Separation distance between two adjacent buildings a case study (Clause 7.11.3, Is 1893:2016)

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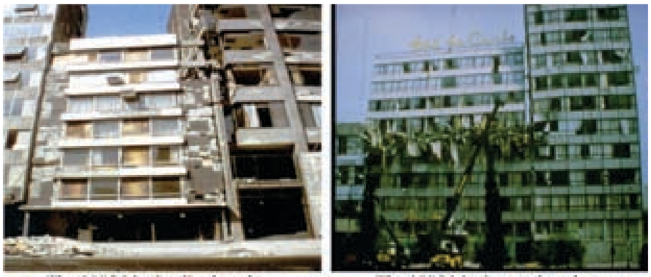
Abstract

Construction of buildings without keeping enough setback from plot boundary is very common practise in India. This lead to very closely spaced buildings with practically zero or few *mm* gap between them. The intension behind this is to utilize the maximum plot area, without knowing the consequences of damage due to pounding during moderate-to-severe earthquake shaking. In this study, an attempt is made to check the adequacy of separation distance clause of IS 1893:2016 and also a comparison is made with similar clauses in international codes of practise. For this purpose, four low to mid-rise RC buildings located in seismic zone IV were designed as per IS 456:2000 and IS 1893:2016. These buildings are assumed to be closely spaced with each other, in pair of two, for four different cases. Further, the linear and non-linear time history analysis (NLTHA) were carried out by considering ground motion time histories of three moderate earthquakes recorded in India. From the study, it was found that the separation distance clauses prescribed in IS 1893-2016 are on conservative side.

Keywords: Pounding, Separation joint, Seismic joint, adjacent buildings, seismic design

1. Introduction

Due to increase in cost of land, many masonry and reinforced concrete buildings are constructed close to each other. In the absence of sufficient gap, such structure comes in contact with each other during earthquake shaking. This phenomenon of colliding of buildings during the earthquakes is known as pounding. This colliding effect will cause architectural, structural or non-structural damage to the structure. The structural damage could be as low as damage of few members locally in moderate shaking to as high as total collapse of structure during severe shaking (Figure 1). Knowingly or unknowingly construction of closely spaced buildings are still in practise in many parts of India including Bhuj, Gujarat (Figure 2).



The 1985 Mexico Earthquake (Anagnostopoulos 1988) | The 1985 Mexico earthquake (Johnmartin 2018, NCEI 2018)

Figure 1: Damage in building due to pounding

(a) (b)

Figure 2: Closely spaced RC buildings in Bhuj City, Gujarat (a) Low-rise buildings (b) Medium-rise building

Damage to the buildings due to pounding can be avoided by a) providing sufficient gap between two buildings; b) Linking two buildings so that the transfer of force from one building to the other is possible during earthquake oscillation; c) the design of buildings and it's elements to resist the additional force due to pounding. Providing enough gap between structure to avoid pounding is the easiest solution for new buildings, and is also recommended by IS 1893:2016. The clause 7.11.3 of this standard clearly states that the *"Two adjacent buildings, or two adjacent units of the same building with separation joint between them, shall be separated by a distance equal to R times sum of storey displacements* Δ_1 *and* Δ_2 *(calculated as per 7.11.1) of the two buildings or two units of the same building, to avoid pounding as the two buildings or two units of the same building oscillate towards each other."* This can be written as equation (1).

$$\text{Separation Gap} = R(\Delta_1 + \Delta_2) \quad (1)$$

The code further states that *"When floor levels of the adjacent units of a building or buildings are at the same level, the separation distance shall be calculated as* $(R_1\Delta_1 + R_2\Delta_2)$*, where* R_1 *and* Δ_1 *correspond to building 1, and* R_2 *and* Δ_2 *to building 2."* Which can be shown as Figure 3 and written as equation (2). The earlier version of IS 1893:2002 use to have equation (3).

$$\text{Separation Gap} = R_1\Delta_1 + R_2\Delta_2 \text{ [IS 1893:2016]} \quad (2)$$

$$\text{Separation Gap} = R/2\,(\Delta_1 + \Delta_2) \text{ [IS 1893:2002]} \quad (3)$$

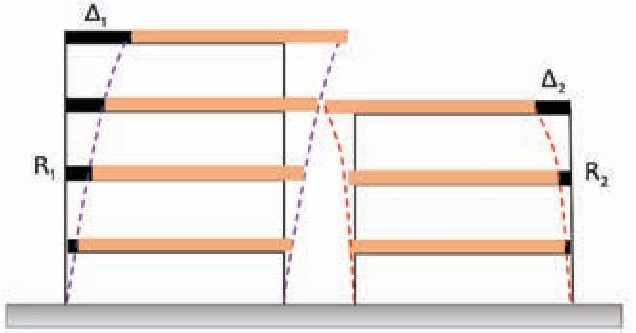


Figure 3: Separation distance between two building

When compared to previous version, i.e., equation (3), current version, i.e., equation (2), separation distance is double. Hence, the motivation of current study is to check the adequacy of clause given in IS 1893:2016 and IS 1893:2002 about the separation distance between adjacent buildings, or two adjacent units of the same building.

2. CODAL PROVISION

The region with active seismicity acknowledges the adverse effect of building pounding during earthquake shaking. This can be clearly observed by looking at the guidelines given in the seismic code of all such countries. However, the provision laid by all such earthquake resistance design code books or less formal regulatory guides, vary from country to country. All such codes specify a minimum separation gap to be left between two structures to avoid the damage due to pounding. The minimum separation gap required to be left between two buildings are computed based on anticipated inelastic displacement of structure at the level of pounding.

By and large these formulae can be categorised into four forms of expression viz. absolute sum (ABS), square root of sum of the square (SRSS), fixed distance and separation distance corelated with height. Most of these formulae are found to be following a common approach of computing the inelastic deformation first and later to use SRMM or ABS method to arrive at separation distance. For example, Australia [AS 1170.4:2007], Canada [NBCC 2015], Chile [NCh 433.0f96], India [IS 1893:2016], and New Zealand [NZS 1170.5:2004] code book uses the absolute sum method whereas Eurocode [EN 1998-1 :2004 (E)] and USA[ASCE 7-10] formulae are based on SRSS method.

All of them recommends to compute the elastic deformation based on seismic load demand specified in the respective code books.

In addition, Chilean code also specifies to maintain the minimum fixed distance of 1.5 cm irrespective of type of structure and computed separation distance. On similar lines, in the absence of exact details of building, Eurocode allows designer to compute the deformation by multiplying some constant factor with the height, of possible pounding location from grade level. Australian [AS 1170.4:2007], and New Zealand [NZS 1170.5:2004] codes do not specify any specific amplification factor to be multiplied with elastic deformation. Whereas, Canada [NBCC 2015], Chile [NCh 433.0f96], and India [IS 1893:2016] uses Reponses reduction factor *'R'* for the computation of inelastic deformation. In USA, ASCE 7-10 is very particular about pounding effect and found to incorporate torsional displacement along with translation displacement. On the other hand, Eurocode [EN 1998-1 :2004 (E)] allows the designer to reduce the separation distance by 30% if both buildings are at the same elevation. Whereas, FEMA 356 exempts designer to keep minimum separation distance provided the structure is designed to withstand the additional load due to pounding. All these formulae are summarized in Table 1.

Table 1: List of codal provisions on pounding

Country	Provision	Remark
Australia (Clause 5.4.5, AS 1170.4:2007)	$S_i = \Delta_{i1} + \Delta_{i2}$	• Structure over 15 m shall be separated from adjacent structures or set back from a building boundary by a distance sufficient to avoid damaging contact. • This Clause is deemed to be satisfied if the primary seismic force-resisting elements are structural walls that extend to the base, or the setback from a boundary is more than 1% of the structure height.
Canada (Clause 4.1.9.2, NBCC 2015)	$S_i = \Delta_{i1} + \Delta_{i2}$	Δ_{ij} = Lateral deflection obtained from an elastic analysis using the loads give in code and incorporating the effects of torsion shall be multiplied by *R*
Chile (Clause 5.10, NCh 433.0f96[3rd Edition 2012])	$S_i = \Delta_{i1} + \Delta_{i2}$	Where, Δ_{ij} is maximum of following $\Delta_{ij} = \left\{ \begin{array}{c} \frac{2R_1}{3} \times \Delta_i \\ 0.002h_i \\ 1.5\text{ cm} \end{array} \right\}_{\textit{maximum of}}$ *R* = Response reduction factor D_i= Displacement at level '*i*' h_i= Height up to level '*i*'
Europe Union (Clause 4.4.2.7, EN 1998-1 :2004 (E))	$S_i = \sqrt{(\Delta_{i1})^2 + (\Delta_{i2})^2}$	Δ_{ij}= Elastic displacement due to design seismic action computed as per code (equation 4.23) *Note: For unit or buildings with same elevation s_i will be reduce by factor 0.7.*

Country	Provision	Remark
New Zealand (Clause 7.4.1.2, NZS 1170.5:2004)	$S_i = \Delta_{i1} + \Delta_{i2}$	The design horizontal deflection of the structure shall be such that, when combined with the design horizontal deflection of any adjacent structure at the same height, contact does not occur.
USA (Clause 12.12.3, ASCE 7-10)	$\delta_{MT} = \sqrt{(\delta_{M1})^2 + (\delta_{M2})^2}$	$$\delta_M = \frac{C_d \delta max}{I_e}$$ C_d = Deflection Amplification factor δ_{max}= Maximum elastic displacement at critical location I_e= Importance factor
USA (Clause 2.6.10.1, FEMA 356)	$S_i = \sqrt{(\Delta_{i1})^2 + (\Delta_{i2})^2}$	Δ_{i1}= Lateral deflection of the building under consideration, at level *i*, relative to the ground, calculated in accordance with the provisions of this standard for the selected hazard level. Δ_{i2}= Lateral deflection of the building under consideration, at level *i*, relative to the ground, calculated in accordance with the provisions of this standard or other approved approximate procedure. Alternatively, it shall be permitted to assume $\Delta_{i2}=0.03h_i$ for any structure in lieu of a more detailed analysis, where h_i is the height of level *i* above grade. The value of s_i need not exceed 0.04 times the height of the level under consideration above grade at the location of potential impact. Buildings rehabilitated using an approved analysis procedure that account for the change in dynamic response of the structure due to impact need not meet the minimum separation distance specified. Such analysis shall demonstrate that: a. The structure are capable of transferring forces resulting from impact when diaphragms are located at the same elevation; or b. The structure are capable of resisting all required vertical and lateral forces considering the loss of any elements or components damaged by impact of the structures.

3. CASE STUDY

In order to check the adequacy of separation distance recommended by IS 1893:2016, following linear and non-linear time history case study was conducted. Study consists of designing the RC building as per IS 456:2000 and IS 1893:2016 for office use. All the buildings considered in this study are of a regular plan with no infill wall and have cladding along periphery. The buildings were modelled without slab using a commercial software. The self-weight of slab (125mm thick), floor finish and appropriate imposed load were given as UDL on beams by using yield line theory. Reduced moment inertia for beams and columns were used as recommend by clause 6.4.3.1 of IS 1893:2016. The details of material and loading is given in Table 2.

Table 2: Material and Loading details

Basic material:	Load property:	Seismic Load Details:
• Slab and Beams: M30 • Columns: M40 • Steel: HYSD415	• Imposed Load (Typical floor): 4 kN/m^2 • Imposed Load (Roof): 1.5 kN/m^2 • Floor Finish (Typical Floor): 1 kN/m^2 • Floor Finish (Roof): 1.5 kN/m^2 • Cladding: 2 kN/m^2 • Parapet wall: 4.6 kN/m	• Seismic Zone: IV (0.24g) • Importance factor: 1.2 • Response Reduction factor: 5 • Soil Type: Medium (Type II)

Once buildings were designed the linear and non-linear time history analysis was conducted. The three major satisfy the design code requirement.

b. Types of case studies

Table 3: List of Earthquakes considered

Sr No.	*Date*	*Time (UTC)*	*Lat*	*Long*	*Depth (km)*	*Magnitude*	*Region*
1	January 26, 2001	03:16:40	23.420	70.230	16	M_b 7.0	Bhuj/Kachchh
2	March 28, 1999	19:05:11	30.512	79.403	15	M_b 6.6	Chamoli
3	October 19, 1991	21:23:15	30.780	78.774	10	M_s 7.0	Uttarkashi

Table 4: Details of Acceleration Ground motion time history used in study

Sr No.	*Ground Motion Name*	*Earthquake Name*	*Ground Motion Duration (sec)*	*Recording Station*	*Component*	*Lat & Long*
1.	Bhuj	Bhuj Earthquake	133.53	Ahmedabad	N78E	23.02 N, 72.38 E
2.	Chamoli_L	Chamoli (NW Himalaya) Earthquake	024.32	Gopeshwar	N70W	30.24 N, 79.20 E
3.	Chamoli_T				N20E	
4.	Uttarkashi_L	Uttarkashi Earthquake	036.14	Bhatwari	N85E	30.48 N, 78.36 E
5.	Uttarkashi_T				N05W	

Four typical case were considered in order to evaluate the minimum distance required for avoiding pounding. The four buildings designed above are paired in a such a way that to get cases such as Case I: Identical building located close to each other, Case II: Buildings with equal overall height but different width, Case III: Buildings with different height and width; Case IV: Buildings having

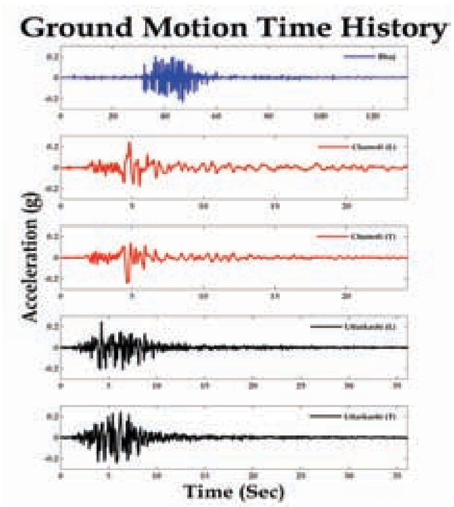
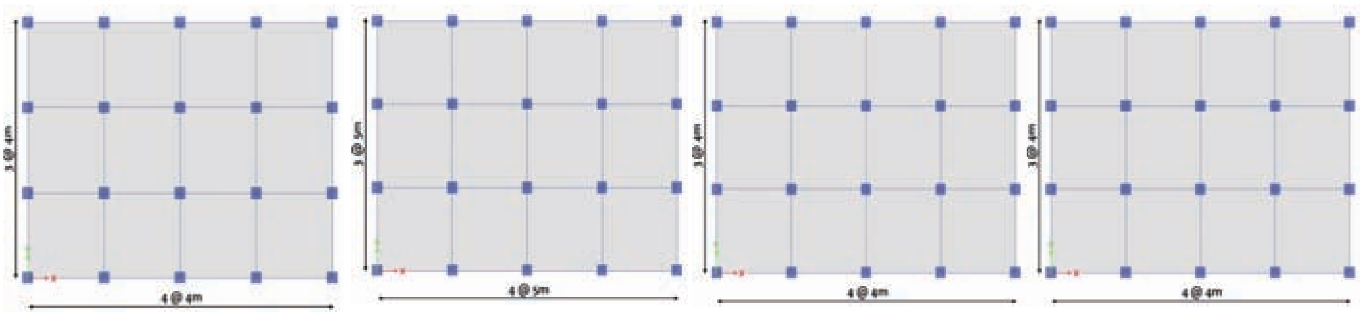


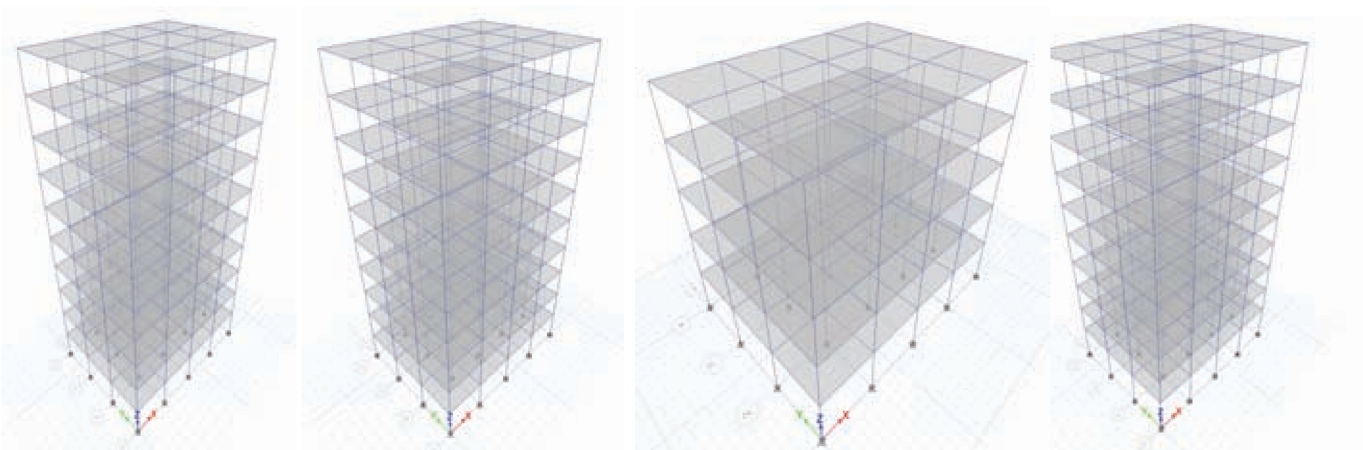
Figure 4: Ground motions considered in analysis

Table 5: Buildings geometry

Particular	Building A	Building B	Building C	Building D
Total Storey	(G+9)	(G+9)	(G+4)	(G+9)
Building size	X=4 @ 4m=16m Y=3 @ 4m=12m	X=4 @ 5m=20m Y=3 @ 5m=15m	X=4 @ 4m=16m Y=3 @ 4m=12m	X=4 @ 4m=16m Y=3 @ 4m=12m
Height Details	Ground Storey: 3m Typical: 3m Total Height: 30m	Ground Storey: 3m Typical: 3m Total Height: 30m	Ground Storey: 3m Typical: 3m Total Height: 15m	Ground Storey: 3m Typical: 3.5m Total Height: 30.5m



Plan Plan Plan Plan



Elevation Elevation Elevation Elevation

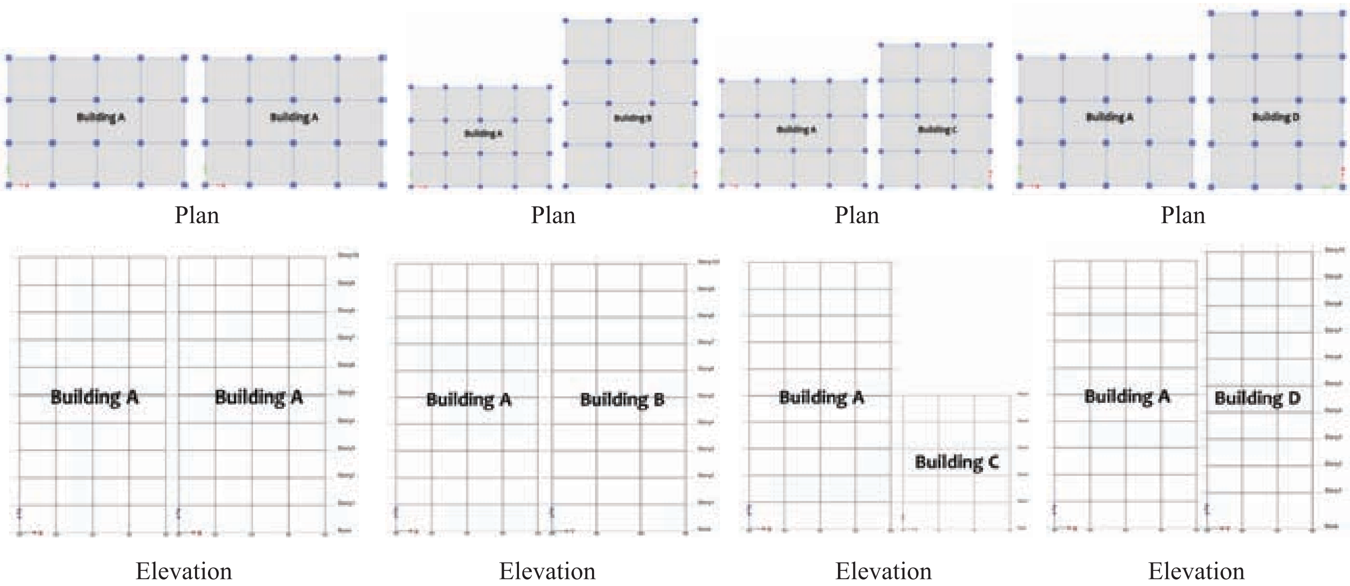
(a) **Building A** (b) **Building B** (c) **Building C** (d) **Building D**

Figure 5: Different types of buildings modelled in the current work

equal typical floor height but having difference in ground storey height. Pictorial representation of all four cases is given inFigure 6.

4. Results And Discussion

In all four cases, the separation distance required by the current and previous versions were computed. The Δ values for all four buildings, computed as per clause 7.11.1 of IS 1893:2016 is tabulated in Table 6. Further, the linear and non-linear time history displacement for all four cases were extracted. Now, to compare the NLTHA results with IS code provision the difference in displacement for each time step of displacement time history was computed. The



(a) Case I (b) Case II (c) Case III (d) Case IV

Figure 6: Case studies considered in the current work

maximum difference in displacement between any two building of respective case for all five-ground motion are tabulated in Table 7. The same table has value of separation distance as recommended by current and earlier seismic code of country.

It is obvious that a distance required for NLTHA Case I will be zero since both the buildings are of identical nature and hence for any given ground motion they never go out of phase. This justifies the reduction in minimum separation distance for identical buildings imposed by many codes. However, such condition may not exist since the identical building might rest on soil of different property which will change its behaviour during earthquake shaking. Or In spite of having identical dimensions the error in execution of building or alteration in functional use by an owner leads to changes in overall stiffness or mass distribution in building there by change in oscillation. Among all ground motions, only Bhuj earthquake was found to be giving a minimum separation distance for all 3 cases (Case II to Case IV). Such reduced value indicates that for Bhuj earthquake, recorded at Ahmedabad, all buildings are deflecting with very little out of phase from each other. Further, no pattern was observed for rest four ground motion and separation distance from NLTHA is found to be in the range of 42mm to 168mm.

Table 6: Storey Displacements D_i as per Clause 7.11.1, IS 1893:2016

	Building A	Building B	Building C	Building D
Top Floor Elastic Displacement Δ_i(mm)	70.83 & 41.90*	98.72	42.36	87.90

The separation distance recommended by current code for Case II to Case IV was found to be in the range of 2.1 to 6.6 and 3.2 to 6.5 times the value arrived from LTHA and NLTHA, respectively. Whereas, for earlier version it was found to be in the range of 1.1-3.3 and 1.6-3.3 times for LTHA and NLTHA, respectively. This indicates that the current provision on separation distance is conservative enough to safe guard the low-rise and medium-rise buildings against adverse effect of pounding. Study also find that provision from earlier code was just correct. As

Table 7: Separation distance as per IS 1893 and based on Time History Analysis

			Separation Distance (mm)					
	IS 1893		Linear Time History Analysis					
	2002	2016	Bhuj	Chamoli_L	Chamoli_T	Uttarkashi_L	Uttarkashi_T
Case I	354.15	708.30	00.00	000.00	000.00	00.00	000.00
Case II	423.88	847.75	04.99	177.94	110.69	72.76	180.15
Case III	210.65	421.30	12.83	121.93	120.81	91.92	196.57
Case IV	396.83	793.65	03.93	109.36	066.48	49.97	120.65

Table 8: Separation distance as per IS 1893 and based on Time History Analysis

			Separation Distance (mm)				
	IS 1893		Linear Time History Analysis				
	2002	2016	Bhuj	Chamoli_L	Chamoli_T	Uttarkashi_L	Uttarkashi_T
Case I	354.15	708.30	0.00	000.00	00.00	00.00	000.00
Case II	423.88	847.75	4.88	167.94	88.66	61.97	158.77
Case III	210.65	421.30	6.36	121.26	80.22	59.63	130.29
Case IV	396.83	793.65	3.66	122.01	66.43	41.69	103.15

per authors, code committee decision of replacing '*R/2*' with '*R*' is correct and found to be appropriate for given study.

The current study can be extended by choosing more number of ground motion such that dominant periods of buildings is matching with dominant period of ground motion. Further, pairing of more than two buildings located unevenly will also give new insight in this direction.

5. CONCLUSIONS

Following salient conclusions are drawn from the present study:

a) IS code recommended approach in calculation of separation distance is found to be appropriate when compared with an international practice of region with active seismicity.

b) The code recommended value for separation distance was found to be conservative, hence to be safe for all the cases covered in the current paper for major three devasting earthquakes of India.

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