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Research Article

LINEAR AND NON-LINEAR DYAMIC EVALUATION OF CONCRETE STRUCTURES DUE TO POUNDING EFFECTS

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ABSTRACT

The study of past histories has been shown that the buildings are disposed to severe damage during a strong seismicity. These buildings are striking to each other due to imperfect design and different dynamic properties. Hence to prevent the collapse of buildings, Indian Standards suggest that the minimum separation gap should be provided to prevent colliding of adjacent buildings.

Structural pounding occurs when two adjacent buildings collide. Earthquakes can cause pounding when adjacent buildings have little or no gap providing separation. This paper examines the dynamic evaluation of a concrete structures and pounding effects with multiple heights of buildings for time history analysis and response spectrum analysis by using ETABS. The results were obtained in the form of point displacement and pounding force. The effect of pounding is more when the structures are kept at extreme levels of setback. The collision force is developed at the mid height of structure. Proper separation distance was proposed to prevent the linear pounding and torsional pounding. Also by providing shear wall, effect of pounding reduces.

INTRODUCTION

Due to increasing population, lack of space availability and high land esteem buildings are constructed very close to each other. These buildings suffered very worst damage during strong earthquake motions. Due to strong earthquake motion the adjacent buildings moves out of phase and hitting to each other. The adjacent buildings with same dynamic properties never collide with each other. Buildings suffered to complete damage due to different dynamic properties like different loading conditions, difference in elevations, building in rows, unequal distribution of stiffness and mass, improper design of structural component, adjacent buildings with same height and same floor level, buildings with different total heights,

Structural pounding nothing but colliding of two adjacent buildings to each other. This phenomenon is occurred due to swaying of adjacent buildings with different mode shapes and periods. Structural pounding damages most commonly observed during 1999 Kobe earthquake, 1988 Sequenay earthquake, 1944 Elcentro earthquake, 1985 Mexico City earthquake, 1992 Cairo earthquake. Mostly structural pounding is occurred in old buildings because that buildings were constructed earthquake resistant design without taking into consideration.

The pounding effects can be reduced by following ways:

1. Provide the safe separation distance between two adjacent buildings specified in (IS 1893, 2002; IS 456, 2000).

2. To provide reinforced structural system cast-in-place reinforced concrete walls

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3. Use bracing system, shear wall to reduce lateral displacement of building.

Provision of seismic separation distance to avoid structural pounding

As per the bureau of Indian standards (IS 1893(Part 1), 2002), “Indian standard criteria for earthquake design part 1 general provisions and buildings”, it states that the two adjacent buildings or two different units of same building with separation joint in between shall be separated by a distance equal to the sum of calculated storey displacement class 7.11.1 of each of them, to avoid damaging contact when the two units deflects towards each other. When floor levels of two similar adjacent units or buildings are at the same elevation levels, factor R in this requirement may be replaced by R/2.

As per (IS 4326, 1993), “Indian code of practice for earthquake resistant design and construction of buildings” states that the safe separation distance of adjoining structures or parts of the same structure is required for structures having different total heights and different dynamic characteristics. This is to avoid collision during an earthquake. The codes mentioned the gap widths shown in the Table 1 (IS 4326, 1993).

Occurrence of structural pounding damage

Due to inadequate separation gap to which high intensity of earthquake strike due different dynamic characteristics, loading and structural pattern of adjacent buildings vibrate out of phase.

OBJECTIVE

The fundamental scope and objective of this paper is to find out the pounding force developed in link element, to evaluate separation distance to prevent torsional pounding by adopting R. C. shear wall. The pounding force is evaluated when the floors of adjacent buildings are at same level but buildings with different heights by using Time history and Response spectrum analysis.

MATERIALS AND METHODS

The present study examines the behavior of reinforced concrete structure by using time history analysis and response spectrum analysis using ETABS software. The adjacent buildings of G+20 and G+25 are analyzed with multiple heights for displacement and pounding force aspects. For time history function EI-Centro earthquake data considered for Table 2.

GAP ELEMENT MODEL

Gap has been defined as a link element in ETABS. The main goal to watch pounding between adjoining structures. The fundamental reason to adopt link element is that to assess the impact force of structural pounding between two adjacent buildings. The gap element is compression in nature. The stiffness of gap element is generally adopted as 102 to 104 times the stiffness of the adjacent element.

SEISMIC ANALYSIS PROCEDURE

The seismic analysis is carried out by two methods. One is static analysis and another is dynamic analysis. Further they are divided into two type’s i.e., linear and nonlinear analysis.

1. **Linear procedures**

Linear static analysis (Seismic coefficient analysis)

Linear dynamic analysis (Response spectrum analysis)

2. **Non-linear procedure**

Non-linear dynamic analysis (Time history analysis)

DETAILS OF STRUCTURE

The real structures are located in Bombay region. Time history analysis and response spectrum analysis were carried out for following cases.

Two adjacent buildings have been created in a single

Table 1. Structural pounding gap for various structures

S. No.	Type of constructions	Gap width/ storey, in mm for design seismic coefficient αh=0.1
1	Box system or frames with shear walls	15.0
2	Moment resistant reinforced concrete frame	20.0
3	Moment resisting steel frame	30.0

Table 2. Dimensions of structural elements of adjacent buildings

Member Properties	Building A	Building B
Beam	230 × 600 mm	150 × 450 mm
		230 × 600 mm
Thickness of Shear Wall	SW230M40	SW230M40
Thickness of slab	125 mm	125 mm
Thickness of brick wall	230 mm	230 mm

grid by using ETABS. In this study 230 mm shear walls are adopted to decreasing displacement and increasing the stiffness of structure. Building A and B are G+25 and G+30 storey. These two buildings are analyzed different heights like G+10 and G+15, G+ 15 and G+20, G +20 and G+25, G+25 and G+30. Height of each storey at stilt level is 4.2 m for parking provision and from 1st onwards 3 m in elevation. Grade of concrete M30, M40 and for steel FE415. Gap element i.e., link between two adjacent buildings shown in (Fig. 1).

LOAD CASES AND LOAD COMBINATIONS

In ETABS software auto assigns the self-weight of structural elements and various load combinations. Tables 3 and 4 shows the assigned loads and load combinations.

LITERATURE REVIEW

Lin et al. in 2002 studied on structural pounding probability of adjacent building in Taiwan metropolitan city designed as per Taiwan building code 1997 to achieve an insight into the validity of pounding related provisions. Total 36 cases of adjacent buildings were investigated under 1000 artificial earthquakes with conditional probabilities of adjacent buildings separated by minimum code specified separation distance under earthquake. From that result it was concluded that for same building and soil properties safe separation distance mentioned in Taiwan building code is approximately 1.6 times that specified in Uniform building code.

(Anagnostopoulos and Karamaneas, 2008; Ramachandra and Chenna, 2012) an Investigates on earthquake induced pounding between adjacent buildings. They considered multi degree of freedom system as a lumped mass and shear beam type with bilinear force deformation. By using five real earthquake motions they studied impact element properties, safe separation distance and found that shear wall resist transverse forces induced in the structure so that a pounding forces and damage of structure is minimized.

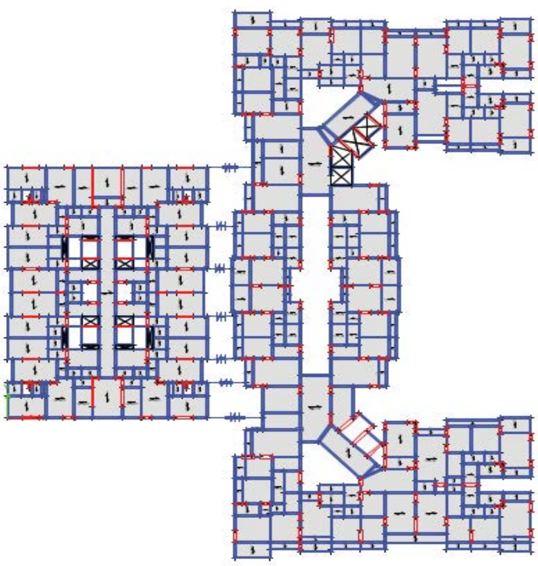

Fig. 1 Plan view of shear wall model with gap element.

K Kasai and V Jeng et al. in 1988 studied a structural damage occurred in San Francisco bay area due to pounding from data provided by engineers and government officials. They divided pounding in four type's 1. Major structural damage, 2. Failure and falling of building appurtenances creating a life safety hazard, 3. Loss of building functions due to failure of electrical system, key mechanical. 4. Architectural and minor structural damage. For type 1 two adjacent 10 and 5 storied buildings were constructed of thick masonry wall combined with 9 steel plane frames. He concluded that pounding force developed at 7th floor in 10 storied building and at the roof level in 5 storied building (Khaja and Vidyadhara, 2013; Subash and Elavenil, 2011).

TIME HISTORY ANALYSIS

Time history analysis nothing but step by step analysis of a dynamic response of a structure to a specified loading that may vary with time. Due to different dynamic properties two adjacent buildings will have out of phase movement and the two buildings will collide each other if separation distance is insufficient than specified in (IS 1893(Part 1), 2002). For both time history and response spectrum analysis models are carried for zone II (Raheem, 2006).

Importance factor (I) = 1.0, Sa/g = 2.19

RESULTS AND DISCUSSION

As per (IS 1893(Part 1), 2002), clause 7.11.3 the safe separation gap between two adjacent building units provided to prevent pounding effect is 300 mm. Initially the center line of plan is made in single grid in AUTOCAD and that center line plan is export in ETABS. Then the buildings are modelled and the results in terms of displacement shown in Table 5 and displacement graphs for different models shown in (Fig. 2-5).

The safe separation distance can be calculated by two methods.

i) As per square roots of sum of squares method

$$S = \sqrt{(\mathrm{Ua}^{\wedge}\ 2 + \mathrm{Ub}^{\wedge}\ 2)}$$

ii) A.B.S. method

Table 3. Various loads assigned on the structural model

Load case	Load pattern	Building A	Building B
Gravity Loads	Live load	2 kN/m²	2.5 kN/m²
	(Floor) Roof	2 kN/m²	2 kN/m²
	Floor Finish	1 kN/m²	1.25 kN/m²
	Roof	3 kN/m²	3 kN/m²
	Filling load	4 kN/m²	4 kN/m²
	(Bathroom) Toilet	-	3 kN/m²
	Load due to 230 mm thick	5 kN/m	5 kN/m
Lateral loads	Earthquake load	Zone factor, Z=2 (Zone II) Importance Factor = 1	
		Response reduction factor, R=3.0 (MRF)	
		Type of soil = II (Medium)	

Table 4. Load combinations

Load Combinations	1.5(DL + LL) 1.2 (DL + IL + EL)
	1.2 (DL + IL - EL)
	1.5 (DL + EL)
	1.5 (DL – EL)
	0.9 (Dl + 1.5EL)
	0.9 (Dl + 1.5EL)
(DL-- Dead Load, IL-- Live Load, EL—Earthquake load)	

Table 5. Maximum positive displacement of adjacent buildings

Variables	Building A	Building B
G +10 and G + 15	172.45	140.89
G +15 and G + 20	154.49	106.03
G +20 and G + 25	130.96	95.38
G +25 and G + 30	96.23	67.76

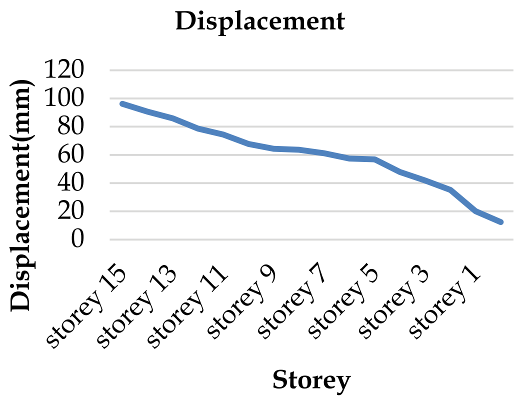

Fig. 2 Displacement of G + 10 and G + 15 structures.

S = Ua + Ub

Where,

Ua, Ub = Maximum displacement of each of adjacent buildings.

Safe separation gap calculated as per SRRS

- G + 10 and G + 15= 117.69mm
- G + 15 and G + 20= 162.01 mm
- G + 20 and G + 25= 187.37 mm
- G + 25 and G + 30= 222.68 mm

Safe separation distance to prevent torsional pounding

Even though the separation gap as per the (IS 1893, 2002) i.e., 350 mm it is observed that it could prevent linear pounding but torsional pounding could occur. The 3D view and plan representing the torsional pounding collision phenomenon for all four models for different modes shown in (Fig. 6-9).

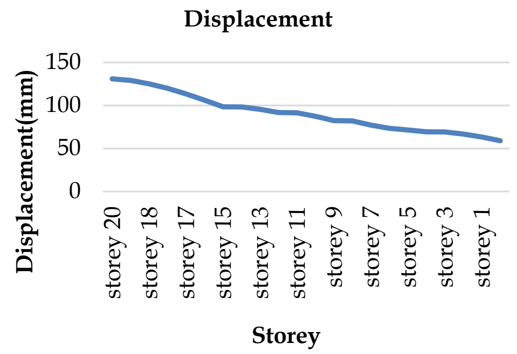

Fig. 3 Displacement of G + 15 and G + 20 structures.

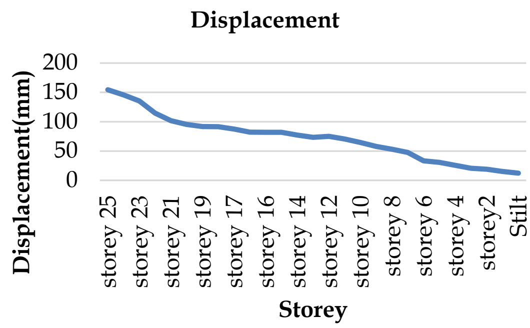

Fig. 4 Displacement of G + 20 and G + 25 structures.

Fig. 5 Displacement of G + 25 and G +3 0 structure.

For preventing the torsional effects the safe separation distance was increased and that is mentioned in (IS 1893 (Part 1), 2002). A safe separation distance to prevent torsional pounding was found out and mentioned in Table 6.

Axial force in gap element link

The axial force in gap element were found out for each of the model and are shown with the help of graph in (Fig. 10-13).

CONCLUSION

The conclusion for the pounding effect of Concrete structures is that, if separation distance is less than 100 mm the pounding would occur. By providing safe separation distance as mentioned in (IS, 1893 (Part 1), 2002) linear structural pounding was prevented but unable to prevent the torsional pounding. The shear walls were provided over siporex infill wall at suitable locations to resist lateral forces and there is gradual decrease in lateral displacement and increase

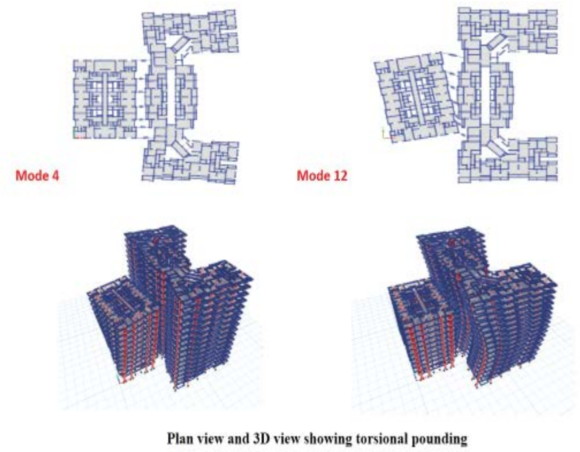

Fig. 6 Plan view and 3D torsional pounding view of G + 10 and G + 15.

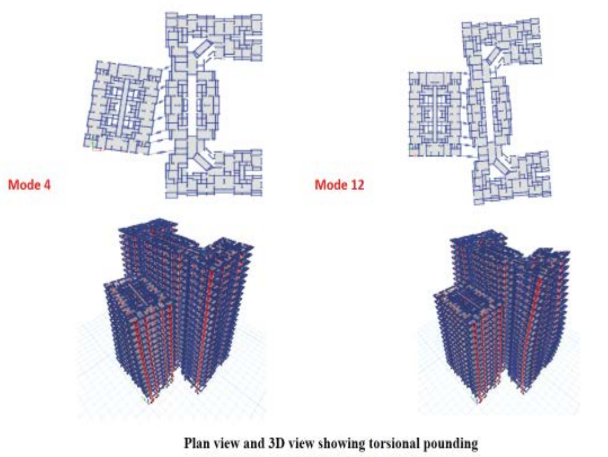

Fig. 7 Plan view and 3D torsional pounding view of G + 15 and G + 20.

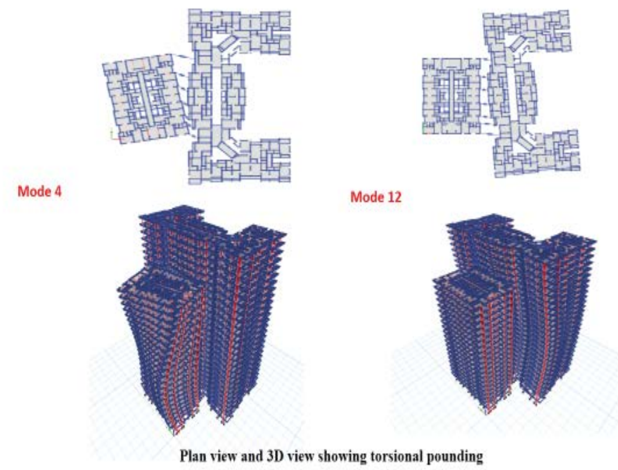

Fig. 8 Plan view and 3D torsional pounding view of G + 20 and G + 25.

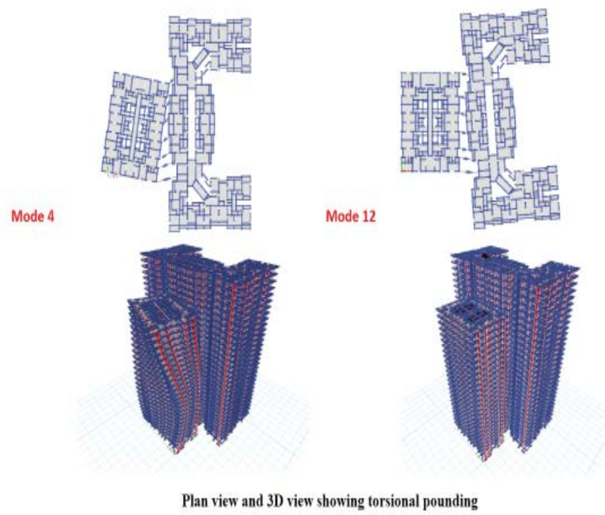

Fig. 9 Plan view and 3D torsional pounding view of G + 25 and G + 30.

Table 6. A safe separation distance to prevent torsional pounding

S. No.	Structure	Safe Separation Gap (mm)
1	G + 10 and G + 15	295
2	G + 15 and G + 20	385
3	G + 20 and G + 25	475
4	G + 25 and G + 30	565

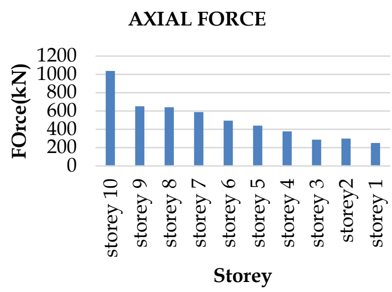

Fig. 10 Axial force in gap element for G+10 and G+15.

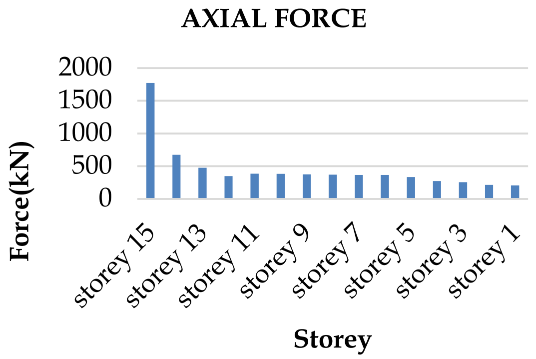

Fig. 11 Axial force in gap element for G + 15 and G + 20.

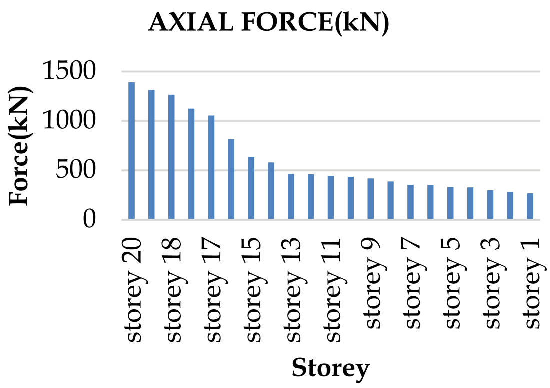

Fig. 12 Axial force in gap element for G+20 and G+25.

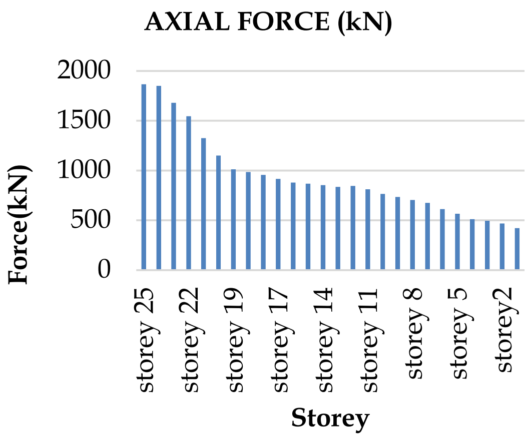

Fig. 13 Axial force in gap element for G + 25 and G + 30.

in the stiffness of the structure. The minimum seismic gap can be reduced by adopting shear wall when safe separation distance is less. The pounding forces are decreased by 10% to 15% between two adjacent buildings by gradually increasing safe separation distance of 10 mm. The pounding effect can be mitigated by adopting shear walls over brick infill wall.

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