Study on Impact Between Adjacent Buildings: Comparison of Codal Provisions

Chenna Rajaram
Graduate Student, Earthquake Engineering Research Centre,
International Institute of Information Technology, Hyderabad, India

Ramancharla Pradeep Kumar
Associate Professor, Earthquake Engineering Research Centre,
International Institute of Information Technology, Hyderabad, India

SUMMARY:
Structures are being built very close to each other in metropolitan areas where the cost of land is very high. Due to closeness of the structures, they often collide with each other when subjected to earthquakes. Many studies have been carried out on separation distance between adjacent structures to mitigate pounding. Although some modern codes included seismic separation requirement for adjacent structures, some of them have failed in providing the appropriate minimum separation distance.

In this paper, two linear single degree of freedom oscillators are used to study the impact force for five different ground motions ranging from 0.2 g to 0.8 g. The separation distance is calculated from the codal provisions of different countries. The separation distance between the two structures decreases, the amount of impact increases which is applicable when the impact time is same. It may also decreases when separation distance decreases. For structures having same period, no need to provide separation distance. The amount of impact depends on response of the structures at particular time, minimum space between the structures and velocity of the structures.

Keywords: Pounding, Separation distance, codal provisions

1. INTRODUCTION

Pounding is the phenomena of collision between adjacent buildings or different parts of the same building during strong vibrations. It may cause either architectural and or structural damage and may lead to partial or complete collapse of the structure. Reported case studies of pounding are as follows: During 1985 Mexico City earthquake (J Aguilar et.al, 1989), more than 20% of buildings were damaged because of pounding. During 1989 Loma Prieta earthquake (Kazuhiko Kasai et.al., 1997) (M7.1) over 200 structures were affected. These structures were located around 90 km away from the epicenter. A ten storied building experienced pounding with an adjacent massive five-storey building. The typical floor mass of the five-storey building is about eight times that of the ten-storey building and was separated by about 4cm. Pounding occurred at the 6th level in the ten-storey building and at the roof level in the five-storey building. The 1999 Chi-Chi earthquake (Jeng Hsiang Lin et.al., 2002) in central Taiwan, caused severe destruction to towns and villages near the epicenter. Structural pounding events were also observed after the earthquake. During 2004 Sumatra earthquake (Mw9.3), pounding damage at junctions was noticed at the top ends of piles of the approach jetty. In 2002 Diglipur earthquake (Durgesh C Rai et.al., 2005) (Mw6.5), pounding damage was observed at the junction of the approach segment and main berthing structure. During 2006 Sikkim earthquake (Hemanth B Kaushik er.al., 2006) (Mw5.3), damage to a nine storey masonry infill RC frame hostel building of Sikkim Manipal Institute of Medical Sciences (SMIMS) was observed. Pounding damages were observed between two long wings in the building and corridors connecting the wings. From the above observation it is evident that pounding is usual phenomena between adjacent buildings if the separation distance is inadequate. In the proposed study, first review the code provisions across the world is discussed and later, the impact force is evaluated between the structures which followed the provisions.

2. LITERATURE REVIEW

Pounding is one of the recent topics of interest in the research community. Many investigations have been carried out on pounding damage during previous earthquake events. Stavros A Anagnostopoulos (1987) studied the pounding of several adjacent buildings in a block, due to strong earthquakes. Each structure is modeled as a single degree of freedom (SDOF) system and pounding is simulated using impact elements. The parametric investigation of this problem showed that the end structures displace more than the interior structures. Maison and Kasai (1992) studied pounding between 15-storey and 8-storey buildings. They assessed the influence of building separation, relative mass, and contact location on the impact force. Van Jeng, Kazuhiko Kasai and B F Maison (1992) developed spectral difference method (Double Difference Combination rule) to estimate the required separation to preclude pounding. This was based on response spectrum approach. This method is useful not only for the assessment of pounding but also for studying the problems involving relative displacement. Filiatrault and Wagner (1995) proposed pounding mitigation techniques. They suggested separation distance to deal with pounding. Solutions were either filling the gaps between the buildings with a material or by connecting them with bumper walls.

3. REVIEW OF CODE PROVISIONS ON POUNDING

Most of the world regulations for seismic design do not take into account the pounding phenomenon. Among the exceptions are the codes of Argentina, Australia, Canada, France, India, Indonesia, Mexico, Taiwan and USA. These codes specify a minimum separation distance between adjacent buildings. However, the procedure to determine the separation distance varies from country to country. In UBC-1997, it depends on the maximum displacements of each building. In Canada and Israel, it is simple sum of the displacements of each building. In France it is a quadratic combination of the maximum displacements. In Taiwan it is depends on the building height and in Argentina minimum gap is 2.5 cm. Also, in some cases, these values depend on the type of soil and seismic action.

The provisions on separation distance are very similar in the 2000 and 2003 International Building Code (IBC, 2003). In 2006 version there is no code provision on building separation. According to IBC-2009 the separation distance between two adjacent buildings is computed from equation 1:

$$\delta_M = \frac{C_d \delta_{\max}}{I} \tag{3.1}$$

Where, δ_{max} is the maximum elastic displacement that occurs anywhere in a floor from the application of the design base shear to the structure. C_d is the deflection amplification factor and 'I' is the importance factor for seismic loading.

Indian seismic code (IS:1893-2002) recommends that the separation between two adjacent units or buildings shall be a distance equal to response reduction factor (R) times the sum of the calculated storey displacements. When the two buildings are at the same elevation levels, the factor R may be replaced by R/2. This clause assumes only two dimensional behavior of building i.e., only translational pounding, and no torsional pounding. But in reality torsional pounding tends to be more realistic than uni-directional pounding during real ground motions.

According to Federal Emergency Management Agency (FEMA: 273-1997) the separation distance between adjacent structures shall be less than 4% of the building height and above to avoid pounding. FEMA states that buildings intended to meet enhanced objectives shall be adequately separated from adjacent structures to prevent pounding during response to the design earthquakes, except as indicated in section 2.11.10.2. Pounding may be presumed not to occur whenever the buildings are separated at any level i by a distance greater than or equal to s_i. The value of s_i need not exceed 0.04 times the height of the buildings above grade at the zone of potential impacts.

Peru code (NBC-PERU E030) states that every structure should be separated from other close structures a minimum distances to avoid contact during strong ground motions. This minimum distance not be lower than 2/3 of the sum of the maximum displacement of adjacent blocks. ASCE 7-10 states that all portions of the structure shall be designed and constructed to act as an integral unit in resisting seismic forces unless separated structurally by a distance sufficient to avoid damaging contact under total deflection as determined in section 12.12.3. Separation distance between two structures depends on deflection amplification factor and importance factor.

From the observation of all code provisions, the minimum separation distance is not only depends on the response of the structure but also on various factors like importance factor, amplification factor etc. The details of code provision for different countries are as shown in table 3.1. This case study deals with the collision force of first impact of the structure by using linear impact models. The response is considered in translational direction only and not consider in torsional direction.

Table 3.1. Building separation distance between two adjacent structures from different country code provisions

S.No	Country	Formula
1	INDIA (IS- 1893:2007 (Draft))	R times the sum of the calculated storey displacements using design seismic forces to avoid damage of the two structures when the two units deflect towards each other. When the two buildings are at the same elevation levels, the factor R may be replaced by R/2. *(Clause 7.12.3)*
2	IBC-2009	$\delta_M = \frac{C_d \delta_{\max}}{I}$
3	UBC 1997	$\delta_M = \sqrt{\delta_{M1}^2 + \delta_{M2}^2}$ ..... (Adjacent Buildings located on the same property line) *(Clause 1633.2.11)*
4	FEMA:273-1997	Separation distance between adjacent structures shall be less than 4% of the building height and above to avoid pounding.
5	NBC Peru E030-2003	This minimum distance not be lower than 2/3 of the sum of the maximum displacement of adjacent blocks nor lower than S=3+0.004(h-500). *(Clause 3.8.2)*
6	ASCE:7-2010	$\delta_M = \frac{C_d \delta_{\max}}{I}$ *(Clause 12.12.3)*

S = Separation distance (in cms)
h = Height of structure (in cms)
R = Response reduction factor
δ_M = Separation distance between two structures
δ_{M1} and δ_{M2} = Peak Displacement response of adjacent structures 1 & 2
C_d = Total deflection amplification factor
δ_{max} = Maximum elastic displacement that occurs anywhere in a floor from the application of design base shear to the structure.
I = Importance factor for seismic loading

4. MINIMUM SEPARATION BETWEEN BUILDINGS

For the numerical study pounding between adjacent buildings, two buildings as shown in figure 4.1 are considered. These buildings are idealized as two equivalent linear single degree of freedom (SDOF) systems. The two buildings are referred hereafter as Building 1 and Building 2 and are separated by a distance δ between them. The two buildings have lumped masses m_1 = 11400kg, m_2 = 6410kg, equal stiffnesses k = 45000kN/m and equal damping ratios ξ=0.05. Let $u_1(t)$ and $u_2(t)$ are independent responses of Building 1 and Building 2. The governing differential equation of motion for SDOF system is expressed as follows:

$$m_i\ddot{u}_i(t)+c_i\dot{u}_i(t)+k_iu_i(t)=-m_i\ddot{u}_g(t) \tag{4.1}$$

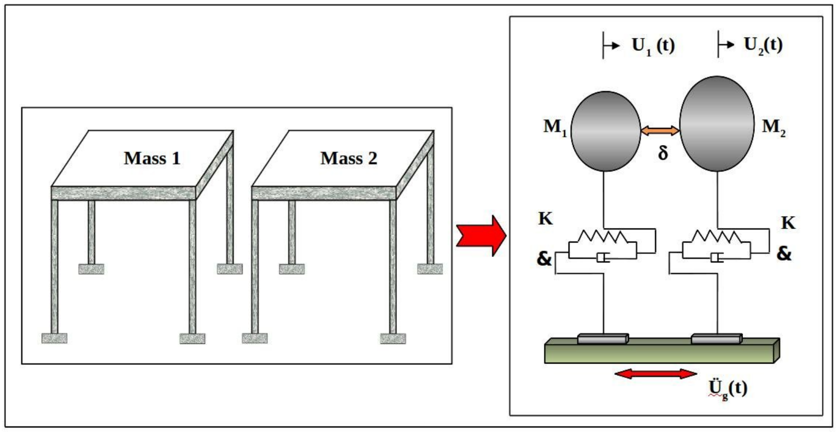
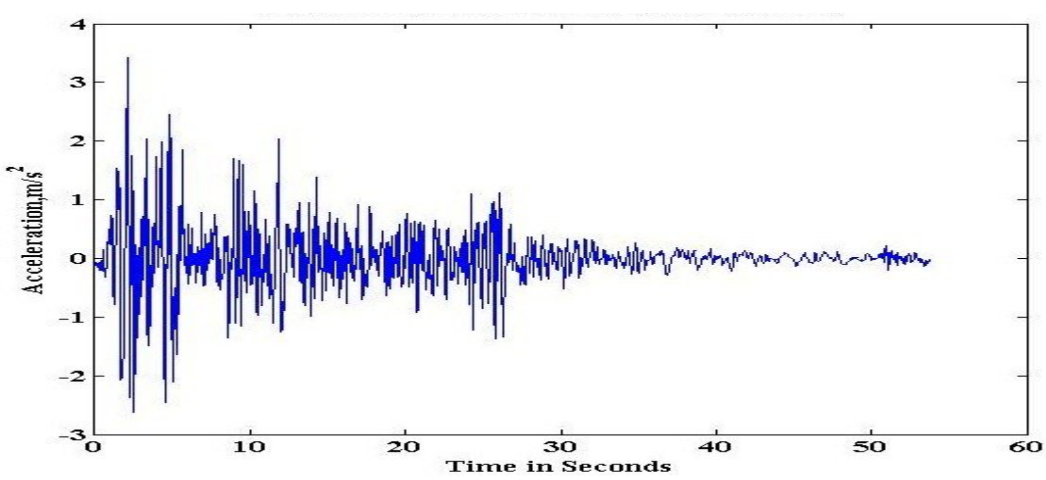


Figure 4.1. Modeling of pounding between two adjacent structures

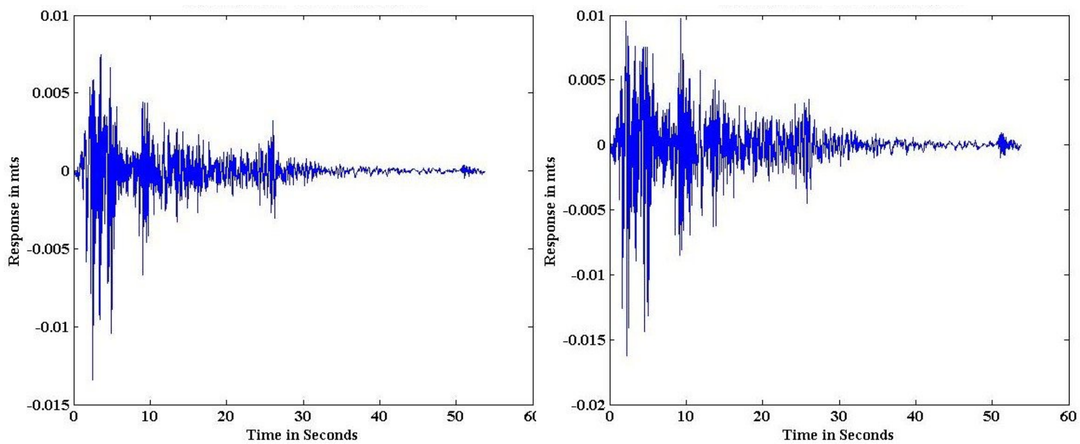
Where, 'i' denotes the building under consideration. For the purpose of studying the collision between the buildings, SE component of El-Centro ground motion (see Figure 4.2 (a)) whose PGA is 0.348 g is considered. Also for finding the response of building to earthquake ground motion, Newmark's approach is used. Typical response of building to El-Centro ground motion is shown in Figure 4.2 (b) & (c). Now if another building (say Building 2) is placed adjacent to Building 1, minimum distance between the buildings can be checked by the following condition:

$$u_1(t)-u_2(t)\geq\delta \tag{4.2}$$

If the above condition satisfies then collision occurs. For the purpose of finding the minimum gap between two buildings, different time periods for Building 2 i.e., 0.075, 0.10, 0.125, 0.15, 0.175, 0.20, 0.225 and 0.25 sec are considered. The peak of relative response of adjacent buildings gives the minimum separation distance between them. The minimum separation distance between two adjacent structures is as shown in Figure 4.3.



(a)



(b) (c)

Figure 4.2. Elcentro ground motion and response (a) Elcentro earthquake ground motion, (b) Response of structure to El-centro ground motion (T=0.075 sec, ξ=0.05) (c) Response of structure to El-centro ground motion (T=0.10 sec, ξ=0.05)

From this figure it can be observed that as the time period of the structure increases minimum distance is increases. And for the two structures with same natural period, there is no need to provide any separation distance because these buildings will vibrate in phase and does not collide at any point of time. However, this situation is not realistic because it is very difficult to construct two structures with same natural period. Also, it can be observed from the figure that the minimum separation distance is getting saturated when natural period of building 2 is increasing say beyond 1 sec. To study this case, nonlinear analysis is necessary. As most of the code provisions are based on linear analysis, and hence linear analysis is used in this study.

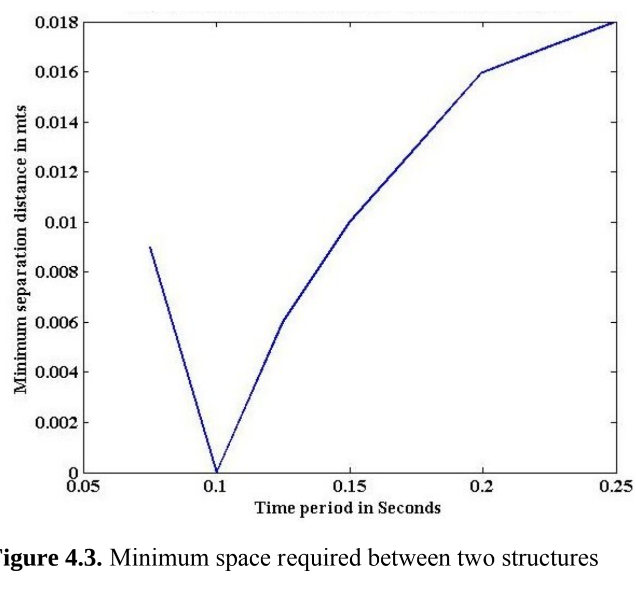


Figure 4.3. Minimum space required between two structures

5. CASE STUDY

Impact force is evaluated between two buildings by providing minimum separation distance between buildings as per the code recommendations. For this purpose, Building 1 with time period 0.1 sec natural period and natural period of Building 2 i.e, 0.075, 0.1, 0.15, 0.2 sec are considered. Five earthquake records, viz., Loma-Prieta earthquake, Elcentro earthquake, Parkfield earthquake, Petrolia earthquake and Northridge earthquake were selected. Characteristics of the selected ground motions are given in Table 5.1.

Table 5.1. Details of ground motion data

S.No	Earthquake Name	Location	Year	M_w	PGA, (g)	Trifunac Duration (sec)	Predominant Time Period Range, sec	Energy, ergs
1	Lomaprieta	Lomaprieta, California, USA	1989	6.9	0.220	9.58	0.41-1.61	1.41×10^{22}
2	Elcentro	Imperial Valley, California, USA	1940	7.1	0.348	24.44	0.45-0.87	2.81×10^{22}
3	Parkfield	Parkfield, California, USA	1966	6.0	0.430	6.76	0.30-1.20	6.31×10^{20}
4	Petrolia	Cape Mendocino, California, USA	1992	7.2	0.662	48.74	0.50-0.83	4.00×10^{22}
5	Northridge	Northridge, California, USA	1994	6.7	0.883	8.94	0.20-2.20	7.08×10^{21}

When both the buildings are subjected to ground motion, collision may take place and during collision usually energy transfer from one building to another building is a natural phenomenon. Due to this energy transfer, both the structures behave differently due to either loss of energy or gaining energy. There are different impact models available for calculation of impact. For example linear spring model, Kelvin model (Susender Muthukumar et.al., 2004) are linear models. Hertz model and hertz damp model are nonlinear models. In linear spring model, energy loss during impact is not considered for calculating the impact force. The contact force during impact is taken as,

$$\begin{aligned} F_c &= k_k(u_1 - u_2 - \delta); && u_1 - u_2 - \delta \geq 0 \\ &= 0; && u_1 - u_2 - \delta < 0 \end{aligned} \tag{5.1}$$

Kelvin approach takes into account damping also. The calculation of collision force according to Kelvin model is as follows,

$$\begin{aligned} F_c &= k_k(u_1 - u_2 - \delta) + c_k(\dot{u}_1 - \dot{u}_2); && u_1 - u_2 - \delta \geq 0 \\ &= 0; && u_1 - u_2 - \delta < 0 \end{aligned} \tag{5.2}$$

The damping co-efficient c_k can be related to the coefficient restitution e by equating energy loss during impact.

$$c_k = 2\xi\sqrt{k_k\left(\frac{m_1 m_2}{m_1 + m_2}\right)};\ \xi = -\frac{\ln e}{\sqrt{\pi^2 + (\ln e)^2}} \tag{5.3}$$

In this study, Kelvin model is used. For the calculation of impact force between two structures stiffness of the spring, k_k is assumed as 4378 MN/m (Ref. Susender et al.). The co-efficient of restitution, e = 0.6 is assumed and it is defined as the ratio of the relative velocities of the bodies after collision to the relative velocities of the bodies before collision.

6. RESULTS & DISCUSSIONS

In this study structures having natural period range from 0.075 sec to 0.2 sec with an interval of 0.025 sec are taken. Structure having natural period 0.1 sec is kept constant and other building period is kept varying and the minimum separation distances are calculated from above code provisions (see table 6.1). As the structure's natural period increases, the response of the structure also increases for a given ground motion and damping. The structures are subjected to Lomaprieta ground motion. The predominant frequencies range present in the ground motion is 0.41-1.61 sec, which is far away from the fundamental period of the structures. All ground motion records which are considered in this analysis are shown from figure 6.1 (a) to (d).

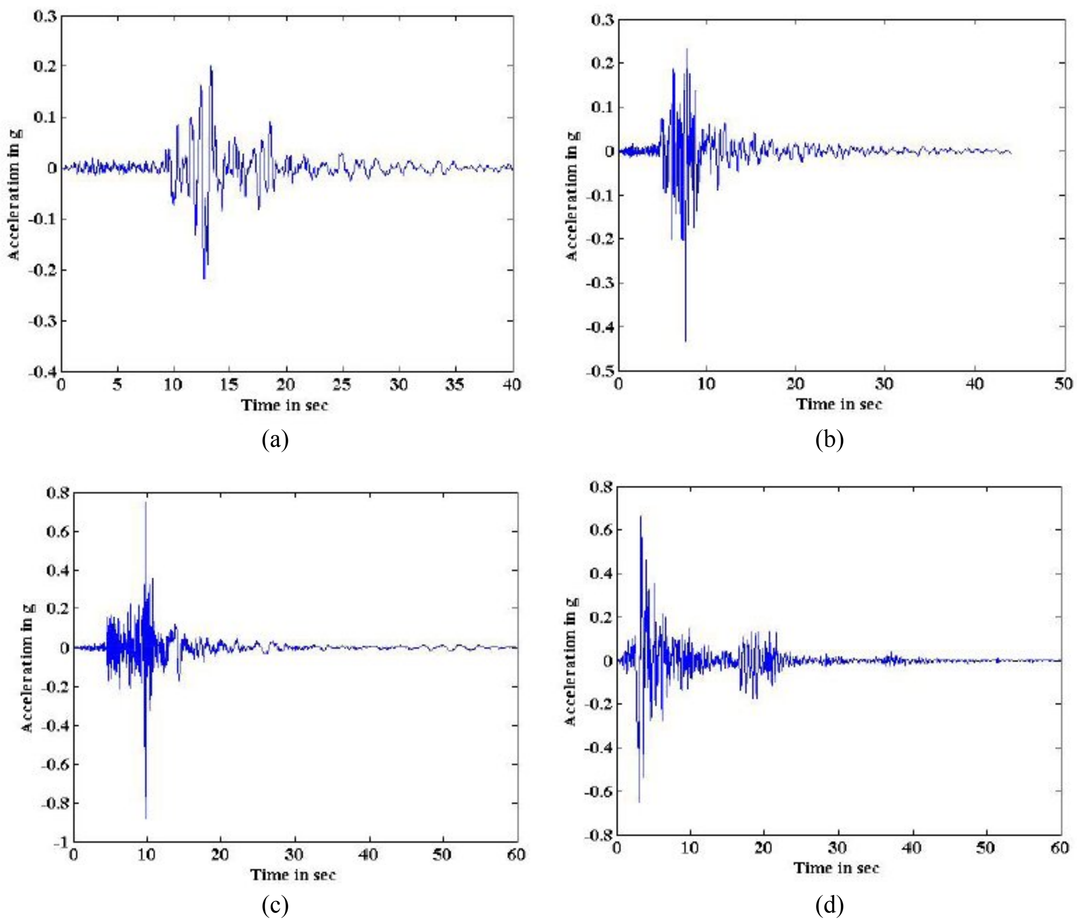


Figure 6.1. Ground motions considered in this analysis (a) Lomaprieta, (b) Parkfield (c) Petrolia and (d) Northridge

As per code provisions, the separation distances are kept between the structures and initial impact forces are calculated using Kelvin model approach (see table 6.2). According to UBC-1997, ASCE and IBC, the initial collision force generated between T_1 and T_2=0.075 s is 137 kN when structures subjected to Lomaprieta ground motion. Because the separation distance is very less compared to all other codal provisions. The summary of impact forces for all structures and codes are listed in table 4. For structures T_1=0.1 s and T_2=0.15 s, the impact force is 800 kN as per ASCE and IBC codal provisions.

The impact force between the buildings (T_1=0.10 and T_2=0.075 s) is 389 kN as per IS:1893-2002(see table 6.3) when subjected to Elcentro ground motion (Refer fig 4.2(a)). For other buildings (T_2=0.1, 0.15 0.2 s) the impact force is zero. For the structures having same time period, no need to provide minimum space between them. Because the response for both structures is same. The impact force for structures having time period 0.1 and 0.075 s is 26.57 kN according to UBC-1997 even though the separation distance is less. The amount of impact depends on response of the structures at particular time, minimum space between the structures and velocity of the structures. In case of UBC-1997, the velocity of structures (0.1 and 0.075 s) is less compared to IS:1893-2002 code during impact. As the minimum space between structures decreases the amount of impact increases, but this impact occurs at the same time even the separation distance decreases. The separation distance and impact forces are same as per ASCE:07-2010 and IBC-2009. For structures having period of 0.1 and 0.15 s, the impact force is 1170 kN as per UBC-1997. But for the same structures (0.1 and 0.15 s), the impact force is 6052 kN as per ASCE:07-2010 and IBC-2009. Here the separation distance decreases from 0.002 m to 0.001 m and the impact occurs at the same time. For structures T_1=0.10 and T_2=0.2 s, the impact forces are 460 and 5762 kN as per UBC and ASCE/IBC respectively. In this case the impact force reduces as the separation distance increases. Because the impact occurs at the same time.

Now the structures are subjected to Parkfield ground motion. As per IS:1893-2002, the impact force between structures T_1=0.1 s & T_2=0.075 s is 150 kN(see table 6.4). But the impact force is 248 kN as per UBC and ASCE/IBC. Here the impact occurs at the same time. For structures having same period no need to provide separation distance. For structures having periods T_1=0.1 and T_2=0.15 s, the impact force is 2442 kN as per UBC-1997. But as per ASCE/IBC, the impact force is less even though the separation distance is less. It means the impact has not occurred at the same time. This is also happened with structure having period T_2=0.2 s. Even though the ground motion is same, the impact occur at same time for structure 0.075 s and not occurred at the same time for structures 0.15 and 0.2 s. It is clearly showed that the impact is dependent on velocity of structure also. The structure is not effected by its amplitude of ground motion. It is effected by frequency of ground motion.

Now the structures are subjected to Petrolia ground motion. For structures 0.10 s and 0.075 s, the initial impact force is 326 kN as per IS:1893-2002 (see table 6.5). The impact force between the same structures is 72 kN as per UBC and ASCE/IBC even though the separation distance decreases from 0.0005 m to 0.0001 m. It means that the impact forces are not occurred at the same time. For structures having same period, no need to provide separation distance. The impact force between structures 0.1 s and 0.15 s is 2032 kN as per IS:1893-2002. But the impact values are less as per UBC and ASCE/IBC even though the separation distances are small. Here, the impact values are initially increases and then decreases. For structures 0.1 s and 0.2 s, the impact values are 911 kN and 3466 kN as per UBC and ASCE/IBC respectively. Here, the amount of impact decreases as the separation distance increases.

Now the structures are subjected to Northridge ground motion. The structure having period 0.2 s is matched with ground motion frequency. At predominant frequencies, the response of structure will be more and may lead to high impact force. This effect can be clearly seen in the table 6.6 for structures T_1=0.10 s and T_2=0.20 s. The impact force initially increases and then decreases with increase of separation distance. With the same separation distance between two structures, the initial impact force will be same in both linear and nonlinear analysis before yield starts. The impact values between structures having period 0.1 s and 0.2 s, are 20878 kN, 88 kN, 10700 kN and 245 kN as per IS:1893-2002, UBC-1997, NBC-PERU and ASCE/IBC respectively. From the comparison of all codal provisions, FEMA:273-1997 and NBC-PERU codes have no collisions in all the ground motions (except Northridge ground motion). The calculated separation distances are high for these (FEMA and NBC-PERU) code provisions. Also the clauses in the codes on pounding are based on height of the structure only.

Table 6.1. Minimum gap required between adjacent structures having time period T_1 and T_2 with respect to different codal provisions

S.No	Code	T_1=0.10 sec			
		T_2=0.075 sec	T_2=0.10 sec	T_2=0.15 sec	T_2=0.20 sec
		Gap(m)	Gap(m)	Gap(m)	Gap(m)
1	IS:1893-2002	0.0005	0.001	0.004	0.01

2	UBC-1997	0.0001	0.0004	0.002	0.004
3	FEMA:273-1997	0.120	0.120	0.120	0.120
4	NBC-Peru:E030-2003	0.022	0.022	0.022	0.022
5	ASCE:07-2010 and IBC-2009	0.0001	0.0003	0.001	0.003

Table 6.2. Initial impact forces when structures subjected to Lomaprieta ground motion

S.No	Code	T_1=0.10 sec			
		T_2=0.075 sec	T_2=0.10 sec	T_2=0.15 sec	T_2=0.20 sec
		Force(kN)	Force(kN)	Force(kN)	Force(kN)
1	IS:1893-2002	0	0	0	0
2	UBC-1997	137	0	0	0
3	FEMA:273-1997	0	0	0	0
4	NBC-Peru:E030-2003	0	0	0	0
5	ASCE:07-2010 and IBC-2009	137	0	800	0

Table 6.3. Initial impact forces when structures subjected to Elcentro ground motion

S.No	Code	T_1=0.10 sec			
		T_2=0.075 sec	T_2=0.10 sec	T_2=0.15 sec	T_2=0.20 sec
		Force(kN)	Force(kN)	Force(kN)	Force(kN)
1	IS:1893-2002	389	0	0	0
2	UBC-1997	26.57	0	1170	460
3	FEMA:273-1997	0	0	0	0
4	NBC-Peru:E030-2003	0	0	0	0
5	ASCE:07-2010 and IBC-2009	26.57	0	6052	5762

Table 6.4. Initial impact forces when structures subjected to Parkfield ground motion

S.No	Code	T_1=0.10 sec			
		T_2=0.075 sec	T_2=0.10 sec	T_2=0.15 sec	T_2=0.20 sec
		Force(kN)	Force(kN)	Force(kN)	Force(kN)
1	IS:1893-2002	150	0	0	0
2	UBC-1997	248	0	2442	3757
3	FEMA:273-1997	0	0	0	0
4	NBC-Peru:E030-2003	0	0	0	0
5	ASCE:07-2010 and IBC-2009	248	0	412	2236

Table 6.5. Initial impact forces when structures subjected to Petrolia ground motion

S.No	Code	T_1=0.10 sec			
		T_2=0.075 sec	T_2=0.10 sec	T_2=0.15 sec	T_2=0.20 sec
		Force(kN)	Force(kN)	Force(kN)	Force(kN)
1	IS:1893-2002	326	0	2032	0
2	UBC-1997	72	0	598	911
3	FEMA:273-1997	0	0	0	0
4	NBC-Peru:E030-2003	0	0	0	0
5	ASCE:07-2010 and IBC-2009	72	0	1582	3466

Table 6.6. Initial impact forces when structures subjected to Northridge ground motion

S.No	Code	T_1=0.10 sec			
		T_2=0.075 sec	T_2=0.10 sec	T_2=0.15 sec	T_2=0.20 sec
		Force(kN)	Force(kN)	Force(kN)	Force(kN)
1	IS:1893-2002	1130	0	348	20878
2	UBC-1997	51	0	2204	88
3	FEMA:273-1997	0	0	0	0
4	NBC-Peru:E030-2003	0	0	0	10700

5	ASCE:07-2010 and IBC-2009	51	0	1505	245

7. CONCLUSIONS

From the above observations, the duration of strong motion increases with an increase of magnitude of ground motion. The conclusions are drawn from this study are as follows:

- In general when the separation distance between the two structures decreases, the amount of impact is increases, which is not in all cases.
- At predominant frequencies, the response of the structure is more and may lead to collapse of the whole structure. In this case, structure having period of 0.2 s is matched with the frequency of ground motion. The amount of impact is also high when subjected to Northridge ground motion.
- Among all the codal provisions, the calculated separation distance is high for FEMA: 273-1997 and NBC PeruE030-2003. Because the clauses for these codes depends on height of the structure.
- For structures having same period, no need to provide separation distance. The amount of impact depends on response of the structures at particular time, minimum space between the structures and velocity of the structures.

REFERENCES

J. Aguilar, H. Juárez, R. Ortega, and J. Iglesias (1989), The Mexico Earthquake of September 19, 1985—Statistics of Damage and of Retrofitting Techniques in Reinforced Concrete Buildings Affected by the 1985 Earthquake, *Earthquake Spectra,* **Vol. 5: Issue 1,** pp. 145-151.

Kazuhiko kasai and B.F Maison (1997), Building pounding damage during the 1989 Lomaprieta earthquake, *Engineering Structures,* **Vol. 19: No. 3,** pp. 195-207.

Jeng-Hsiang Lin and Cheng Chiang Weng (2002), A study on seismic pounding probability of buildings in Taipei metropolitan area, *Journal of the Chinese Institute of Engineers,* **Vol. 25: No. 2,** pp. 123-135.

Durgesh C Rai and C V R Murthy (2005), Engineering lessons not learnt from 2002 Diglipur earthquake-A review after 2004 sumatra earthquake, *Current Science,* **Vol. 89: No. 10,** pp. 1681-1689.

Hemant B Kaushik, Kastubh Dasgupta, Dipti R Sahoo and Gayatri Kharel (2006), Performance of structures during the Sikkim earthquake of 14 feb.06, *Current Science,* **Vol. 91: No. 4,** pp. 449-455.

Stavros A. Anagnostopoulos (1988), Pounding of buildings in series during earthquakes, *Earthquake Engineering and Structural Dynamics,* **Vol. 16,** pp. 443-456.

Bruce F. Maison and Kazuhiko Kasai (1992), Dynamics of pounding when two buildings collide, *Earthquake Engineering and Structural Dynamics,* **Vol. 21: Issue 9,** pp. 771-786.

Van Jeng, Kazuhiko Kasai and Bruce F. Maison (1992), A Spectral Difference Method to Estimate Building Separations to Avoid Pounding, *Earthquake Spectra,* **Vol. 8: Issue 2,** pp. 201-223.

Andre Filiatrault and Pierre Wagner (1995), Analytical prediction of experimental building pounding, *Earthquake Engineering and Structural Dynamics,* **Vol. 24: Issue 8,** pp. 1131-1154.

______*International Building Code,* IBC-2003, International Code Council. INC.

______ *Indian standard criteria for earthquake resistant design of structures, part-1 general provisions and buildings,* IS:1893-2002, Bureau of Indian standards, New Delhi.

______ Federal Emergency Management Agency (FEMA), *NEHRP Guidelines for the seismic rehabilitation of buildings*, FEMA:273-1997, Washington D.C., USA.

______*Uniform Building Code*, UBC-1997, Volume-2, Structural Engineering Design Provisions, International Conference of Building Officials, California.

______*National Building Code- PERU*, Technical Standard of Building E.030, Earthquake Resistant Design.

______*American Society of Civil Engineers for Minimum Design Loads for Buildings and Other Structures*, ASCE/SEI 7-05, USA

Susender Muthukumar and Reginald Desroches (2004), Evaluation of impact models for seismic pounding, *Proceedings of Thirteenth World Conference on Earthquake Engineering,* paper No.235.