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ANALYSIS OF SEISMIC POUNDING BETWEEN ADJACENT RC BUILDINGS

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Abstract: Major seismic events during the past decade have continued to demonstrate the destructive power of earthquakes, with destruction of engineered buildings, bridges, industrial and port facilities as well as giving rise to great economic losses. In urban/metropolitan cities buildings are constructed very close to each other because of high land value. Because of the insufficient gap, which is provided between adjacent buildings or adjacent units of same building are most vulnerable to seismic damage due to Pounding. Adjacent buildings may have different functional requirements such as one is for residential and another is for public/commercials buildings based on the owner interests, so they may have different configurations and dynamic properties .During an earthquake these adjacent buildings may vibrate out of phase leads to slight architectural damage to severe structural damages.

In this paper Nonlinear Time History analysis is done for different cases of building positions and their floor levels are mentioned below.Two adjacent buildings are constructed with (1) 'Buildings with Same Height and Same Floor', (2) 'Buildings with Different Height and Same Floor Levels'. The adjacent buildings are modeled in ETABS sotware and analysis is carried out to find the Seismic response (Impact force) of buildings with connecting two floor levels of adjacent buildings by 'Gap Element model' when subjected to Different ground motions. When the two buildings are placed at different heights the impact force is more than buildings with the same height.

***Index Terms* - Pounding, Damage, Ground motion, Seismic response.**

I. Introduction

Structures are built very close to each other in metropolitan areas where the cost of land is very high. Due to closeness of the structures, they collide with each other when subjected to earthquake or any vibration. This collision of buildings or different parts of the building during any vibration is called pounding which may cause either architectural and structural damage or collapse of the whole structure. This may happen not only in buildings but also in bridges and towers which are constructed close to each other. Although some modern codes have included seismic separation requirement for adjacent structures, large areas of cities in seismically active regions were built before such requirements were introduced. Many investigations have been carried out on pounding damage caused by previous earthquakes.

Structural pounding damage in structures can arise from the following:
(1) Adjacent buildings with the same heights and the same floor levels.
(2) Adjacent buildings with the same floor levels but with different heights.
(3) Adjacent structures with different total height and with different floor levels
(4) Structures are situated in a row.
(5) Adjacent units of the same buildings which are connected by one or more bridges or through expansion joints.
(6) Structures having different dynamic characteristics, which are separated by a distance small enough so that pounding can occur
(7) Pounding occurred at the unsupported part (e.g., mid-height) of column or wall resulting in severe pounding damage.
(8) The majority of buildings were constructed according to the earlier code that was vague on separation distance.
(9) Possible settlement and rocking of the structures located on soft soils lead to large lateral deflections which results in pounding.
(10) Buildings having irregular lateral load resisting systems in plan rotate during an earthquake, and due to the torsional rotations, pounding occurs near the building periphery against the adjacent buildings.

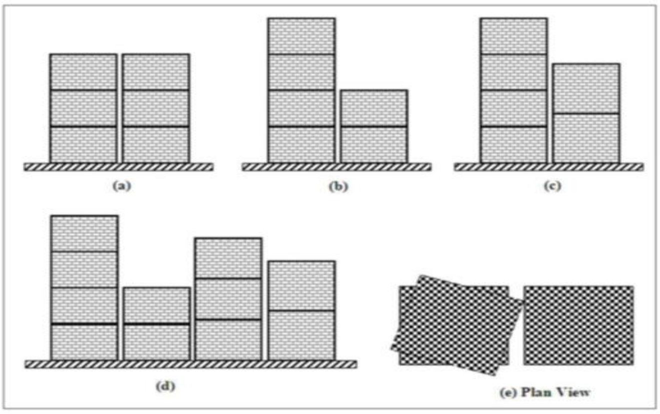

Fig.1.1: Representation of different places where pounding occurs

The main objective of this research is:

(1) To analysis of seismic pounding on adjacent RC buildings.

(2) Comparison of codal provisions.

II. CODE REQUIREMENTS TO AVOID POUNDING

Most of the design codes and standards allow a minimum separation distance or gap between adjacent buildings to avoid or to prevent pounding. The specified separation or gap is mainly depending on the maximum displacement of the adjacent buildings. The methods used to calculate this gap are different from code to code because of the needs to calculate reliable and economic separation. This part of the paper summarizes the provision used in different codes to calculate the safe separation.

According to latest edition of International Building code and in many seismic design codes and regulations worldwide, the minimum separation distances are given by Absolute Sum (ABS) or Square Root of Sum of Squares (SRSS) as follows.

The Separation distance

$S = Ua + Ub$ for ABS……………………………….(1)

$S = \sqrt{(Ua^2 + Ub^2)}$ for SRSS………………………...(2)

Where S = Separation distance.

Ua = Peak displacement response of building A.

Ub = Peak displacement response of building B.

III. METHODOLOGY

1) Literature survey is to be done by referring and going through articles and journals published in the related area of the studies to get detail subject knowledge.

2) Model selection and related data collection that will aid in completing the work has to be done, such as validation model detail collection, earth quake data collection etc.

3) Software study is an important step in this project; one should do a software study to get used to the software tools. This helps to eliminate all possible errors that could creep up during modelling and analysis.

4) Modelling of case study building. In this process case study building is properly modelled in the software, proper load cases should be assigned to the building as per code provisions.

5) Validation process is an important process which ensures correctness of the end product, this process helps to check product quality obtained from the software.

6) Analysis of the case study building after proper modelling helps to understand forces acting on the building, any possibility of collapse of structure could be understood after conducting proper seismic analysis. Mode shape, behaviour of the structure under dynamic loading etc. could be obtained from proper analysis.

7) Result and discussion is a key step in the project. After conducting analysis, results obtained are carefully studied and reasons for such outputs have to be discussed in detail to understand the obtained output.

8) Conclusions have to be drawn from the obtained result. This should consist of a brief account of the entire project including procedure adopted and result.

9) Future scope proposition refers to listing out of all the areas that were omitted in the current project. All the criteria that were not accounted in the scope of this study could be listed as future scope. Further studies could be done by future researchers based on this future scope.

IV. NUMERICAL MODELING OF POUNDING

The main focus of this paper is to study the pounding behaviour of structures with un-equal heights. Also discuss on separation distance from different country seismic codes for different structures subjected to different ground motions. Furthermore, provide suggestions for the codes which are underestimated on separation distance. For the purpose of analysis, a seven storey and a five storey building are considered. Models were developed and analysed for dead, live and seismic loads based on Indian standard codes IS 456:2000, IS 1893: 2016 and IS 875:1987.The building is modelled in ETABS 2018.and subjected to gravity load and seismic load.). Concrete compressive strength of 25 MPa are used for the columns and beams and steel with grade 415 is used for all beams and columns. The buildings consist of square columns with dimension 240mm x 240mm, all beams with dimension 200mm x 240mm. Each combination combines two planar moment-resisting reinforced concrete frames with three bays each. Each bay is 3m in width and each story is 3 m in height for all frames. The two planar frames in each model are separated by a specific gap. The gap is defined as a link element through ETABS simulation platform. Besides the self-weight, a superimposed dead load of 12.96 kN/m and a live load of 3 kN/m² are applied to the beams. The restraints are all fixed, and the frames are considered fixed on the ground.

4.1. Gap Element:

Gap (compression-only) element is used to model the pounding force between buildings. Non-linear properties of the gap element are taken into consideration by the used software program. The gap element transmits axial compression force only. Both of the stiffness of the gap and the separation distance between buildings are required to model that gap element. The stiffness of GAP element does not affect the analysis results however it is found from the available literature that the Gap element should be approximately 20 times stiffer than the lateral storey stiffness of stiffer building.

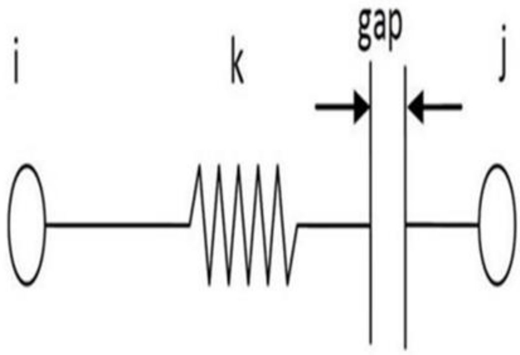

Fig.4.1: Gap element model

The used separation distance in this study is:
- 95mm separation
- 0mm separation

4.2. Seismic Action

To study the effect of seismic ground motion on pounding force, an earthquake with low, moderate and high ground motion were selected are Imperial Valley Ground Motion.

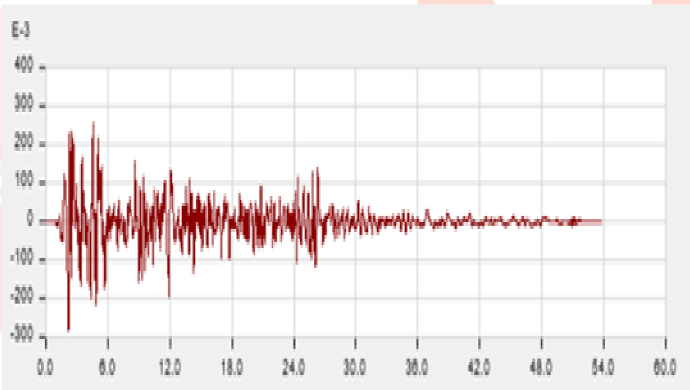

Fig.4.2: Define Time History function

V. POUNDING ANALYSIS FOR STRUCTURES WITH UN-EQUAL HEIGHTS

Analysis is done using nonlinear time history under the different ground motion which are specified above. The two adjacent buildings are connected by gap contact element with 95 mm & 0 mm separation gap. The dynamic analysis is performed by time history analysis. The different ground motions are given as input for time history analysis.

The distribution of pounding forces along the building height for 7-story building to 5-story building is shown in Figure with different gap distances. It could be seen that the top storey show maximum displacement than the lower ones.

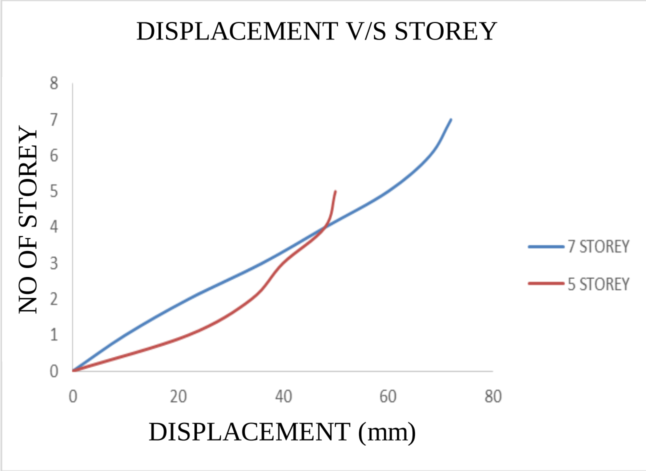

Fig.5.1: Displacement of Building 7 storey & 5 storey

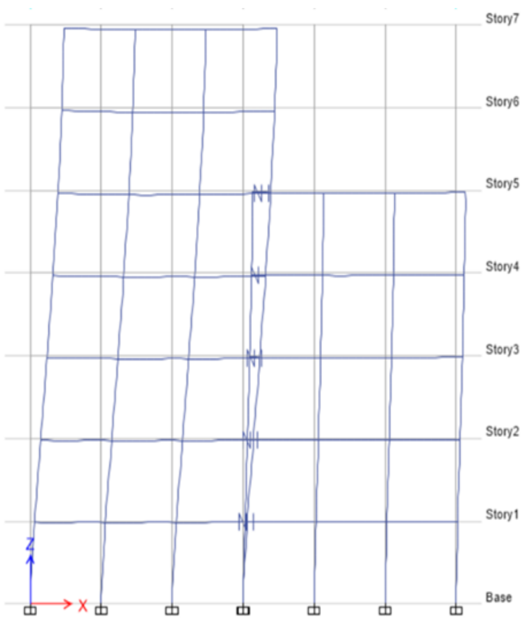

Fig.5.2: Building 7 storey & 5 storey after collision

5.1. Results

Table 5.1: Pounding forces induced at different storeys of building due to impact between 5 and 7 storey buildings

Sl No	Gap	Storey	Storey(kN)
1	95mm	5	1065.65
		4	0
		3	0
		2	0
		1	0
2	0mm	5	1601.72
		4	1301.05
		3	984.52
		2	716.68
		1	620.32

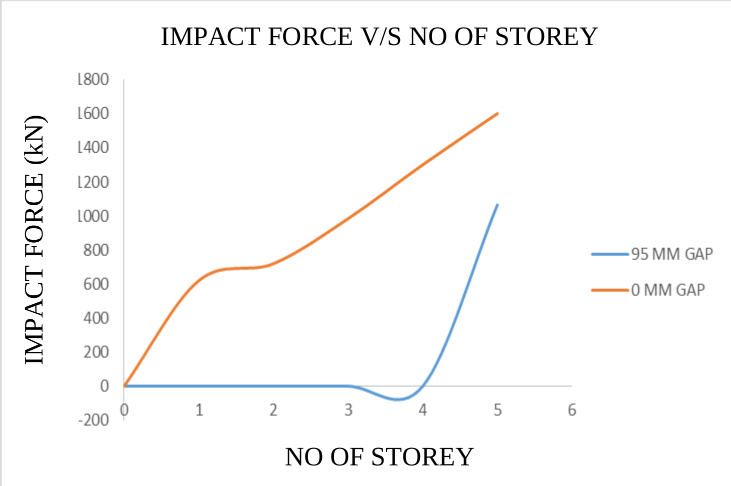

Fig.5.3: Impact force v/s Dispacement graph

In this paper, the seismic response (impact force) of adjacent buildings buildings are found based on the ground motions. The impact force is maximum when the heights of two adjacent buildings are different compare to same height of buildings, and also proved that the impact force is maximum at exterior buildings compare to interior buildings.

VI. COMPARISION OF CODAL PROVISIONS ON POUNDING

6.1. Review on codal provisions

Most of the world regulations for seismic design do not take into account the pounding phenomenon. Among of the ones who do consider it, do not provide specific rules that must be followed. Codes specify a minimum separation distance between adjacent buildings. In some cases this depends only on the maximum displacements of the each building. The separation distance is made dependent on the building height. According to International Building Code (IBC) all the structures shall be separated from adjoining structures. If the adjacent buildings are on the same property line, the minimum separation distance simply follows SRSS rule and if they are not located on the same property line (adjacent buildings separated by property line) simply follows the sum of maximum displacements of the structures. From the observation of all codal provisions it is seen that most of the codal provisions follow SRSS method only. The minimum separation distance is not only depending on the response of the structure but also various factors like importance factor,.This case study deals about the collision force of structure.
Elcentro earthquake occurred in 1940 having a magnitude of 7.1 and PGA value of 0.348g. The duration of this ground motion is 24.44 sec according to trifunac and broady calculation. Structure having time period 0.1 sec is kept constant and others are varying and the minimum separation distances are calculated from above codal provisions.

6.2. Result

Table 6.1: Pounding forces induced at different storeys of building due to impact between 5 and 7 storey buildings

Sl No	Code	Gap (m)	Storey	Force (kN)
1	IS 4326:1993	1 m	5	0
			4	0
			3	0
			2	0
			1	0
2	IS 1893:2016	2 m	5	0
			4	0
			3	0
			2	0
			1	0

As the minimum space between the structures decreases the amount of impact increases, but this impact occurs at the same time even the separation distance decreases. For the structures having same time period, no need to provide minimum space between them. Because both structures response is same. The amount of impact depends on response of the structures at particular time, minimum space between the structures and velocity of the structures. Even though the predominant time period is not presented, there are collisions for the structures. If the predominant time period range structures are present, the collision will be more. As the time period of the structures near to the predominant time period range, the response of the structures are more and the impact,damage are more and may lead to collapse of the structure.

VII. CONCLUSIONS

The impact force between adjacent buildings lead to local damage cracks to severe damage like failure of structural members and it is hazardous for buildings. The conclusions regarding pounding effect (Impact force) are as follows :

1. Pounding damage occurs during the strong earthquakes between the adjacent buildings or different units of the same building. Providing sufficient separation gap between adjacent buildings which are going to construct is the best mitigation measure for pounding damage.
2. Pounding damage is more when the adjacent buildings are constructed with different floor levels because the total lateral force (impact force) is directly upon column elements, so the buildings with different floor levels are undesirable compared to same floor levels.
3. It is preferable to construct adjacent buildings with same floor level and with suitable separation gap by considering dynamic analysis to avoid pounding.
4. The adjacent buildings collide with each other when they have different building configurations and dynamic properties so that they vibrate out of phase.
5. The pounding damage is severe in exterior buildings compare to interior buildings when the buildings are in series because seismic response (impact force) of exterior buildings is more.
6. Buildings which are already constructed without proper seismic separation gap are need to be coupled with supplemental damping devices is an effective method to mitigate pounding damage.
7. One of the ways to mitigate impact due to pounding of adjacent structures during seismic excitation is to harden the buildings such that the displacements and impact effects are decreased.

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