Analysis and Retrofitting of Building Structures for Ponding Forces

Qureshi Taqweem.B.S[1], Arshad K.Hashmi[2]
[1]PG Student,
Department of Civil Engineering, MGM's College of Engineering, Nanded, BATU Lonere - 4021031,
(Maharashtra, India.),
m18_qureshi_taqweembegum@mgmcen.ac.in
[2] *Associate Professor,*
Department of Civil Engineering, MGM's College of Engineering, Nanded, BATU Lonere - 4021031,
(Maharashtra, India.),
hashmi_arshad@mgmcen.ac.in

Abstract*: Learned from recent and past Earthquake, post-earthquake damages sustain structural and non-structural damage in the building even collapse of structures. This may cause the building non-functional after the earthquake, which may be problematic in some structures, like hospitals, which need to remain functional even after the earthquake. Among the all-possible damages pounding is commonly observed in several earthquakes. A parametric study carried by taking two adjacent buildings G+13(45.1m) and G+8 (24.1m) for pounding forces. Two different ground motion data for input Chamoli, Elcentro Considered. The effect of pounding force is studied using nonlinear time histories in ETABS Software. Gap element is connected to calculate the pounding force between buildings. Pounding Force can be reduced effectively when separation gap provided is sufficient but Due to high land cost in densely populated areas these structures are constructed very close to each other. When two buildings are too close to each other they may Collides, which leads to pounding during strong ground motion .so it's required to protect buildings by using special tools. For that small building is considered stiff and taller building retrofitted with fluid viscous damper to reduced pounding forces significantly. This paper deals with the analysis of pounding behavior of adjacent buildings retrofitted with fluid viscous damper. Comparative Study for different model is carried out in terms of pounding force (impact force), displacement, number of impacts, Effect fluid viscous damper to reduce global damping with or without retrofitting.

***Keywords*: Seismic pounding, Retrofitting, Nonlinear time History, Seismic analysis.**

(**Article history: Received**: **Received: 30th October 2021 and accepted 22nd December 2022)**

I. INTRODUCTION

Nowadays in Metropolitan areas industries as well as population are growing fast. Because land cost is very high so the buildings were constructed close to each other. Due to inadequate Separation gap between the structures, they gets collides with each other when earthquake comes. Collision of neighbouring buildings or different parts of the buildings during ground motion is called pounding which can be cause damages to the structure even collapse of the whole structure seen in some cases.

A. Factors affecting pounding

The following factors which are influencing the pounding between two adjacent buildings: Seismic pounding damages maximum occurs, if two adjacent buildings having different heights with floors at different levels and with inadequate separation. Such buildings can vibrate out of phase and collides with each other introduces impact loads.

B. Fluid viscous dampers

Incorporating fluid viscous damper is best way to dissipate energy which is absorbed by Structural member in the form of global damping. It reduces up to 30% of critical damping in the structure or in some cases more. The fluid viscous damper activated even for small movement of structure during strong motion and consequently impact forces reduce significantly. Critical to the Structure and sometimes even more. Fluid viscous damper proves effective to reduce impact forces

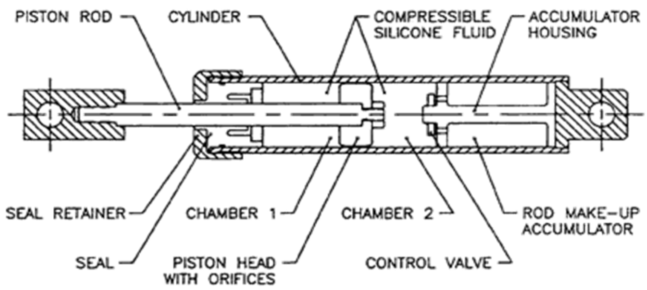


Figure. 1 of Fluid Viscous Damper [1]

exerted on building. The output force of Damper can be determined using formula:

$$F= C * V^{\alpha}$$

Above equation gives relation between output force of damper and its relation with the velocity.

Where, 'C' is the damping coefficient, 'V' is velocity and 'α' is the velocity exponent respectively.

A value is equal to 1.0 shows linear dampers, whereas values of α ranges from 0.3 to 1.0 for nonlinear dampers.

II. Case Studies on Pounding

Followings are several instances of pounding damages. Mexico City earthquake [2-9] on 19th September 1985, out of the 114 structure 20% structures was damaged because of pounding. During Loma Prieta earthquake in 1989 many old buildings suffered [10-19]. Pounding damages observed because of insufficient separation gap seen at 6^{th} level of ten storey building. Indian earthquakes observations on pounding from are as follows: pounding damages seen at expansion joint of hostel building at Manipal institute of medical science during Sikkim earthquake on 14th February 2006 [20-26]. The most damaging earthquake in India from last five decades is Bhuj earthquake [27-31]. Because of poor construction and designing so many Reinforced concrete buildings suffered to heaviest damage during the earthquake. Significant damages of Pounding between adjacent buildings seen at Ayodhya apartments in Ahmadabad. Pounding damage was observed at expansion hinges of the Santa Clara River Bridge during 1994 Northridge earthquake [32-34].

III. Statement of Problem

When Adjacent Structure or buildings are too close to each other they may collides which leads to pounding phenomenon. This may sustain structural and non-structural damage in the building even collapse of structures. This may be big problem in important structures, like hospitals, educational buildings. structures need to remain functional even after the earthquake. To prevent pounding it's necessary to provide safe separation distance specified by code. In metropolitan cities getting sufficient separation gap is really big problem to prevent pounding, so we need some cost-effective and secures retrofitting methods to reduce pounding forces. To reduce pounding damages different ways can be adopted. It can be reduced by Improving Stiffness of buildings to reduce displacements or by adding some energy dissipating device to the structure. In this study the fluid viscous damper is used to retrofit the structure to smoothen sudden changes in stiffness during pounding or to reduce pounding forces significantly. This study focuses on behavior of adjacent building for pounding using ETABS software to predict pounding forces nonlinear time histories carried out. The main objective of this paper is to evaluate pounding forces, to retrofit already existing buildings as well new buildings. Investigation carried out to identify different parameter with or without retrofitting.

IV. Analysis and Retrofitting

Two existing buildings are considered [35]. An expansion gap of 50mm is provided. Both the buildings then connected using gap element. First building is G+13 having height of (45.1m) and second building is G+8 having total height (24.1m). The provided gap is an expansion gap and not a seismic gap to have better idea about pounding behavior of adjacent buildings. The maximum lateral displacement of both the structure is calculated as per clause7.11.1 of IS 1893(Part1). In this clause state that, Storey drifts shall not exceed 0.004 times Storey height. The calculated seismic gap as per clause 7.11.3 of IS 1893:2002 is 1392 mm. It shows that there is chances of pounding. it is really very difficult to predict the pounding force because of its nonlinear behavior Pounding is purely dynamic in nature. To have better understanding about pounding force the buildings are then subjected El Centro and Chamoli earthquake ground motion. for the study different model were modeled in ETABS software.

Model I (M1): G+13 and G+8 buildings separated by a gap of 50mm.both the building then connected by link element.thickness of slab is cosidered as 150 mm.floor to floor height is taken 3.2m. 3.0 kn/m2 live load considered.floor finish is taken as 1.87 kn/m2. the first model is of without damper. This model considered as basic model. Nonlinear time history is carried out for Elcentro, Chamoli ground motion data using ETABS Software. For the modal analysis Modal Ritz's vector are used. The beams and column sizes are used Describe in Table 4.1.

Table 4.1 Sizes of members

Building Description	Storey	Sizes of beams (mm)	Size of columns
G+13	1,2,3	300 x 450	600 x 600
	3 to 9	300 x 450	500 x 500
	9 to 14	300 x 450	400 x 400
G+8	1,2,3	300 x 450	500 x 500
	4 to 9	300 x 450	400 x 400

Slab is modeled using membrane element. Gap element is used to connect buildings having properties gap. G+8 Building considered stiff building and the stiffness of the gap element calculated by taking 20 times the stiffness of the stiffer building (Anagnostopoulos and Spiliopoulos). M25 grade of concrete and Fe 415 grade of Steel are used for all columns slabs and beams of the building.

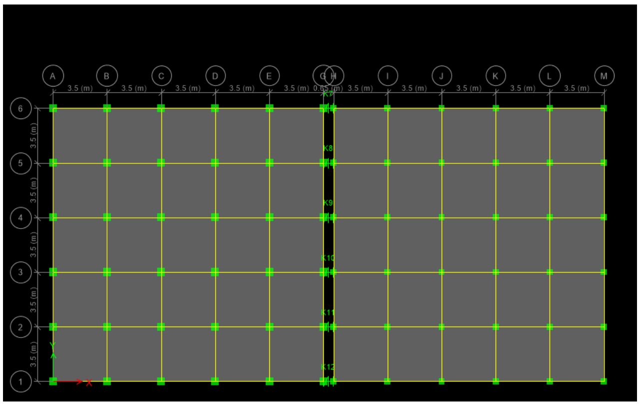


Figure 4.1 Typical plan of building

Figure 4.2 Showing Gap Elements

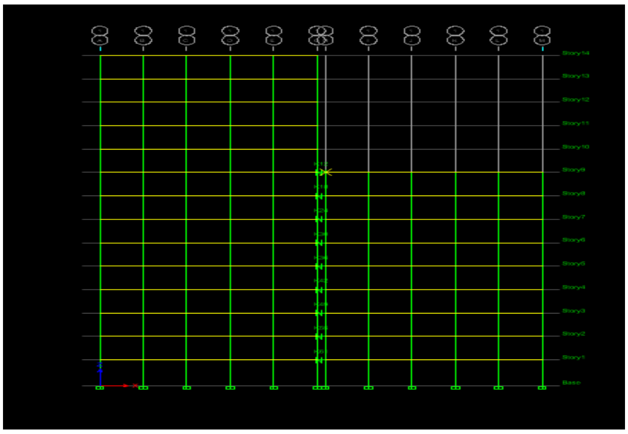


Figure 4.3 (a) Elevation of Model M1

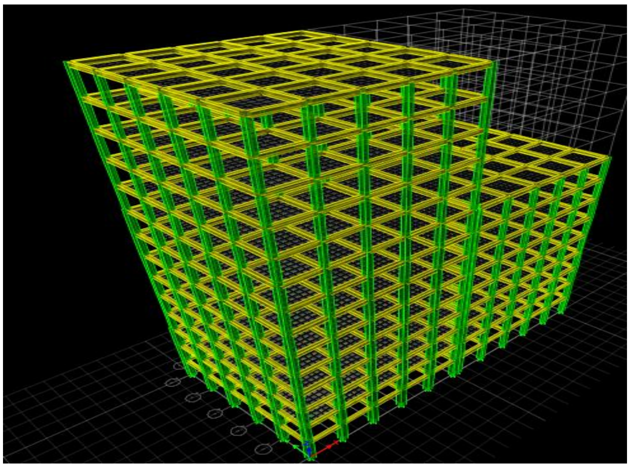


Figure 4.4 (b) building 3D Model M1

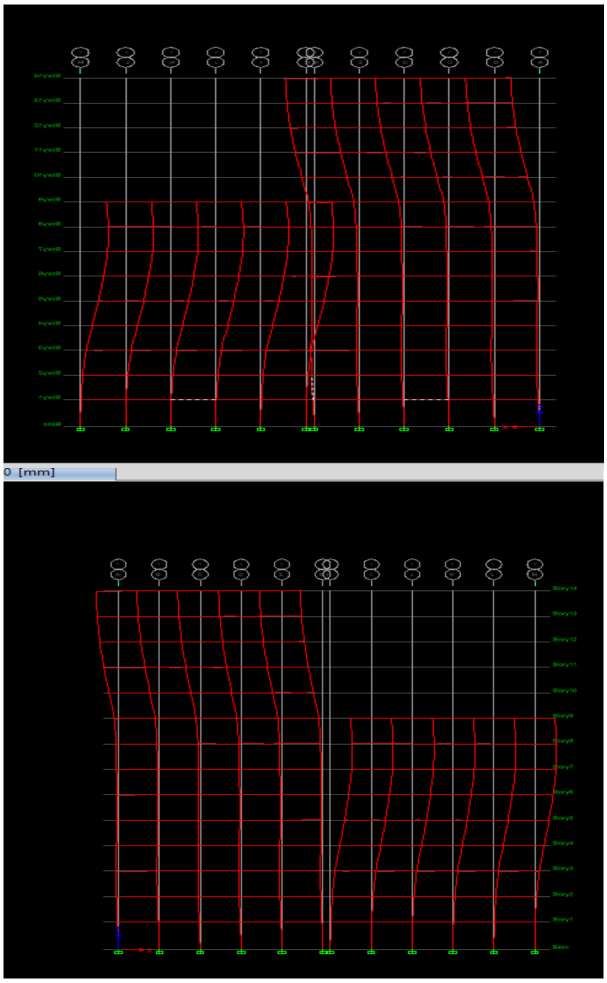


Fig 4.5 Model M1 Shows Pounding Effect

*A. Model II (M2):*Both adjacent buildings are separated by gap of 50mm. with FVD at outer corner. The damper is modeled as link element type damper exponential were selected the property of Damper used in this Study is provided by Taylor's Devices India after Request. the stiffness of damper is kept around 10^2 times the stiffness of surrounding elements.

TABLE 4.2 CALCULATED PROPERTIES OF DAMPERS

Mass (Kg)	*Weight (KN)*	*Damping Coefficient(C) (KN-s/m)*	*Damping exponent*
302	2.96	1600	0.3

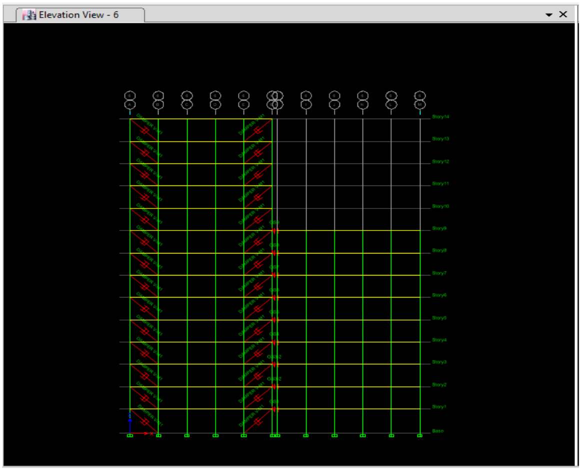


Figure 4.6 (a) Model M2 Elevation

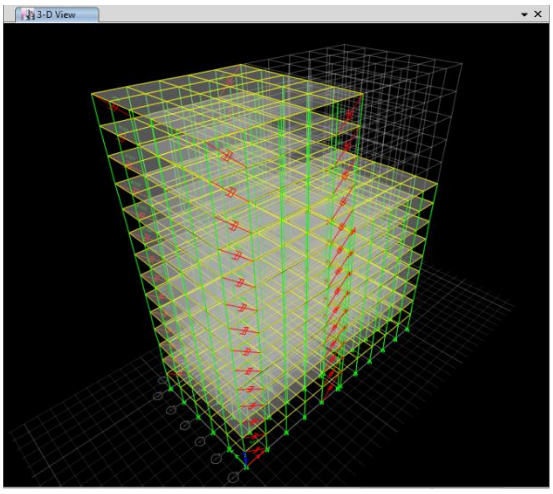


Figure 4.6 (b) 3D Model M2

B. *Model II (M3)*

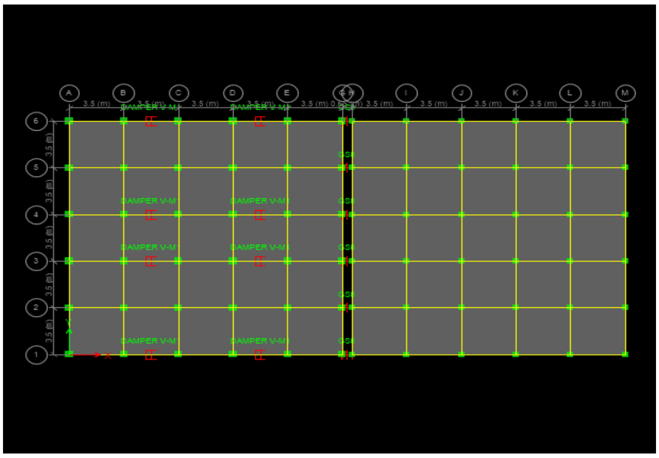


Figure 4.7 (a) Plan model M3

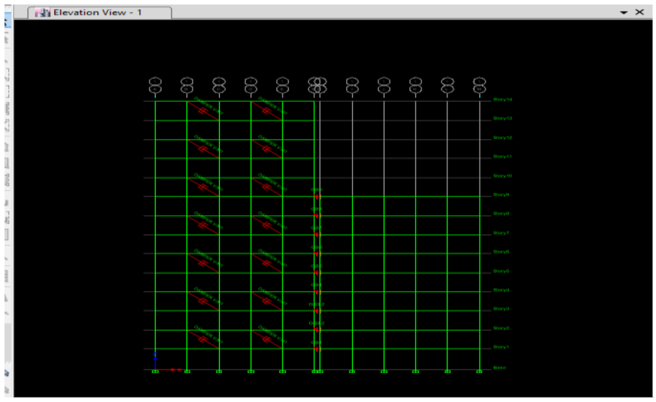


Figure 4.7 (b) Elevation model M3

V. RESULTS AND DISCUSSION

The results obtained from analysis subjected to different ground motion in the form of pounding force are presented below. Figures 5.1 illustrated impact forces vs. time history responses at the roof levels of the G+8 story building for different models under Elcentro and Chamoli earthquake, since the top levels experience the most critical condition.

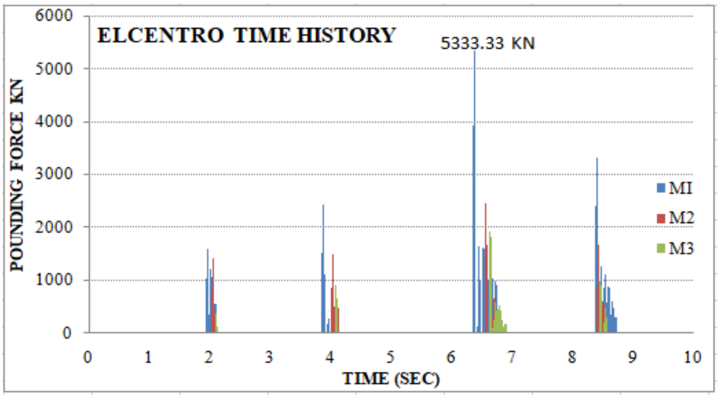


Figure 5.1 Time history of pounding force at Roof Level G+8

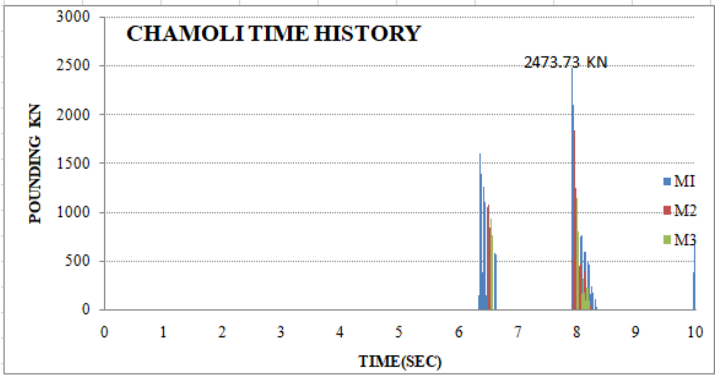
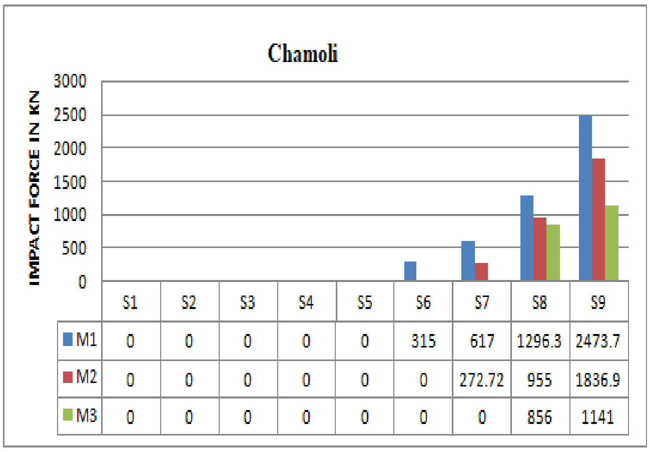


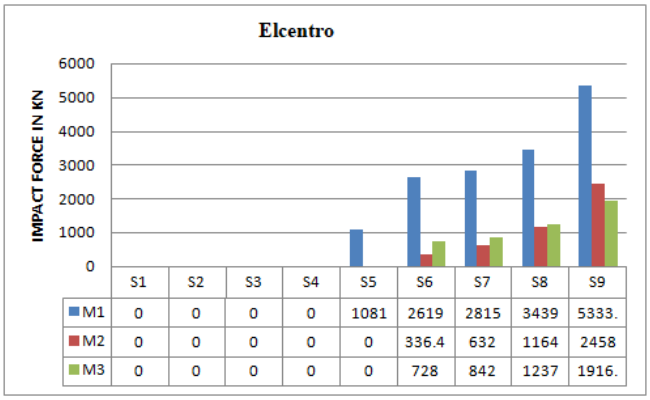
Figure 5.2 Time history of pounding force at Roof Level G+8

The story wise impact forces for all the time histories are shown below.



	S1	S2	S3	S4	S5	S6	S7	S8	S9
M1	0	0	0	0	0	315	617	1296.3	2473.7
M2	0	0	0	0	0	0	272.72	955	1836.9
M3	0	0	0	0	0	0	0	856	1141

Figure 5.3 Storey wise maximum impact force



	S1	S2	S3	S4	S5	S6	S7	S8	S9
M1	0	0	0	0	1081	2619	2815	3439	5333.
M2	0	0	0	0	0	336.4	632	1164	2458
M3	0	0	0	0	0	728	842	1237	1916.

Figure 5.4 Storey wise maximum impact force

It's observed that the reduction in impact forces is maximum in third case up to 64% where damper is provided at alternate bay alternate floor (M3) as compared to MI. also Seems that in both the case the story 5 becomes fully free from impact forces. In M2 the percentage of Reduction is unto 54% as compare to model without Damper.

Figure shown below is for the relative displacement time history. Displacement for model MI is more for Elcentro at initial stages whereas in Chamoli its seen minimum. The displacement time history for gap element shows Positive values opening and relative displacements, while negative values result from the event of impact causing the pounding i.e., maximum Displacement is limited to 50mm.the values beyond the 50 shows there is impact which cause pounding. Large displacement has controlled in M3for Chamoli case as compare to model MI. so changes of pounding is reduced as in Chamoli case as compare to Elcentro.

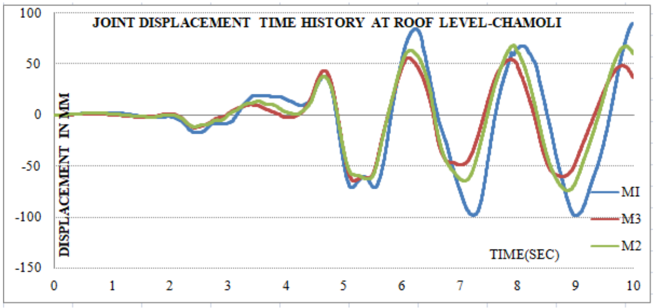


Figure 5.5 Joint Displacements at Roof Level of G+9 Chamoli.

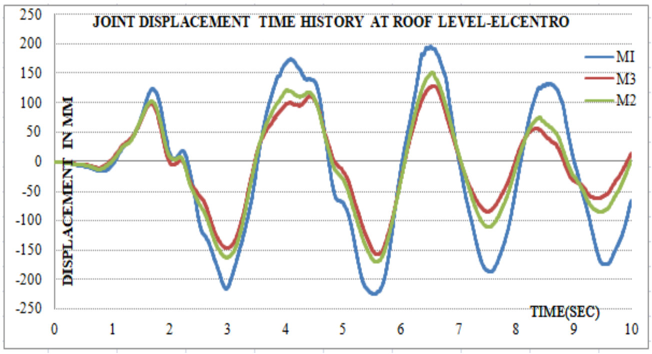


Figure 5.6 Joint Displacements at Roof Level of G+9 Elcentro

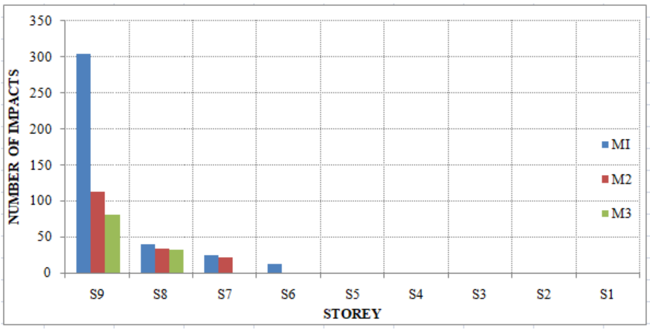


Figure 5.7 Storey Wise number of impact Chamoli

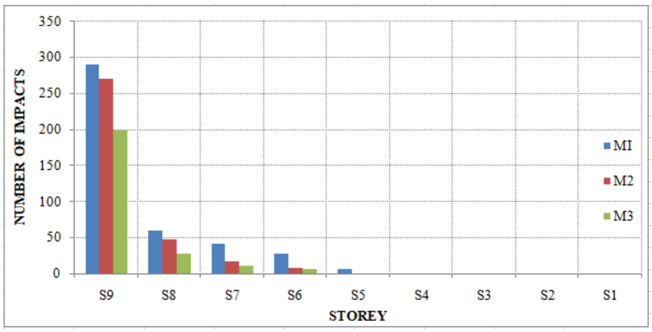


Figure 5.8 Story wise no. of impact for Elcentro

Damages due to pounding are not only due to high magnitude of collision but also, it's due to impact forces. Above figure shows the story wise impact force. large number of impacts is observed in Elcentro at storey 9. There is no collision seen at story 5 for M2 M3 as compare to MI.

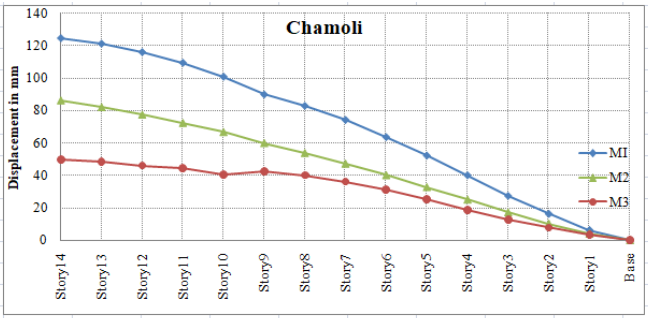


Figure 5.9 Storey wise Roof Displacement Chamoli

It can be seen that displacement of porposed structure with damper i.e M3 less than that of Structure without damper . the avarege percentage of reduction is upto 60% at roof level of taller buiding.whereas in M2 the percenage of reduction is 31%

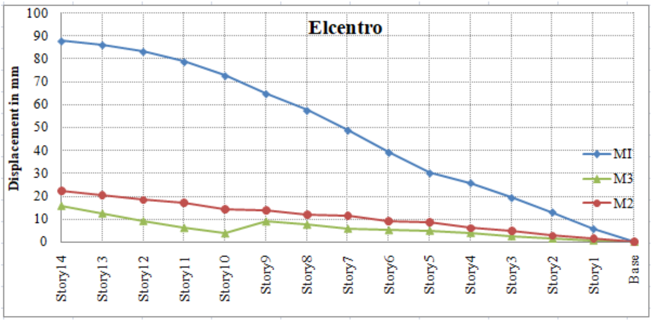


Figure 5.10 Storey wise Roof Displacement Elcentro

In case of elcentro time history large displacemnt control observed in both the case i.e M2 and M3 as compare to MI Cumulative Energy plot shown below

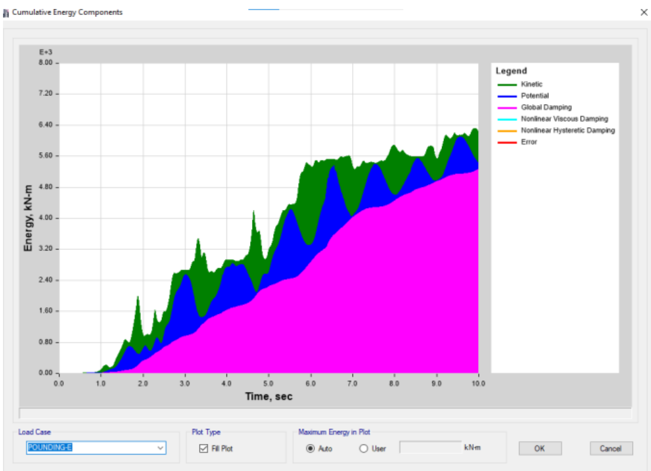


Figure 5.11 Cumulative Energugy plot model MI

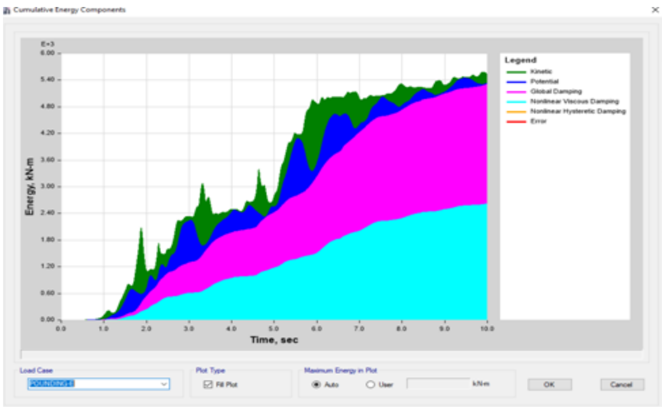


Figure.5.12 Cumulative Energy plot model M2

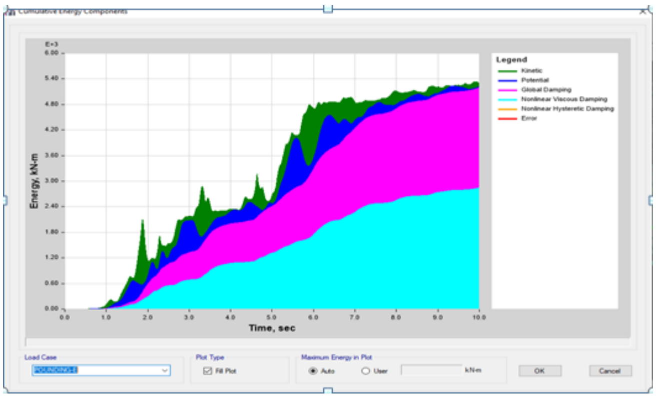


Figure.5.13 Cumulative Energy plot model M3

Figure 5.11 to 5.13 illustrates the cumulative energy absorption by the structures during the seismic event due to pounding load. Fig. 5.11 illustrates energy response of M1; the major portion of energy is damped (or absorbed) through global damping by different structural elements of the building giving huge cumulative structural damage. On the other side Fig 5.11 and 5.12 shows the energy response of Model M1 and M2, it illustrates that major portion of global damping is reduced by non-linear viscous damping. Thus, in M2 and M3 the damping due to structural elements is less, thus overall structural damage/ deformation has been reduced. This can be validated through figure 3.23 where retrofitted buildings (i.e., M2 and M3) give less displacement and thereby less structural damage.

VI. CONCLUSION

- It does always recommend that to provide sufficient gap as per codal provision.
- If not possible due to unavoidable circumstances, then provide energy dissipating systems i.e., use of Fluid viscous damper because its damping capacity is more.
- Pounding is more when the buildings having different heights like small building is colliding at mid height of building which make the buildings none functionally.
- Dampers are really effective in reducing pounding force, number of impacts also in reducing story

displacement. It can be used as retrofitting measure to reduce pounding effect.

- Maximum impact force is for Elcentro earthquake seen in model MI at story 9
- The reduction in impact forces is maximum in third case up to 64% where damper is provided at alternate bay alternate floor (M3) as compared to MI.
- In M2 the percentage of Reduction is unto 54% as compare to model without Damper. Both the case the story 5 becomes fully free from impact forces.
- Large number of impacts is observed in Elcentro at storey 9. There is no collision seen at story 5 for M2 M3 as compare to MI.
- It can be seen that displacement of porposed structure with damper i.e M3 less than that of Structure without damper . the avarege percentage of reduction is upto 60% at roof level of taller buiding.whereas in M2 the percenage of reduction is 31%.
- The location of damper is higly influence the pounding force.

ACKNOWLEDGEMENT

I express thanks from bottom of heart to my guide Dr. Arshad.K.Hashmi for providing the valuable guidance and encouragement to embark on this Dissertation. I acknowledge my gratitude and immense respect to our Head of Department, Prof. P. M. Shimpale. I extend my sincerely thanks to our respected Director, Dr. Mrs. Geeta. S. Lathkar inspired me a lot to achieve the highest goal. Finally, I would like to expand my thanks to all teaching and non-teaching MGM College Civil Engineering Department staff that helped me directly or indirectly complete my Dissertation.

REFERENCES

[1] Taylor D.P., Michael C. Constantian, "Development and testing of an improved fluid damper configuration for structures having high rigidity" Report by Taylor Devices Inc.

[2] Bruce F Maison and Kazuhiko Kasai., "Analysis for Type of Structural Pounding", Journal of Structural Engineering, vol.116, No. 4, pp. 957-977, 1990.

[3] Anagnostopoulos S A and Konstantinos V Spiliopoulos, "An Investigation of Earthquake Induced Pounding between Adjacent Buildings", Earthquake Engineering and Structural Dynamics, vol.21, pp. 289-302, 1992.

[4] Jeng-Hsiang Lin., "Separation Distance to Avoid Seismic Pounding of Adjacent Buildings", Earthquake Engineering and Structural Dynamics, vol 26, pp. 395-403, 1997.

[5] Pantelides C P and Ma X, "Linear and Nonlinear Pounding of Structural Systems", Computers and Structures, vol.66, No.1, pp.79-92, 1998.

[6] Symans, M. D., & Constantinou, M. C.., "Passive fluid viscous damping system for seismic energy dissipation". ISET Journal of Earthquake Technology, 35(4), 1998, 185-206.

[7] Jain, S. K., Murty, C. V. R., Dayal, U., Jaswant, N. A., & Sailender, K. C. (2001). "A field report on structural and geotechnical damages sustained during the 26 January 2001 M7. 9 Bhuj Earthquakes in Western India." Department of Civil Engineering, Indian Institute of Technology, Kanpur, India.

[8] Lee, D., & Taylor, D. P.., "Viscous damper development and future trends". The Structural Design of Tall Buildings, 10(5), 2001 ,311-320.

[9] Jeng-Hsiang Lin and Cheng-Chiang Weng, "A Study on Seismic Pounding Probability of Buildings in Taipei Metropolitan Area", Journal of the Chinese Institute of Engineers, vol. 25, No. 2, pp. 123-135, 2002.

[10] Chau K T, Wei X X, Guo X and Shen C Y., "Experimental and Theoretical Simulations of Seismic Poundings between Two Adjacent Structures", Earthquake Engineering and Structural Dynamics, vol.32, pp. 537-554, 2003.

[11] Diego Lopez Garcia., "Separation between Adjacent Nonlinear Structures for Prevention of Seismic Pounding", Proceedings on 13th World Conference on Earthquake Engineering, 2004.

[12] Abdel, R. and E. Shehata., "Seismic Pounding between Adjacent Building Structures". Electronic Journal of Structural Engineering.pp. 66-74 2006.

[13] Kaushik, H. B., Dasgupta, K., Sahoo, D. R., & Kharel, G. (2006). "Performance of structures during the Sikkim earthquake of 14 February 2006". Current Science, 449-455.

[14] S. A. Anagnostopoulos and C. E. Karamaneas., "Collision Shear Walls to Mitigate Seismic Pounding of Adjacent Buildings", The 14th World Conference on Earthquake Engineering October 12-17, 2008, Beijing, China.

[15] Alireza M Goltabar, R Shamstabar Kami and An Ebadi. "Study of Impact between Adjacent Structures during of Earthquake and Their Elective Parameters", American of Engineering and Applied Sciences, pp. 210-218, 2008

[16] Abdel-Mooty, M., H. Al-Atrpy, and M. Ghouneim., "Modeling and analysis of factors affecting seismic pounding of adjacent multi-story buildings." WIT Trans Built Environ 104 (2009): 127-138.

[17] Aguilar J, Jurez H, Ortega R and Iglesias J., "The Mexico Earthquake of September 19, 1985. Statistics of Damage and of Retroftting Techniques in Reinforced Concrete Buildings Affected by the 1985 Earthquake", Earthquake Spectra, vol.5, Issue1, pp.145-151, February.

[18] Madan A. and Hashmi A.," Performance Based Seismic Retrofit of Masonry Infilled Reinforced Concrete Frames using Passive Energy Dissipation Devices", International Journal of Civil, Architectural, Structural and Construction Engineering, World Academy of Science, Engineering and Technology, 8(12);2014; 1256-1264

[19] Madan Alok, Gupta A. Hashmi A., "Pushover analysis of masonry Infilled Reinforced Concrete Frames for Performance Based Design for Near Field Earthquakes", International Journal of Civil, Architectural, Structural and Construction Engineering, 9(8);2015; 1049-1055.

[20] Sinha, A. K., & Singh, S., "Seismic protection of RC frames using friction dampers". Journal of Civil Engineering and Technology, 8(2), 2017.

[21] Hashmi.A.K .,"Design Aids for Seismic Strengthening of Reinforced Concrete Beams", The Indian Concrete Journal, 90(4); 2016, 93-100.

[22] Raheem, Shehata E. Abdel, "Numerical simulation of potential seismic pounding among adjacent buildings in series" Bulletin of Earthquake Engineering 17.1 (2019): 439-471.

[23] Hashmi A., Madan A., "Seismic Performance of Masonry Infilled Reinforced Concrete Structures", Indian Concrete Journal, 91 (5), 2017, 24-33.

[24] Bruce D.Westermo., "The Dynamics of Interstructural Connection to Prevent Pounding", Earthquake Engineering and Structural Dynamics, vol.18, pp. 687-699, 1989.

[25] William E. Gates, Gary Hart, Hamid Mahramzadeh, Sampson Huang, David Lee and Larry Jacobson, "Torsional control of two adjacent office buildings using viscous dampers", Applied Technology Council-17-2.

[26] Hashmi.A., "Preliminary Design and Analysis of Masonry Reinforced Concrete Frame Based on Storey Drift Limitations under Lateral Loads", Journal of Structural Engineer, SERC, CSIR, 41(5); 2014; 509-523.

[27] Yukihiro Tokuda and Kenzo Taga., "A case of structural design in which viscous dampers is used to enhance earthquake resisting performance of a building". The 14th World Conference on Earthquake Engineering Beijing, China. October 12-17, 2008.

[28] Hashmi A. and Madan A, "Fragility Analysis of Masonry Infilled Reinforced Concrete Frames for Near Field Earthquakes", KSCE Journal of Civil Engineering, 24(1), 2020, 122-130.

[29]Hashmi A and Madan A., "Damage Forecast of Masonry Infilled Reinforced Concrete Framed Building Subjected To Earthquakes In India" Current Science, 94 (1); 2008; 61-73.

[30] Mcnamara, Robert J., and Douglas P. Taylor., "Fluid viscous dampers for high- rise buildings." The structural design of tall and special buildings" 12.2 (2003): 145-154.

[31] Madan A., D. Das and Hashmi A, "Performance Based Design of Masonry InfilledReinforced Concrete Frames for Near Field Earthquakes." Proceedings of 12th international conference on Optimum Design of Structures and Materials in Engineering, WIT Transactions on The Built Environment, 125, (2012),203-216, New Forest, UK.

[32] Kazuhiko Kasai and Bruce F. Maison, "Building Pounding Damage during the 1989 Loma Prieta Earthquake", Engineering Structures, vol.19, No.3, pp.195-207, 1997.

[33] Murty, C.V.R, "Earthquake Tips Learning and Earthquake Design and Construction", National Information Center of Earthquake Engineering, IIT Kanpur, India, September, 2005.

[34] IS 1893 (part 1):2002 "Indian standard Criteria for Earthquake Resistant Design of Structures", part 1 General Provisions and buildings, New Delhi.

[35] CSI Analysis Reference Manual, Computers and Structures, Inc.

AUTHOR PROFILE

Taqweem.B.S Qureshi
PG Student,Department of Civil Engineering, MGM's College of Engineering,Nanded, BATU Lonere - 4021031,(Maharashtra, India.).

Arshad K. Hashmi
Associate Professor, Department of civil Engineering, MGM's College of Engineering, Nanded, 431605 (Maharashtra, India.).