Sustainability, Agri, Food and Environmental Research, (ISSN: 0719-3726), 11(X), 2023:
http://dx.doi.org/10.7770/safer-V12N1-art2782

Seismic pounding effect on two adjacent RC framed multistorey buildings using time history analysis.

Efecto de golpe sísmico en dos edificios de varios pisos con armazón de RC adyacentes utilizando análisis de historia de tiempo.

Aditi V. Khurd[1], Jui S. Dixit[2], Manjiri V. Paraskar[3], Nitin R. More[4] & Prof. Suhasini N. Madhekar[5]

1- Kolhapur, INDIA, email: khurdav17.civil@coep.ac.in

2- Pune, INDIA, email: dixitjs17.civil@coep.ac.in

3- Amravati, INDIA, email: paraskarmv18.civil@coep.ac.in

4- Jalgaon, INDIA, email: morenr17.civil@coep.ac.in

5- Department of Civil Engineering, College of Engineering Pune, INDIA, email: snm.civil@coep.ac.in

ABSTRACT

Seismic pounding is defined as the collision of structures during earthquakes when these structures have different dynamic characteristics. It is an instance of rapid strong pulsation like hammering and repeated heavy blows. This pounding of closely spaced buildings can be seen largely in some densely populated urban areas. Some modern codes have included seismic separation gap requirement clauses for adjacent structures but since large parts of metropolitan cities in seismically active regions of India were built before such requirements were introduced, the seismic separation gap requirements have not been fulfilled. Pounding can be catastrophic and even more dangerous than the effect of earthquakes on a single building. Thus, the action of pounding of buildings needs to be mitigated to avoid loss of life and property during earthquakes. The problem of pounding is particularly common in many cities in India, located in seismically active zones, where due to various socio-economic factors and land usage requirements, buildings are often constructed crowded together. This paper is focused on the study of the seismic pounding between two RC buildings with different dynamic characteristics. A systematic study of response of seismic pounding between adjacent buildings and seismic hazard mitigation practices like effect of different separation distances and effect of providing dampers are investigated, using the ETABS software. A 12-storey and a 16-storey building have been considered for the study of pounding. Time history analysis is carried out for seven real earthquake ground motions on the models with varying separation gaps. The results were obtained in the form of pounding force and point displacements. It is revealed that the pounding effect varies inversely with the separation distance. With increasing separation distance pounding effect is reduced greatly and so the damage to the neighbouring buildings is also minimized. Also, the pounding forces are seen to be decreasing considerably between the adjacent buildings due to the provision of dampers at suitable locations, as compared to the case of adjacent buildings without dampers. The study even confirms that the pounding effect can be mitigated considerably by installing dampers between adjacent structures. Dampers modelled in this study prove to be effective in reducing the displacement and drift in the range of 15%-20%.

Keywords—ETABS, Seismic pounding, separation gap, time history analysis.

RESUMEN

El golpe sísmico se define como la colisión de estructuras durante terremotos cuando estas estructuras tienen diferentes características dinámicas. Es un ejemplo de pulsaciones fuertes y rápidas, como martilleos y golpes fuertes repetidos. Este golpeteo de edificios poco espaciados se puede ver principalmente en algunas áreas urbanas densamente pobladas. Algunos códigos modernos han incluido cláusulas de requisitos de brecha de separación sísmica para estructuras adyacentes, pero dado que gran parte de las ciudades metropolitanas en regiones sísmicamente activas de la India se construyeron antes de que se introdujeran tales requisitos, los requisitos de brecha de separación sísmica no se han cumplido. Los golpes pueden ser catastróficos e incluso más peligrosos que el efecto de los terremotos en un solo edificio. Por lo tanto, la acción de golpear los edificios debe mitigarse para evitar la pérdida de vidas y propiedades durante los terremotos. El problema de los golpes es particularmente común en muchas ciudades de la India, ubicadas en zonas sísmicamente activas, donde debido a diversos factores socioeconómicos y requisitos de uso de la tierra, los edificios a menudo se construyen apiñados. Este artículo se centra en el estudio de los golpes sísmicos entre dos edificios RC con diferentes características dinámicas. Se investiga un estudio sistemático de respuesta a golpes sísmicos entre edificios adyacentes y prácticas de mitigación de peligros sísmicos como el efecto de diferentes distancias de separación y el efecto de proporcionar amortiguadores, utilizando el software ETABS. Se ha considerado un edificio de 12 pisos y uno de 16 pisos para el estudio de los golpes. El análisis del historial de tiempo se lleva a cabo para siete movimientos de tierra reales de terremotos en los modelos con diferentes espacios de separación. Los resultados se obtuvieron en forma de fuerza de golpe y desplazamientos de puntos. Se revela que el efecto de golpe varía inversamente con la distancia de separación. Al aumentar la distancia de separación, el efecto de los golpes se reduce en gran medida y, por lo tanto, también se minimiza el daño a los edificios vecinos. Además, se ve que las fuerzas de golpe disminuyen considerablemente entre los edificios adyacentes debido a la provisión de amortiguadores en ubicaciones adecuadas, en comparación con el caso de edificios adyacentes sin amortiguadores. El estudio incluso confirma que el efecto de los golpes se puede mitigar considerablemente instalando amortiguadores entre estructuras adyacentes. Los amortiguadores modelados en este estudio demostraron ser efectivos para reducir el desplazamiento y la deriva en el rango del 15% al 20%.

Palabras clave: ETABS, golpes sísmicos, brecha de separación, análisis de la historia del tiempo.

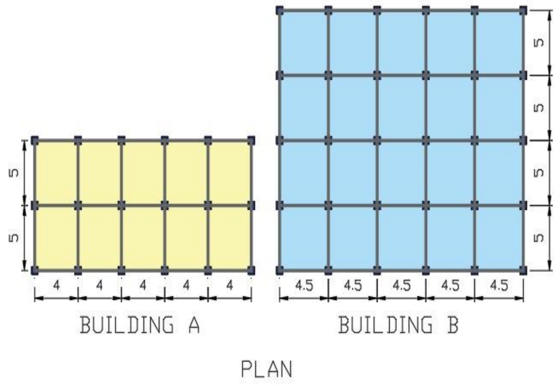
INTRODUCTION

Earthquake is one of the natural disasters affecting the buildings adversely, ranging from mild damage to collapse, depending upon characteristics of the earthquake like magnitude, peak ground acceleration, etc. In case of buildings built very close to each other, without necessary seismic gap, they tend to collide with each other due to differential dynamic characteristics. This is very common in urban areas where buildings are being built without providing required gaps. This phenomenon is called pounding, which results in generation of additional stresses, shear forces and collision forces in the buildings. Some examples where seismic pounding led to huge damage for buildings are Alaska Earthquake (1964), San Fernando Earthquake (1971), Mexico City Earthquake (1985), Loma Prieta Earthquake (1989), Kobe Earthquake (1995) and Taiwan Chi-Chi Earthquake (1999). Numerousstudies are already being carried out to understand the occurrence and the magnitude of damage due to pounding.

The alertness is to control pounding parameters viz. shear, displacement and acceleration with the use of dampers. Dampers are provided in between the buildings and the results are compared with respect to buildings without damper cases. Passoni (2010) studied the use of dampers in structures in order to improve the seismic characteristics of buildings, especially for control of pounding, like placing them in between two floors or providing them along with bracings or in adjacent buildings between which pounding was expected to occur. In this study, different ways to implement dampers in buildings are also investigated.

STRUCTURAL ANALYSIS & MODELLING

The building system considered for study, consists of two buildings adjacent to each other, with same floor height of 4.5m. A 16-storey building is modelled adjacent to a 12-storey building, with plan and elevation shown in [Fig.1,2]. The buildings are considered as RC ordinary moment resisting frames. In addition to self-wight, an additional total imposed load of 3kN/m^2 (as per recommendations in IS 875, Part 2 (1987)) is considered all over floor. Beam and column dimension of elements in the numerical model are of 0.30m × 0.60m and 0.60m × 0.60m respectively.



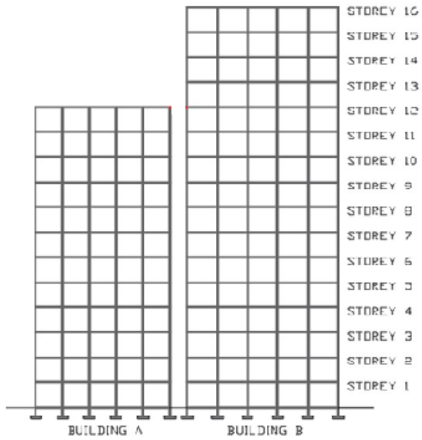


Fig. 1 and Fig. 2 buildings are provided with gaps between them and the other case when they are connected with dampers

The study is carried out for two cases; viz. when the buildings are provided with gaps between them and the other case when they are connected with dampers.

- Buildingsseparated with gaps:

The buildings are modelled in ETABS with varying gap between them as 0mm, 20mm, 40mm, 60mm, 80mm, 100mm, 120mm, 140mm, and 160mm, considering the possibility of pounding. Time history analysis is carried out for seven real earthquake ground motions, viz. El Centro- California, Uttarkashi-Uttarakhand, Cape Mendocino-California, Bhuj-Gujrat, Sumatra-Indonesia, Chile and Nepal earthquake ground motions, with varying separation gaps. Modelling is carried out by providing gap element in between the buildings. The element gets activated when the net displacement of the building exceeds the gap space, leading to generation of collision forces. The results were obtained in the form of pounding force and point displacements.

- Buildings connected with dampers:

Several studies have investigated the use of damper connectors in order to reduce pounding induced damage, and to increase the seismic resistance of a structure. Viscous damping involves taking advantage of the high flow resistance of viscous fluids. When the damper is installed in a building, friction converts some of the earthquake energy transferred into the moving building, into heat energy. The forces developed in a viscous damper are proportional to the velocity of its connected ends. In the present study, the two buildings in the models are linked with non-linear fluid viscous dampers (placing them in between two successive floors) of effective damping 5% and the results are obtained for varying separation gaps, for seven earthquake ground motions.

Sustainability, Agri, Food and Environmental Research, (ISSN: 0719-3726), 11(X), 2023:
http://dx.doi.org/10.7770/safer-V12N1-art2782

Ways to implement dissipative devices in buildings:

Dampers connecting adjacent buildings[Fig.3]

Case 1 : Uniformly distributed dampers at each storey from storey 1 to storey 12 having damping coefficient 1000 kN.s/m.

Case 2 : Only one damper at storey 12 having damping coefficient 12000 kN.s/m.

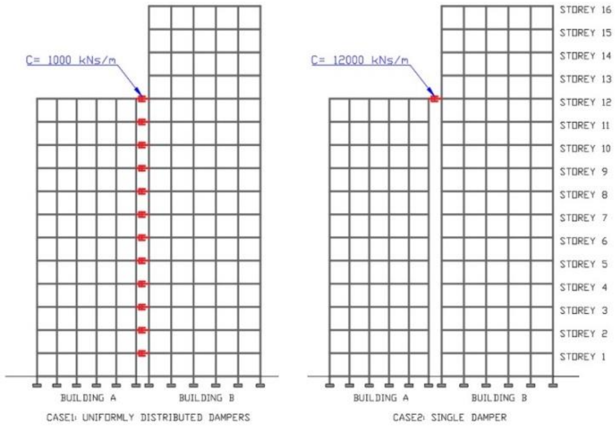


Fig. 3 Dampers connecting adjacent buildings

Dampers connecting adjacent storeys of individual building[Fig.4]

Three dampers with different damping coefficient and capacities have been considered to determine the best suitable damper to reduce the pounding of buildings subjected to Chile earthquake ground motion and its effects with 100mm separation gap.

Model 1: Damping coefficient=1000 kN.s/m

Model 2: Damping coefficient=2000 kN.s/m

Model 3: Damping coefficient=3000 kN.s/m

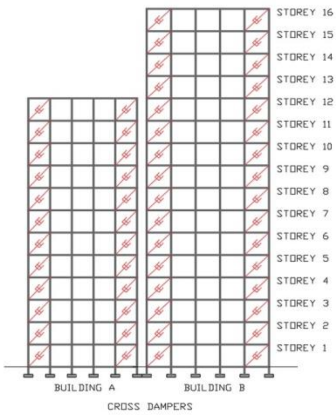


Fig. 4 Dampers connecting adjacent storeys of individual building

RESULTS & DISCUSSION

From this study, it is observed that the shear forces, axial forces and bending moments amplify due to the pounding of buildings. Theshear force amplification factor

(SFAF) is defined as the ratio of the maximum shear force due to pounding, to the minimum shear force of stand-alone structure. Similarly, the axial force amplification factor (AFAF) is defined as the ratio of the maximum axial force due to pounding, to the minimum axial force of stand-alone structure. Further, the bending moment amplification factor (BMAF) is defined as the ratio of the maximum bending moment due to pounding to the minimum bending moment of stand-alone structure.

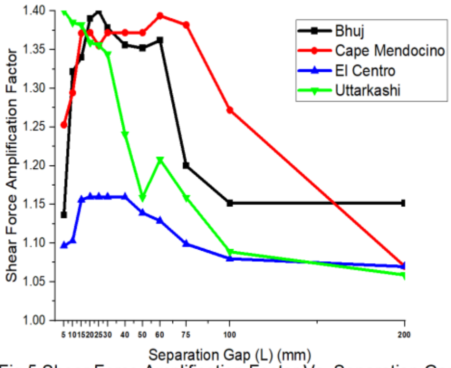


Fig.5 Shear Force Amplification Factor Vs. Separation Gap

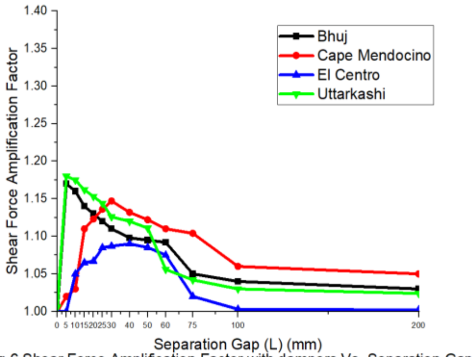


Fig.6 Shear Force Amplification Factor with dampers Vs. Separation Gap

From [Fig.5]it is clear that, the SFAF increased with increase in separation gap till it reached the peak value at critical separation gap, and then decreased with increase in separation gap for all the four earthquake ground motions considered. The maximum SFAF was 1.4 which reduced to 1.18 with the use of dampers [Fig.6]. The maximum separation gap beyond which no significant pounding occur is reduced from 100mm to 75mm. Similar results were found for maximum AFAF with & without dampers being 1.25 & 1.11 respectively andmaximum BMAF with & without dampers being 1.395 & 1.25 respectively.

Top displacement response of buildings with and without dampers:

With introduction of dampers in between adjacent buildings, the damping properties of structural system enhance. Thus, the displacement response of structural systems reduces considerably [Fig.7,8,9,10]. It can be seen that the maximum displacement reductions are for Nepal Earthquake, from 42.01mm to 23.26mm & Uttarkashi Earthquake, from 68.8mm to 58.7mm.

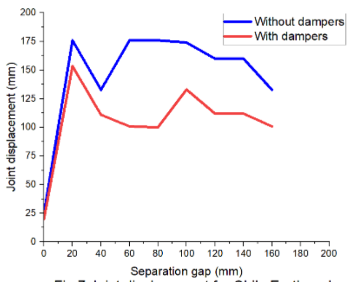


Fig.7 Joint displacement for Chile Earthquake

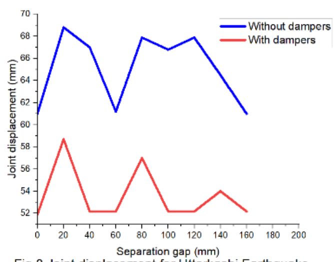


Fig.8 Joint displacement for Uttarkashi Earthquake

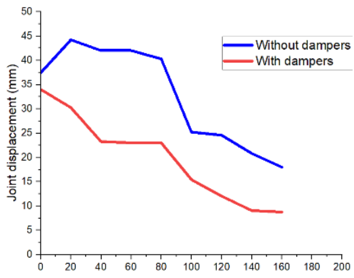


Fig.9 Joint displacement for Nepal Earthquake

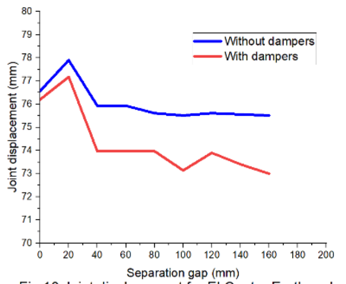


Fig.10 Joint displacement for El Centro Earthquake

- Single Damper Vs Uniform Damper Performance:

Shown below [Fig.11] is the comparison made between performance of uniform dampers and single damper in terms of displacement and drift response in X-direction [Fig.3].Obtained resultsdisplay an approximate variation averaged over all floors of about 8% in the displacement response & 12% in the drift response. The maximum displacement recorded for 12^{th} storey of shorter building for single & uniform damper was 77.062mm and 56.975mm respectively in y-direction. It can be prima facie understood that applying single damper at the topmost storey of shorter building in place of uniform dampers, is almost equally effective in damping the seismic response & highly economical in terms of installation.

This result coheres with the inference obtained in the research paper titled as "Pounding Mitigation in Buildings using Localized Interconnections" (Mohamed A. N. Abdel-Mooty and Nasser Z. Ahmed, 2017), which stated that linking of adjacent buildings, particularly at roof level of the short building is an effective technique in eliminating and reducing their seismic pounding.

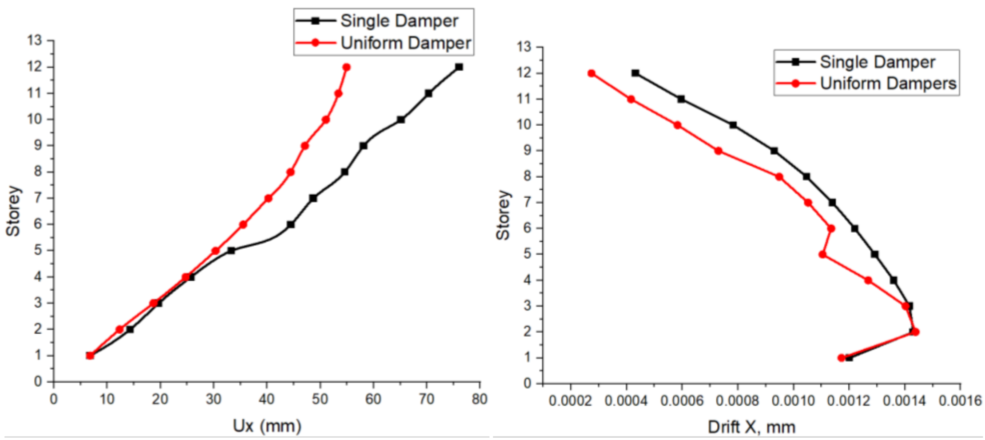


Fig. 11 comparison made between performance of uniform dampers and single damper in terms of displacement and drift response in X-direction

- Fluid Viscous Dampers connecting adjacent storeys of individual building

The [Fig. 4] defines the arrangement of Fluid Viscous Dampers, connecting adjacent storeys of individual buildings. The effectiveness of a fluid viscous damper depends upon the provision of optimum properties. To observe the trend over different damping coefficients, three typical values of damping constant (c) say A, B and C, i.e., 1000kNs/m, 2000kNs/m and 3000kNs/m, respectively are considered and the response in terms of displacement & drift in X-direction is observed. The displacement response between A-B and A-C shows an average reduction of 17% and 26% respectively. The 12th storey displacement was found to be 59.936mm, 53.015mm &49.786mm for the 3 respective values of damping coefficients mentioned above. Likewise, the response of drift between A-B and A-C shows an average reduction of 4.4% and 8% respectively as shown in [Fig.12].

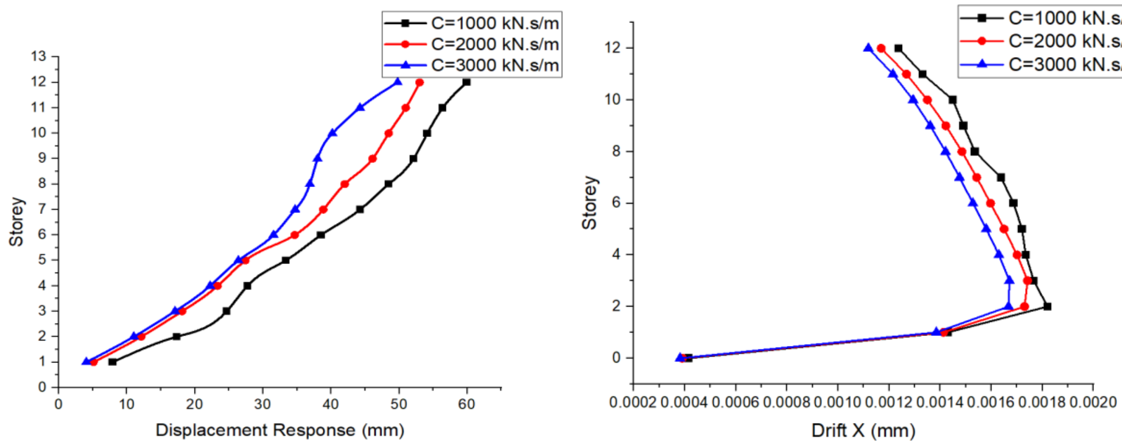


Fig. 12 the response of drift between A-B and A-C shows an average reduction of 4.4% and 8% respectively

IS 1893 (2016) CODE PROVISION

The most accepted way to prevent earthquake-induced structural pounding is to assure sufficiently large gap size between structural elements. As per IS 1893-2016 (Part-I) clause 7.11.3, the minimum separation gap between two structures should be at least equal to sum of top displacements of structures times half of the response reduction factor(R).

$$S = 0.5 \times R \times (\Delta 1 + \Delta 2),$$

where, $\Delta 1$ = Top Displacement of structure 1, and $\Delta 2$ = Top Displacement of structure 2

Table 1. Minimum separation gap as per IS 1893, Cl. 7.11.3

Time History	16StoreyStand alone$\Delta 1$(mm)	12 Storey Stand-alone $\Delta 2$(mm)	$\frac{R1\times \Delta 1}{2} + \frac{R2 \times \Delta 2}{2}$(mm)
Cape Mendocino 1992	13.518	12.402	64.8
El-Centro1940	24.674	18.579	108.13
Uttarkashi 1991	11.434	9.363	51.985
Bhuj 2001	24.974	16.589	103.8875
Nepal 2015	18.736	14.240	82.44
Chile 2010	28.132	21.631	124.4075
Sumatra 2007	27.415	19.847	118.155

From the [Table 1], it is noted that the minimum separation gap that should be provided between the modelled structures varies between 51.985 mm to 124.4075 mm.

Hence, it is implied that the IS recommended separation gap can avoid pounding between structures to occur.

CONCLUSIONS

Following conclusions can bedrawn from this study:

1. Two adjacent RC framed structures are successfully modelled and analysed by applyingdiffered earthquake time histories on ETABS.
2. The pounding forces are much affected by the characteristics of the earthquake records,dynamic and stiffness characteristics of the building.
3. The pounding force & other parameters reduce with increasing separation distance between twoadjacent buildings. The Member force amplification factor of buildings dueto pounding increases approximately by 25% to 30% with separation gap, till it reaches thepeak value at critical separation gapand then it decreases with separation gap.
4. Viscous dampers reduce the displacement of buildings considerably,along with the reduction of axial forces, shear forces and bending moments up to 15% to 20% approximately.
5. Linking of adjacent buildings, particularly at roof level of short building is an effectivetechnique in eliminating / reducing their seismic pounding compared to uniform positioning of dampers at all floors.

REFERENCES

Jawalkar G.C., Yadav A.S.,“Seismic pounding of multistoried R.C. framed buildings,” International Journal of Advances in Engineering and Management, Volume 2, Issue 11, pp: 389-395, ISSN: 2395-5252, December 2020.

Khante S.N. and Kale A.D., “Effect of pounding on multistorey adjacent elastic RC buildings without seismic gaps under earthquake excitation,” Journal of Structural Engineering, Vol.40, No. 4, pp: 332-342, November 2013.

IS 456: 2000, “Plain and reinforced concrete - code of practice”, 4th Revision, 2000, Bureau of Indian Standards, New Delhi, India.

IS 1893 (Part 1): 2016, “Criteria for earthquake resistant design of structures”- part 1general provisions and buildings”, Sixth Revision, 2016, Bureau of Indian Standards, New Delhi, India.

Khaja Afroz Jamal, H.S. Vidyadhara, “Seismic pounding of multi-storeyed buildings,”International Journal of Research in Engineering and Technology, eISSN: 2319-1163, pp: 12-17, November 2013.

M. Abdel-Mooty, H. Al-Atrpy& M. Ghouneim, “Modeling and analysis of factors affecting seismic pounding of adjacent multi story buildings,” Educational Records and Evaluation Service, Vol.104, April 2009.

Mohamed A. N. Abdel-Mooty and Nasser Z. Ahmed, "Pounding Mitigation in Buildings using Localized Interconnections," The 2017 World Congress on Advances in Structural Engineering & Mechanics, August 2017.

G.L. Cole, R.P. Dhakal& N. Chouw,"Building pounding damage observed in the 2011 Christchurch earthquake,"15th World Conference on Earthquake Engineering 2012.

Manohar and Madhekar, "Seismic design of RC buildings" Springer 15th publication, 2014.

PEER Ground Motion Database peer.berkeley.edu, CESMD Strong-Motion Data Setstrongmotioncenter.org

CSI Knowledge Base, http://wiki.csiamerica.com/

Received: 03th November 2020; Accepted: 06th January 2022; First distribution: 06th November 2022.