Analysis of Seismic Pounding between Two Adjacent Reinforced Concrete Buildings

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Abstract - There have been many various kinds of building failures during earthquake events in the past, thus it is crucial to comprehend building failure patterns and the causes of those failures in order to lower the building failure ratio and strengthen the building against future seismic occurrences. Seismic-induced pounding is one of the potential structural damages that most frequently results in significant building damage and has been seen in a number of previous earthquakes. The use of viscous dampers is being researched in the current study to prevent or lessen the impact of pounding between nearby buildings. Two nearby buildings, a 15-story building and an 11-story building in SAP2000, are evaluated to demonstrate the behavior and impact of viscous dampers. An examination of the linear time history of these two nearby buildings that experience ground motion during earthquakes has been conducted. For time history study, El Centro earthquake acceleration record (NS) is utilized. The building's behavior in relation to the pounding effects is compared and interpreted using storey drift and inter-story drift values.

Key words: *viscous dampers, pounding, reinforced concrete buildings*

1. INTRODUCTION

The simple definition of "pounding" is the collision of buildings that are constructed close to one another. The inadequate distance between the nearby buildings is the main cause of the seismic pounding. A multitude of other factors could also be involved, including the non-compliance with codal provisions, especially for lateral and torsional stiffness due to inadequate building configuration and structural framing system, the unexpected severity of the ground motion, and cumulative tilting caused by foundation movement. The majority of older structures that were built prior to the introduction and widespread use of earthquake-resistant design concepts exhibit this phenomena. Two kinds of pounding damage are often possible. The first is damage that occurs locally at the site of impact, and the second is damage that occurs globally as a result of the collision's energy and momentum transfer. The force of the collision causes local damage, whilst the dynamic features of both buildings at the moment of the contact determine global damage. To maximize space use, buildings that are constructed without being divided all the way up to property lines might sustain this kind of damage. If the floors of these structures are often built to the same height, pounding damage is usually not as severe; however, if this is not the case, there are two issues. Because the floors of nearby structures are at different altitudes, each structure's floor may operate as a ramp, hammering the other building's columns. When a building is higher than the other, the higher building has a significant stiffness discontinuity while the lower building experiences an unexpectedly high amount of lateral load. Even if a minimum seismic spacing is specified by many modern codes, it is still insufficient. Globally, seismic rules and laws stipulate that, in order to prevent pounding, there must be a minimum space between neighboring structures that equals the relative displacement demand of the two potentially colliding structural systems. The previous seismic course did not provide clear rules to avoid pounding because of economic factors, such as maximum consumption requirements, particularly in densely populated urban regions. Around the world, there are a lot of buildings that are either directly next to one another or already in contact and could sustain catastrophic harm.

The simplest and most efficient way to mitigate pounding and lessen damage caused by pounding is to provide enough separation; however, because of the high cost of land, this is not always possible. An alternative to providing a seismic separation gap is to lessen the impact of pounding by aligning floors in nearby buildings and reducing lateral motion drift. To enhance the performance of structures lacking enough seismic separation between two buildings, several vibration reduction techniques can be taken into consideration as an additional strategy to lessen the impact of pounding during seismic excitation. One method is to connect the buildings next to each other, which eliminates interactions by allowing forces to flow between the structures. For this objective, tests have been conducted on viscoelastic elements and stiff linkages. Adding more stiff beams to connect neighboring structures is another way to create a stiff link. Impacts may be partially absorbed and connections between nearby structures may also have certain energy dissipation characteristics. Structural conflicts between two neighboring structures can be controlled and eliminated with the use of joining elements. In the current study, the pounding effect is reduced and adjacent buildings are connected using fluid viscous dampers.

Fig -1: Adjacent Buildings in Tehran with different floor heights & without separation gap between them

Basanagouda I. Patil, Bapugouda B. Biradar, and Rashmi Doddamani (2022) has presented in their paper "Mitigation of Seismic Pounding Observed in Adjacent Buildings with Fluid Viscous Damper." The use of FVD to lessen the seismic pounding effect between nearby buildings. The multi-story neighboring buildings G+14 and G+9 are modeled and examined using ETABS 2017. An investigation is conducted on nearby structures with varying heights (G+14 and G+9 floors) that are connected to FVDs impacted by the El Centro earthquake. Analysis of the non-linear temporal history is done. The comparison of nearby structures with and without FVDs is based on displacement and seismic spacing as important factors. When the displacement of structures with and without dampers is compared, it can be seen that the pounding impact is successfully managed when dampers are provided since they lessen building displacement. It was discovered that two storeys connected by a single fluid viscous damper (FVD) were very useful in preventing seismic pounding and very successful in minimizing seismic responses between structures.

Rajaram Chenna, Pradeep Kumar Ramancharla (July2018) has presented in their paper "Damage assessment due to pounding between adjacent structures with equal and unequal heights." the investigation of pounding reactions and impact consequences on ground motion-exposed structures. A nonlinear time-history analysis with 20 mm intervals was carried out for nearby buildings that were experiencing ground motion from Northridge. Therefore, regardless of whether they are equivalent in height or not, the pounding response of stiff buildings is larger than that of flexible ones throughout the dominant period of frequency of ground motion. A flexible building will respond more forcefully than a stiff one if it vibrates at the non-dominant period or frequency of the ground motion. When two slabs collide on the same slab level, it results in a rigid body motion; however, when buildings are on separate levels, this interaction happens between the slab and the column and can be lethal. Buildings with varying heights sustained greater damage than buildings with the same height, as this study's numerical results showed.

B. Thamizhinian1, D Ghosh, H. Gupta, AK Mittal (2018) has presented in their paper "Seismic pounding effect on buildings and its control." The impact of striking in high-rise structures and mitigating the harm caused by striking using appropriate dampers. A nonlinear analysis of ground motion was conducted with the Uttarkashi earthquake of 1991 in mind. Between the two buildings, there is a pounding effect that increases the stresses and shear forces on the components of the two buildings. The extra loads and displacements brought on by the pounding effect are managed by the employment of modeled dampers in the spaces between the buildings. Each case's acceleration and displacement time histories were evaluated, and the results were compared to determine how well the dampers controlled the seismic pounding between the nearby structures. Seismic pounding causes an increase in acceleration, storey displacement, and collision force that affects the nearby buildings. Buildings can be saved mostly by installing dampers between them and other neighboring structures to reduce the effects of pounding. A damper can be used to effectively lessen the displacement response.

E. Aydin, B. Ozturk, H. cetin and T. simsek (2017) has presented in their paper "Application of Viscous Dampers for Prevention of Pounding in Adjacent Reinforced Concrete Buildings." The use of viscous dampers, which are passive dampers, to prevent or lessen the impact of pounding on nearby buildings is being researched. The behavior and impact of viscous dampers are examined in two nearby structures, each with 20 and 10 floors. Time history analyses are carried out for these two nearby buildings that are susceptible to ground vibrations during earthquakes. The El Centro earthquake acceleration record (NS) is taken into consideration for time history analysis. The scenarios of viscous damper, uniform damper application, and no damper are compared for the model buildings. Building behavior in terms of pounding impacts is compared and interpreted using storey drift and inter-story drift values. It is concluded that story displacements and inter-story relative displacements are greatly reduced when viscous dampers are used for neighboring reinforced concrete buildings. Therefore, the pounding impact between adjacent structures can be lessened by installing a viscous damper. Based on the study's results, employing a single damper could be more advantageous and cost-effective than using viscous dampers that are evenly dispersed in terms of material, application time, and craftsmanship.

Elif Cagda Kandemir-Mazanoglu, Kemal Mazanoglu (2016) has presented in their paper "An optimization study for viscous dampers between adjacent buildings." The optimal quantity and capability of viscous dampers to prevent structural pounding between two adjacent structures during seismic activity. The structures believed to be shear-type buildings are modeled using the lumped mass-stiffness approach. A nonlinear elastic spring approximation that mimics the impact forces from hammering is called the Hertz model. A parametric investigation is conducted by varying the number of stories, the stiffness of the buildings, the viscous damper capacity, and other characteristics. This study detailed the optimization process to determine the position and capacity of the viscous damper between adjacent structures. Structural poundings can result from the various vibrational properties of nearby buildings, which can lead to dangerous damage. The auxiliary damping ratio and the change in pounding force are stated using a dimensionless natural frequency scale that was created to compare situations involving structures with various structural features. The building's structural characteristics mostly determine the hammering force. Furthermore, it was determined that the impact force is not proportional to the supplementary damping ratio used for impact prevention.

1.1 Provide minimum seismic gap between adjacent buildings

When there is not enough space between neighboring buildings to allow the relative motion during earthquake events, seismic pounding happens. In order to prevent pounding, neighboring buildings must have a minimum separation of at least the relative displacement demand of the two possibly colliding structural systems, as specified by seismic rules and regulations.

Minimum safe separation distance between adjacent structures according to the various codal provision are as shown in Table No 1 below

Table 1: Codal provision for minimum seismic gap calculation

SR NO.	CODE	FORMULA
1	INDIA IS-1893:2016 CLAUSE 7.11.3	Separation distance equal to R times the sum of the calculated storey displacements as the two buildings or two units of same building oscillate towards each other as per clause7.11.1. R = Response reduction factor
2	FEDERAL EMERGENCY MANAGEMENT AGENCY–273-1997	Si = √ (Δi12+ Δi22) as per Clause 2.11.10 Where Δi1 = Peak displacement of building -1 Δi2 = Peak displacement of building – 2 Si should not be greater than 0.04 times the height above the impact
3	INTERNATIONAL BUILDING CODE (IBC)–2003	δ M = √ (δ M12 +δ M22) --(Adjacent Buildings located on the same property line) (Clause 1620.4.5 in IBC 2003 & Clause 1633.2.11) in UBC Where, δM = Separation distance between two structures δ M1 and δ M2= Peak Displacement response of adjacent structures 1 and 2
4	NATIONAL BUILDING CODE-PERU E.030-2003	The minimum separation distance will not be lower than 2/3 of the sum of the maximum displacements of the adjacent blocks nor less than S=3+0.004(h-500) (h and s in centimeters) S> 3 cm (Clause 3.8.2) h = Height of structure (in cm)
5	ASCE/SEI – 7- 05	δ x =C d. δmax/I as per (Clause 12.12.3) Where Cd = Total deflection amplification factor δ max = Maximum elastic displacement that occurs anywhere in a floor from the application of design base shear to the structure. I = Importance factor for seismic loading

1.2 Increasing the stiffness of structure by providing damper

A mechanical device that dissipates the kinetic energy of seismic waves traveling through a building or other structure is known as a seismic damper. Innovative devices called earthquake dampers lessen the vibrations that buildings produce during an earthquake. Vibrations are caused by seismic waves penetrating through buildings. The purpose of the seismic damper is to reduce the dampening effect and enhance the structure's seismic performance.

Purpose of seismic dampers:

1. Protect the structure against earthquake by increasing the strength and life span of structures.

2. Reduce the structural damage by decreasing the seismic force which further reduce structural deformation.

1.3 Objectives of investigation

1. Linear ground motion analysis for adjacent R.C.C. Buildings with different geometry and floor height in SAP2000.
2. To find minimum spacing requirements for safe separation distances between adjacent buildings to avoid Pounding.
3. Control of additional stresses and displacements which are caused during Pounding by application of a fluid viscous damper connected between two adjacent buildings.
4. Evaluation of acceleration and displacement time histories for cases with adequate seismic gap and FVD connected between adjacent buildings and compare them to obtain the effectiveness of the FVD in controlling the seismic pounding of buildings.
5. The amount of reduction in seismic gap size while structural pounding can still be prevented.

2. MODELLING

For adjacent R.C.C. buildings with unequal floor counts, different geometries, and varying floor to floor heights, non-linear ground motion analysis must be used to determine the minimum gap requirement, which provides the safe separation distance between the buildings for pounding avoidance with rigid floor diaphragms. A spring with the appropriate stiffness and a defined gap make up a fluid viscous damper, which is used to mimic the gaps between the structures. The ground motion characteristics and metrics, including maximum lateral displacement, maximum story drift ratio, maximum link displacement, time period, pounding force, etc., are compared in the time history study of the EL-Centro and Bhuj ground motion. The finite element analysis program SAP2000 is used in section 5.3 to replicate the structural parameters of both R.C.C. buildings. To develop 3D models, analyses, and designs, this is utilized. The software can do nonlinear dynamic analyses, eigen values, and nonlinear static pushover in addition to accepting static loads (forces or displacements) and dynamic actions (accelerations).

Following cases has been considered for analysis purpose:

i. Both buildings having floor to floor height 3.2m for EL Centro earthquake time history data without FVD.

ii. Both buildings having floor to floor height 3.2m for EL Centro earthquake time history data with FVD.

iii. Both buildings having floor to floor height 3.2m for Bhuj earthquake time history data without FVD.

iv. Both buildings having floor to floor height 3.2m for Bhuj earthquake time history data without FVD.

v. G+15 building with 3.2m floor to floor height & G+11 buildings with 3.5m floor to floor height for EL Centro earthquake time history data without FVD.

vi. G+15 building with 3.2m floor to floor height & G+11 buildings with 3.5m floor to floor height for EL Centro earthquake time history data with FVD.

vii. G+15 building with 3.2m floor to floor height & G+11 buildings with 3.5m floor to floor height for Bhuj earthquake time history data without FVD.

viii. G+15 building with 3.2m floor to floor height & G+11 buildings with 3.5m floor to floor height for Bhuj earthquake time history data with FVD.

ix. G+15 building with 3.2m floor to floor height & G+11 buildings with 4m floor to floor height for EL Centro earthquake time history data without FVD

x. G+15 building with 3.2m floor to floor height & G+11 buildings with 4m floor to floor height for EL Centro earthquake time history data with FVD.

xi. G+15 building with 3.2m floor to floor height & G+11 buildings with 4m floor to floor height for Bhuj earthquake time history data without FVD.

xii. G+15 building with 3.2m floor to floor height & G+11 buildings with 4m floor to floor height for Bhuj earthquake time history data with FVD.

xiii. G+15 building with 3.2m floor to floor height & G+11 buildings with 4.5m floor to floor height for EL Centro earthquake time history data without FVD.

xiv. G+15 building with 3.2m floor to floor height & G+11 buildings with 4.5m floor to floor height for EL Centro earthquake time history data with FVD.

xv. G+15 building with 3.2m floor to floor height & G+11 buildings with 4.5m floor to floor height for Bhuj earthquake time history data without FVD.

xvi. G+15 building with 3.2m floor to floor height & G+11 buildings with 4.5m floor to floor height for Bhuj earthquake time history data with FVD.

2.1 Structural parameters of the models

The models that have been chosen for the study are symmetric (G+15) storey buildings and unsymmetrical (G+11) storey buildings in order to observe the pounding impact between nearby structures. There are different sizes of seismic gaps between these buildings. Both dynamic loading and gravity apply to these. "Frame elements" include beams and column members. Slabs are defined as area elements that are modeled as rigid diaphragms and possess the characteristics of membrane elements. The columns have been constrained and the interaction between the soil and structure has not been taken into Table No. displays the structural parameters needed for modeling and analyzing various structural instances. At the base, all six degrees of freedom are -5.1 below. Grade of concrete taken as M30 for column, beam and slab. Grade of steel- Fe 500.

Structural parameters for modelling & analysis of different structural cases are as shown in Table No: -2 below:

Table 2 -Details of Structural Parameters

Building	**Height of Storey**	**Slab Thickness**	**Column Size (mm)**	**Beam Sizes (mm)**
1.(Left Building) G+15	3.2 m	125 mm	400x750	230x430
2. (Right Building) G+11	3.2m, 3.5m, 4.0m, 4.5m	125 mm	400x750	230x430

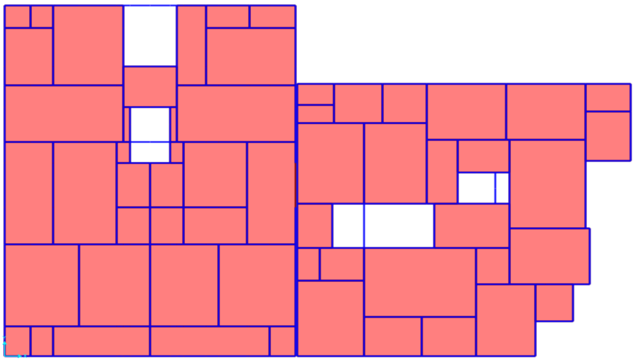

Fig. 2: Plan View of adjacent R.C.C. Unsymmetrical buildings

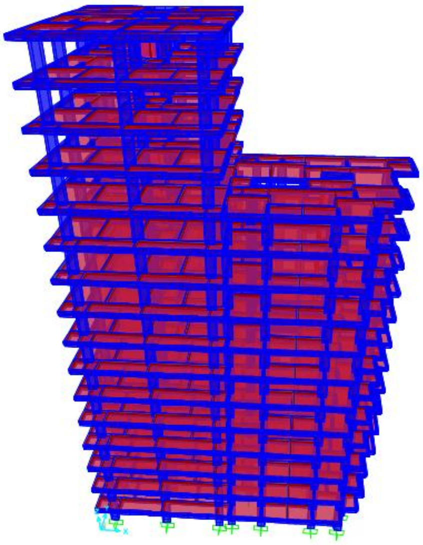

Fig. 3: 3D View of G+15 building with 3.2m floor to floor height & G+11 buildings with 3.2m floor to floor height without FVD

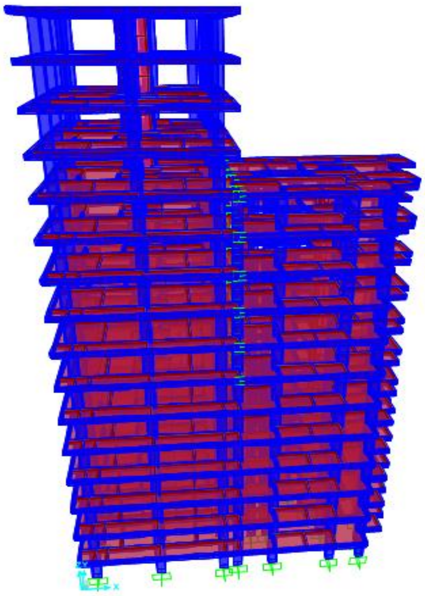

Fig. 4: 3D View of G+15 building with 3.2m floor to floor height & G+11 buildings with 3.2m floor to floor height with FVD

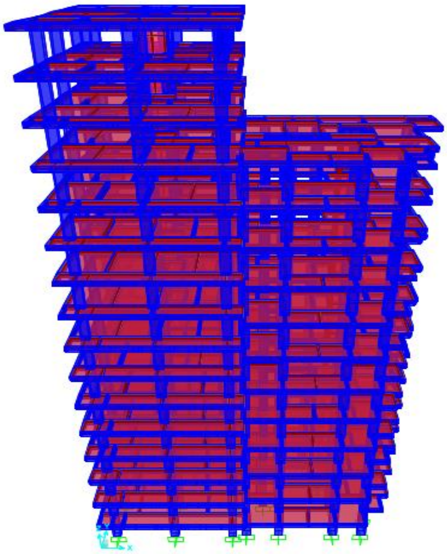

Fig. 5: 3D View of G+15 building with 3.2m floor to floor height & G+11 buildings with 3.5m floor to floor height without FVD

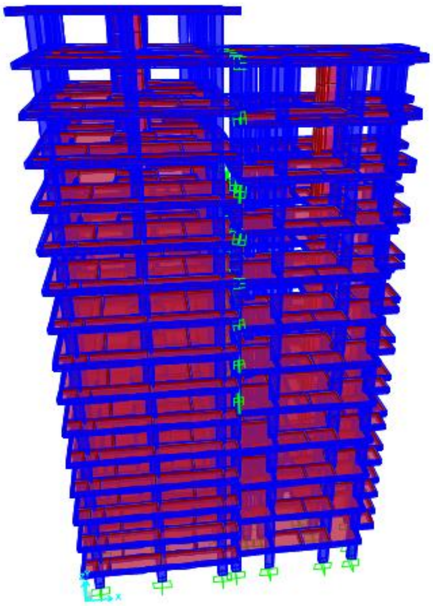

Fig. 7: 3D View of G+15 building with 3.2m floor to floor height & G+11 buildings with 4m floor to floor height without FVD

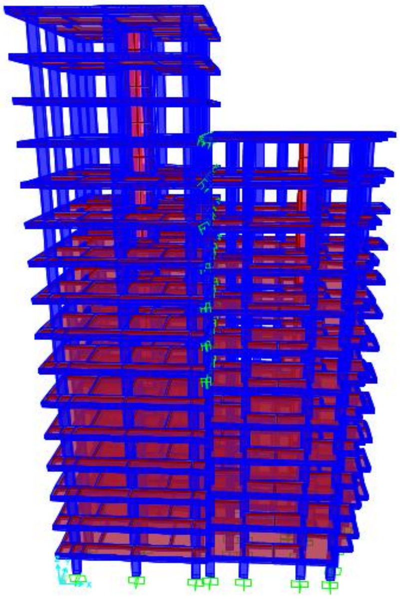

Fig. 6: 3D View of G+15 building with 3.2m floor to floor height & G+11 buildings with 3.5m floor to floor height with FVD

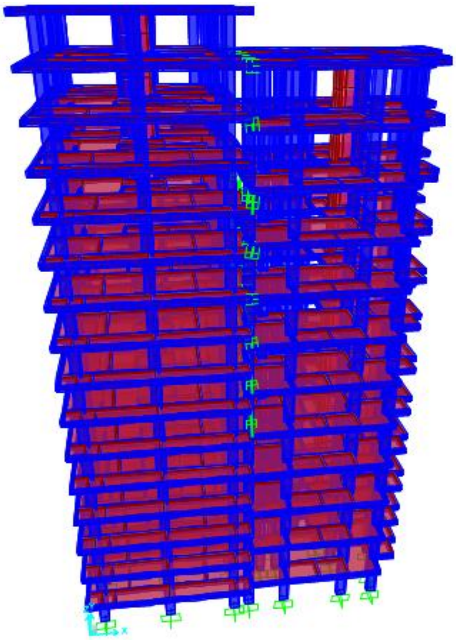

Fig. 8: 3D View of G+15 building with 3.2m floor to floor height & G+11 buildings with 4m floor to floor height with FVD

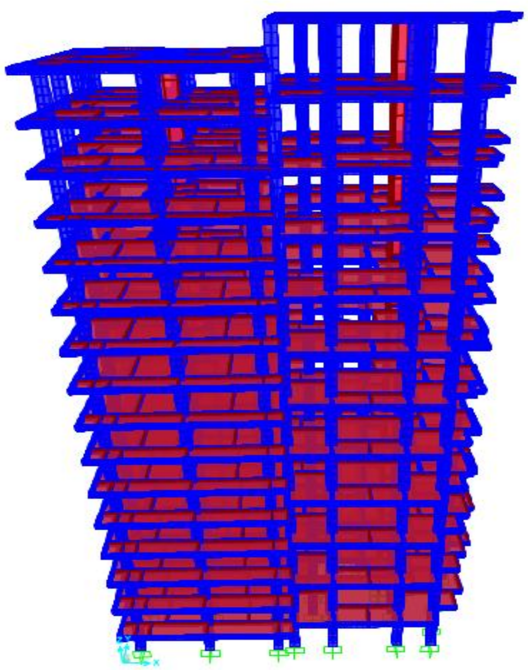

Fig. 9: 3D View of G+15 building with 3.2m floor to floor height & G+11 buildings with 4.5m floor to floor height without FVD

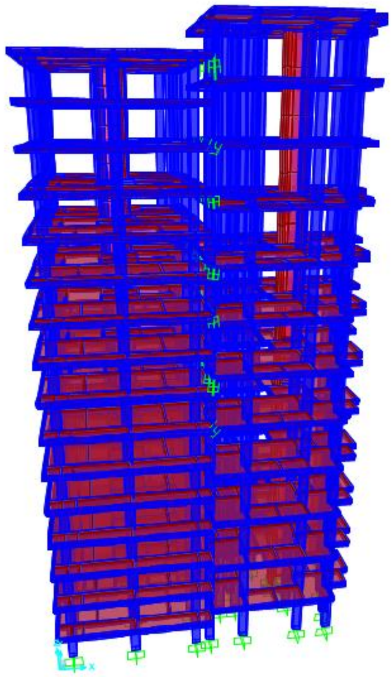

Fig. 10: 3D View of G+15 building with 3.2m floor to floor height & G+11 buildings with 4.5m floor to floor height with FVD

2.2 Properties of Fluid Viscous Damper

FVD 250 has a damping force of 250kN, & Weight of 41kg.

Damping Force= Damping constant(C) x Velocity^α as per Taylor devices inc General guidelines for Engineers

Where α is the damping exponent which lies in the range of 0.3 to 0.5 for seismic applications in buildings.

To calculate Damping Constant (C) for this value of α considered is 0.3 and velocity=0.508 m/s is considered. For FVD 250, we get value of C=299.9 kN.sec/m

For FVD 250 has model number 17120

For FVD250 we get Stiffness=625 Kips/in=109455 kN/m

3. RESULTS AND DISCUSSIONS

The analysis to be taken into consideration is the linear time history analysis for the ground motion of EL Centro and the seismic motion of Bhuj. The findings are derived in terms of variance in the seismic gap needed to avoid ponding. Impact force is determined by the following factors: story drift ratio, storey displacement caused by the seismic gap, and link stiffness and damping. SAP 2000 is used to calculate the structure's time period and link deformation, in addition to the code-provided calculations.

SAP2000 software was used to analyze all models for earthquake data from Bhuj and EL Centro, both with and without fluid viscous dampers connected to the structures. Various parameters have been compared regarding links, including base shear, maximum story displacement, maximum storey drift ratios, minimum seismic gap needed, maximum link deflection, time period, and maximum impact force. The findings are displayed both graphically and in tabular form.

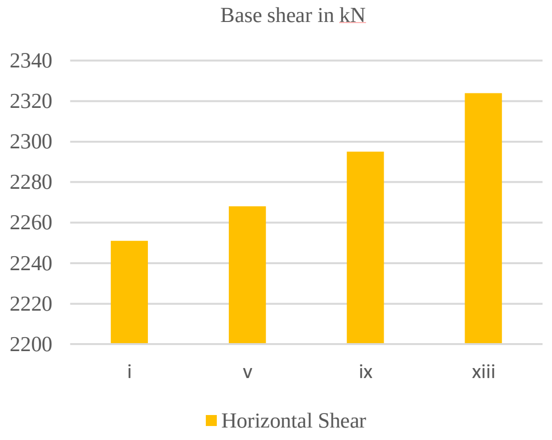

Chart-1: Variation of base shear in kN for different cases considered

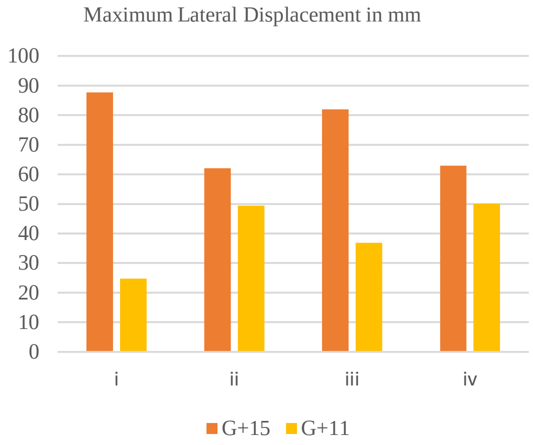

Chart-2: Variation of Maximum Lateral Displacement in mm for cases i to iv

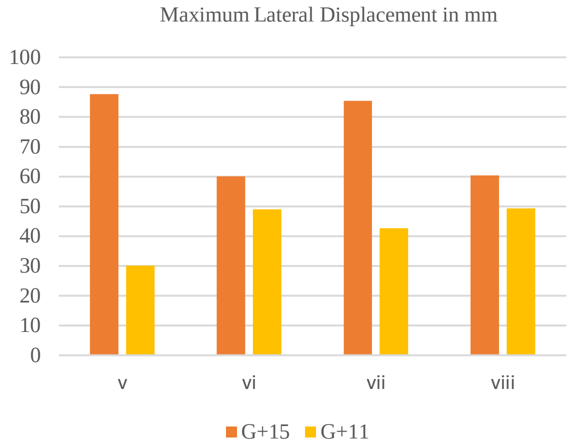

Chart-3: Variation of Maximum Lateral Displacement in mm for cases v to viii

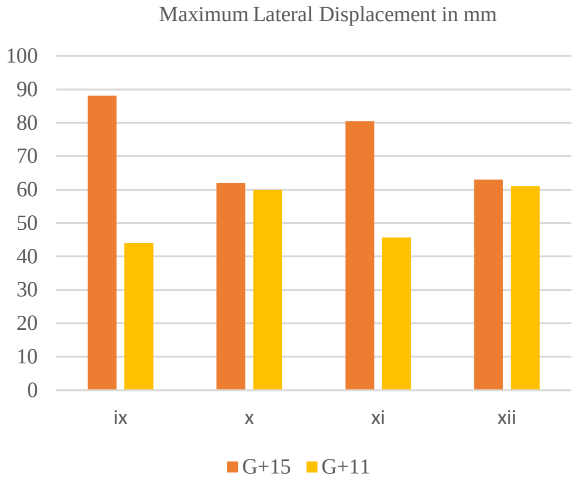

Chart-4: Variation of Maximum Lateral Displacement in mm for cases ix to xii

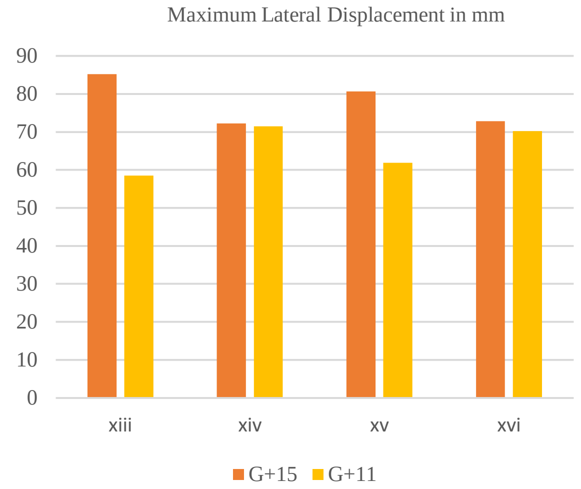

Chart-5: Variation of Maximum Lateral Displacement in mm for cases xiii to xv

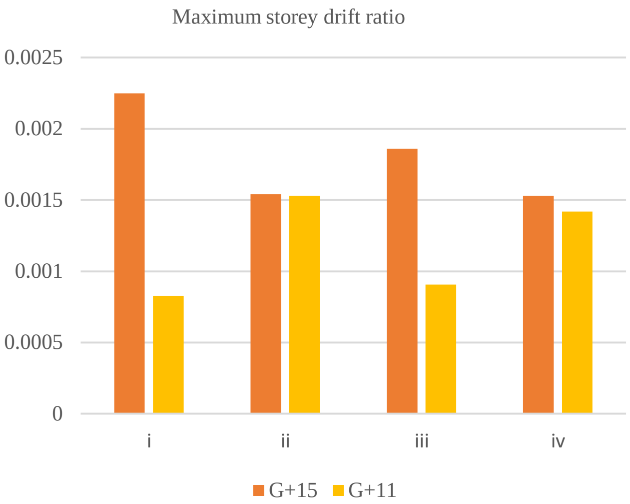

Chart-6: Variation of Maximum Storey Drift Ratio for cases i to iv

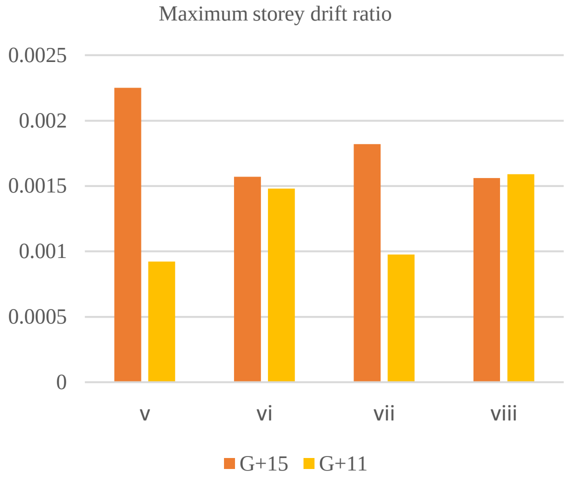

Chart-7: Variation of Maximum Storey Drift Ratio for cases v to vii

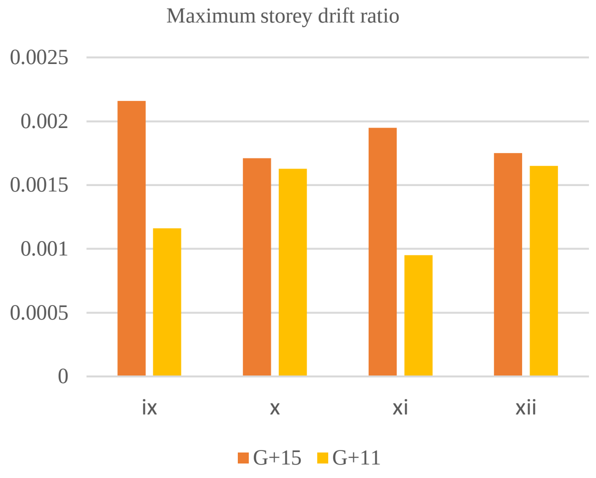

Chart-8: Variation of Maximum Storey Drift Ratio for cases ix to xii

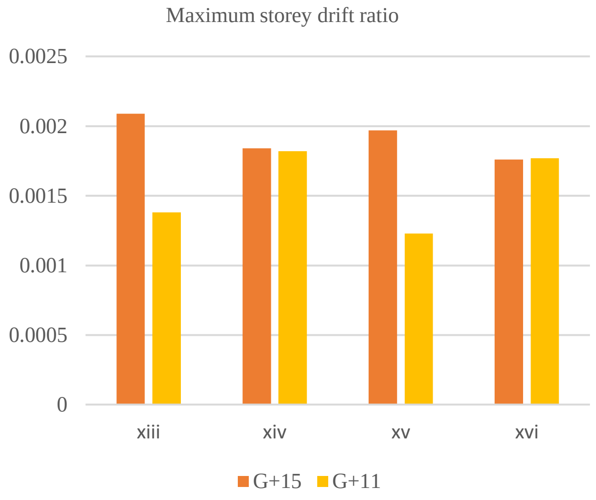

Chart-9: Variation of Maximum Storey Drift Ratio for cases xiii to xvi

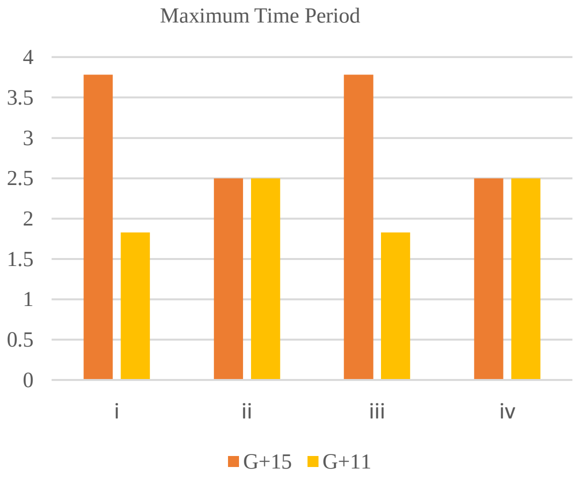

Chart-10: Variation of Maximum Time period for cases i to iv

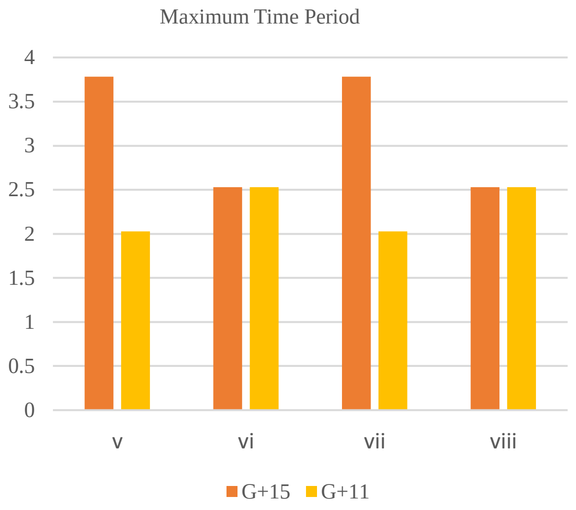

Chart-11: Variation of Maximum Time period for cases v to viii

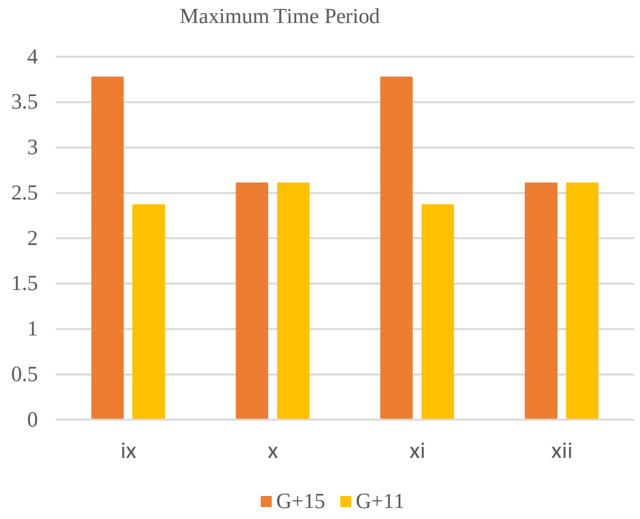

Chart-12: Variation of Maximum Time period for cases ix to xii

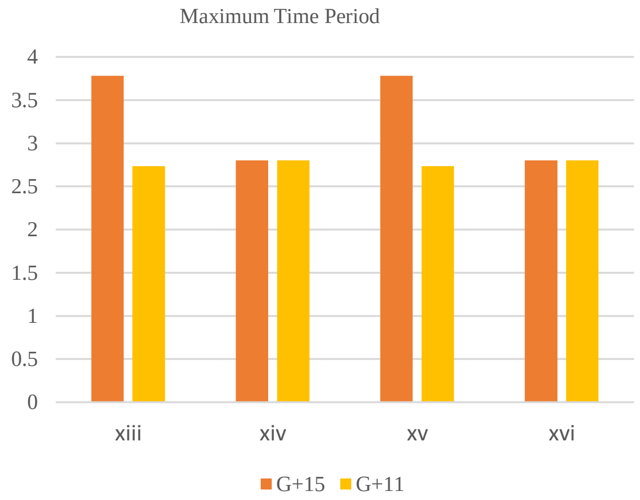

Chart-13 Variation of Maximum Time period for cases xiii to xvi

Table 2 - Values of maximum seismic gap for different cases

Case No.	As Per IS 1893:2016	As Per FEMA-273-1997
i	281mm	91.08mm
iii	297.175mm	89.91mm
v	588.975mm	92.695mm
vii	640.5mm	95.5mm
ix	660.65mm	98.522mm
xi	630.45mm	92.5mm
xiii	720mm	103.45mm
xv	715mm	102mm

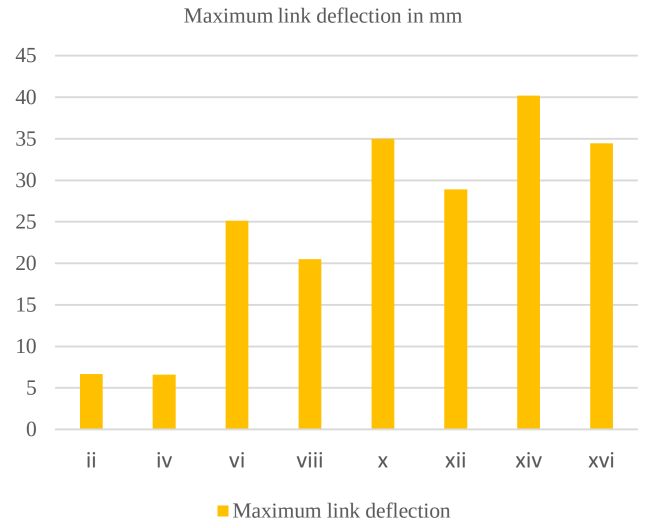

Chart-14 Variation of Maximum link deflection for cases ii, iv, vi, viii, x, xii, xiv, xvi

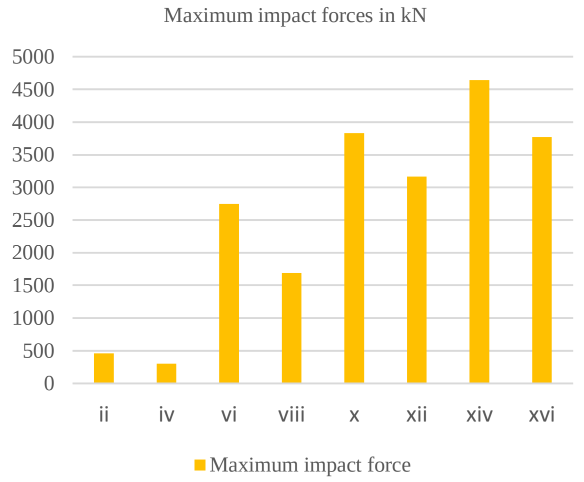

Chart-15 Variation of Maximum impact force for cases ii, iv, vi, viii, x, xii, xiv, xvi

4. CONCLUSIONS

The height of the G+11 structure increased from 3.2 meters to 4.5 meters, while base shear only increased by 3-4%. Since base shear is dependent on seismic weight and seismic characteristics such as soil type and seismic zones, this slight increase in base shear is caused by an increase in the structures' seismic weight while maintaining all other parameters constant. Using FVD has no effect on the basic shear value. When FVD is used, the modal time period is significantly reduced. The greatest reduction occurs when the floor-to-floor heights of the two structures are equal, or roughly 33%. The G+11 skyscraper experiences a minimum floor-to-floor height loss of 4.5 meters, or around 26%, as its height increases. When FVD is used, the maximum lateral displacement for G+15 buildings is significantly reduced—roughly 30%. However, the usage of FVD increases the maximum lateral displacement for the G+11 building since it dissipates energy with some deformation, which raises the maximum lateral displacement in the G+11 building. Comparable outcomes were noted for the seismic data from Bhuj and EL Centro.

Story drift increases in the G+11 building as a result of energy dissipation at links, but it decreases dramatically in the G+15 building when FVD is used. When FVD is linked, drift in the G+15 building is reduced by about 30%. For G+11 buildings, where a minimum floor-to-floor height of 4.5 meters is required, this reduction in drift decreases as floor-to-floor height increases. Enhancing the seismic separation between two nearby buildings aids in preventing pounding. It is evident that the IS code's minimum gap is more stringent than FEMA's and ought to be adhered to in order to prevent the "pounding effect." The FVD link deformation is nearly the same for the earthquake data from Bhuj and EL Centro, and it is at its lowest when the floor-to-floor heights of the two buildings are equal. However, the link deformation significantly increases as the floor-to-floor height of the G+11 building rises, reaching its maximum at 4.5 meters, or 40.141 millimeters, for the EL Centro earthquake data and 34.47 millimeters for the Bhuj earthquake data. This demonstrates that more hammering forces are produced when floor to floor heights differ. When comparing the impact forces from pounding action between the earthquakes in Bhuj and EL Centro, they are about 30–35% lower. Impact forces increase dramatically when G+11 building floor to ceiling heights rise from 3.2 meters to 4.5 meters, or 4642.52 kN for EL Centro and 3773.99 KN for earthquake data from Bhuj.

Therefore, we may deduce that the pounding effect increases for both structures when the floor to ceiling height varies, with the G+11 building having the largest pounding effect at 4.5 meters. Energy dissipates, maximum lateral displacement balances out, and time period shortens when FVD is used, all of which lessen the impact of earthquake pressures on both buildings.

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