LESSONS LEARNT FROM PAST EARTHQUAKES

H S Rai

GNDEC, Ludhiana

INTRODUCTION

The study of earthquake damage provide invaluable information about the performance of real structures during actual earthquake. It is like full scale testing of variety of prototype structures under real earthquakes. Each earthquake exposes the inadequacies of the prevalent design and construction practices in a region. It also provides good features of the design and construction as these are based on actual behaviour of prototype structure during the earthquakes. The buildings designed and constructed by taking proper earthquake resistant measures have helped in minimising the damage. The earthquake resistant design and construction have been evolved as a result of lessons learnt from the damages due to past earthquakes and helped in evaluation and modification of the provisions of the code of practice. In many cases, illustrates the effectiveness of earthquake resistant measures.

It is fortunate that earthquakes have not occurred close to any of the mega cities in India. many of these cities are located in the indo-gangetic belt which is very highly populated with vulnerable. Most of the multistory buildings are either not designed for earthquake forces at all or not designed and detailed adequately. In an event of an major earthquake, most of these buildings are likely to damage/ collapse and may lead to very severe disaster. It may be very difficult to cope up with such a disaster.

PAST EARTHQUAKES

In the first half-century, six mega earthquakes of magnitude 8+ had occurred in India. They were the 1819 Kutch earthquake, 1897 Shillong earthquake, 1905 Kangra earthquake, 1934 Bihar-Nepal earthquake, 1941 Andaman earthquake and the 1950 Assam earthquake. Out of these three earthquakes have occurred in Himalaya and is considered prone to great earthquakes of magnitude 8 or more. In the second half of this century, such large earthquakes magnitude greater than 8.0 have not occurred. The earthquakes of importance which caused damage were Anjar(1956), Kapkote(1958), Badgam(1962), Koyna (1967), Baroach(1970), Kinnaur (1975), Pithoragarh(1980), Silchar (1984), Dharamshala(1986), Shillong(1986), N.E. India (Indo-Burma Border (1987), Indo-Bangladesh boundary (1988), N.E. India (1988), Bihar-Nepal(1988),Uttarkashi (1991), Latur (1993), Jabalpur(1998), Chamauli (1999), Bhuj(2001), Kashmir (2005), Sumatra &

Andaman(2004); Sikkim(2006) and Sikkim Earthquake of September 18, 2011. Damage survey of the above damaging earthquakes have been reported in GSI Memoir and DEQ Reports wherein important lesson learnt have been reported. A very few R.C. buildings have been exposed to major earthquakes and none of the major cities have been subjected to major earthquakes in India .

The numerous buildings suffered severe damage in Caracas during the Venezuela earthquake (1967) which were designed according to modern methods as reported by Borges et al.(1969) and Degenkolb et al. (1969).

Similar experiences were observed in many other earthquakes. There is a need for better understanding of the behaviour of buildings during earthquakes. Finally, important lessons learnt from the damage behaviour of buildings during past earthquakes are summarized.

The indirect damages to buildings during earthquakes are sometimes far greater than the damages due to earthquake itself, such as, outbreak of fire, rock fall, landslide, avalanche and tsunamis. However, these damages are not due to inadequacies in the design and planning and therefore, not discussed here.

Numerical techniques have made great stride in Earthquake Engineering and it is important to critically evaluate the validity of these techniques by the experience of instrumented buildings during actual strong motion earthquakes. In the absence of actual response data, lab experiments are generally carried out using

earthquake simulators.

PERFORMANCE OF MULTI STOREY R.C. BUILDINGS

The modern r.c. frame construction consists of bare r.c. beam-column frame and the masonry infill. The masonry infill varies from dressed stone in mud mortar, clay brick masonry in cement mortar, cement concrete block masonry in mud/ cement mortar. Here, performance of M.S. R.C. buildings for following earthquakes are presented in brief.

Performance of Buildings Damaged During Mexico Earthquake 1985:(M 8.1)

The earthquake of magnitude 8.1 lasted only 3 minutes. The quake was located off the Mexican Pacific coast, more than 350 km away, but due to strength of the quake and the fact that Mexico City sits on an old lakebed, Mexico City suffered major damage. During the event 412 buildings collapsed and another 3,124 were seriously damaged.

Two reasons for damage were the resonance in the lakebed sediments and the long duration of the shaking. Most of the buildings damaged were from 6 to 15 stories in height. These buildings tended to resonate most with the predominant frequency band of the lakebed motions. Several notable buildings were relatively untouched by the quake. One significant example is the Torre Latinoamericana. Despite being 44 stories tall, it survived the 1985 event almost undamaged. It was constructed with two hundred piles extending down over a hundred feet into the stable earth stratum.

Performance of Multi-storey R.C. Framed Buildings during Bhuj Earthquake, 2001

As the prosperity of Gujarat state flourished, multi-storey buildings started mushrooming. Many four storey and ten storey multi-storey buildings were constructed. The multi-storey buildings without a lift were constructed upto four storeys and buildings with lift were constructed upto ten storeys. Unscrupulous builders and architects unaware of any earthquake resistant provisions have been constructing buildings. The collapse of newly built apartments and office blocks prove this point. Most of the multi-storey buildings in

Ahmedabad and Ghandhinagar were of r.c. frame construction with brick/ cement concrete block masonry in cement mortar as infill material. Most of these type of construction was of stilt type i.e. soft storey construction.

The Ahmedabad city had many multistorey buildings apart from load bearing buildings. Several of the multistorey buildings were totally collapsed killing the inmates. In Ahmedabad about 75 buildings totally collapsed out of almost 250, 000 buildings which comprises only 0.03%. The main reason for wide spread damage was that the building construction possibly did not follow the Indian Code of Practice. The other reasons seem to be poor detailing, poor quality of construction and inadequate supervision

The damage to multi-storey buildings in Bhuj is found to be wide spread. It is interesting to note that multistorey buildings have also damaged as far distances as Ahmedabad, Gandhidham and Surat. Whereas well designed and well constructed R.C. framed buildings following the Indian Standard Code of practice have performed very well during the earthquake. Most of the buildings constructed by CPWD, Post and Telegraph and other government agencies have performed well.

Damage to R.C. Frame Buildings:- The damage is mostly due to failure of infill, or failure of columns or beams. Spalling of concrete in columns. The column damaged by cracking or buckling due to excessive bending combined with axial load. The buckling of columns is significant when the columns are slender and the spacing of the stirrup in the column is large. Severe crack occurs near the rigid joints of frame due to shearing action which lead to complete collapse. Most of the damage occurred at the beam column junction. Widespread damage was also observed at the interface of stone or brick masonry infill and r.c. frame. In most of the cases diagonal cracks appeared in the stone or brick infill.

The buildings resting on soft ground storey columns without or with very few infill walls undergone severe damage which may lead to collapse. The Shikher apartments in Ahmedabad which had a soft ground storey. One of the adjacent apartment collapsed. The soft ground storey columns showing the unequal horizontal stiffness of the columns in the two principal directions of the building. It also shows jacketing of column without removal of plaster of the column and without proper connection of jacketing reinforcement at the top and bottom of the column. The foundation showed the isolated footing and the exposed column reinforcement. It is appeared that the main reinforcement and the ties in the columns at the foundation level were not adequate. The failure of R.C. columns of the Bus Station, Bachhau. The various floors can be seen resting one over the other. A R.C. framed warehouse with stone masonry infill in Bhuj. The structure behaved well but undergone some minor cracks in the infill masonry. The columns show buckling of reinforcement in columns due to inadequate tie reinforcement. The navigation tower of about 150m height at Kandla port got tilted by 30 cm at the top because of liquefaction of foundation soil.

Causes of damage/ failure of r.c. frame buildings:- The failures are due to mainly lack of good design of beams/columns frame action and foundation. Poor quality of construction. Inadequate detailing or laying of reinforcement in various components particularly at joints and in columns/beams for ductility. Inadequate diaphragm action of roofs/floors. Inadequate treatment of infill masonry walls. Inadequate strength to resist torsional forces due to eccentricity. The concreting between the beam and the column junction is done afterward, where honey combing in concrete cannot be avoided fully. Buildings have been raised on cantilever beams leading to failure. The buildings have been constructed on reclaimed land without proper foundation. Buildings have subsided and tilted due to liquefaction in the foundation soil. Building resting on soft soil or reclaimed land without proper foundation is likely to get damage due to uneven settlement due to earthquake shaking.

The response spectra obtained at a site in Ahmedabad from recorded instrumental data show peaks at about 0.35, 0.55 and 0.8 sec. This means that multi-storey buildings having time period of vibration about 0.55 and 0.8 sec i.e. 6 to 10 storey buildings must have been subjected to severe shaking and the buildings not properly designed and constructed for earthquake forces could not bear the shaking and collapsed.

SOFT STORY AND THE WEAK STORY

The soft story and the weak story are building irregularities which influence the stiffness and resistance of building are the main causes of building failures.

Soft Storey: As per ASCE 7-10, soft story irregularity is defined to exist where there is a story in which the lateral stiffness is less than 70% of that in the story above or less than 80% of the average stiffness of the three stories above. We can find soft ground story as the most common type of soft story irregularities.

The soft ground story is the most common type of irregularity. In a building, the earthquake shear forces increase towards the ground story. So in soft story buildings, the ground story columns which have to take axial and shear load also, may fail due to ground shaking.

In double height first soft stories, columns are very flexible not only due to the total or partial absence of walls but as a result of their significantly greater height in relation with those from the upper floors. This configuration is one of the characteristic models of modern design for office buildings, hotels and hospitals, in which the access for general public has a great importance.

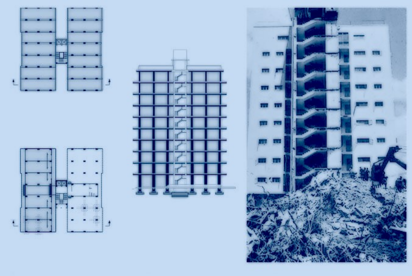
Weak Storey: As per ASCE 7-10, weak story irregularity is defined to exist where the story lateral strength is less than 80% of that in the story above. The story lateral strength is the total lateral strength of all seismic-resisting elements sharing the story shear for the direction under consideration.

Due to its inability to withstand the different types of loads (lateral, vertical and moments) produced by the ground motion the building's weakest part would suffer severe damages. Weak story configuration is often generated in hotel, hospital buildings and public buildings where people assemble, in which not only the first floor is designed less walls than the other floors, but generally, due to its importance, it also has a greater height than the rest of the floors. There are numerous examples of many buildings presenting a combination of these types of irregularities, soft and weak story, making them seismically vulnerable.

Fig. 1: “The Palace Corvin” with one of two towers collapsed

Plan: Typical

Level



Section at

AA

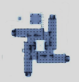
A A

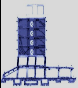
A A

Plan: Ground

The failure of “The Palace Corvin” during the 1967 Caracas, Venezuela earthquake, is a classic case of soft first story failure as seen in Fig.1.. It consisted of an H-shaped first floor. The two main bodies of the building housed residential apartments and were joined in the middle by corridor. In the east wing, the first floor was left open for the parking lot, while in the west wing with shear walls were continued, following the upper floors. “The portion of the building on the east side collapsed completely while the part on the west side survived the earthquake without structural damage.

The main building of the “Sylmar Olive View hospital” (1971 San Fernando, California earthquake) consisted of four wings joined around a courtyard, as shown at the structural layout (Fig. 2). Each wing had six floors and a penthouse. While the upper four stories consisted of shear walls combined with moment resisting space frames, the lower two stories had only a moment resisting space frame system. The floor system consisted primarily of a flat slab





column system with drop panels at the columns. Tied and spirally reinforced concrete columns were used. The shape and reinforcement of these columns differed from story to story." This explains why that the large inter story drift in the main Treatment and Care Unit, which induced significant non-structural and structural damage and led to the demolishing of the building, was a consequence of the formation of a soft story at the first story level because on the lower floors there were columns, while there were reinforced concrete walls above the second floor level.

LESSONS LEARNT

General

- ☑ The performance of buildings during earthquakes reveals that if the earthquake resistant measures as specified in building codes are adopted, buildings are quite safe.
- ☑ Fig. 2: “Sylmar Olive View hospital” damaged in 1971, San

  Fernando, California earthquake
- ☑ Plan
- ☑ Section
- ☑ Location of building has profound influence on the performance of buildings. Site selection should be based on local geology and the subsoil properties which modify the earthquake ground motion. A

seismic microzonation in high seismic area will be helpful in the decision making. o The architects either have little or ignorant about the earthquake resistant provisions in the building and there is no method of fixing accountability.

Configuration

- ☑ The layout of buildings should be as simple as possible and there should not be any sudden change in the distribution of mass or stiffness.
- ☑ Avoid construction of heavy structures at the top such as water tank, swimming pool, garden etc.
- ☑ Failure results due to soft storey and weak storey conditions and therefore should be avoided.
- ☑ Integrity of the whole building should be achieved. Proper detailing of joints and splicing should be made.

Design

- ☑ The most of the Structural Engineers and Architects are not conversant with the latest codal provisions on earthquake resistance design.
- ☑ Buildings designed and constructed as per Indian Codal practices have withstood the earthquake well and therefore Codal practices must be followed.
- ☑ Adequate strength in both the longitudinal and transverse directions should be provided.
- ☑ Avoid quasi resonance i.e. the fundamental natural frequency of structure should be away from the predominant period band of the ground motion.

- ☑ The frame of a building should have adequate ductility so as to permit energy dissipation through plastic deformations.

- ☑ For important and tall buildings proper dynamic analysis should be carried out.

Soil & Foundation

- ☑ Building constructed on fills suffer severe damage
- ☑ Hard foundation is found to be suitable for all types of building. Construction of buildings on loose soil such as filled up should be avoided unless proper care is taken in the foundation design.
- ☑ Loose sandy soil with high water table subjected to violent ground shaking which may lead to liquefaction. The liquefaction causes damage to buildings due to differential settlement, tilting or sinking.
- ☑ Isolated footings undergo differential settlement. Tall buildings resting on piles withstood earthquakes well.
- ☑ Structures on hill slopes where landslide is expected, should be avoided.

Detailing

- ☑ Inadequate quantities and anchorage of longitudinal and transverse reinforcement cause damage/ failure.
- ☑ Splicing joints are weak against earthquakes. Column splicing should be provided in the middle of the column height. Close stirrups should be used at overlap portion.
- ☑ Proper detailing of beam-column joints should be made. The beam reinforcements should go well inside the column for better anchorage.
- ☑ Strong columns and weak beam design concept should be aimed so as to prevent total collapse. Close ties should be provided in columns were large moment is expected.

Construction

- ☑ The various builders constructed the buildings with the sole idea to make large profits taking advantage of the inadequate building bye-laws and hardly any building control regulation.
- ☑ It is observed that there is lack of awareness about the earthquake resistant design codes and practices. their implementation is not mandatory either in the building bylaws of the local bodies or in various departments of central and the state governments.
- ☑ There was not adequate supervision of construction and quality control.

CONCLUSIONS

The multi storey R.C. buildings are being designed and constructed without much attention to earthquake resistant features. There exists a lack of compatibility among urban zoning regulations, building bye laws and seismic codes regarding vulnerable modern building configurations that generate vulnerability in urban cities. Although seismic codes have included design methodologies to consider irregularities which result in the increase of the design lateral force or shear at the base, still unsafe buildings are being constructed.

There is a impression that multi-storied buildings are liable to more earthquake damage and should not be built. In fact earthquake safe multi-storied buildings can also be built. Very tall multi-storied buildings have been constructed throughout the world in high seismic zones which have performed well during severe earthquakes. It is criminal to construct multi-storied buildings with total disregard to resist earthquake forces. If multi-storied buildings are not designed to resist earthquakes, it will lead to catastrophic failures as it did in

case of Mexico and Bhuj earthquakes.

An active interaction between earthquake engineers, structural engineers, seismologist, architects, and government authorities, should take place which will greatly help in reducing the building seismic vulnerability.

Education of field engineers, the undergraduate and graduate engineers about Earthquake Resistant Design and Construction practices should be imparted on a continued basis.