Ideally, these tanks should be placed at a location where they do not cause the mass eccentricity in vertical plane. Further, either the tank should have its own structural system or the structure of the building must take care of water storage tank during an earthquake.

Professional practice in India is rather disorganized and the laxity on the part of statutory organizations to implement and monitor codal norms and safe practices compounds the problem and make buildings vulnerable to earthquake forces in most of the cases where heavy roof top water storage tanks are placed. The decisions related to structural system are not taken at right time. Dead load is taken care of by the structural columns of the RC frame buildings or load bearing walls of masonry structures, but the

Fig. 6: Two adjacent buildings of different heights and structural systems. The taller building got damaged due to pounding and open ground floor. The water tank kept eccentrically on top of the roof collapsed and fell on the lower building.

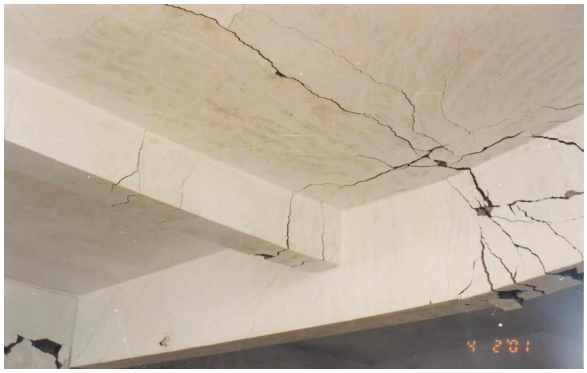

Fig. 8: The beams of ground floor roofs were heavily damaged due to fall of filled water tank from the roof of the adjacent building.

Fig.7: The water tank pierced through the roof and fell on the first floor, damaging the structural members of the building beyond repair.

dynamic behavior of these tanks remains unattended. This wrong practice has its own obvious implications. This paper discusses one such example pertaining to Kutch earthquake.

A row of 2 and 3 story buildings, facing a wide road and a park in Gandhidham was an ideal setting for the existing buildings. Apparently there was no problem and most of the buildings performed fairly well during the earthquake. The problem arose for two buildings of different heights, adjacent to each other Figure 6. The lower 2 story RC frame structure was well designed and properly built, but the adjoining structure was a 5 story residential apartment building, with stilt floor for parking. Each floor had 3 residential units, totaling to 12 units on 4 floors. This structure had a rooftop RC water storage tank for all the 12 units, measuring 2 m.X2m.X3m. The tank was placed eccentrically at the front right corner, adjacent to the 2-story building.

The design and placement of this concrete tank was an after thought. Obviously, therefore, it was not properly tied with the main structural system of the building to take care of the dynamic forces due to earthquake. When the earthquake took place, lower building performed very well, like most of the building in the vicinity. There were minor damage to non-structural components, like glass walls and

interior objects like computer etc. that fell down. But the building was subjected to a heavy impact on the roof due to fall of water filled tank from a height of 9 meter from the adjoining building Figure 7. The tank pierced through the RC roof of the building and damaged the structural beams of ground floor roof Figure 8.

ADDITIONS AND ALTERATIONS IN THE BUILDINGS

Modern buildings are like organism. It grows over a period of time, depending upon the changing needs and demands of the time. Non-structural components are liberally used to meet the changed requirements and use of the building. These elements, if not used and incorporated properly, may change the behavior of structural components of the building. Further, these additional non-structural elements themselves, if not properly tied to the structure, may cause casualty and damage to the building during an earthquake. The authors visited many such buildings during damage survey. One building, visited by them on February 4, 2001; 8 days after the earthquake hit the region was a Public School in Gandhidham.

Public School Building in Gandhidham

This school is a 2-story building. Performance of the structural system of the building was very good during the earthquake. Minor damage and disruption, like toppling of furniture in classrooms and library was observed. Glass panes of few window shutters were also broken. In short, mostly the contents of the building were disturbed or partially damaged. But, the main problem was observed in the corridors of ground floor of the building.

The building has a plinth height of 60 centimeters. It had an open corridor with structural columns at a distance of about 5 meters. Young children of lower classes of the school used to jump from the corridor and play during recess time. Couples of children, while playing, were hurt and the management of the school decided to put barriers to stop children jumping from the corridor. What they did was ridiculous. Concrete piers of 40cm. X 40cm. section were placed at the edge of the corridor to act as barrier Figure 9. These heavy piers were inserted without any tie at the top or bottom. When these piers were subjected to dynamic forces due to earthquake, they could not resist and fell down, snapping its nonexistent ties with the structural system of the building Figure 10 and 11. Children of the school were very fortunate, as they were celebrating Republic day celebrations in the open ground of the school, when the earthquake hit the school building. If they had been in the corridor many of them would have been hit and crushed by these heavy concrete piers. A school building, which was otherwise well built, became vulnerable to earthquake forces because of wrong decision and insertion of non-structural components at a later date, without considering its behavior during earthquake.

VERTICAL PROJECTIONS ON THE ROOF

Vertical projection on the roof could be the parapet or any other appendage. They have both utilitarian as well as aesthetic role to play in the building. Indian Institute of Management (IIM) Ahemadabad, a famous academic institution campus, designed by world-renowned architect, Louis I Kahn, was constructed in 1960s. The buildings of the campus were not subjected to earthquake forces during its existence of almost four decades, till January 26, 2001, when an earthquake, epicenter of which was more than 250 kilometers away, hit it. Non-structural components, mainly parapet walls and staircase mumty of the buildings were heavily damaged or collapsed. Parapets and high walls, without any lateral supports, were subjected to great accelerations. Fortunately, the failure of these components did not cause any casualties, nevertheless there were lot of non-structural damage, and the debris of the damage fell from a height of more than 10 meters Figure 12.

Fig. 9: Concrete piers, inserted as barrier at the edge of the corridor, to stop junior inmates of the school from jumping from the corridor.

Fig. 11: 26 January 2001 was lucky for the Children of the school, because they escaped unhurt in spite of heavy non-structural damage to the concrete piers, which fell in the corridor due to earthquake.

Fig. 10: Concrete piers fell on the corridor due to poor detailing of fixing with the structural system of the building.

Another such appendage on the roof was observed at Gangarampar in the residential school building. Decorative domical non-structural features adorned all the corners of the building; this is an example of symbolism par excellence, which is commonly used in important public buildings in India. Problem with these non-structural architectural features are that they are not usually tied with the main structure, and are designed for self dead load only. The behaviors of these appendages during an earthquake are generally not considered. The result of one such feature is shown in Figure 13. In this case also, like in the IIM building, the appendages experienced great acceleration at the top and the fragile support of the domical member were not strong enough to resist the forces generated by the acceleration. Result was obvious. Only consolation in this case was that it did not fall on the ground, thereby sparing the lives of inmates of the school.

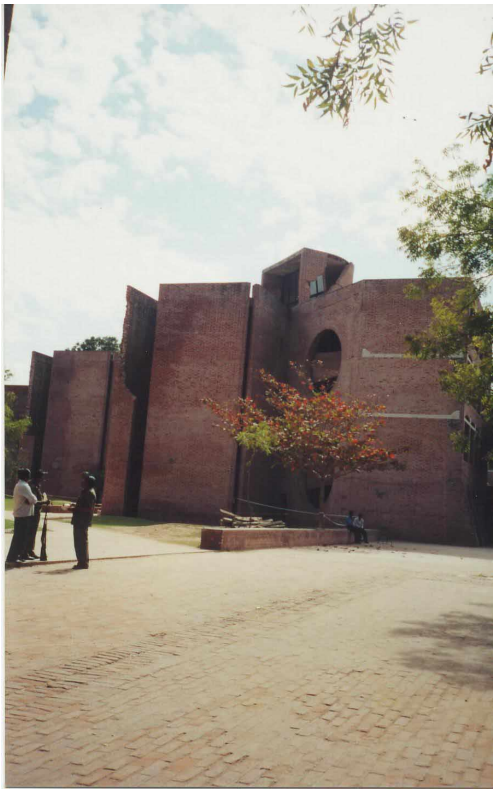

Fig. 12: Damaged parapet wall and mumty of the staircase in the academic block of Institute of Management, Ahemadabad.

Fig. 13: Toppled decorated dome due to high acceleration and poor connectivity to structural system of the building.

CONCLUSIONS

Non-structural elements are inevitable features for the functioning of any building. The efficiency of the building, due to rapid changes in the way we use our built form, are largely governed by non-structural elements. Requirements pertaining to the codes and norms of practice in this regard have not been attended to. In countries like India, where seismic design codes are in existence for more than 3 decades, implementation has been rather tardy. The professionals in this field have to traverse a long distance, by paying focused attention. World-over, due to historical and other unexplained reasons, an important professional group has been kept out of the movement of earthquake engineering. It may have been accidental, but the fact remains that the architects first conceive any built form, and then the structural system is dovetailed in that form. If the architects are not trained regarding seismic behavior of buildings

at a right time in their professional academic pursuit, chances are that we will keep on adding unsafe buildings to our not so safe building stock. Non-structural interior components are always provided after the structure has been completed. Very scanty literature is available on the behavior of non-structural elements, and how to make them safe against the earthquake forces at an affordable cost.

It is very easy to be wiser after the damage has been inflicted to the buildings by an earthquake. Remedy of many of the obvious reasons of non-structural damages are easy to find, but as the authors observed during their survey, most of the damages are unique in nature, which requires specific solutions. A concerted effort must be made by the international community of professionals to evolve workable and innovative solutions to different types of non-structural detailing. Affordability, both technological and economic, are essential for the success of implementation of these solutions.

Finally, after appropriate solutions have been worked out, codes and guidelines must be written in a language keeping the end user of these documents in mind. As far as possible, the codes and guidelines pertaining to non-structural elements should be full of illustrations, explaining the logic of each solution recommended.

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