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COMPARISON OF INTERSTOREY DRIFT IN GENERAL RC BUILDINGS IN POUNDING AND NO POUNDING CASE

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Abstract

Inter-storey drift is an important parameter of structural behavior in seismic analysis of buildings. Pounding effect in building simply means collision between adjacent buildings due to earthquake load caused by out of phase vibration of adjacent buildings. There is variation in inter-storey drift of adjacent buildings during pounding case and no pounding case.

The main objective of this research was to compare the inter-storey drift of general adjacent RC buildings in pounding and no pounding case. For this study two adjacent RC buildings having same number of stories have been considered. For pounding case analysis there is no gap in between adjacent buildings and for no pounding case analysis there is sufficient distance between adjacent buildings.

The model consists of adjacent buildings having 4 and 4 stories but unequal storey height. Both the buildings have same material & sectional properties. Fast non-linear time history analysis was performed by using El-centro earthquake data as ground motion. Adjacent buildings having different overall height were modelled in SAP 2000 v 15 using gap element for pounding case. Finally, analysis was done and inter-storey drift was compared. It was found that in higher building inter-storey drift is greater in no pounding case than in pounding case but in adjacent lower height building the result was reversed. Additionally, it was found that in general residential RC buildings maximum inter-storey drift occurs in 2nd floor.

Keywords

Inter-storey drift, Pounding, Fast Non-linear Analysis (FNA), RC Building, SAP 2000

Introduction

Drift in building is defined in terms of total drift (the total lateral displacement at the top of the building) and inter-storey drift is the difference in lateral deflection occurring between two consecutive floor levels. The drift index is a simple estimate of the lateral stiffness of the building and is used almost exclusively to limit damage to nonstructural components (Jaya and Alandkar, 2016). Inter-storey drift ratio (IDR), defined as the relative translational displacement between two consecutive floors divided by the storey height.

Equations defining drift and drift index are,

Total drift of i^{th} floor = Δ_i

Inter-storey drift of i^{th} floor (δ_i) = $\Delta_i - \Delta_{i-1}$

Drift Index = deflection/height

Total Drift Index of i^{th} floor $(TDI_i) = \Delta_i / H_i$

Inter-storey Drift Index of i^{th} floor $(IDI_i) = \delta_i / h_i$

Where,

h_i=storey height of i^{th} floor

H_i=total height of i^{th} floor

Δ_i=total drift of i^{th} floor

δ_i=inter-storey drift of i^{th} floor

Pounding is the result of irregular response of adjacent buildings of different heights and of different dynamic properties (Agrawal and Shrikhande, 2016). It is the phenomenon, in which two buildings strike due to their lateral movements induced by lateral forces (Noman et. al., 2016). 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.

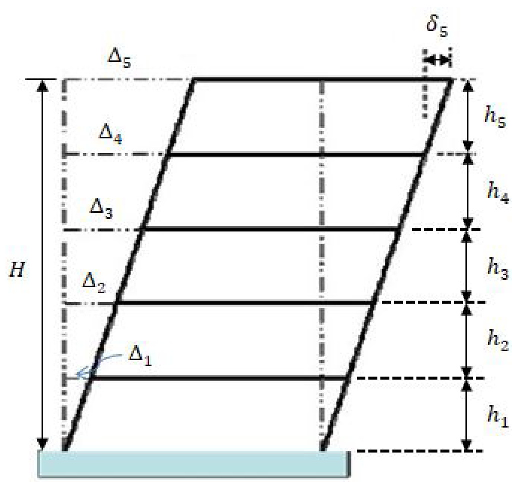

Figure 1 Drift Measurement

Background Review

Earthquake causes sudden ground motion and ground shaking which is transferred from the ground to the superstructure through foundation (Chopra, 1996). During the earthquake there are many types of failures and damages that may occur to the building. Some are due to design errors and others are due to external factors that have not been taken into account in design such as, pounding effect between adjacent structures. Pounding effect between adjacent buildings is one of the most serious factors affecting the building during the earthquake.

Pounding between adjacent buildings has been observed during many historical earthquakes where it is one of the reasons that led to significant damage to buildings such as the 2015 Gorkha Earthquake (Gautam and Rodrigues, 2018), The Mexico Earthquake – 1985 (Kasai et. al., 1992).

Nepal is seismically vulnerable region as it lies in subduction zone of Indo – Australian and Eurasian tectonic plate and such region is prone to moderate to strong ground shaking. Buildings are major Civil Infrastructures that may get damaged due to earthquake. The rapid increase in population, higher land cost in urban areas and unplanned urbanization has increases the building construction by adjoining the buildings at property line, which may causes pounding effect during earthquake. When no separation gap is provided in the buildings, effects of shear are greater. The effect decreases with the increase in separation gap (Noman et. al., 2016). Also, impact force between adjacent buildings decreases as the separation distance increases (Mooty et. al., 2009).

Joint displacement and inter-storey drift are the major parameters that may get affected during pounding effect occurring between adjoining buildings. Also, inter-storey drift is the useful engineering response quantity and indicator of structural performance, relation between pounding effect and inter-storey has great importance during building design.

Research Objective

Inter-storey drift is the indicator of structural performance which may get affected during pounding effect. Thus the main objective of this research is to compare the inter-storey drift of general adjacent RC buildings in pounding and no pounding case.

Another objective of this study is to find out the maximum inter-storey drift in the general adjacent RC buildings in pounding case and no pounding case during earthquake.

Methodology

In order to fulfill the objective of this study, the following Methods have been adopted.

- Two buildings having same plan, same material property and same section property with different storey height was taken for analysis. Both the buildings have same number of stories (4 and 4 stories) but different storey height (10 ft and 9 ft).
- Buildings were modeled using software SAP 2000 v 15 and analysis was done using Non-linear Time History Analysis (Fast Non-linear Analysis) by taking time history data of El Centro earthquake.
- Pounding and No Pounding cases were analyzed. For pounding case analysis there is no gap in between adjacent buildings and for no pounding case analysis there is sufficient distance between adjacent buildings.

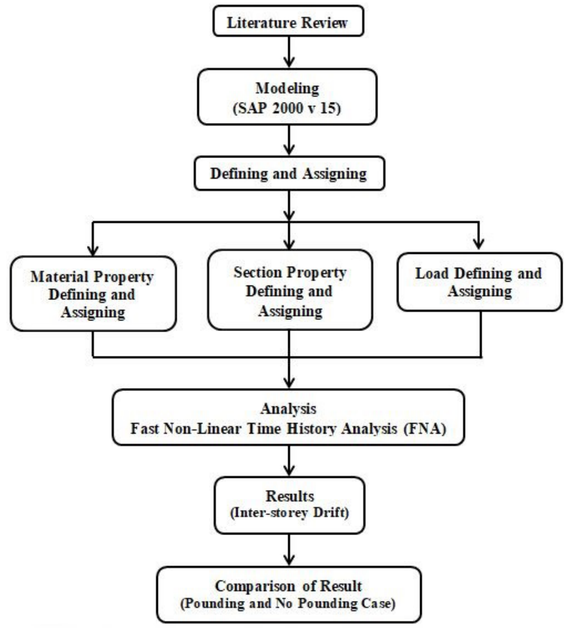

Figure 2 Methodology Flowchart

Building Modeling

Table 1 Building Modeling Details

Building Dimensions and Materials Detail	
Plan Area	7.62 m × 10.98 m
Storey Height	10 ft higher building and 9 ft for lower height buildings
Beam Size	300 mm × 400 mm
Column Size	400 mm × 400 mm
Slab Thickness	125 mm
Steel Grade	Fe415
Concrete Grade	M20
Loading	
Live Load	3 kN/m^2 for all floor except top 1.5 kN/m^2 on terrace
Floor Finishing Load	1 kN/m^2

Wall Load	11 kN/m of outer wall on outer peripheral beams 6 kN/m of inner wall on inner beams
Earthquake load	As per IS 1893: 2002
Seismic Parameters	
Seismic Zone	V (Zone Factor =0.36)
Soil Type	Medium Soil (Type II Soil)
Response Reduction Factor	5.0
Importance Factor	1.0
Finite Element Software	SAP 2000 v 15
Analysis Method	Non – Linear Time History Analysis (Fast Non – Linear Analysis (FNA))

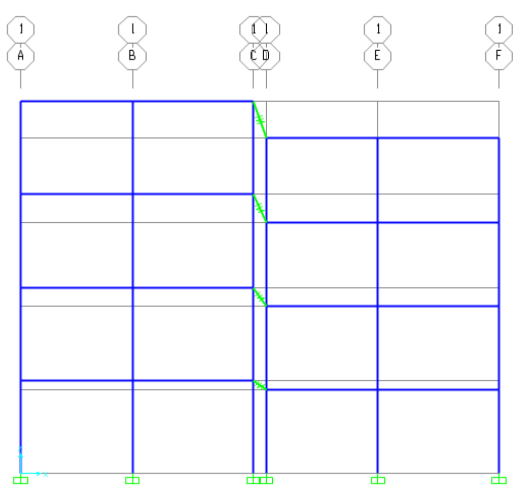

Figure 3 Common building plan adopted in Pokhara Metropolitan City taken for study

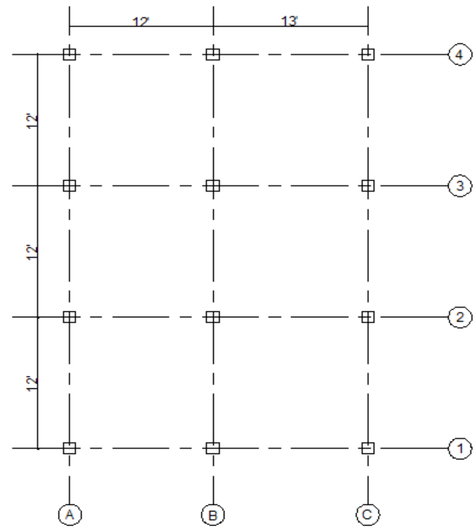

Figure 4 Gap Element Modeling of Grid 1-1 of Building Models

Gap has been defined as link element in SAP 2000. It is a compression – only element required to assess force of pounding and simulate the effect of pounding. Gap element carries compression load only; it has zero stiffness when subjected to tension (CSI, 2011).

A gap element is the element which connects two adjacent nodes to model the contact. This is activated when structures come closer and deactivate when they go far away. A collision force or pounding force will generate when they come closer. In SAP modeling each element is assumed to be composed of six degree of freedom (DOF) as shown in figure 6. Every DOF may have linear effective stiffness and damping properties. The mass contributed by link or support element is lumped at the joints i and j and half of the mass is assigned to the three translational degrees of freedom at each of the elements joint. Generally the effective stiffness of gap element is in the range of 10^2 to 10^4 times more than stiffness in any connected elements.

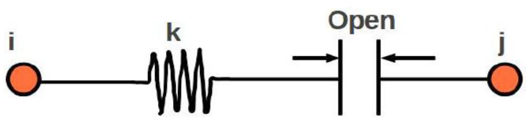

Figure 5 *Gap Element*

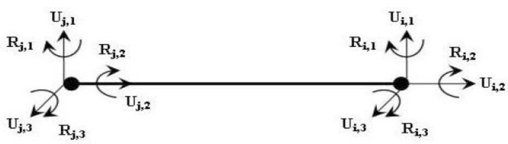

Figure 6 Link element internal forces and moments at the joints

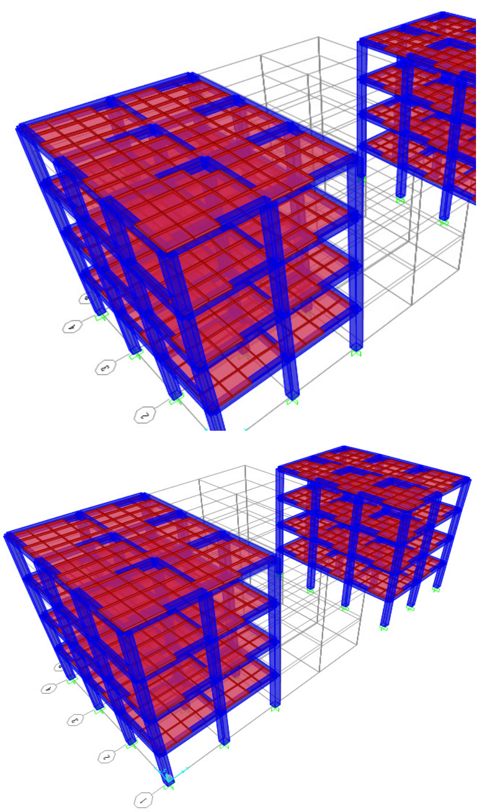

Figure 7 Building Model a) Pounding Case, b) No Pounding Case

Analysis

Seismic Data Input

Traditionally for most of the common structures, seismic design is performed by the means of linear analysis either by equivalent lateral static loading or response spectrum analysis. But in some cases such as, irregular, highly ductile, critical or higher modes induced structures, linear analysis are not capable of estimating maximum response of structures, for which time – integration scheme is deemed more appropriate. A complete seismic design of structures requires non – linear time history analysis. In this research, time history data of El-Centro earthquake having peak ground acceleration 0.318 g at 2 second is taken.

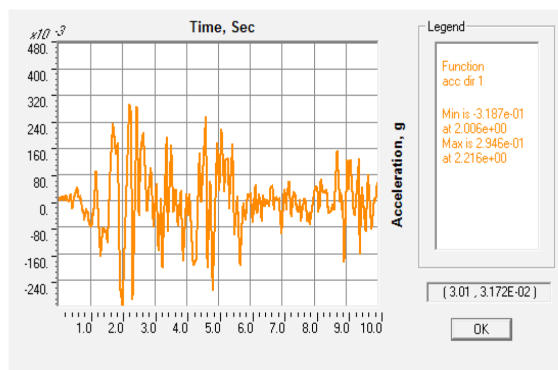

Figure 8 El – Centro Earthquake, 1940: Ground Motion Record of 0.318 g (PGA)

Results and Discussion

In this research study adjacent buildings with same number of stories but different storey height were analyzed. Gap element has been used at floor levels of adjacent buildings in SAP 2000 v 15 to simulate pounding effect and time history analysis was carried out by applying El-Centro earthquake having peak ground acceleration of 0.318 g and duration of 10 sec.

Impact between two buildings occurred due to the difference in their fundamental time period as shown in table 2. The collision induces the frequent and high extent lateral force for small time duration at points of contact in all storey level. This collision will produce more impact (more inter-storey drift) on lower height building as presented below in tabular form (table 2 and table 3) and graphical form (figure 9 and figure 10).

Fundamental Time Period

Table 2 Fundamental time period of building models, in seconds

Mode	For Building having 10' storey height (T_1)	For Building having 9' storey height (T_2)	Difference (T_1-T_2)
1	0.886115	0.77277	0.113345
2	0.853211	0.743505	0.109706
3	0.736625	0.643143	0.093482

Since there is difference in time period of adjacent buildings thus out of phase vibration occurs between buildings during ground shaking and which causes pounding effect.

Inter-storey Drift

Inter-storey drift of grid 1-1 of higher building is presented below:

Table 3 Inter-storey Drift of Higher Building, in m (Grid 1-1)

Floor	Pounding Case		No Pounding Case	
	Negative X Direction	Positive X Direction	Negative X Direction	Positive X Direction
4	-0.011316	0.007555	-0.016341	0.015524
3	-0.023236	0.015578	-0.030989	0.028385
2	-0.033588	0.022491	-0.040251	0.036317
1	-0.027681	0.019018	-0.029364	0.026704
0	0.00000	0.00000	0.00000	0.00000

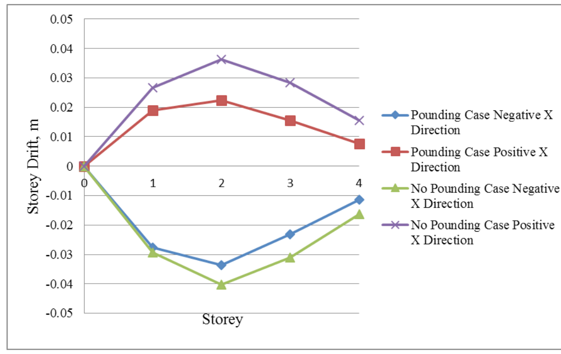

Figure 9 Inter-storey Drift of Grid 1-1 of Higher Building

Similarly, inter-storey drift of grid 1-1 of adjacent lower height building is presented below:

Table 4 Inter-storey Drift of Lower Height Building, in m (Grid 1-1)

Floor	Pounding Case		No Pounding Case	
	Negative X Direction	Positive X Direction	Negative X Direction	Positive X Direction
4	-0.00623	0.008417	-0.006008	0.007934
3	-0.01376	0.017496	-0.01281	0.013933
2	-0.020428	0.025328	-0.018489	0.019382
1	-0.016644	0.020206	-0.01406	0.014786
0	0.00000	0.00000	0.00000	0.00000

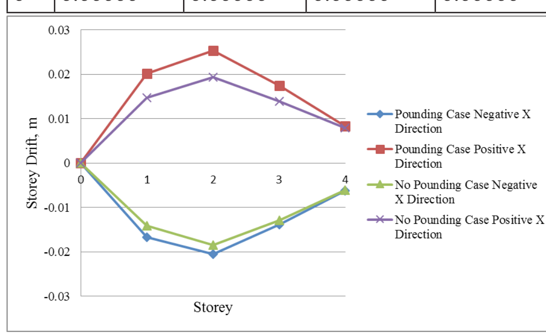

Figure 10 Inter-storey Drift of Grid 1-1 of Lower Height Building

From these graphs, it can be seen that; in case of higher building inter-storey drift in no pounding case is greater than that in pounding case but in case of lower height building inter-storey drift in pounding case is greater than that in no pounding case. The reason behind this is that push force generated by higher mass is greater than that generated by lighter building. Thus higher building pushes the lower building during ground motion. The percentage increase or decrease in inter-storey drift in pounding case for both building is presented below:

Floor	Percentage decrease in inter-storey drift for higher building		Percentage increase in inter-storey drift for lower height building	
	Negative X Direction	Positive X Direction	Negative X Direction	Positive X Direction
4	30.75	51.33	3.70	6.09
3	25.02	45.12	7.42	25.57
2	16.55	38.07	10.49	30.68
1	5.73	28.78	18.38	36.66
0	0.00	0.00	0.00	0.00

Additionally, from above graphs it can be clearly seen that maximum inter-storey drift occurs at second floor of common residential RC building.

Conclusion

As the objective of this research were to compare the inter-storey drift and to find out the maximum inter-storey drift in general adjacent RC buildings in pounding and no pounding case, the following Conclusions were made:

1. During pounding lower height building (lighter building) experiences more inter-storey drift thus it is more vulnerable to damage than adjacent higher building (adjacent building with higher mass).
2. In each case and in either direction inter-storey drift is maximum at second floor. This means that in general residential RC building maximum inter-storey drift occurs at second floor and the floor is more vulnerable to damage during earthquake. Therefore, special care should be done to prevent damage of second floor by increasing stiffness of that floor.

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