Mid-Column Pounding Effects On Adjacent Tall Buildings and Its Mitigation Using Viscous Dampers and Friction Dampers

Nishath P.V and Abhilash P.P

Abstract— Seismologists have shown that, during earthquake, the building structures are vulnerable to severe damages. Among the possible structural damages, the seismic induced pounding has been commonly observed phenomenon. Collision of two building which are of different dynamic characteristics is called as seismic pounding. It may be much more serious if floors of one building hit at the mid height of columns in the other building (Mid-column pounding). In order to prevent this failure, the seismic gap between the structures must be sufficient to let structural displacements during strong ground motions. But sometimes availability of required safe separation gap is not possible in metropolitan cities due to high land value and limited availability of land. Among the different innovative techniques, which allow to control and modify the seismic response of structures, an important role have assumed for the passive control techniques such as dampers. In this paper, systematic studies regarding the mid-column pounding of regular RC buildings without dampers and with dampers at different locations of the buildings are investigated in ETABS V.16. For performing analysis, nonlinear dynamic time history analysis has applied to structure using El Centro ground motion data.

Index Terms— friction dampers, Gap element, Mid-column pounding, Non-linear time history analysis, Seismic pounding, Seismic gap, viscous dampers

1 Introduction

Adjacent buildings with insufficient separation, having different dynamic characteristics may vibrate out of phase during earthquakes causing pounding between them. The pounding of structures may lead to severe damage and even result in complete collapse. Seismic pounding damage was found to be significant between adjacent buildings during the 1985 Mexico, 1994 Northridge, 1995 Kobe, 1999 Kocaeli and 2008 Sichuan earthquakes. Pounding building scenarios can be generally categorized as floor-to-floor and floor to column pounding (mid-column pounding) as shown in Fig.1. Some of the major consequences of seismic pounding in buildings are concentrated local damage and increased floor accelerations.

The simplest and most appropriate way for pounding mitigation is to provide safe separation gap. But in metropolitan cities it is tough to fulfill due to high land value and non-availability of the land. The current research is focusing to evaluate the effects of structural pounding on the global response of building; to determine proper seismic hazard mitigation practice for already existing buildings as well as new buildings. Decreasing the lateral displacement and the effect of pounding by introducing the stiffeners like RC walls, bracings, dampers etc., is an alternative to the seismic separation gap provision in the structure design.

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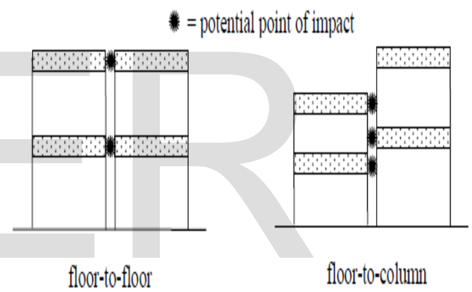

Fig. 1
pounding categorisation (source: G.L Cole (2010), Ref [15])

2 Mitigation Using Non-Linear Fluid Viscous Dampers

The current study focuses on fluid viscous dampers shown in Fig. 2. When the fluid viscous damper is subjected to external loads, the piston rod with piston will make reciprocating motion in the cylinder to force the silicone oil filled in it to move back and forth between the two cavities separated by the piston. When the fluid viscous damper strokes in compression, fluid flows from Chamber 2 to Chamber 1. When the fluid viscous damper strokes in tension, fluid flows from Chamber 1 to Chamber 2. The high pressure drop across the annular orifice produces a pressure differential across the piston head, which creates the damping force.

It develops a force which is a function of the relative velocity between its ends. The force/velocity relationship for this kind of damper, can be characterized as

$F = CV^{\alpha}$

α is the damping exponent and C is the damping coefficient. For non-linear viscous dampers, α is less than 1.

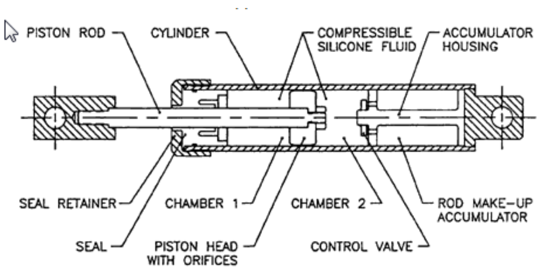

Fig.2 Fluid Viscous Damper

3 MITIGATION USING FRICTION DAMPERS

It is an excellent mechanism for energy dissipation, and has been used for many years in automotive brakes to dissipate kinetic energy of motion. In the development of friction dampers, it is important to minimize stick-slip phenomena to avoid introducing high frequency excitation. During severe seismic excitations, friction dampers slip at a predetermined optimum load before yielding occurs in other structural members and dissipate major portion of the seismic energy. This allows the building to remain elastic or at least yielding is delayed to be available during catastrophic conditions. By selecting proper slip load, it is possible to tune the response of the structure to an optimum value. The value of slip load ranges between 0.75 x yield strength to 1.3 x Shear force due to lateral loads. Stiffness of the damper is given as

$$K = 300 \, x \, Slip \; load$$

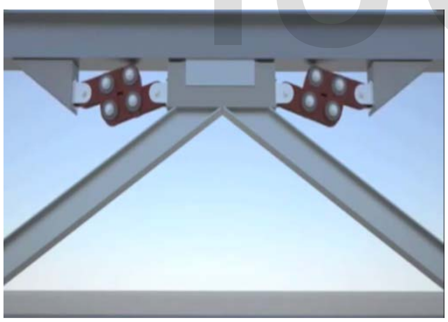

Fig 3. Friction Damper

4 NON-LINEAR TIME HISTORY ANALYSIS

Nonlinear dynamic analysis of structure is analysed under the ground excitation data of El Centro earthquake (magnitude 7.1, total duration 12.113 sec) at Imperial valley USA in year 1940, which is obtained from the PEER database [7]. It has a peak pounding acceleration of 0.319g at time 2.006 seconds. Damping of 5% is taken for earthquake ground motion. The graph of the function is illustrated in the Fig.4. Each record is divided into 6000 points of acceleration data equally spaced at 0.002 sec.

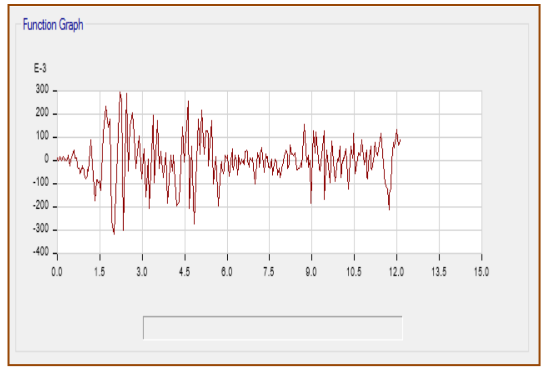

Fig 4. El Centro EQ Data

5 METHODOLOGY

The selected (G+9) and (G+6) buildings are assumed to be special moment resisting frame located in zone IV in medium soil having a separation gap of 80 mm intended for residential use. Both buildings are analyzed using ETABS v.16 and designed as per IS: 456:2000 [6]. Hertz non-linear spring gap element is used having stiffness of 4.77 x 10^5 kN/m [18]. They are subjected to gravity and dynamic loading. Live load on floor is taken as 3kN/m^2 and on roof is 1.5kN/m^2. Floor finish on the floor is 1kN/m^2 and weathering course on roof is 1kN/m^2. The seismic weight is calculated conforming to IS 1893-2002(Part-I) [3]. The unit weight of concrete is taken as 24kN/m^3. The weight of the masonry infill wall of 230 mm thickness is considered as UDL on the beam and also for seismic mass calculation. All columns in the models are assumed to be fixed at the base for simplicity. The height of ground floor for ten storey building is 4.5m and all the upper storey are 3m. The height of ground floor and upper floor of seven storey building is 3m. Slab of ten stories and seven stories are modeled as rigid diaphragm element of 0.14m and 0.13m thickness respectively, for all stories considered. The grade of concrete for column is M-25 and for beam and slab M-20.

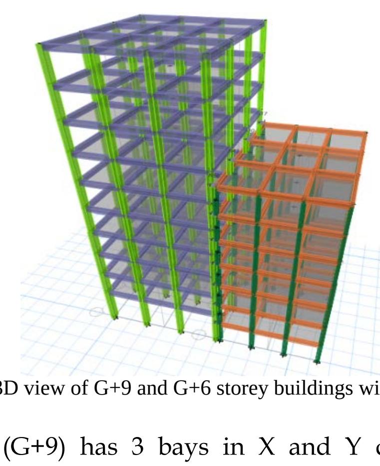

Fig.5 3D view of G+9 and G+6 storey buildings with gap element

Building-1 (G+9) has 3 bays in X and Y directions having width 3.5m and 4.5m respectively. Bottom four storeys of building has column dimension of 300 mm x 750 mm, whereas remaining columns of top six storeys are of 300 mm x 750 mm. The beam size is 300 mm x 475 mm in both the direction.
Building-2 (G+6) has 3 bays in X and Y directions having

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width 3.5m and 4.5m respectively. Bottom four storeys of building has column dimension of 300 mm x 450 mm, whereas remaining top three storeys are of 230 x 450 mm. Beam size is 230 mm x 475 mm in both the direction.

5 .1 Introducing Non-Linear Fluid Viscous dampers

In ETABS v.16, Viscous damper of type Damper-exponential is assigned to the structure in the form of chevron bracings of ISMC 225 throughout the height of the structure in both X and Y direction. They are provided at mid bays, end bays and all outer bays of the buildings.

TABLE 1

Properties of Viscous Damper along the X and Y Direction of Both the Building

Properties of viscous damper	G+6 along X direction	G+6 along Y direction	G+9 along X direction	G+9 along Y direction
Direction	U2	U3	U2	U3
Stiffness (KN/m)	350000	350000	250000	250000
Damping (KN*(s/m)^C exp)	750	750	750	750
Damping exponent	0.5	0.5	0.5	0.5

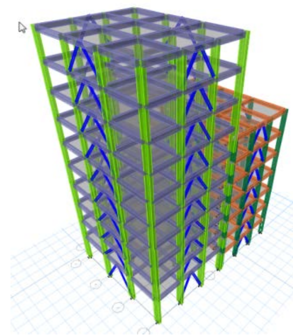
5.2 Introducing Friction dampers

The friction damper element is assigned to the structure in the form of chevron bracing throughout the height of the structure in both X and Y direction. Braces of ISMC 250 and ISMC 300 are used for G+9 and G+6 buildings respectively. They are provided at mid bays, end bays and all outer bays of the buildings

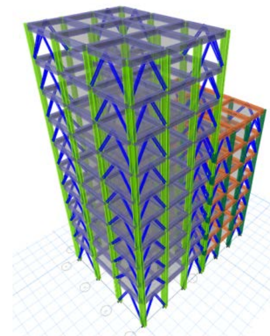
TABLE 2

Properties of friction dampers along the x and y direction of both the building

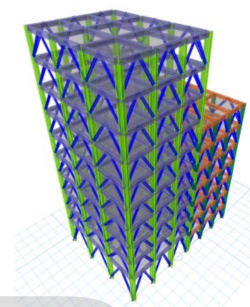
Properties of Friction dampers	G+6 along X direction	G+6 along Y direction	G+9 along X direction	G+9 along Y direction
Direction	U2	U3	U2	U3
Type	Plastic (Wen)	Plastic (Wen)	Plastic (Wen)	Plastic (Wen)
Stiffness (KN/m)	34800	34800	121500	121500
Yield strength (KN)	116	116	405	405
Post yield stiffness ratio	0.0001	0.0001	0.0001	0.0001
Yield exponent	10	10	10	10



(a) Mid Bays



(b) End Bays



(c) All Bays

Fig 6 Position of Viscous dampers and Friction dampers in buildings

6 RESULTS AND DISCUSSION

6.1 Time period

Modal analysis using Ritz method is carried out to obtain the mode shapes and fundamental time period of buildings with and without dampers.

TABLE 3

Fundamental time period of buildings without dampers

Cases	Fundamental time period in sec
Without dampers	1.902
With VD at mid bay	1.9
With VD at end bays	1.897
With VD at all bays	1.896
With FD at mid bay	1.435
With FD at end bays	1.242
With FD at all bays	1.03

6.2 Displacement and Pounding force

Displacement and pounding force of both G+9 and G+6 buildings at pounding level without dampers and with dampers at different locations of the buildings are shown in Figures given below.

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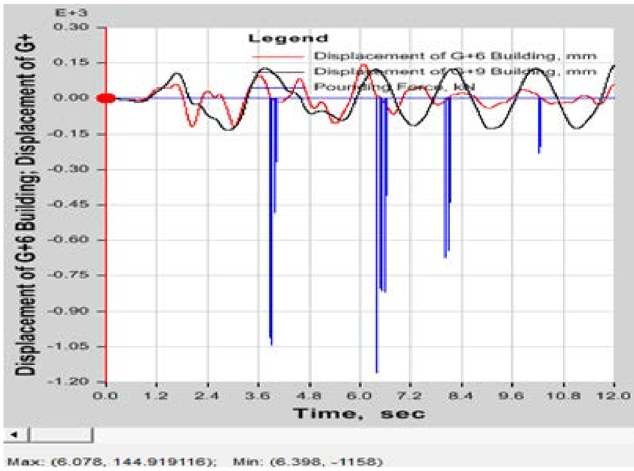

Fig7 Displacement and pounding force of buildings without dampers

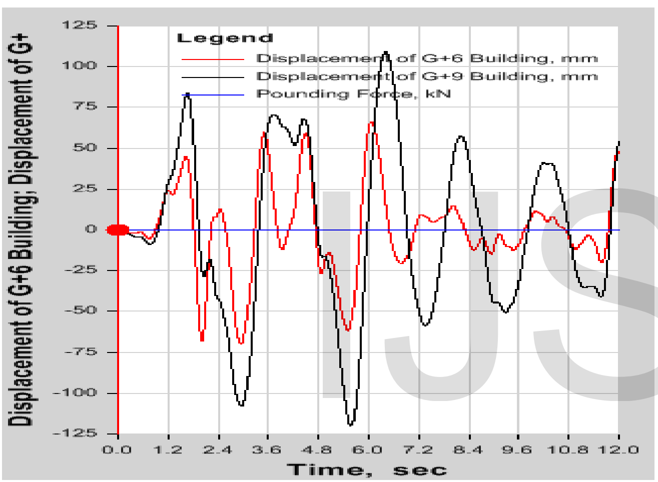

Fig 8 Displacement time history and pounding force of buildings with VD at mid bays

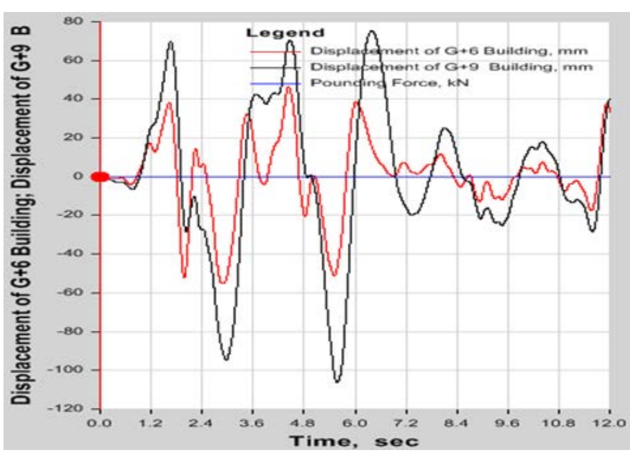

Fig 9 Displacement time history and pounding force of buildings with VD at end bays

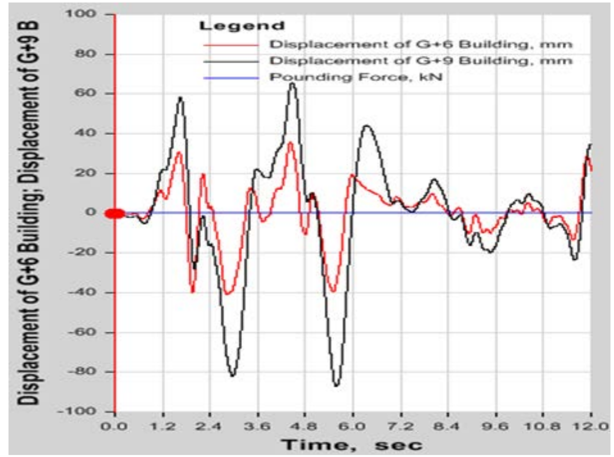

Fig 10 Displacement time history and pounding force of buildings with VD at all bays

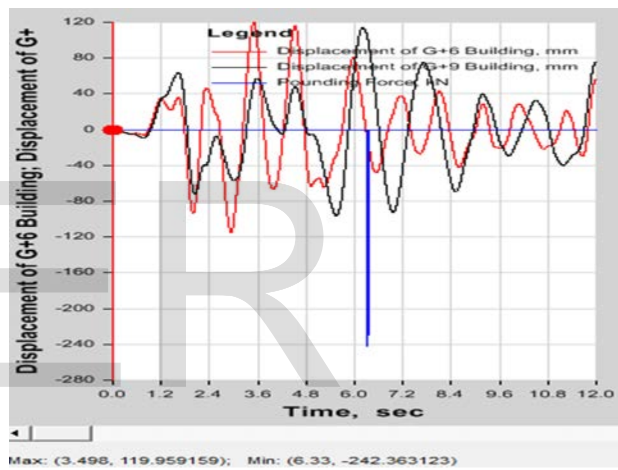

Fig 11 Displacement and Pounding force on buildings with FD at mid bays

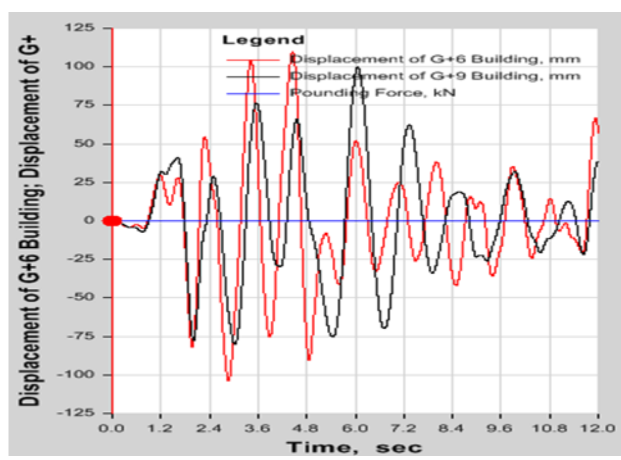

Fig 12 Displacement time history and pounding force of buildings with FD at end bays

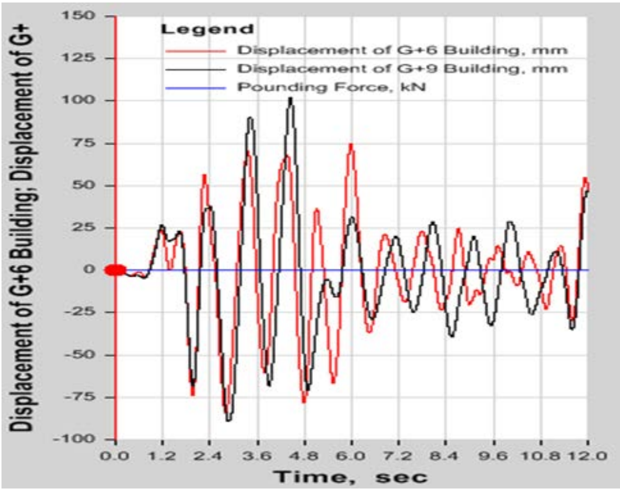

Fig 13 Displacement time history and pounding force of buildings with FD at all bays

TABLE 4

Displacement of buildings with and without dampers

Cases	Displacement in mm			
	G+9 Building		G+6 Building	
	Maximum positive	Maximum negative	Maximum positive	Maximum negative
Without dampers	+140	-134.64	+144.91	-119.29
With VD at mid bays	108.96	-119.85	66.16	-69.79
With VD at end bays	75.36	-106.31	46.58	-55.15
With VD at all bays	65.65	-87.35	35.86	- 41.08
With FD at mid bays	113.88	-96.24	119.95	-114.85
With FD at end bays	99.98	-80.30	109.54	-103.92
With FD at all bays	101.77	-89.27	74.54	- 84.17

TABLE 5

Pounding force and number of impacts with and without dampers

Cases	Pounding force in KN	No. of Impacts
Without dampers	1158	78
With VD at mid bays	0	0
With VD at end bays	0	0
With VD at all bays	0	0
With FD at mid bays	242.36	9
With FD at end bays	0	0
With FD at all bays	0	0

7 CONCLUSION

1. Time period, pounding force, number of impacts and displacement are more without placing dampers at the buildings
2. By placing dampers at different location of the buildings, Time period, displacement, number of impacts and pounding forces are reduced.
3. Providing sufficient seismic gap is the best solution to avoid pounding phenomenon.
4. Viscous dampers placed at different locations of the buildings mentioned in this study are highly promising for pounding mitigation.
7. Considering the functionality of buildings and the economy, providing Viscous dampers at mid bays of buildings are more effective in pounding mitigation.
8. Among Friction dampers at different locations of the buildings, which is provided at end bays of buildings are more economic.

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