PROTECTING STILT BUILDINGS FROM DAMAGE DUE TO RAYLEIGH WAVES DURING LARGE MAGNITUDE EARTHQUAKES LOCATED AT DISTANCE FROM EPICENTER- CASE FROM INDIA

Arun BAPAT
Consulting Seismologist, India
arunbapateq@gmail.com

Abstract: Large magnitude earthquakes of magnitude M = 7.5 or more has two types of destructions. First is due to Shear Waves (S Waves) more or less confined to highest epicentral area. While the other is distance damage which occurs beyond 100 to 150 km. Such damages are due to Rayleigh Waves which have long period of more than 14 seconds. These waves cause damages to high rise structures of height equal to or more than 17 meters.

Keywords: *Rayleigh Wave damages, tall structures of h = or > 17 meters, structures located beyond 150 km from epicentre.*

Introduction

The expansion of urban areas in India has been almost phenomenal during last three decades or so. Rapid rise in urban population increases the demand of dwellings. The infrastructure facilities have undergone a very rapid change. As the number of houses and motor vehicles has shown a rapid geometric growth and the surface areas of the roads have remain almost unchanged or stationary, parking of vehicles has become acute problem. To partially overcome this, most of the Municipal Authorities have a regulation that the ground floor should be used for parking. To have this facility a large number of high rise structures have stilt construction.

Most of the damage in the Epicentral area of any earthquake is by Shear Waves (S wave) and within the highest Isoseismal (Imax) on MM Scale. The maximum destruction is within about 30 to 70 km diameter of elliptical (at times circular) area depending up on the magnitude of the earthquake. However, there is one more type of damage during large magnitude (M > or = 7.0) earthquake. This is due to Rayleigh Waves (also known as surface waves). Such damages are located at a distance of more than 100 km from earthquake epicenter. The damages due to Rayleigh Waves at distance from epicenter are limited to high rise (h > 17 m) structures. Other structures of two to three storeys at similar locations normally do not suffer any damage or the damage is minimal. It could suffer some vibrations which may not cause any damage. The NW Himalayas is likely to experience a large magnitude earthquake (Bapat, 2007; Billham, 2001; Aizwal and Sinhala, 2007). Waves from such an earthquake could adversely affect high rise structures in Delhi and near by locations of National Capital Region Delhi (NCR). To overcome the likely damage from such a seismic contingency, a number of scientific measures are being undertaken. One of the major measures is Microzonation of Delhi had been undertaken (Singh et al., 2002). Another vulnerable urban area is Guwahati City (Assam). Delhi and Guwahati lie in Seismic Zone IV as per Indian Seismic Code. Both the cities have a large number of tall stilt structures.

Stilt Structure Damage

For the first time such damage was observed at Mexico City during the 19 September 1985 earthquake of magnitude 8.0. The epicenter was located at a distance of about 530 km from Mexico City where only tall structures suffered heavy damages. In India, during the 26 January 2001 Bhuj earthquake of M = 7.9, damage to tall structures was observed. The Ahmedabad City is located at a distance of about 320 km from the Bhuj earthquake epicenter. In Ahmedabad tall structures have suffered heavy damages. But there was some new observation. This was damage to stilt structures of two or three storey. **Fig. 1** shows damage to tall structure. While **Fig. 2 (a), (b) and (c)** shows damages to stilt floor structures at Ahmedabad. All structures in **Fig. 2 (a), (b) and (c)** are two / three storey.

The M = 8 earthquake of 08 October 2005 in (Pakistan) had severely damaged a tall building Margala

Towers at Islamabad situated at distance of about 150 km from the epicenter. **Fig 3(a)** and **Fig. 3 (b)**

Fig. 1. Damage to tall structures at Mexico (left), and damage at Ahmedabad (right).

Fig. 2. Damages of structures with stilt structure: Left (a), three storey, center (b) two storey, and right (c), damage to a parking lot.

Fig. 3. Margala Tower in Pakistan before earthquake, left figure, and after earthquake, right.

An historical example from Qutab Minar at Delhi

During 01 September 1803 earthquake in NW Himalayas, the upper two floors of the 72 m high Qutab Minar were dislodged. This is due to Rayleigh Waves. This has been mentioned on a marble plaque on the inner staircase. The damage was subsequently repaired. See **Fig. 4**.

Architectural beautification causes maximum damage. **Fig. 5 (a), (b), and (c)** show a building in Jawaharlal Nehru University (JNU) in Delhi. The structure is stilt structure and is in the shape of inverted pyramid. All three floors have floating columns. In case an earthquake of magnitude more than 7.5 occurs in NW Himalayas this structure could suffer heavy damage including collapse.

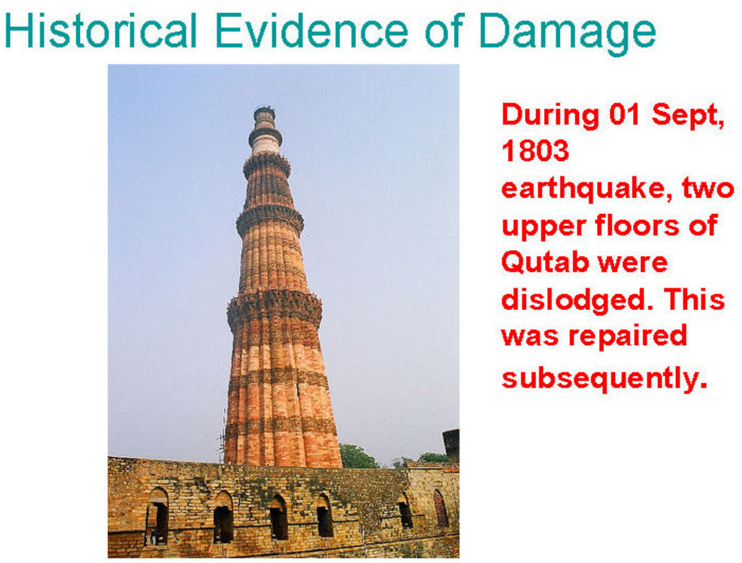

Fig. 4. Qutab Minar a 72.5 m tall minaret at Delhi. The upper two floors were dislodged during an earthquake in 1803. This was subsequently repaired.

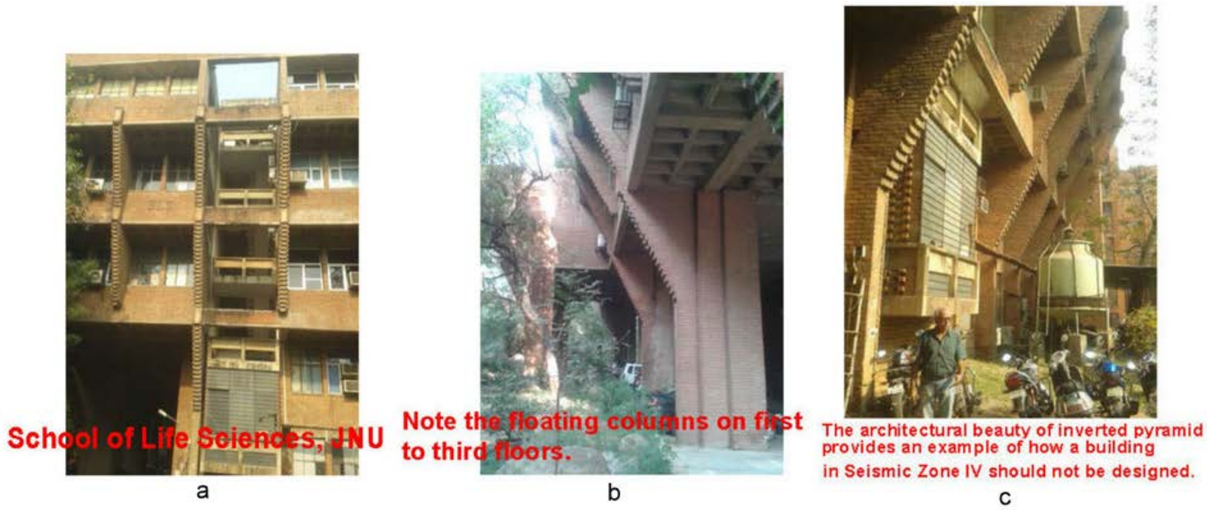

Fig. 5. An inverted pyramid shape structure at Jawaharlal Nehru University (JNU), New Delhi. It is stilt building and three floors have floating columns.

Why does stilt structure fail?

When any building starts vibrating under seismic force, the stress wave starts from the top floor and goes down to earth, **Fig. 6.** From the top floor to the first floor the area of cross section of the structure is almost uniform. When the stress wave comes to the stilt floor, the entire load comes on columns. If we take the area of each floor as 100 then the area of stilt floor is about 3 % or less. As such the heavy concentration of stress cannot be taken by columns and the column suffers damage. It could be yielding, breaking or buckling depending on design, reinforcement and direction of waves etc.

Fig. 6. Graphical presentation of seismic vibrations. Top figure, single, double, three and multi-storied structures. Lower figure vibrations of these structures. The last figures (extreme right) shows that the structure vibrates in two directions.

If this situation could be overcome, then possibility of damage could definitely be reduced or minimized. The design provides a uniform path for the stress wave and there is no damage. This is shown in **Fig. 7.**

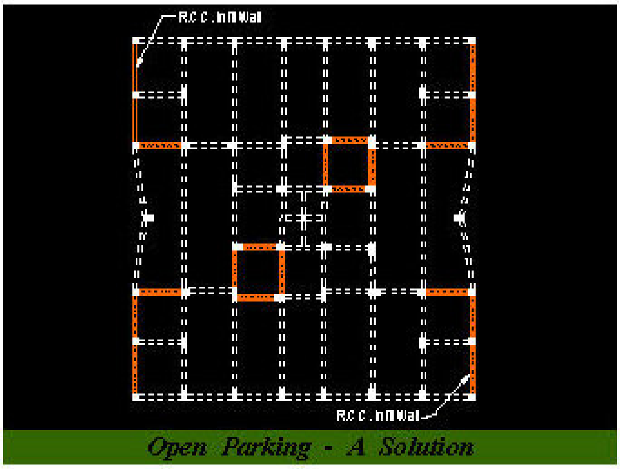

Fig. 7. Proposed design for protection due to damage by Rayleigh waves. The red line shows where strengthening is required.

The design provides for construction of concrete or brick walls shown by red colour in **Fig. 7**. The red line shows the proposed addition. It could be a RCC construction or a simple brick wall would also serve the purpose. The design is made so that there is no loss of driving and parking maneuverability. Depending on the structure and design of the building there could be some variations in the design. The central part is lift shaft and it is always strong. Such additional arrangements would definitely help in saving the stilt floor buildings from any damage. In number of cities, suitable parking has been made mandatory by municipal or state regulations. In big cities such as National Capital Region of Delhi (NCR Delhi), Kolkata, Mumbai, Guwahati and other big cities very large number of buildings have stilt floor used for parking. The structures in NCR Delhi could suffer heavy damage under such conditions. In Delhi the Delhi Development Authority (DDA) headquarters has a high rise building on stilt. The above arrangement would definitely help in reducing or totally avoiding any damage to stilt structure. A number of colonies with high rise buildings (with ten floors) have been constructed by Delhi Development Authority (DDA). All these are stilt construction. Suitable retrofitting measure as suggested may be undertaken at the earliest to avoid any damage to the stilt floor structures. In the NE region, Guwahati, Jorhat and other locations on hilly terrain such as Gangtok, Kohima, Imphal, Aizwal etc. a large number of high rise structures are constructed during last few years. Siliguri in West Bengal is now having some high rise buildings with stilt floor and cross section of the columns is square. These could be protected with the above technique. In Kolkata the entire area of Salt Lake City is sitting on filled land (Bapat, 2009). This was a lake of about 15 sq km area. This lake was filled by the sediments from Kolkata port. For this purpose an eight km long pipeline of one meter diameter was used to pump the sediments from the port. It took nine (1971 to 1980) years to fill the lake. Initially the area was developed as housing for middle and lower class population and houses were of two or three storey. But during recent past the old small constructions have been demolished and new high rise buildings have cropped the area. These high rise structures of up to 20 floors or more are definitely vulnerable to damage by Rayleigh waves due to a large magnitude (M > 7.25) earthquake within 500 km from Salt Lake City. Similar situations exist in Himachal Pradesh and Uttarakhand.

With rise in population, rapid urbanization the residential space demand is increasing. This is one of the reasons for construction of high rise structures. But it would be desirable if suitable measures are undertaken to protect the structures from damage due to Rayleigh Waves. In other Asian countries where there are no codal provisions to account for adverse effect of Rayleigh Waves on tall structures, the design suggested in this paper may be useful.

References cited

Aizwal, K. and Sinhala, R., 2007. Probabilistic seismic-hazard estimation for peninsular India. *Bull. Seism. Soc. Am.*, v. 97, 1B, p. 318-330.

Bapat, A., 2007. Lack of statistical confidence. *Curr. Sci.*, v. 93, p. 1468 – 69.

Bapat, A., 2009. Natural Hazards at Mumbai and Kolkata. *Industrial Safety Chronicle*, XL, no. 1, p. 42 – 47. Pub. National Safety Council of India.

Billham, R., Gaur, V.K. and Molnar, P., 2001. Himalayan Seismic Hazard, *Science*, v. 293, p. 1442-1444,

Singh, S.K. et al., 2002. Ground motion in Delhi from future large / great earthquake in the central seismic gap of the Himalayan arc. *Bull. Seism. Soc. Am*., v. 92, p. 535.