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Evaluation of Lead Rubber Base Isolation in High Rise Structure

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Abstract: Seismic isolation also known as base isolation is one of the best earthquake resistant design concept in which a building is decoupled from the earthquake ground motion or seismic waves. In base isolation the base of the structure is isolated using isolators which help in decoupling. This study will therefore evaluate the performance of High-Rise structure with Lead Rubber Bearing as an Isolation System for different structures using seismic and wind analysis with focus on determining the effect of soft storeys within structures on variables such as storey displacement, storey drift, storey stiffness and time period. The objective of the research is to provide optimum position for isolation. However, there have only been a few studies on the impact of soft storeys at various levels in tall structures. This study will therefore investigate the impact of soft storey level variation in 25 storey building with and without LRB isolated structures.

Keywords: Seismic isolation, decoupling, storey displacement, storey drift, storey stiffness, time period, soft story

I. INTRODUCTION

Buildings with one or more floors that have much less lateral resistance to seismic forces than the floors above are said to have soft stories. It is a situation that presents a significant risk during earthquakes and may result in the structure failing in a catastrophic way. The rigidity and strength of a soft story are significantly lower than those of the levels around it. Typically, soft stories are found in multi-story structures with big openings on the ground level or some intermediary floors, such as parking lots, lobbies, or commercial spaces, which lessen lateral resistance. The soft story experiences high lateral stresses from the above levels during an earthquake, leading to severe deformation and possible collapse. This happens as a result of the weak story's inability to appropriately withstand the horizontal forces, which concentrates stress and raises the possibility of structural failure. The best part of the Base isolation is that it can be implemented on both new as well as old structures. Base isolation can also implemented in other infrastructures like: - bridge, nuclear power plant, water storage tanks and dams which will help the country to reduce the losses of life and economy due to seismic hazard.

A. Lead Rubber Bearing

Lead Rubber Bearings (LRB) are the bearings formed of horizontal layers of synthetic or natural rubber in thin layers bound between steel plates and containing lead core. The components of the LRB are lead plug, endplates, steel shims and rubber layers. The steel shims provide vertical stiffness to the LRB and layers of rubber provide lateral flexibility or horizontal stiffness. These bearings are capable of supporting high vertical loads with very small deformations. These bearings are flexible under lateral loads. Steel plates prevent the rubber layers from bulging. Lead core of the LRB gives extra stiffness to the isolators and it also provides damping to the system. Lead cores are provided to increase damping capacity as plain elastomeric bearings does not provide significant damping. LRB was first invented in 1975 in New-Zealand. LRB has the properties of both damper and isolator, lead plug's plastic deformation makes LRB to absorb energy from vibration hence has property of damper and it has a flexibility property to deflect seismic waves hence act also as isolator.

B. Response Spectrum Analysis

Response Spectrum Analysis in ETABS is a robust method for assessing the seismic performance of buildings. By leveraging ETABS's capabilities, engineers can ensure that structures are designed to withstand seismic events, providing safety and compliance with relevant codes.

The process involves setting up the model, defining load cases, performing modal analysis, and interpreting the results for informed decision-making in design and assessment.

C. Wind Analysis

Wind Analysis refers to the process of evaluating how a structure responds to wind loads. This type of analysis is essential for ensuring that buildings can withstand the lateral forces exerted by wind. The results inform design decisions, ensuring that structures are both safe and comfortable for occupants, complying with relevant building codes.

II. LITERATURE REVIEW

Walid A. Al-Kutti, et al., (2018) deals with the incorporation of base isolation system and focuses the changes of structural responses for different types of Lead Rubber Bearing (LRB) isolators. A number of sixteen model buildings of 8 storeys have been simulated selecting twelve types of bearing systems as well as conventional fixed-base (FB) scheme. Static and dynamic analyses are carried out for Fixed base and base isolated buildings. The results of the 3D multistory structures show that the lateral forces, displacement, inertia and story accelerations of the superstructure of the seismic prone buildings are significantly reduced due to bearing insertion.

Mohd Irfan Khan, et al., (2018) studies the effectiveness of the lead rubber isolator for G+15 storey RCC framed structure. The structure is analyzed in ETABS software using Bhuj earthquake data for two cases; one is for rigid jointed framed RCC structure and second is by the introduction of lead rubber bearing (LRB) isolators under the most seismically active region in India i.e. in zone V resting on loose soil (type III). From the analysis of both fixed base building and the base isolated building after providing LRB isolators the following conclusions are made: The time period of fixed base building shifts from 1.75 seconds to 3.94 seconds in base isolated building with LRB isolator. A huge amount of reduction is observed in base shear values from 2219kN in case of fixed base building to 1285kN in case of base isolated building with LRB isolator.

Anant Vats, et al., (2019) analyzes by Time History analysis , Fixed based and base isolated by providing lead rubber bearing for G+9 building. From these building models following conclusions can be made. Storey shear reduced for each storey after the lead rubber bearing (LRB) is provided as base isolation system which reduces the seismic effect on building Storey drift are also reduced for each storey specially in higher stories which makes structure safe against earthquake Base shear reduced up to 3258.02 KN in case of base isolated structure as compared to that of the 5764.79 KN in case of fixed base supported structure.

Aamir Riyaz Dar, et al., (2019) in this paper, an approximate procedure is generated to perform the seismic analysis of simple and tubular tall building system with base isolation (lead-rubber bearings) system and the outcome compared with the results obtained without base isolation (lead-rubber bearing) of tall buildings. This analysis of G+19 rigid joint plane RCC frame has for four cases. First case is simple RCC frame with fixed base and with base isolation (LRB), second case is simple tube RCC frame with fixed base and with base isolation (LRB), third case is tube in tube system RCC frame with fixed base and with base isolation (LRB) and fourth case is bundle tube system RCC frame with fixed base and with base isolation (LRB) .The time period in all models like simple RCC frame, simple tube, bundle tube and tube in tube decreases about 24%, 13%, 10% and 26% after providing base isolation (LBR) in models. After providing base isolation system (LBR) in every model base shear decreases between 10% to 30% which make the building stable.

Prof. Anubhav Rai, et al., (2020) studies the configuration of buildings of G+4 and G+9 with storey height of 3m. Static analysis and lateral load for response spectrum analysis is done as per UBC 1997 and the modelling approach includes the development of model, used ETABS 2016. It is observed that use of LRB isolation system average drift for 5 storey structure reduces to almost 53% while in case of 10 storey structure it reduces to 26% only w.r.t. fixed base structure. Average percentage reduction in storey shear of LRB building w.r.t. fixed base building is 48.765% and 70.37% in 5 and 10 storey building respectively.

Rohan G Raikar, et al., (2020) for this study,(G+13) storied R.C. frame building is considered and time history analysis is carried out using E-Tabs 2017 software, and also study investigates structural behavior of multi-story building with or without base isolation subjected earthquake ground motion. It has been observed that maximum shear force, bending moment, storey acceleration, base shear decreases; whereas increase in lateral displacements were observed for bottom storey of base isolated building as compared with fixed base building model. At base more storey drift was observed for base isolated model as compared to model of fixed base building. As storey height increases, the storey drifts in base isolation building model drastically decreases as compared to model of fixed base building.

Mahmoud Fakih, et al., (2020) presents the dynamic behavior of an 18 storey RC building with dynamic isolators (lead-rubber-bearing), in comparison with a traditional shear wall system of the same building. In this study, a non-linear structural response analysis of high rise building in an active seismic region was performed by the incorporation of the innovative LRB isolators. The seismic analysis compared two structural models of the same high rise building. It was concluded by the comparison of the two models that: The reduction in the energy dissipation, i.e., acceleration, at the roof storey is 55.24%.

The base shear force is reduced from 8368 Ton in the fixed base, to 1169 Ton in the isolated base structure. There is a decrease in the inter-storey drift ratio. The lead rubber bearing can be used as an isolator system for high-rise buildings with efficient results.

Shashi Prakash Pandey, et al., (2021) attempts to study the effectiveness of base isolation using lead rubber bearings (LRB) over conventional construction, using a case study of identical conventional and isolated building constructed in the most seismically active region in India. This paper deals with design, modelling and analysis of G+12 multistorey building for two cases. First case is fixed base and second case is base isolated (LRB). After the analysis of fixed base and base isolated (LRB) building by response spectrum analysis following conclusions can be made. Base shear is reduced after providing LRB which makes structure stable during earthquake. Story drift are reduced in higher stories which makes structure safe against earthquake. Finally, it is concluded that after LRB is provided as base isolation system it increases the structures stability against earthquake and reduces reinforcement hence make structure economical.

Bommena Karthik, et al., (2022) modelled & analysed a G+10 storey of seismic zone V building with and without base isolator (LPRB) for Seismic Coefficient Method (SC) and Response Spectrum Method (RSA) in ETABS software. Various responses of the structure like Story Displacement, Shear, Drift and natural period are compared for SC and RSA with and without LPRB. Fundamental natural period got increased, which is helpful for less natural period structures in earthquake to withstand against collapse without damaging the non-structural elements. Storey Drift reduces as the elevation increases which results in structures safety against earthquake. Storey Displacement value of RSA with LPRB is slightly higher than RSA without LPRB and lower than others, with this can conclude that storey displacement can be reduced slightly with LPRB.

III.METHODOLOGY & PRELIMINARY DATA

A. Methodology

1) Structures having soft storeys in different elevation i.e., Ground floor, 10th floor and 20th floor will be modelled with and without LRB isolation system with the help of ETABS 18.
2) Three buildings with LRB below the soft storey, whereas the remaining three can be modelled without LRB for each model.
3) All models can be analyzed for response spectrum, results can be obtained, such as storey displacement, storey drift, storey stiffness and time period which can be analyzed and validated.
4) All models can be analyzed for wind analysis, obtained results such as storey displacement & storey drift can be analyzed and validated
5) Observation and comparison of result.
6) Conclusion

B. Preliminary Data

Table 1: Detail of building plan and properties of material

Sr. No.	Description	Value
1	No. of Storeys	25
2	Total length along X-direction	22.45 m
3	Total length along Y-direction	16.05 m
4	Slab thickness	150 mm
5	Columns	C3,7,22,32,34(300x750mm);C21,27(300x825mm);C16(300x900mm); C12,24,26,33,35(300x975mm);C10,13,18,25 (300x1050mm); C5,8,11(300x1125mm); C9,15(300x1200mm); C2(300x1275mm); C14(300x1350mm); C4,17,19,20,23,29,31,36,37,40(400x1500mm)
6	Shear Wall	C1,6,28,30,38,39(300x1200mm)
7	Beams	230mm x 350mm, 230mm x 450mm, 300mm x 600mm
8	Height of the building	78 m
9	Grade of Concrete for column & shear wall	M45
10	Grade of Concrete for beams	M30
11	Grade of steel	Fe500

Table 2: Response spectrum properties as per IS 1893 part 1 (2016)

Sr. No.	Description	Value
1	Zone	III
2	Soil Condition	II
3	Seismic zone factor	0.16
4	Response reduction factor	4
5	Importance factor	1.2

Table 3: Load types and their values as per IS 875 part 1 & IS 875 part 2

Sr. No.	Type of load	Load Calculation
1	Live load on typical storey	2 KN/m^2
2	Floor finish on typical floor	1 KN/m^2

Table 4: Gust factor constants and parameters as per IS 875 PART 3-2015

Sr. No.	Description	Value
1	Basic wind speed (Vb) (m/sec)	44
2	Risk coefficient K1	1
3	Terrain Category K2	4
4	Topography Factor K3	1
5	Importance Factor K4	1
6	Soil Type	II (medium)

Table 5: Input values for LRB at ground floor

Sr. No.	Description	Value
1	Rotational Inertia-1	0.0667 KN/m
2	For U1 Effective Stiffness	2308340 KN/m
3	For U2&U3Effective Stiffness	2308.34 KN-m
4	For U2&U3Effective Damping	5%
5	For U2&U3 non- linear Stiffness	21270.8 KN/m
6	For U2&U3Yield Strength	67.61 KN
7	Distance from End-J	0.0032 m

Table 6: Input values for LRB at 10th floor

Sr. No.	Description	Value
1	Rotational Inertia-1	0.0256 KN/m
2	For U1 Effective Stiffness	1426210 KN/m
3	For U2&U3Effective Stiffness	1426.21 KN-m
4	For U2&U3Effective Damping	5%
5	For U2&U3 non- linear Stiffness	13142.2 KN/m
6	For U2&U3Yield Strength	41.77 KN
7	Distance from End-J	0.0032 m

Table 7: Input values for LRB at 20th floor

Sr. No.	Description	Value
1	Rotational Inertia-1	0.0030 KN/m
2	For U1 Effective Stiffness	499650 KN/m
3	For U2&U3Effective Stiffness	499.65 KN-m
4	For U2&U3Effective Damping	5%
5	For U2&U3 non- linear Stiffness	4604.5 KN/m
6	For U2&U3Yield Strength	14.62 KN
7	Distance from End-J	0.0032 m

C. Building Structural Plan

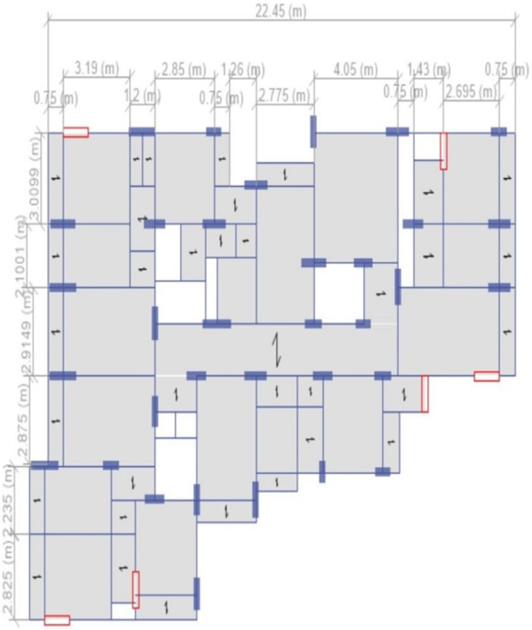

Fig 1: Typical ETABS model plan with dimensions

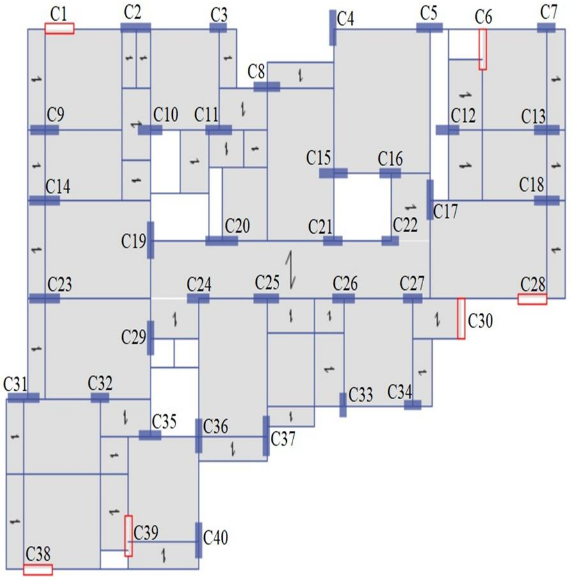

Fig 2: Typical ETABS model plan with column markings

D. Building 3D View

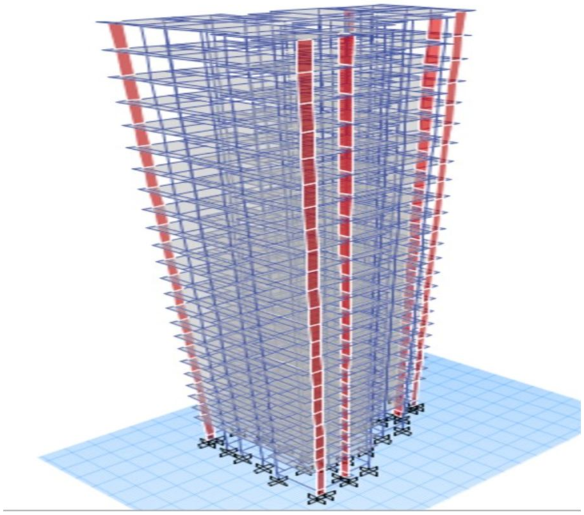

Fig. 3: Soft Storey at G floor (storey 1) without LRB

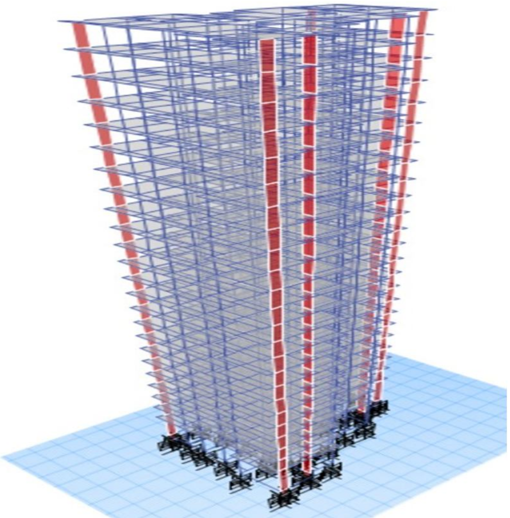

Fig. 4: Soft Storey at G floor (storey 1) with LRB

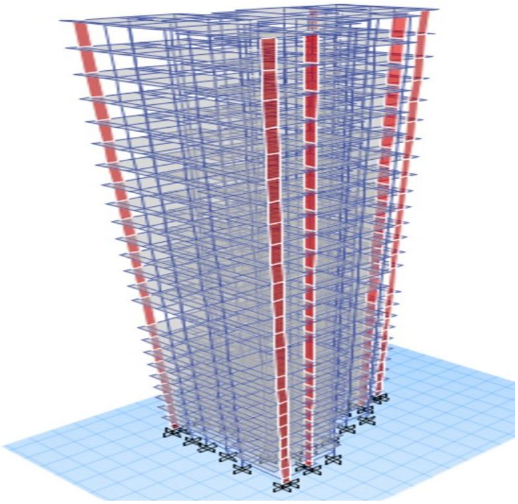

Fig. 5: Soft Storey at 10th floor without LRB

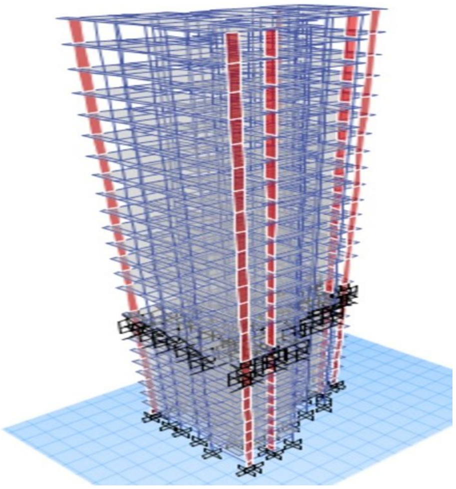

Fig. 6: Soft Storey at 10th floor with LRB

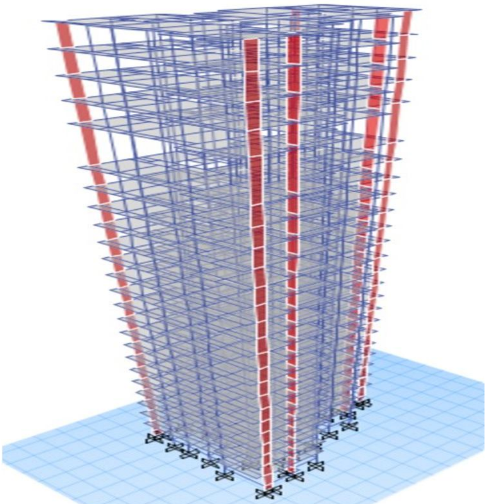

Fig. 7: Soft Storey at 20th floor without LRB

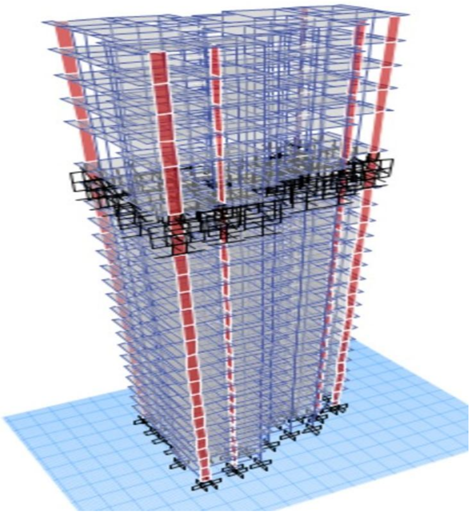

Fig. 8: Soft Storey at 20th floor with LRB

IV. RESULT AND DISCUSSION

A. *Response Spectrum Analysis*

1) *Effect of Story Displacement with and without LRB*

The displacement in soft storey on ground floor decrease slightly in isolated building compared to non-isolated building when LRB is on ground floor , while displacement in soft storey on 10th floor is reduced by 72.88% in X direction and 53.30% in Y direction in isolated building compared to non-isolated building when LRB is on 10th floor. The displacement is decreased by 29.46% in X direction and 24.46% Y direction when compared to the absence of the isolated structure when soft story and LRB are on 20th floor. The results reveal that when the structure is isolated at ground level, the building is more flexible than when it is isolated at mid floor.

2) *Effect of Story Drift on Soft Storeys with and without LRB*

When compared to a non-isolated building, the drift in the soft story on the ground level of the isolated building is slightly less while in non-isolated structure the drift is slightly more when LRB is on ground. This is due to the isolators' flexible nature absorbing energy and allowing additional movement in the structure. When compared to a non- isolated building, the drift in the soft story on the 10th level of the isolated building was reduced by 63.88% in X direction and 66.98% in Y direction when LRB is on 10th floor. This decrease implies that isolating the 10th level makes it more resistant to lateral movement during seismic events. The isolators have restricted the transfer of lateral forces to this floor, reducing its drift.

When compared to a non-isolated building, the drift in the 20th soft storey was reduced by 58.96% in X direction and 59.78% in Y direction in the isolated building when LRB is on 20th floor. This outcome is comparable to the 10th-floor situation, demonstrating that isolation helps prevent drift in soft levels in general.

3) Effect of Story Stiffness on Soft Storeys with and without LRB

The Story Stiffness increases in X direction and Y direction on ground floor after providing LRB on ground floor due to its flexible nature.

In structures without isolation, the stiffness of the 10th floor is 54.4% less than that of the 11th floor. According to the data, the story stiffness of the 10th floor with respect to 11th floor increases by 14.5% when without LRB is compared to LRB implementation on 10th floor.

In structures without isolation, the stiffness of the 20th floor is 53.47% less than that of the 21th floor. According to the data, the story stiffness of the 20th floor with respect to 21st floor increases by 11% when without LRB is compared to LRB implementation on 20th floor.

This indicates the isolation system's effectiveness in limiting the soft storey effect by reducing the transfer of forces to the floors above in isolating 10th and 20th floor.

4) Effect of Time Period of Structure with and without LRB

The time period decreases by 1.42 % after isolating the ground floor.

Whereas on the 10th floor after isolation, time period is decreased by 38% since the floor below moves with the isolator.

The time period on the 20th floor after isolation is decreased by 38.5% because the below floor moves with the isolator and the above floor stiffens.

B. Wind Analysis

1) Effect of Story Displacement on Soft Storeys with and without LRB

When compared to a non-isolated building, displacement in the soft storey on the ground level of the building isolated on ground floor was reduced by 32.3 % in X direction and 25.8% in Y direction. This displacement decrease is due to the isolators' flexibility in absorbing wind-induced forces.

When compared to a non-isolated building, displacement in the soft storey on the 10th level of the building isolated on 10th floor was reduced by 84 % in X direction and 77.77 %in Y direction. This indicates that isolating the 10th floor has greatly reduced its displacement during strong wind events. The wind forces were absorbed and dissipated by the isolators, limiting excessive movement.

When compared to a non-isolated building, displacement in a 20th floor soft story was reduced by 54.2 % in X direction and 66.41 %in Y direction in the building isolated on 20th floor. This result, like the 10th-floor case, shows that isolation can be beneficial in limiting displacement during gust wind events.

2) Effect of Story Drift on Soft Storeys with and without LRB

The isolated building has 32.26% reduction in X direction and 25.8% reduction in Y direction in soft storey drift on the ground level when compared to non-isolated buildings.

The isolated building has 75.6% reduction in X direction and 75.54% reduction in Y direction in soft storey drift on the 10th level when compared to non-isolated buildings.

The isolated buildings have a significant 97.97% reduction in X direction and 88.07% reduction in Y direction in soft storey drift on the 20th level when compared to non-isolated buildings.

This data imply that isolated structures perform better in terms of minimizing drift during strong winds, especially on higher floors. The somewhat larger drift observed on the ground level in the isolated building is due to the isolation system's particular features and force distribution.

V. CONCLUSION

This research involved the analysis of various structures through seismic and wind analysis. The study aimed to determine the effect of soft storeys within structures on variables such as storey displacement, storey drift, storey stiffness and time period. Based on the results obtained by analysis the following conclusions have been made:

1) The findings revealed that isolating the building at three distinct levels—ground, mid, and top—effectively reduced the forces transmitted to the floors above. The isolation system demonstrated significant effectiveness in mitigating the soft storey effect.
2) Analysis of the time period indicated that isolating the structure at the ground level resulted in greater flexibility compared to isolation at the mid and top levels. This increased flexibility led to higher drift and displacement when the structure was isolated at the ground level, as opposed to the mid and top levels.
3) Under wind loading, the building exhibited increased drift and displacement when isolated at the ground level. In contrast, isolating the building at the mid and top levels resulted in a more significant reduction in drift and displacement.

Ground-level isolation proved effective in reducing force transmission, while isolation at upper levels was more successful in minimizing soft storey effects. The study highlights the potential of storey isolation for enhancing seismic and wind resistance in structures. The results suggest that isolating the mid and top floors is more effective in all aspects compared to ground-floor isolation.

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