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EFFECT OF SEISMIC POUNDING BETWEEN ADJACENT IRREGULAR BUILDINGS AND MITIGATION MEASURES

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ABSTRACT: *Post-earthquake damage analysis in past and recent earthquakes found that building structures are susceptible to severe damage and/or collapse during moderate to severe ground movement. Earthquake induced pounding between adjacent buildings was identified as one of the causes of major damage or even collapse of colliding structures. A major reason for building interactions is the variations in their complex parameters(structure shapes and sizes, seismic zone) and also the inadequate space between the structures. This study aims to analyze the seismic pounding response of irregular buildings(H and Tube Shaped)having equal heights, two adjacent buildings varying the number of floors G+12 and G+8 are considered for study with the seismic gap width 150mm.The models are analyzed using ETABS software for the nonlinear link elements using Fast Nonlinear Analysis(FNA).This study also covers the mitigation measures of pounding between adjacent buildings due to earthquakes. The use of dampers, with proper placement, is proposed as a possible mitigation measure for pounding between adjacent buildings*.

Key words: SEISMIC POUNDING, NONLINEAR LINK ELEMENTS, FAST NONLINEAR ANALYSIS(FNA), FLUID VISCOUS DAMPER, PLASTIC(WEN) FRICTION DAMPER, ETABS SOFTWARE.

1. INTRODUCTION

Earthquakes are the most volatile and destructive of all natural disasters that are difficult to save over infrastructure resources and life. Therefore we need to define the seismic quality of the built environment through the design of various analytical techniques in order to overcome these problems. The dynamic characteristics of the adjacent structures lead to the out of the phase oscillation of the structures when they are subjected to external excitation. If the separation gap between structures is insufficient to accommodate the lateral displacements due to this out-of-phase oscillation, impacts will occur. The magnitudes of the impact forces and the location of the impacts along the heights of the structures depend on the magnitude of the existing separation gap, the extent of difference between the dynamic properties of the impacting structures and the characteristics of the excitation.

The most simplest and effective way for avoiding pounding and reducing damage due to pounding is to provide enough separation gap between the structures, but it is sometimes difficult to be implemented. An alternative to the seismic separation gap provision in the structure design is to minimize the effect of pounding through decreasing lateral motion by means of lateral load resisting structural systems, such as shear wall, Bracing and dampers. By adding supplementary damping to the structure, it is possible to reduce the flexural stiffness of the building to minimize seismic base shear and at the same time control the response.

The main objective of the study is to determine the pounding effect between adjacent H and Tube shaped buildings and to determine displacements variations in the structure due to introduction of dampers. To find the reduction in base shear by using dampers in buildings.

The research aim is to reduce the response of the structure effectively using Fluid viscous dampers and Plastic (wen) frictional dampers and proving it as most efficient in the stability of the structure.

1.2 GAP ELEMENT

A link object connects two joints, *i* and *j*, separated by length *L*, such that specialized structural behavior may be modelled. Linear, nonlinear, and frequency-dependent properties may be assigned to each of the six deformational degrees-of-freedom (DOF) which are internal to a link, including axial, shear, torsion, and pure bending. Internal deformation is then calculated from joint *j* displacement relative to joint *i*, where *i* may be grounded to simulate a support point. To utilize nonlinear and frequency-dependent properties, corresponding analysis cases must be defined and run. GAP element is an compression only member.

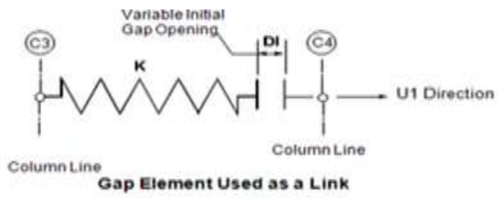

Figure 1 : Gap Element

2. THE MATERIAL PROPERTIES AND GEOMETRY OF THE MODEL

1. The models which is adopted for study are,

a. H SHAPED Building b. TUBE SHAPED Building

2. Grade of concrete is M30 for columns and M25 for beams and slabs.

3. Grade of steel Fe415.

4. The buildings have columns of dimension 450mm x 600m for G+12 BUILDING and 400mm x 500mm for G+8 BUILDING respectively.

5. Beam dimensions 300mm x 450mm

6. The floor slabs thickness is taken as 150 mm

7. Height of the base Storey is 3.5 m and remaining stories is 3 m.

8. Slabs are defined as area elements having the properties of membrane elements with the required thickness.

9. Slabs have been modelled as rigid diaphragm.

10.support conditions are fixed.

11. Gap between adjacent buildings is taken as 150 mm.

3. APPLIED LOADS

The structures are acted upon by different loads such as dead load (DL), Live load(LL)and Earthquake load (EL).

A. Self-weight of the structure comprises of the weight of the beams, columns and slab of the structure.

B. Live load: It consist of Floor load which is taken as 3 KN/m^2 and Roof load as 2 KN/m^2, according to (IS 875 (Part 2)).

C. Seismic Load: The different seismic parameters are taken as follows, IS 1893(Part-1):2016.

For RESPONSE SPECTRUM

Seismic zone: V (Z=0.36), Soil type: II, Importance factor: 1.5,Response reduction factor: 5,Damping: 5%.

For NON LINEAR TIME HISTORY ANALYSIS

Time function CENTURY CITY - LACC NORTH AT 0 DEG. is taken.

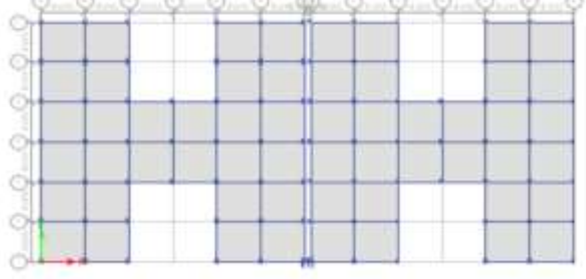

Figure 2 : Plan Of H Shaped Adjacent Buildings

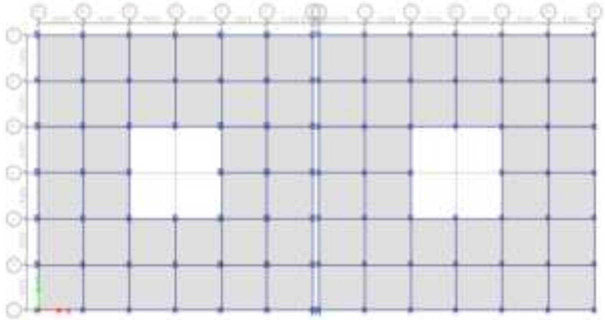

Figure 3: Plan of Tube Shaped Adjacent Buildings

4. REQUIRED SEPARATION GAP

As per IS 1893(Part 1): 2016 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 D_1 and D_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. When floor levels of the adjacent units of a building or buildings are at the same level, the separation distance shall be calculated as (RD_1 + RD_2), where R_1 and D1 correspond to building 1, and R_2 and D_2 to building 2.(R is response reduction factor)

5. MODELING OF DAMPERS

The dampers used in modeling these buildings are from Taylor Devices Inc. made in USA and Pall Dynamics, Canada. They provide two types of data with data that can be used in ETABS 2016 for modeling of structure. They are: -

5.1 FLUID VISCOUS DAMPERS & LOCK-UP DEVICES CLEVIS – CLEVIS CONFIGURATION.-(DAMPER1)

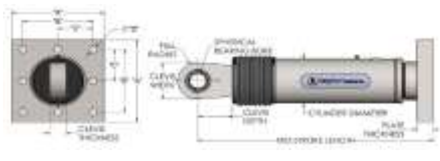

Figure 4 : Fluid viscous dampers & lock-up devices clevis – base plate configuration.

Force =250 KN WEIGHT =44 kg

Fluid viscous dampers(FVD) with different forces can be used for different types of buildings, since structure modelled is of low height; smaller devices were used to start analysis. FVD is added to structure after defining in Link properties by adding a new Damper-Exponential in Link Property Data.

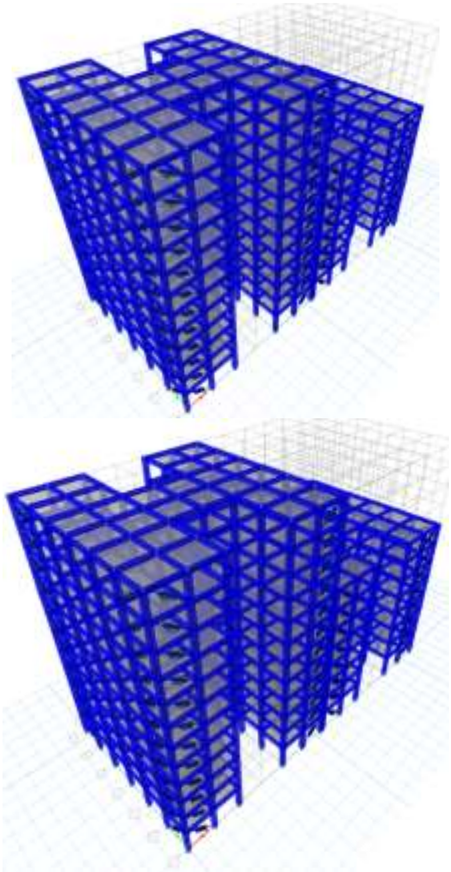

Figure 5 : 3D View Of H Shaped Adjacent Buildings With Damper1 and Damper2

5.2 Plastic(Wen) Friction Damper (Damper2)

Tension-compression diagonal brace with Pall FD has been modelled as per suggestions available on manufactures website (Pall Dynamics, Canada). Since the dampers are installed with supportive bracing systems, the combined system is modelled together as a link element. The damper is modelled only along one longitudinal direction and restrained in other two transverse directions, in its local coordinate system. Non-linearity is considered along the active direction U l. Rotational inertia is zero and rotation is restrained. Following values have been used to model the damper

Table 1: Damper Properties Used In Modeling

LINK TYPE	PLASTIC (WEN)
MASS (Kg)	429.32
WEIGHT (KN)	4.2116
EFFECTIVE STIFNESS (KN/m)	23772.825
EFFECTIVE DAMPING (KNs/m)	0
YIELF STRENGHT= SLIP LOAD (KN)	700
POST YIELD STIFFNESS RATIO	0.0001
YIELDING EXPONENT	10

6. RESULTS AND DISCUSSIONS

6.1 COMPUTATION OF GAP BETWEEN ADJACENT H SHAPED BUILDINGS

In this case, the maximum negative displacement of G+8 story building at eighth floor level is 78.62mm at 9.95 sec and maximum positive displacement for G+12 story building is 213.072mm at 9.95 sec. it is also noticed that maximum out of phase movement of both building at 9.95 sec is (213.072+78.62)-150= 141.692mm which is greater than expansion joint.. Due to this out of phase moment, impact force is created in the gap element. the maximum impact force of 195256KN created between the adjacent buildings.

6.2 COMPUTATION OF GAP BETWEEN ADJACENT TUBE SHAPED BUILDINGS

In this case, the maximum negative displacement of G+8 story building at eighth floor level is 83.93mm at 9.95 sec and maximum positive displacement for G+12 story building is 196.752mm at 9.95 sec. it is also noticed that maximum out of phase movement of both building at 9.95 sec is (196.752+83.93)-150= 130.682mm which is greater than expansion joint.. Due to this out of phase moment, impact force is created in the gap element. the maximum impact force of 169567KN created between the adjacent buildings.

6.3 COMPUTATION OF GAP BETWEEN ADJACENT H SHAPED BUILDINGS WITH DAMPER 1

In this case, two adjacent buildings are at same floor level, the maximum negative displacement of G+8 story building at eighth floor level is 51.10 mm at 9.95 sec and maximum positive displacement for G+12 story building is 40.38 mm at 9.95 sec. it is also noticed that maximum out of phase movement of both building at 9.95 sec is 150-(51.10+40.38) = 58.52mm which is less than expansion joint .No impact force is created between the adjacent buildings . i.e. Seismic pounding is avoided between the adjacent buildings

6.4 COMPUTATION OF GAP BETWEEN ADJACENT H SHAPED BUILDINGS WITH DAMPER 2

In this case the maximum negative displacement of G+8 story building at eighth floor level is 68.75mm at 9.95 sec and maximum positive displacement for G+12 story building is 66.27mm at 9.95 sec. it is also noticed that maximum out of phase movement of both building at 9.95 sec is 150-(68.75+66.27)= 14.98mm which is less than expansion joint .No impact force is created between the adjacent buildings . i.e. Seismic pounding is avoided between the adjacent buildings

6.5 COMPUTATION OF GAP BETWEEN ADJACENT TUBE SHAPED BUILDINGS WITH DAMPER 1

In this case, the maximum negative displacement of G+8 story building at eighth floor level is 50.745mm at 9.95 sec and maximum positive displacement for G+12 story building is 40.323mm at 9.95 sec. it is also noticed that maximum out of phase movement of both building at 9.95 sec is 150-(50.745+40.323)= 58.932 mm which is less than expansion joint .No impact force is created between the adjacent buildings . i.e. Seismic pounding is avoided between the adjacent buildings

6.6 COMPUTATION OF GAP BETWEEN ADJACENT TUBE SHAPED BUILDINGS WITH DAMPER 2

In this case, the maximum negative displacement of G+8 story building at eighth floor level is 68.45mm at 9.95 sec and maximum positive displacement for G+12 story building is 63.592mm at 9.95 sec. it is also noticed that maximum out of phase movement of both building at 9.95 sec is 150-(68.45+63.592)= 17.958mm which is less than expansion joint .No impact force is created between the adjacent buildings . i.e. Seismic pounding is avoided between the adjacent buildings.

6.7 BASE SHEAR

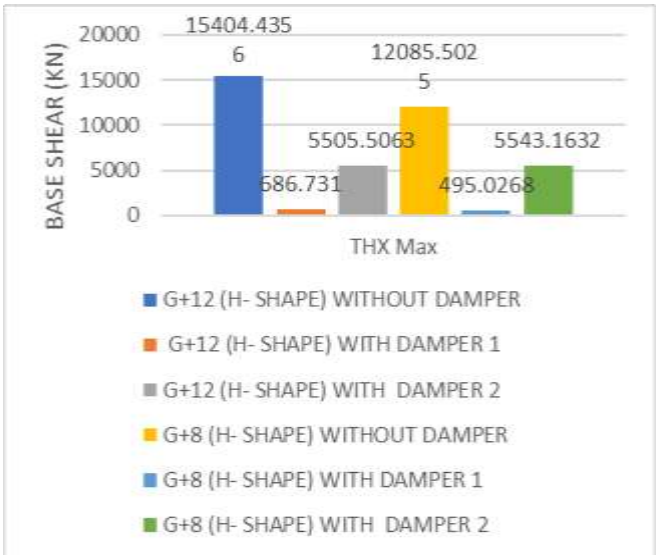

Chart -1 : Base shear comparison for H shaped buildings

- From comparison of the results of Base shear of Buildings without and with dampers it is clearly found that due to introduction of dampers in the structure the base shear is diminished.
- 95.5% decrease is seen in base shear of G+12 (H-Shaped) building with damper 1 when compared to G+12 (H-Shaped) building without dampers.
- 64.26% decrease is seen in base shear of G+12 (H-Shaped) building with damper 2 when compared to G+12(H-Shaped) building without dampers.
- 95.9% decrease is seen in base shear of G+8 (H-Shaped) building with damper 1 when compared to G+8 (H-Shaped) building without dampers.
- 54.1 % decrease is seen in base shear of G+8 (H-Shaped) building with damper 2 when compared to G+8 (H-Shaped) building without dampers.

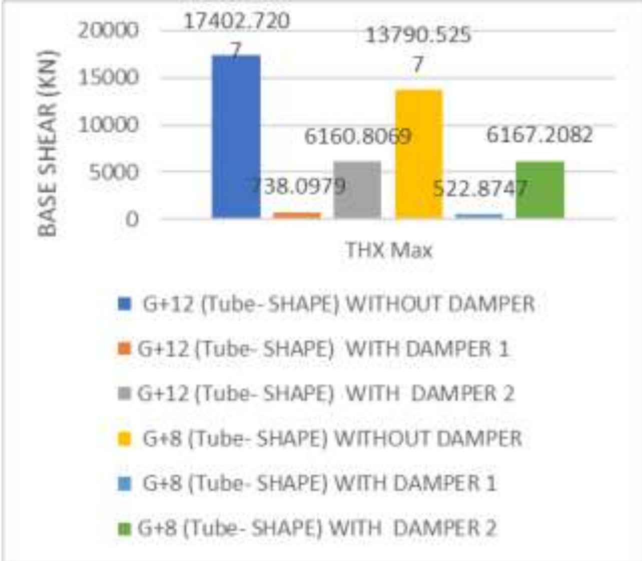

Chart -2: Base shear comparison for Tube shaped buildings

- 95.7 % decrease is seen in base shear of G+12 (Tube-Shaped) building with damper 1 when compared to G+12(Tube-Shaped) building without dampers.
- 64.6 % decrease is seen in base shear of G+12 (Tube-Shaped) building with damper 2 when compared to G+12 (Tube -Shaped) building without dampers.
- 96.2% decrease is seen in base shear of G+8 (Tube -Shaped) building with damper 1 when compared to G+8 (Tube-Shaped) building without dampers.
- 55.3 % decrease is seen in base shear of G+8 (Tube -Shaped)building with damper 2 when compared to G+8 (Tube-Shaped) building without dampers.

6.8 STORY MAX/AVG. DISPLACEMENTS

Chart -3: Story displacement comparison for H shaped G+8 Buildings

- Displacements have been reduced by 85.7% for G+8 (H-Shape) building after insertion of damper 1, 57.371% reduction in displacements after insertion of damper 2 in the buildings.

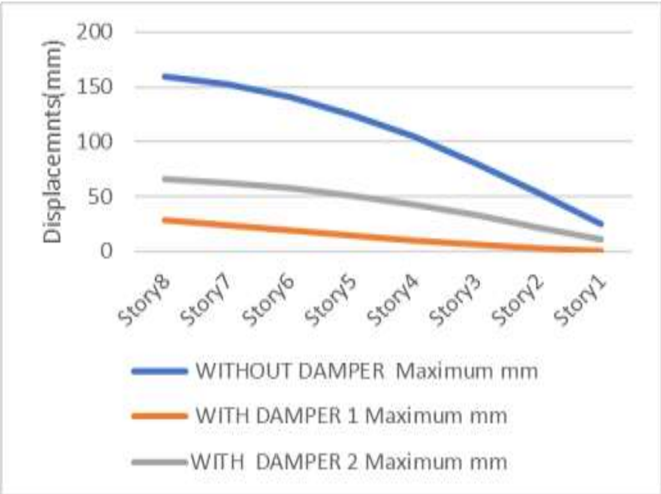

Chart -4: Story displacement comparison for Tube shaped G+8 Buildings

- Displacements have been reduced by 85.7% for G+8 (Tube-Shape) building after insertion of damper 1, 58.2% reduction in displacements after insertion of damper 2 in the buildings.

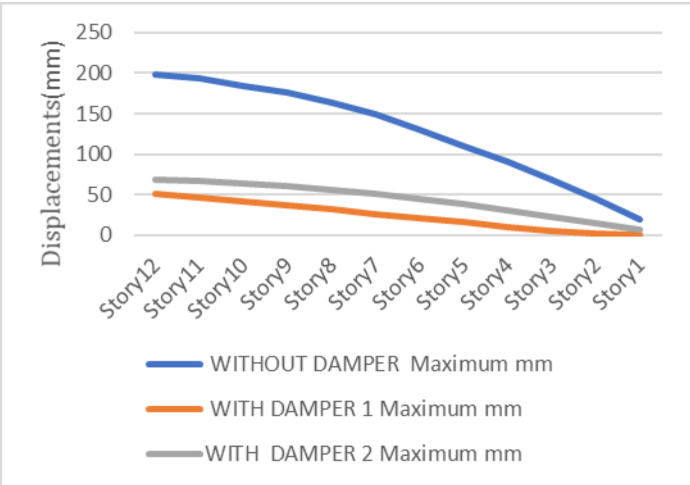

Chart -5 : Story displacement comparison for H shaped G+12 Buildings

- From the interrelation curves in figure , it is found that due to insertion of damper 1 in the building the displacements have been reduced by 86.5051% for G+12 (H-Shape) building, 68.19% reduction for insertion of damper 2 in the buildings.

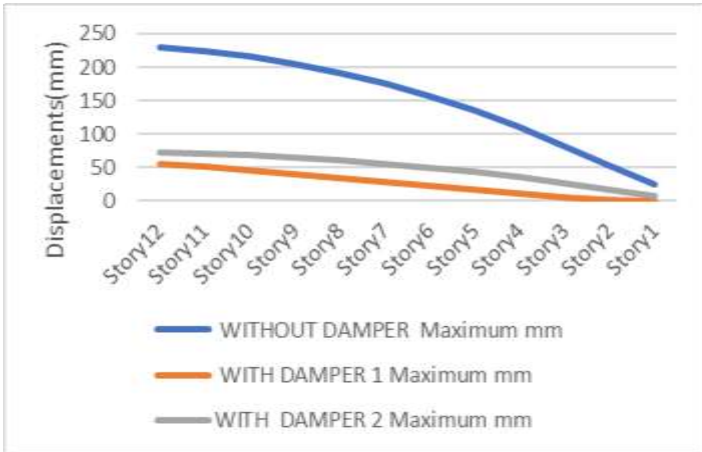

Chart -6: Story displacement comparison for Tube shaped G+12 Buildings

- Displacements have been reduced by 84.6% for G+12(Tube-Shape) building after insertion of damper 1, 66.2% reduction in displacements after insertion of damper 2 in the buildings.

The maximum story displacement permitted is 0.004 times the height of Storey as per IS 1893(Part 1) 2016 clause 7.11.1

- For G+12 Height=36.5meters, maximum story displacement = 0.004*36500=146mm
- For G+8 Height=24.5meters, maximum story displacement = 0.004*24500=98mm

Therefore, obtained values are within limits when dampers are used.

6.9 SAFE SEPERATION GAP

The minimum required gap distance is calculated as the Square Root of Sum of Squares (SRSS) as follows:

$$\Delta max = \sqrt{(\Delta 1^2 + \Delta 2^2)}$$

Where Δ1: the maximum displacement for one of the adjacent buildings.

Δ2: the maximum displacement for the second building at the same level considered in the first building.

Table 2: Safe separation gap

	G+12 AND G+8 (H-Shape)	G+12 AND G+8(Tube-Shape)
SAFE SEPRATION GAP	263mm	252mm

As per IS 1893(Part 1) 2016 clause 7.11.3, separation distance is equal to R/2 times the calculated Storey displacements as per 7.11.1 of each of them, to avoid damaging contact.

Where R is response reduction factor

Separation Gap = 5/2(146+98)=610mm.

7. CONCLUSIONS

The following conclusions are only valid to the limited study conducted

- The maximum response (displacement) is more in taller buildings than the shorter one.
- By providing the Fluid viscous damper(Damper1) at the corners the pounding effect is reduced significantly in terms of displacements by almost 85.625% in all cases when compared to adjacent buildings without dampers.
- By providing the plastic friction damper(Damper2) at the corners the pounding effect is reduced significantly in terms of displacements by almost 62.5% in all cases when compared to adjacent buildings without dampers.
- Base shear is reduced by almost 95% when fluid viscous dampers(Damper1)are used when compared to adjacent buildings without dampers.
- Base shear is reduced by almost 60% when plastic friction dampers(Damper2)are used when compared to adjacent buildings without dampers.
- when both the dampers are compared Fluid Viscous damper(Damper 1) is performing better in reducing the responses of the building than plastic(wen) friction damper(Damper 2).

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