Vulnerability Assessment Of Building Stock At Historic City Of Pune , India. With Reference To Pounding Hazard

Vasudha Ashutosh Gokhale
B.N. College of Architecture, Pune, India.

Deepa Joshi
University of Bhopal, India.

SUMMARY:

The highly congested building system in many metropolitan cities constitutes a major concern for seismic pounding damage as observed in past earthquakes. Majority of buildings located in Indian cities are very closely spaced without adequate seismic separation. Such a building stock has to be identified and analyzed with reference to its vulnerability to earthquake damages to facilitate action taken for its strengthening, retrofitting to minimize pounding in case of earthquake occurrence. Pune is one of rapidly growing Industrial city of India located about 175 miles from Mumbai. In the historic city of Pune where land cost are sky reaching majority of buildings in downtown are constructed with small or no separation. A large amount of such buildings might suffer pounding damage in case of earthquake occurrence. This paper presents a study on this potential hazard to buildings located on old districts of historic city of Pune.

Keywords: Pune, Pounding, Maharashtra, India, Mumbai.

1. INTRODUCTION

Building pounding can be defined as the collision of adjacent buildings as a result of seismic excitation. It is a complex phenomenon which requires a detailed knowledge of the dynamic performance of multiple buildings, as well as knowledge of how the buildings will react to very high magnitude but very small duration earthquake forces. Pounding of buildings imposes unexpected impact loading on buildings and may result in minor damage to total collapse of buildings as observed in past earthquakes. Damage to a considerable number of tall buildings in 1985 Mexico earthquake, 1989 San Francisco earthquake is attributed to pounding phenomenon. This paper presents the current state of the art of building pounding, with particular emphasis on the fundamental concepts of pounding. In recent earthquakes several instances of pounding damage in both building and civil structures were noticed. Pounding of adjacent unreinforced masonry buildings resulting in shear failure of the brickwork leading to partial collapse of the wall was observed during the 1989 Loma Prieta earthquake. Pounding of a six-story building and two-story building in Golcuk, Turkey during the 1999 Kocaeli earthquake contributed to column failure above the third floor slab in the taller building, and shear failure of two second-floor piers in the smaller building .The 1999 Chi-Chi earthquake in Taiwan revealed hammering at the expansion joints in some bridges which resulted in damage to shear keys, bearings and anchor bolts.

Pounding damage were reported after the 2001 Bhuj earthquake in Gujarat, India. Based on the observations from past earthquakes, closely spaced buildings can experience infill wall damage, column shear failure and possible collapse due to pounding. In Chengdu, a number of buildings greater than 3-storeys were located very close or adjacent to each other resulting in pounding damage. The more severe structural pounding damages were observed in Dujiangyan and Mianyang.

Pounding can be classified as:

- Floor-to-column pounding – It generally occur when the columns subject to very high shear forces and collapse or damaged. Such columns face shear failure, although column ductility requirements may also be exceeded.
- Adjacent buildings with greatly differing mass - In such cases the momentum transfer from the heavier building can greatly increase the velocity in the lighter structure during earthquake shaking as a result the lighter building is susceptible to collapse.
- Buildings with significantly differing total heights - When a tall and a short building collides taller building's displacement mode change. The floor that suffers collision in the taller building is restrained, while the rest of the building is 'whip-lashed' over top. This creates a major increase in shear and ductility demands in the taller building in the storey immediately above the top floor of the shorter building.
- External buildings of a row when all buildings have similar properties - In case of a street of similar buildings with little or no building separation, the buildings at the end suffer increased damage due to the momentum transfer from the interior buildings. Subsequently the interior buildings may actually suffer less damage than if pounding were not to occur.
- Building subject to torsional actions arising from pounding- . Certain building configurations can excite torsional modes in one or both structures which can lead to greatly increased loading demands. This is particularly dangerous if floor-to-column pounding occurs.
- Buildings made of brittle materials- Unreinforced masonry is particularly vulnerable to any lateral loading. Collision causes a very high temporary force which may cause explosive failure of brittle structural elements.

3. CASE STUDY : PUNE.

Pune, formerly known as Poona is the eighth largest metropolis and the second largest in the state of Maharashtra after Mumbai. The city is an academic, administrative and industrial centre situated 560 meters above sea level on the Deccan plateau at the confluence of the Mula and Mutha rivers. As per the 2010 census of India, the population of the Pune urban area is around 5,518,688. Pune is emerging as a Information Technology hub, presence of automobile and manufacturing companies resulted to rank as the eight largest metropolitan economy and the sixth highest per capita income in the country. Pune has a mixed type of building stock from modern steel structures to old historic buildings. The city core areas are densely populated with a mix of various building types.

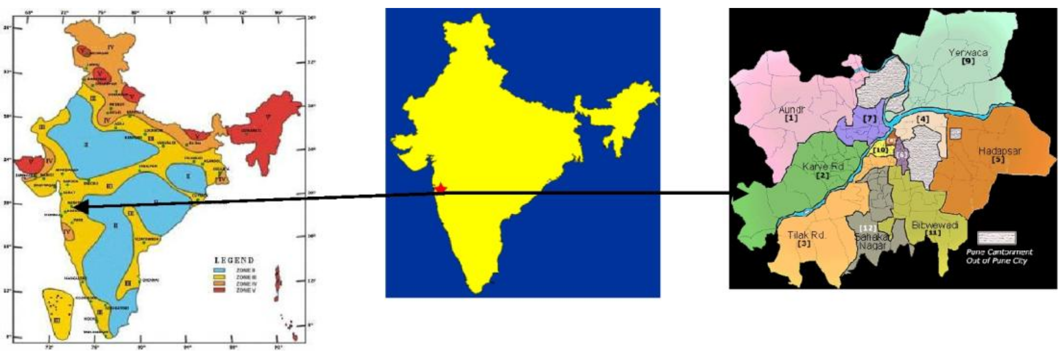

Figure 1. Seismic Zoning map and Location of City of Pune

Pune lies very close to the seismically active zone around Koyna Dam, about 100 km (62 mi) south of the city, and has been rated in Zone 4. Pune has experienced some moderate-intensity and many low-intensity earthquakes in its history. Earthquakes felt in Pune with a magnitude of more than 3.0 are as shown in table 1.

Table 1: Past Earthquakes in Pune Region

Date	Magnitude	Epicenter
May 17, 2004	3.2	Katraj Region, Pune, Maharashtra
July 30, 2008	4.2	Koyna Dam, Koyna Nagar, Maharashtra
April 14, 2012	4.9	Stara District, Maharashtra

Source: www.wikipedia.com

A highly congested and a major traffic carrying street "Kumthekar Street" have been selected for detailed study. Buildings located on this street are surveyed with reference to floor plan, seismic separation with adjacent buildings, relative position with adjacent buildings, age of the buildings, material and technology used for construction, floor height, building height, faced treatment, presence and type of openings, building facade details, use of building, occupancy, accesses to the building.

Legend

	No Seismic Separation		Different Construction Material and Technology
	Age Difference		Difference in Floor Level

Figure 2 : Streetscape Kumthekar Road, Pune

Table 2. Seismic Separation in study area.

SEISMIC SEPARATION	5	5-15	15-25	25-35	35-45	50 YEARS	TOTAL
0	2	18	64	165	66	42	357
0.1	0	1	1	5	12	15	34
0.2	0	0	0	1	1	0	2
0.3	0	2	1	1	3	4	4
0.4	1	2	0	0	0	0	3
0.5	1	0	0	1	1	0	3
0.6	0	2	3	0	5	1	11
0.7	3	2	0	0	0	0	5
0.8	1	2	4	0	1	1	9
0.9	2	2	3	3	0	0	10
1	1	0	0	0	2	1	4
1.1	0	0	0	0	0	1	1
1.2	0	1	0	0	0	0	1
1.3	1	0	1	0	0	0	2
1.4	0	0	0	0	0	0	0
1.5	0	2	0	1	1	0	4
SUBTOTAL	**12**	**32**	**77**	**177**	**82**	**65**	**450**

3. POUNDING DAMAGE PATTERN

In case of minor or negligible pounding, there may be the initiation of mechanisms leading to building failure under further seismic activity. In Christchurch earthquake moderate to serious pounding damage occurred in unreinforced masonry (URM) structures, while concrete structures suffer localized damage. A damaged building is shown In figure 3.

Figure 3. Moderately damages building at Christchurch.

Figure 4. Building at Laxmi Road , Pune

There are a large number of such building with similar configuration are in existence in the selected study area which are likely to suffer from such damage. If URM buildings do not have adequate seismic separation pounding may occur. A four storied building at High St (figure 5). It also suffered localized damage because of the brittle nature of the unreinforced masonry, and presence of R.C.C. lintel immediately above the parapet of the adjacent building result in the damaged masonry. Buildings were identified with identical details in the selected study area (figure 6) which are highly susceptible for damage in case of earthquake occurrence.

Figure 5. Building at High Street, Christchurch.

Figure 6. Building at Pune**.**

In highly populated area of city a number of buildings are in existence without seismic separation. In such circumstances the buildings at the central part may suffer badly. Figure shows the central two of four consecutive buildings with zero separation, where damage was confined to the interface between the two buildings. In addition considerable at first floor level masonry crushing is observed (figure 7,8).

Figure7, Building in series, Christchurch

Figure 8, Building in series, Pune

In downtown area many buildings façade is not in a single line. In such cases where adjacent buildings have a façade setback they are susceptible to pounding damage at the exposed corners (Figure 9). This is a common phenomenon as observed in existing building stock in selected study area (fig 10).

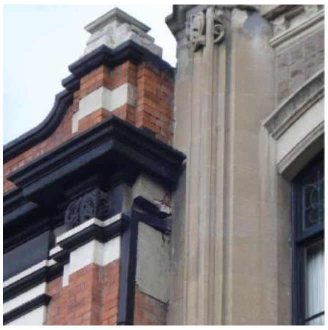

Figure 9. Damaged building with façade setback, Christ Church.

Figure 10. Building with façade setback, Pune.

Adjacent buildings with greatly differing total heights displayed surprisingly little damage, while the most severe damage observed between buildings differing by three or more storeys. In such kind of damage buildings suffer damage to their vertical structural elements and not their horizontal elements (figure 11, 12.).

Figure 11. Minor damage to adjacent building with different height., Christchurch

Figure 12. Adjacent building with different heights Pune.

A survey is conducted to reveal the status of building seismic separation. Based on the survey buildings susceptible for pounding damage is identified. It has been estimate that 18% out of total 450 surveyed buildings at Pune might suffer pounding damage during major earthquake event. Seismic Separation: Out of 450 surveyed buildings 357 buildings found with zero separation while rest of them have a little separation. Adjacent buildings with floors at different levels: There are 124 buildings identified which have floors at different level. If a strong or moderate earthquake occur the floor of one building is likely to colloid into the columns of adjacent building which may suffer severe column failure. Adjacent buildings with unequal floor mass: In the selected study area 14 buildings were identified which have adjacent building with a large floor mass. This heavy building is likely to transfer large momentum into the adjoining buildings which have comparatively light mass and they may suffer large scale damage. Buildings adjacent to each other: The major part of street have buildings in series with no or negligible separation. In case of earthquake occurrence the buildings located at the corner are likely to suffer major damage because of pounding.

3. MITIGATION METHODS

The process of seismic retrofitting of existing buildings must be in accordance with philosophy of

seismic codes which are aimed to avoid collapse and save human lives. Seismic requirements allow inelastic behavior of the resisting structural system during earthquake resulting in deformation of plastic hinges and in a certain degree of structural failure usually accompanied by severe secondary damage and significant economic losses. Since the secondary damage depends on relative lateral displacement between floors the architects must pay adequate attention to control such displacements. In retrofitting operation it is not enough to just add strength to the system the flexibility of structure must also be controlled by adding elements and consequently non structural damages.
Mitigation of existing structures to mitigate pounding damage can be done in the following ways:

- Adding structural systems to replace elements that may be lost due to pounding.
- Improving individual buildings to reduce displacements or increase resilience to pounding.

The retrofitting includes the addition of damping devices or increasing the shear capacity of elements likely to undergo contact. Linking adjacent buildings with any type of element significantly changes their loading distributions and dynamic properties. Many damping devices may be used like viscous, visco-elastic, friction and tuned mass dampers. As far as linking of adjacent building is concerned, existing buildings with small separations provide little room to install damping elements. Besides linking elements require time history analyses to determine their effectiveness, consequently they require considerable design time. A major practical issue is likely to prevent the linking of two buildings with different owners since linking typically requires alterations to both buildings. Finally, the addition of linking elements can affect buildings in unexpected ways. The building loading profile can significantly change, thereby affecting beam and column demands throughout the structure. Considering the potential pounding problems with adjacent buildings, which are not adequately, separated an upgrade of the structure, is needed for the safety of the building. In addition the retrofit techniques which may be adopted are weight reduction, column and waffle slab jacketing, removal of top floors and addition of energy dissipation devices. Seismic gaps (or movement joints) can be created between the adjacent buildings which are to be done with utmost care.

CONCLUSIONS

Based on survey data and analysis the potential pounding damage is evaluated. It has been found that out of 450 surveyed buildings 14% will suffer pounding damage. Among them 2.4% will collapse. 4.1% will suffer severe damage 3.6 will suffer medium damage while rest of them will suffer minor damages. Study and analysis of the existing status of building stock in Pune city with reference to pounding damages and presence of seismic separation it has been found that majority of buildings are highly susceptible for pounding damage. Considering the potential pounding damage hazards in case of likely occurrence of an earthquake the seismic pounding mitigation is urgently required. Buildings which are liable for such damage have to be identified and retrofitted at top priority in order to save life and property loss in future.

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