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# Seismic Pounding Effect in Adjacent RC Buildings

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**Abstract**
In metropolitan areas where the cost of land is very high, structures are being built very close to each other. Due to the togetherness of the structures, they often collide with each other when subjected to earthquakes. To mitigate the amount of damage from pounding, the simplest and the most effective way is to provide sufficient separation gap. Generally, most of the existing buildings in seismically moderate regions are built without codal provisions and thus may undergo structural and non–structural damages in the adjacent buildings. Floor to floor pounding and floor to column pounding are the two types of pounding that are seen in buildings between which, the most common type of pounding in fast developing areas is floor to floor pounding. This research deals with finding the minimum seismic gap between adjacent RC buildings having floor levels at the same level i.e. slab are aligned at the same level. For this, 18 buildings are modeled in SAP 2000 v 20 and response spectrum analysis has been carried out. As a whole, a total of 153 building combinations are carried out and appropriate gap values are recommended. All the building models are considered to be special moment resisting frames and the soil type is taken as medium soil.

**Keywords**
Seismic Pounding, Floor to Floor Pounding, Floor to Column Pounding, SAP 2000, Response Spectrum Analysis (RSA)

## 1. Introduction

Nepal lies in subduction zone of Indo – Australian and Asian tectonic plate which makes it a seismically vulnerable region. Such region is prone to moderate to strong ground shaking. The major civil infrastructures are buildings that may get damaged due to earthquake. The rapid increase in population, higher land cost and unplanned urbanization has increased the building construction by adjoining the buildings at property line, which may causes pounding effect during earthquake. Therefore, there is a need of further research and study to lessen the building damage due to pounding effect.

Seismic pounding effect mainly refers to the colliding of two adjacent buildings which are closely spaced such that it causes severe damage upon the acting of earthquake forces. Pounding is the result of irregular response of adjacent buildings of different heights and of different dynamic properties [1]. It is the phenomenon, in which two buildings strike due to their lateral movements induced by lateral forces[2].

In urban regions with dense populated areas, residential and office buildings are often constructed very close to each other with very less or no gap in between. Due to earthquake induced ground motion, these buildings start vibrating out of phase and may collide with each other causing damage to structure.

Earthquake causes sudden ground motion and ground shaking which is transferred from the ground to the superstructure through foundation [3]. Earthquakes can cause pounding when adjacent buildings have little or no gap providing separation. When two adjacent buildings collide, the resulting change in demand loads can lead to catastrophic collapse of one or both buildings. The causes of structural pounding damages are:

- When adjacent buildings have different dynamic properties like mass, height, orientation, geometry, etc., it is almost impossible to construct two buildings with same dynamic properties. If the dynamic properties of two buildings are same, then there will be no pounding even if the gap is zero[2].

- When buildings have sufficient gap but they are connected by one or more members such as bridges[2].
- When separation gap between adjacent buildings is insufficient or zero[1].
- Pounding may also occur because of non-compliance of codal provisions particularly for lateral and torsional stiffness[1].
- If buildings have unsymmetrical or irregular lateral load resisting system in plan. This leads to rotation of the building during earthquake motion, and due to rotation of building pounding effect may occur at adjacent building around periphery [4].

## 2. Research Objective

The aim of this paper is to find the storey displacements of RC buildings that have different dynamic characteristics and calculate minimum seismic gap for various building systems. Building system means there are two adjacent buildings of random number of bay and storey.

Another objective of this study is to find the influence of storey number and bay number on the value of seismic gap.

## 3. Existing Codal Provisions for Seismic Gap

The codal provisions of various countries on pounding are described below.

### Taiwan

The minimum separation gap is considered as the ratio of Absolute Sum (ABS) of maximum inelastic displacements of adjacent buildings[5].

### Australia

Structures over 15 m shall be the separated from adjacent structures or setback from building boundary by a distance sufficient to avoid damage. 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 percent of the structure height[6].

### Canada

Adjacent structures shall be separated by the sum of their individual lateral deflections obtained from an elastic analysis[7].

### Turkey

Minimum seismic gap shall be 30 mm up to 6 m height and from thereon, a minimum of 10 mm shall be added for every 3 m height increment[8].

### Greece

For building which are in contact with each other but there is no possibility for any columns to be rammed, the width of the respective joint, in the absence of more accurate analysis may be determined on the basis of the total number of storeys in contact above the ground as follows[9]:

- 4cm upto and including 3 storeys in contact
- 8 cm from 4-8 storeys in contact
- 10 cm for more than 8 storeys in contact

### Egypt

Parts of the same buildings or buildings on the same side which are not designed to act as an integral unit shall be separated from each other by a distance of at least 2.0 times the sum of the individual components deflection or 0.4 % times its height whichever is larger[10].

### Peru

The minimum distance shall not be less than 2/3 of the sum of the maximum displacements of the adjacent blocks, nor shall it be less than; s=3+0.004(h-500), where s and h are in cm and h is the height measured from the natural terrain level to the storey considered[11].

### Ethiopia

Separation gap shall be 2.0 times the sum of their individual deflections obtained from an elastic analysis[12].

### Serbia

The minimum width of the seismic joint shall be 3.0 cm. It shall be increased by 1.0 cm for every increase

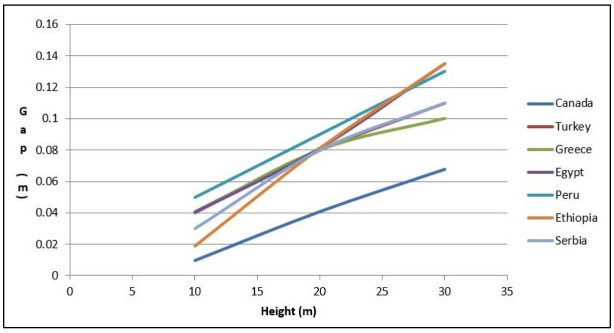


**Figure 1:** Comparison of codal provisions for height-gap relationship

of 3.0 m of height above 5.0 m[13].

### India

Two adjacent buildings, or two adjacent units of the same building with separation joint between them, shall be represented by a distance equal to $R$ times sum of storey displacements ($\Delta 1$ and $\Delta 2$). When floor levels are at the same level, the separation gap shall be calculated as ($R1\Delta 1 + R2\Delta 2$), where $R1$, $\Delta 1$ and $R2$, $\Delta 2$ correspond to buildings 1 and 2[14].

The codal provisions for different countries is shown graphically in Figure 1.

## 4. Methodology

To fulfill the objectives of this research, the following steps have been followed.

1. Three different plans with same material property and section property were chosen whose heights would vary up to two times the width of the building.
2. All together, eighteen buildings were modelled using SAP 2000 v 20 and analysis was carried out using Response Spectrum Method.
3. Deflections at each floor levels of those eighteen buildings were found out after the analysis.
4. Seismic gap for a total of 153 building combinations were calculated based on IS 1893 (part 1):2016, using the values of response reduction factor and storey deflections obtained from the analysis. The 153 building combinations were made from the 18 modelled and analyzed buildings.

## 5. Building Parameters and Material Properties

All the buildings considered for this study are special moment resisting frame surrounded with infill walls. 2, 3 and 4 number of bays are considered and the number of storeys of the building models varies from 1 to 8 storeys depending upon the number of bays. The number of storeys for 2, 3 and 4 bay buildings varies from 1 to 4, 1 to 6 and 1 to 8 respectively. All the building plans are symmetric with bay length of 3.048m. Thus, the overall base dimension of the building varies from 6.09m to 12.2m. The storey height for each storey in all the buildings considered is 3.2m.

All the other properties like material properties, load intensities, size of beam, column and slab for all the building models are same. The building parameters and material properties used for the construction of the models are listed in 1.

**Table 1:** Building Parameters and Material Properties

| | |
|---|---|
| Concrete strength | 25 MPa |
| Modulus of elasticity of concrete | 25000 MPa |
| Poisson's ratio of concrete | 0.2 |
| Unit weight of concrete | 25 kN/m$^3$ |
| Steel tensile yield strength | 500 MPa |
| Modulus of elasticity of steel | 200000 MPa |
| Unit weight of steel | 7850 kg/m$^3$ |
| Size of column | 500 x 500 mm |
| Size of beam | 225 x 450 mm |
| Size of slab | 150 mm |
| Number of bays (spans) | 2, 3, 4 |
| Span (bay) length | 3.048 m |
| Storey height | 3.2 m |
| Floor Finish | 2 kN/m$^2$ |
| Live Load | 3 kN/m$^2$ |
| Unit weight of brick masonry | 20 kN/m$^3$ |

## 6. Design and Modelling of Buildings

With reference to design codes IS456:2000 and IS 1893:2016, all the buildings were designed. Dead loads, live loads and earthquake loads were assigned to the models. In addition to the self-weight of the members, floor finish and live load intensities of 2 kN/m$^2$ and 3 kN/m$^2$ were applied on each floor slab. All the beams were loaded with 230 mm thick wall and the loads due to brick infill walls were applied as uniformly distributed load on beams.

The seismic weight of the building includes the total dead load of the structure and a fraction of the live load assigned to the structure. In this study, 25% of the live load is considered to be included in the seismic weight along with the dead load. The building models were considered to be special moment resisting frames founded on medium soil condition. The seismic zone was considered to be the zone with very severe seismic intensity.

For design and modelling of the buildings, finite element analysis software SAP 2000 v 20 was used. Beams and columns were modeled with two-node frame elements having six degree of freedom per node. Floor slab was modeled using four-node thin shell element. All the floor levels were assumed to be rigid in their own plane by considering rigid floor diaphragm. Secondary effects such as temperature, shrinkage and creep were not considered in the modeling. Also, no soil-structure interaction was considered, hence the foundations of the models were assumed to be rigid foundation.

After the modeling of buildings, linear dynamic method was carried out as an analysis method and deflection parameters were observed.

## 7. Seismic Gap

To determine the values of seismic gap between adjacent RC buildings, various codal provisions are made. In this paper, seismic gap is calculated based on IS 1893:2016.

Seismic Gap = $(R1\Delta1 + R2\Delta2)$[14]

Where, R1, R2, Δ1 and Δ2 are the response reduction factor and storey displacements of two adjacent buildings 1 and 2 respectively.

## 8. Result and Discussion

### 8.1 Displacement and Storey Drifts

Displacements and storey drifts values for 2, 3 and 4 bay RC buildings whose storey number varies from 1 to 4, 1 to 6 and 1 to 8 respectively were obtained after the analysis. As an example, the storey displacements and storey drifts for 4 bay building is shown in figure 2 and 3 respectively. In fig 2, it can be seen that as the number of storey increases, the storey displacement also increases. Also, in figure 3, it can be seen that up to 4 storey, there is increase in the storey drift, however, it decreases as the number of storey increases.

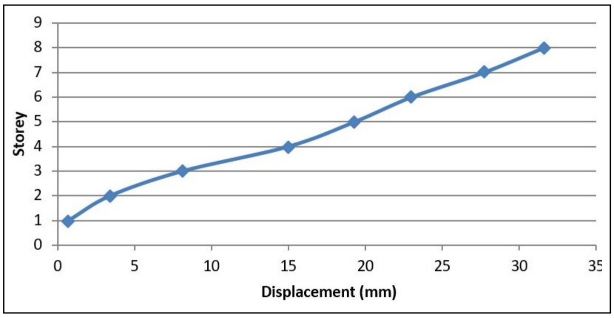


**Figure 2:** Displacement versus number of storey of 4 bay RC building

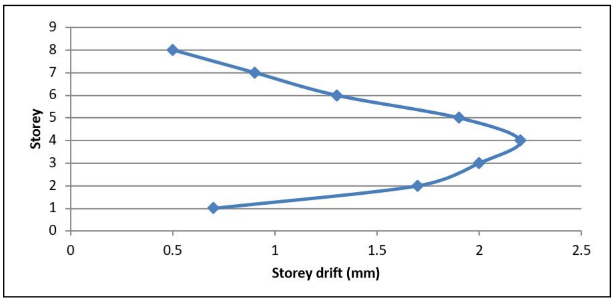


**Figure 3:** Storey drift versus number of storey of 4 bay RC building

### 8.2 Seismic Gap

The values of seismic gap for various building system are show in figure 4. Building system means there are two adjacent buildings of random number of bay and storey. For example: if a 2 bay 3 storey building is adjacent to 4 bay 5 storey building then the minimum seismic gap to be provided is 111mm, which can be seen in the figure 4.

### 8.3 Influence of storey number of the adjacent building on seismic gap

Height of a building plays a major role in affecting the gap value. In this section, the influence of storey number of the two adjacent buildings having same bay number on the seismic gap was investigated. As an example, figure 5 shows the variation of the value of seismic gap between adjacent 2 bay RC buildings in which the storey of one building is kept constant (i.e 1) and the storey of neighboring building is varied. It can be clearly seen that, as the storey number of adjacent building increases, the gap value also increases simultaneously.

Similarly, from figure 6 and 7, the same result can be seen. However, there is no significant difference in the gap value when the number of storey of the adjacent building increases from 4 onwards.

| BAY | → | 2 | | | | 3 | | | | | | 4 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ↓ | Storey | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 5 | 6 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 2 | 1 | - | 11 | 16.5 | 21.5 | 7 | 12 | 18 | 23 | 23.5 | 23.5 | 7 | 12 | 17.5 | 23 | 23.5 | 23.5 | 23.5 | 23.5 |
| | 2 | 11 | - | 45.5 | 59.5 | 11 | 32 | 48.5 | 61.5 | 64 | 65 | 11 | 32.5 | 46 | 60 | 62 | 63 | 63.5 | 63.5 |
| | 3 | 16.5 | 45.5 | - | 106 | 16.5 | 46.5 | 85.5 | 108 | 114.5 | 117.5 | 16.5 | 47 | 81.5 | 105 | 111 | 113.5 | 115.5 | 116 |
| | 4 | 21.5 | 59.5 | 106 | - | 21.5 | 60.5 | 109.5 | 156.5 | 170 | 177 | 21.5 | 61 | 105.5 | 152.5 | 164.5 | 171 | 175 | 177 |
| 3 | 1 | 7 | 11 | 16.5 | 21.5 | - | 12 | 18 | 23 | 23.5 | 23.5 | 3.5 | 8.5 | 14 | 19.5 | 20 | 20 | 20 | 20 |
| | 2 | 12 | 32 | 46.5 | 60.5 | 12 | - | 49.5 | 62.5 | 65 | 66 | 12 | 33.5 | 47 | 61 | 63 | 64 | 64.5 | 64.5 |
| | 3 | 18 | 48.5 | 85.5 | 109.5 | 18 | 49.5 | - | 111.5 | 118 | 121 | 18 | 50 | 85 | 108.5 | 114.5 | 117 | 119 | 119.5 |
| | 4 | 23 | 61.5 | 108 | 156.5 | 23 | 62.5 | 111.5 | - | 171.5 | 178.5 | 23 | 63 | 107.5 | 154 | 166 | 172.5 | 176.5 | 178.5 |
| | 5 | 23.5 | 64 | 114.5 | 170 | 23.5 | 65 | 118 | 171.5 | - | 218 | 23.5 | 65.5 | 114 | 167.5 | 199.5 | 211.5 | 219.5 | 223.5 |
| | 6 | 23.5 | 65 | 117.5 | 177 | 23.5 | 66 | 121 | 178.5 | 218 | - | 23.5 | 66.5 | 117 | 174.5 | 211.5 | 240.5 | 255.5 | 263.5 |
| 4 | 1 | 7 | 11 | 16.5 | 21.5 | 3.5 | 12 | 18 | 23 | 23.5 | 23.5 | - | 12 | 17.5 | 23 | 23.5 | 23.5 | 23.5 | 23.5 |
| | 2 | 12 | 32.5 | 47 | 61 | 8.5 | 33.5 | 50 | 63 | 65.5 | 66.5 | 12 | - | 47.5 | 61.5 | 63.5 | 64.5 | 65 | 65 |
| | 3 | 17.5 | 46 | 81.5 | 105.5 | 14 | 47 | 85 | 107.5 | 114 | 117 | 17.5 | 47.5 | - | 104.5 | 110.5 | 113 | 115 | 115.5 |
| | 4 | 23 | 60 | 105 | 152.5 | 19.5 | 61 | 108.5 | 154 | 167.5 | 174.5 | 23 | 61.5 | 104.5 | - | 162 | 168.5 | 172.5 | 174.5 |
| | 5 | 23.5 | 62 | 111 | 164.5 | 20 | 63 | 114.5 | 166 | 199.5 | 211.5 | 23.5 | 63.5 | 110.5 | 162 | - | 205 | 213 | 217 |
| | 6 | 23.5 | 63 | 113.5 | 171 | 20 | 64 | 117 | 172.5 | 211.5 | 240.5 | 23.5 | 64.5 | 113 | 168.5 | 205 | - | 245 | 253 |
| | 7 | 23.5 | 63.5 | 115.5 | 175 | 20 | 64.5 | 119 | 176.5 | 219.5 | 255.5 | 23.5 | 65 | 115 | 172.5 | 213 | 245 | - | 289 |
| | 8 | 23.5 | 63.5 | 116 | 177 | 20 | 64.5 | 119.5 | 178.5 | 223.5 | 263.5 | 23.5 | 65 | 115.5 | 174.5 | 217 | 253 | 289 | - |

- All values are in mm.

**Figure 4:** Seismic Gap for various building systems

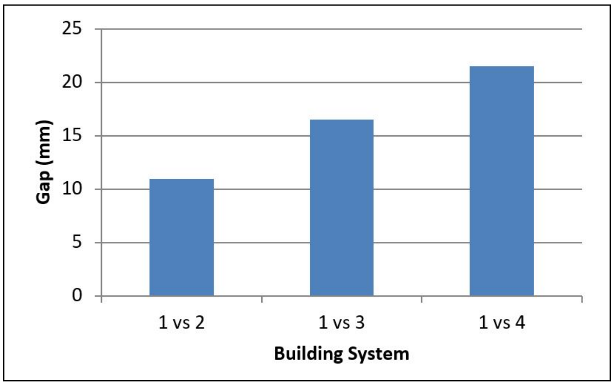


**Figure 5:** Gap versus storey number of two adjacent 2 bay RC buildings

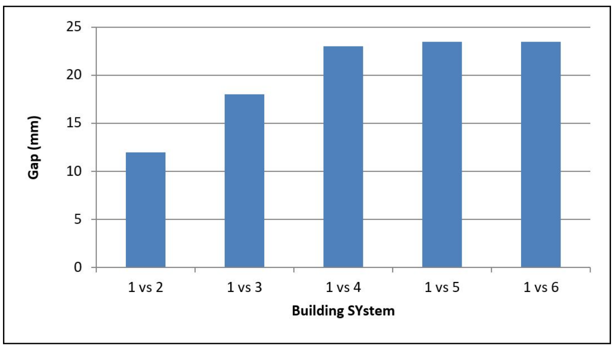


**Figure 6:** Gap versus storey number of two adjacent 3 bay RC buildings

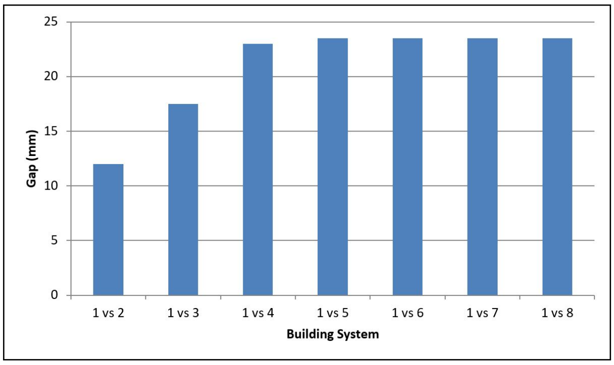


**Figure 7:** Gap versus storey number of two adjacent 4 bay RC buildings

## 8.4 Influence of bay number on seismic gap

In order to find the influence of bay number on the seismic gap, buildings having 2, 3 and 4 bays were studied by keeping number of storey of the adjacent buildings constant.

Figure 8 shows the variation of seismic gap with respect to bay number for both 4 storey adjacent RC buildings. It can be seen that as the bay number increases, there is a decrement in the seismic gap value. However, there is very less decrement (only 4mm) in the gap value due to increment of number of bays. Thus, it can be considered that the number of bays or spans is not a significant parameter affecting the seismic gap value if storey number is kept constant.

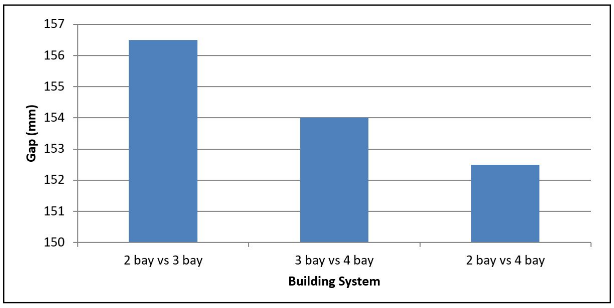


**Figure 8:** Gap versus bay number of two adjacent 4 storey RC buildings

## 9. Conclusion

Although several different parameters affect the values of seismic gap between adjacent RC buildings, design codes throughout the world prescribe empirical expressions which are mostly the function of storey deflections and height. In the present paper, the values of storey deflections was found out and based on that, the seismic gap for various combination of adjacent building was calculated, following IS1893:2016. Also, the influence of the number of storey and the bay number on the seismic gap was investigated.

From the present study, the following conclusions can be drawn:

- To avoid seismic pounding between two adjacent RC buildings, it is recommended to follow the minimum seismic gap values shown in Table 2.

**Table 2:** Minimum Seismic Gap

| Building system | Gap(mm) |
|---|---|
| 2 bay adjacent to 2 bay | 106 |
| 2 bay adjacent to 3 bay | 177 |
| 2 bay adjacent to 4 bay | 177 |
| 3 bay adjacent to 3 bay | 218 |
| 3 bay adjacent to 4 bay | 263.5 |
| 4 bay adjacent to 4 bay | 289 |

- Number of storey of the building is one of the major parameter that influences the value of seismic gap.

- Keeping the bay length constant, the increase in the number of bays does not influence much the value of seismic gap.

This study was carried out to find the values of seismic gap for general and medium rise RC buildings. Also, it was related with the investigation of the influence of number of storey and bay number on the gap values. There are other several different parameters which affect the gap values such as soil-structure interaction, unsymmetrical geometry of buildings, buildings in a row, flexible floor diaphragm, etc. which can be extensively studied on a larger data set for the estimation of the seismic gap between adjacent buildings.

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