Seismic Evaluation of Multistorey Building with Soft Storey at Different Level: A Comparative Study

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Abstract— **The seismic performance of multistorey buildings with soft storeys at different levels is a crucial factor in structural safety, particularly in earthquake-prone regions. Soft storeys, characterized by reduced lateral stiffness relative to adjacent floors, lead to significant seismic vulnerabilities, including excessive inter-storey drifts, plastic hinge formation, and potential structural failure. This study investigates the dynamic behavior of such buildings using nonlinear static and dynamic analyses, considering various configurations where soft storeys are located at the base, intermediate, and upper levels. The impact of shear wall reinforcements at critical locations is also evaluated to determine their effectiveness in mitigating seismic risks. Results indicate that soft storeys, regardless of their position within the structure, exacerbate torsional effects and amplify displacement demands, increasing the risk of localized damage and progressive collapse. The findings emphasize the necessity of advanced design approaches, including optimized reinforcement strategies and the minimization of vertical irregularities, to enhance the seismic resilience of buildings with soft storeys.**

Index Terms— Soft storey, Earthquake, Storey drift, Displacement, Stiffness

I. INTRODUCTION

Multistorey buildings are a fundamental part of urban landscapes worldwide, yet their structural integrity during seismic events remains a critical concern. Among the various irregularities that compromise their performance, the presence of a soft storey is one of the most significant. A soft storey refers to a floor that has substantially lower lateral stiffness compared to the adjacent storeys, often due to architectural or functional requirements such as open spaces for parking, commercial areas, or large window openings. This decrease in stiffness breaks up the continuity of the lateral load-resisting system. This causes too much movement between floors, a concentration of damage, and in the worst cases, the structure collapsing during earthquakes. The vulnerability of soft-storey buildings is particularly pronounced in earthquake-prone regions, where past seismic events have demonstrated the catastrophic consequences of such structural weaknesses. Buildings with soft storeys at the ground level are especially susceptible, as they experience amplified seismic forces that compromise their overall stability. However, soft floors located at intermediate or upper levels also pose significant risks, affecting the dynamic response of the structure, inducing torsional effects, and exacerbating lateral displacements. Recognizing the risks associated with soft storeys, researchers have extensively studied their seismic behavior using analytical, numerical, and experimental approaches. Advanced simulation techniques, including nonlinear dynamic analysis and finite element modeling, have provided deeper insights into how soft storeys influence structural performance under seismic loading. These studies have also led to the creation of ways to make buildings more resistant to earthquakes. These include shear walls, bracing systems, energy dissipation devices, and base isolation techniques. This paper presents a comprehensive literature review on the seismic evaluation of multistorey buildings with soft storeys at different levels. It synthesizes key research findings, explores analytical methodologies, and discusses effective retrofitting techniques. By analyzing the interplay between soft storeys and overall building dynamics, this study aims to provide engineers and architects with critical insights into designing and strengthening structures in earthquake-prone regions.

II. REVIEW OF LITERATURE

Recent advancements in computational modeling and seismic evaluation have improved our understanding of soft storeys. Zhao and Zhang (2023) [1] used finite element modeling (FEM) to simulate the behavior of buildings with soft storeys during earthquakes. Their models accounted for complex factors such as material properties, building geometry, and different ground motion scenarios, yielding more accurate predictions of building response.

Basdogan and Ertugrul (2022) [2] explored the use of machine learning (ML) algorithms to predict the seismic performance of buildings with soft storeys. Their findings suggested that ML models could be trained to identify critical seismic failure modes and estimate building vulnerability, offering a more efficient and cost-effective approach to seismic evaluation. tall buildings.

Recent advancements in seismic evaluation techniques and structural design have focused on optimizing the response of buildings with soft storeys under earthquake loads. Simeonov et al. (2021) [3] introduced multi-objective optimization methods for retrofitting buildings with soft storeys, which consider both cost-effectiveness and performance. The study employed genetic algorithms to identify optimal retrofitting strategies, resulting in designs that minimized both seismic risk and retrofitting costs.

Advanced retrofitting techniques, such as base isolation, energy dissipation systems, and damping devices as Almeida and Lourenco (2020) [4] reviewed. Their study concluded that while base isolation is effective for reducing seismic forces at the base, it does not fully address the issues caused by soft storeys at higher levels. Therefore, a hybrid retrofitting approach, combining base isolation with additional dampers and bracing, was recommended to optimize performance.

The location of the soft storey within the building has a significant impact on the overall seismic performance. Kumar and Sharma (2020) [5] analyzed buildings with soft storeys at various levels and concluded that soft storeys at the base lead to large lateral displacements and inter-storey drifts, which are more dangerous compared to soft storeys located on higher floors. They suggested that buildings with base soft storeys are more likely to collapse or suffer major structural damage in the event of a strong earthquake.

Conversely, Choudhary and Singh (2019) [6] examined buildings with soft storeys at intermediate levels and observed that although the seismic forces were less concentrated at the base, significant torsional motion occurred due to the irregular distribution of mass and stiffness. The study emphasized that buildings with intermediate soft storeys face increased torsional instability, which contributes to large displacements in the upper floors.

In a similar vein, Arslan and Simsek (2019) [7] explored the integration of smart materials and systems in retrofitting soft storeys. Their research focused on the use of adaptive damping systems and shape-memory alloys to reduce seismic displacement and enhance the overall stability of the building.

The challenges posed by soft storeys in high-rise buildings Lee et al. (2016) [8] as also highlighted. Their study focused on the effects of soft storeys on the lateral drift and energy dissipation of the building structure. They found that the addition of base isolation systems could mitigate some of these issues, but the building still required supplementary damping systems to control excessive motion.

Jalal and Moghaddam (2015) [9] extended this analysis to dynamic approaches, using time history analysis to assess the effects of different earthquake scenarios on buildings with soft storeys. Their study underscored the importance of selecting realistic seismic ground motion records to obtain more accurate predictions of the building's response.

Another notable contribution was made by Makris and Vassiliou (2012) [10], who developed a simplified nonlinear static analysis procedure, also known as push-over analysis, for evaluating the seismic capacity of buildings with soft storeys. They demonstrated that push-over analysis can effectively identify the failure mechanisms and critical failure modes of soft storeys in multistorey buildings. This method allows engineers to assess the building's performance under increasing lateral forces and determine the point of collapse, providing valuable information for retrofitting strategies.

A significant amount of research has been devoted to developing mitigation strategies for improving the seismic performance of buildings with soft storeys. Sahoo and Jain (2011) [11] conducted a study on the retrofitting of buildings with soft storeys, exploring several techniques such as the introduction of shear walls, reinforced concrete infill panels, and steel braces. Their study demonstrated that retrofitting the soft storey with shear walls significantly enhanced the building's lateral load resistance and reduced inter-storey drifts.

Chung and Lee (2004) [12] provided further insights by studying the impact of soft storeys at different heights. They concluded that soft storeys at higher levels cause significant torsional effects due to irregular mass distribution.

In contrast, Berman and Bruneau (2003) [13] investigated the seismic vulnerability of buildings with soft storeys located on intermediate floors (e.g., the 3rd or 4th floor). Their research showed that while the vulnerability of base-soft storey buildings is more apparent, intermediate soft storeys could still significantly affect the building's overall performance. The researchers pointed out that buildings with intermediate soft storeys experience increased inter-storey drift and torsional behavior, which results in higher seismic damage to the floors directly above and below the soft storey. These results underlined the importance of evaluating soft storey locations in seismic design and retrofitting.

Shao et al. (2001) [14] conducted a similar study on high-rise buildings and found that the lack of adequate lateral stiffness in soft storeys not only amplifies inter-storey drifts but also increases the risk of overturning or buckling of structural elements. This study highlighted the importance of improving the stiffness distribution throughout the entire height of the building.

Early investigations into the seismic vulnerability of soft storeys were conducted by Chopra and Goel (1999) [15], who analyzed the response of buildings with soft storeys at the base. Their study revealed that ground-floor soft storeys are highly susceptible to collapse due to the concentration of seismic forces at the base, leading to excessive inter-storey drifts and elevated shear forces in the upper floors. This research underscored the critical need for special design considerations in structures with soft storeys, particularly in seismically active regions. The authors suggested that maintaining a uniform stiffness distribution along the building height could help mitigate the detrimental effects associated with soft storey configurations.

In the same vein, Gulkan and Sozen (1974) [16] emphasized the importance of incorporating inelastic behavior in the analysis of soft storeys. They proposed using a nonlinear static analysis method (push-over analysis) to determine the building's lateral load capacity and potential failure modes. Their work demonstrated that buildings with soft storeys require detailed consideration of their inelastic response to earthquake excitation.

III. OBJECTIVES OF THE STUDY

1. The study is carried out on G+20 storey building to determine seismic capacity of reinforced concrete framed buildings with soft storey at different level. All Brick Wall [masonry],soft storey at [5,10,15,20] floor, soft storey at [4,8,12,16] floor, soft storey at [3,6,9,12] floor, Soft storey at [1] floor, Soft storey at [2] floor, Soft storey at [3] floor, Soft storey at [4] floor, Shear Wall Type 1, Shear Wall Type 2, Shear Wall Type 3, Shear Wall Type 4
2. To determine seismic capacity of reinforced concrete framed buildings with soft storey with symmetrical plan.
3. To study the effect of height of building on seismic performance of soft storey building.
4. To analyses the seismic performance of above buildings by using strengthening measures such as reinforced concrete shear wall, displacement, storey drift, Story stiffness, Base shear and to study effects of these strengthening measures on performance of buildings.
5. To model and analyse a G+20 multistorey building with actual plan using ETABS 2019 software.

IV. METHOD OF ANALYSIS

A. Linear Static Method

In the present study, the structural analysis of the building has been carried out using the Linear Static Method, also known as the Equivalent Lateral Force Method, as per the provisions of the Indian Standard IS 1893 (Part 1): 2016. The analysis was performed using ETABS 2019 software, which provides a robust computational platform for the modeling and evaluation of seismic loads on structures. This method is one of the most fundamental and widely accepted procedures for seismic analysis in India, particularly applicable to regular-shaped buildings with limited height and symmetrical mass and stiffness distribution. The Linear Static Method assumes that the building responds elastically to seismic excitation and that the dynamic effects of ground motion can be approximated by a set of static lateral forces acting horizontally at each floor level. These equivalent lateral forces are derived based on the design base shear, which represents the total lateral force expected to act on the structure during the design-level earthquake.

The base shear (Vb) is computed using the expression: Vb=Ah×W Here, Ah is the design horizontal seismic coefficient and W is the seismic weight of the structure. The value of A_h is given by: Ah=Z.I.SA/2RG where: Z = Zone factor (depends on the seismic zone of the site as per IS 1893:2016), I = Importance factor (accounts for the functionality of the building), R = Response reduction factor (depends on the type of lateral load-resisting system and ductility), Sa/g = Average response acceleration coefficient obtained from the standard design spectrum, based on the fundamental natural period (T) of the building and the soil type. The seismic weight W includes the total dead load and applicable portions of live loads as per IS 1893:2016. The calculated base shear is then distributed vertically along the height of the structure in accordance with the dynamic characteristics of the building. The lateral force at any particular floor level iii is given by: $Qi= Wihi^2/ \sum Wihi^2$ x vb where: Qi = Lateral force at level, Wi= Seismic weight at level, hi= Height of level iii from the base. In ETABS 2019, this entire procedure is executed automatically when the user specifies the seismic parameters in accordance with IS 1893:2016. The software allows the user to define the zone factor, importance factor, response reduction factor, and soil type. Based on these inputs, it calculates the fundamental natural time period (either using empirical formulas or through modal analysis), determines the spectral acceleration coefficient Sa/g, and applies the equivalent lateral loads to the structure. These loads are then used in combination with gravity loads to perform the structural analysis. The output from ETABS includes storey displacements, storey drift, and storey stiffness which are used to assess the structural adequacy and ensure compliance with codal provisions. The Linear Static Method, while simplified, is suitable for preliminary design and for structures that do not exhibit complex dynamic behavior. They are recommended as per IS 1893:2016 guidelines. This method forms a reliable basis for evaluating the structural performance of regular buildings under seismic loading and ensures a conservative and code-compliant approach in the early stages of design.

V. STRUCTURAL MODELLING

Analyzing the data: Following data are used in the model

1. Size of Building: 12 m X 12 m.
2. Grade of concrete: M 30
3. Grade of steel: Fe 415
4. Floor to floor height: 3 m
5. Plinth height above foundation: 3 m
6. Slab thickness: 150 mm
7. Wall thickness: 230 mm
8. Shear wall thickness: 300 mm
9. Size of columns,
    a. 400mm × 750mm (1st to 10th floor) and
    b. 300mm × 750mm (10th to 20th floor)
10. Size of beam: 300mm × 600mm
11. Live load on floor: 5KN/m ^{2}
12. Floor finishes is 2 KN/m ^{2}
13. roof treatment: 1.5 KN/m ^{2}
14. Soil condition: Medium
15. Importance factor: 1
16. Building frame: 5 [SMRF]
17. Load case type: Linear static method
18. Wind speed: 50 m/s
19. Terrian category: 2
20. Density of concrete: 25 KN/m ^{3}
21. Density of masonry wall: 20 KN/m ^{3}
22. Seismic Zone: V [0.36]
23. Time period: 1.558 sec

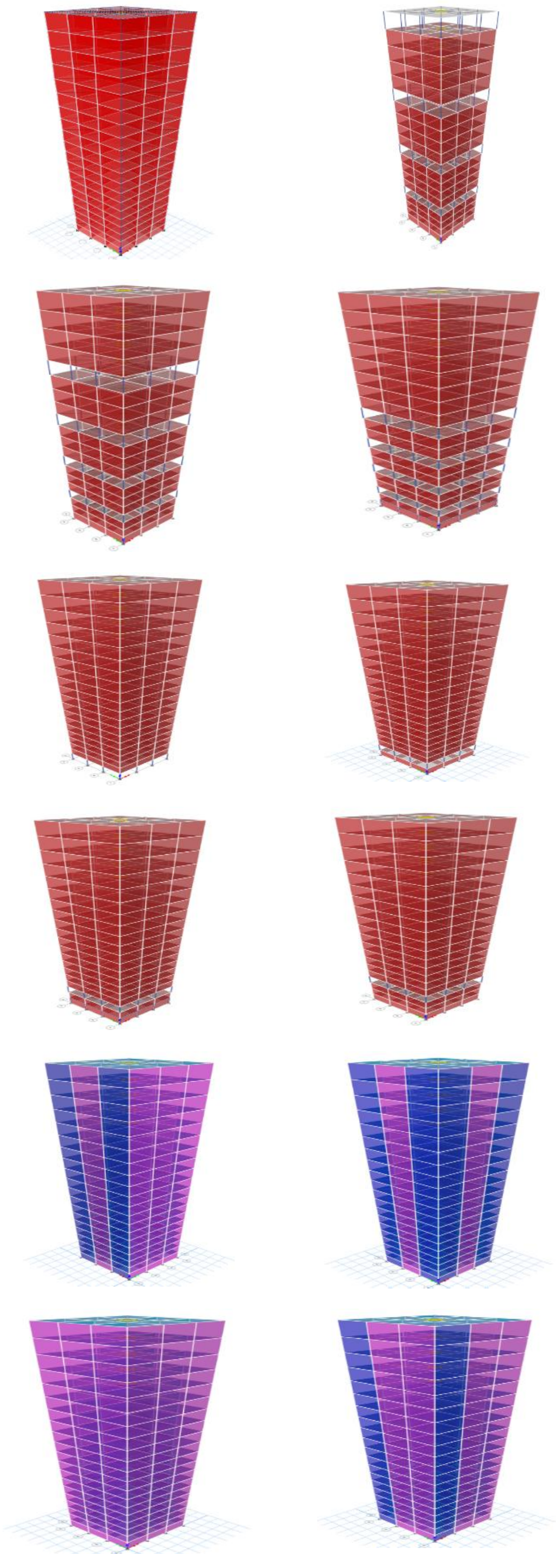

Fig. 1. 3D building models: (a) Infill frame; (b) Soft story 1; (c) Soft story 2; (d) Soft story 3; (e) Soft story 4; (f) Raft footing; (g) Soft story 5; (h) Soft story 6; (i) Soft story 7; (j) Soft story 8; (k to O) shear wall type 1 to 4

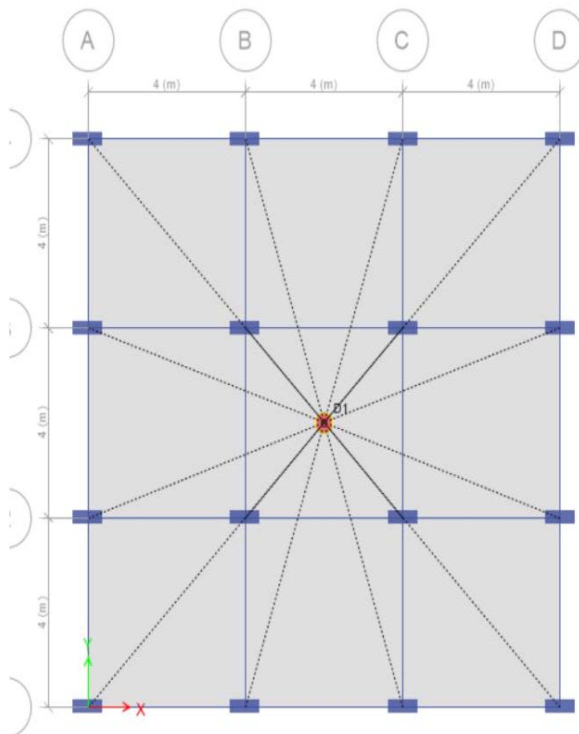

Fig. 2. Structural plan (G+20)

VI. RESULTS AND DISCUSSION

The seismic analysis on the infilled frame, soft story, and shear wall building results are discussed below. And above analysis as done by using the ETABS software. The parameters considered are story displacement, storey drift, and stiffness.

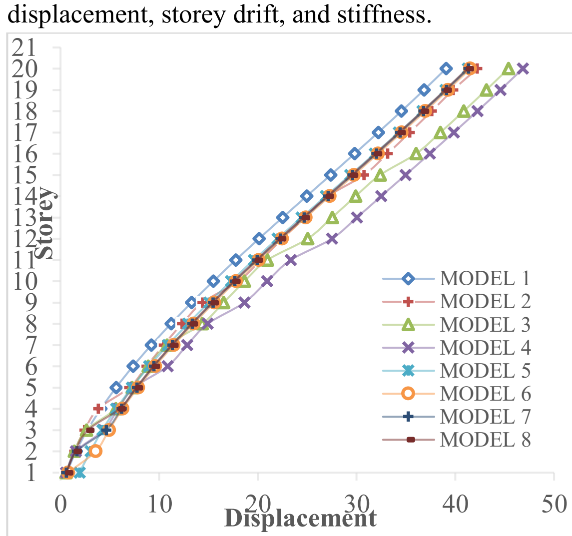

Fig. 3. Soft Story Displacement X – Direction

From table 1, Model 1, 20 storey displacement is 27.359 mm. Model 2 top storey (Storey 20) displacement increased by 8.1%, while mid-storey levels such as Storey 10 and Storey 5 showed more

Table 1. Soft storey Displacement (mm) X- Direction

Storey	Model -1	Model -2	Model -3	Model -4	Model -5	Model- 6	Model- 7	Model -8
	Disp. (mm)	Disp. (% inc.)	Disp. (% inc.)	Disp. (% inc.)	Disp. (% inc.)	Disp. (% inc.)	Disp. (% inc.)	Disp. (% inc.)
Storey 20	39.04	42.2 (8.1%)	45.357 (16%)	46.823 (19.9%)	41.264 (6%)	41.494 (6%)	41.317 (6%)	41.2 (6%)
Storey 15	27.359	30.736 (12.3%)	32.375 (18%)	34.943 (28%)	29.351 (7.3%)	29.719 (9%)	29.56 (8%)	29.459 (8%)
Storey 10	15.471	18.007 (16.4%)	18.624 (20%)	20.93 (35%)	17.264 (12%)	17.773 (15%)	17.631 (14%)	17.546 (13%)
Storey 5	5.624	6.964 (23.8%)	7.241 (29%)	7.46 (33%)	7.22 (28%)	7.848 (40%)	7.725 (37%)	7.668 (36%)
Storey 1	0.63	0.555 (-11.9%)	0.558 (-11%)	0.546 (-13%)	1.923 (205%)	0.767 (22%)	0.578 (-8%)	0.592 (-6%)

pronounced increases of 16.4% and 23.8%, respectively. Model-3, Storey 20 showed a 16% increase in displacement, and Storey 10 and Storey showed increases of 20% and 29%, respectively. Model-4, The top storey displacement increased by 19.9%, and a significant 35% increase was recorded at Storey 10. Models 5, 6, 7, and 8 showed moderate increases in displacement values, typically ranging between 6–9% at upper storeys, and around 28–40% at lower storeys. Model-5 recorded an abnormally high 205% increase in displacement at the ground level.

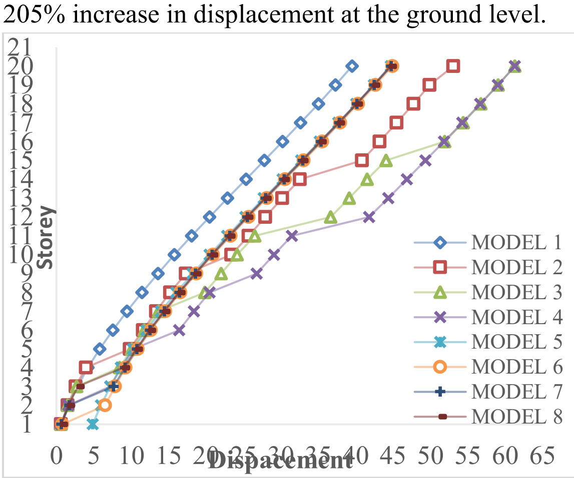

Fig. 4. Soft Story Displacement Y – Direction

From table 2, At the topmost level (Storey 20), Model-1 exhibited the lowest displacement of 39.551 mm while significant increases were observed in Models 2, 3, and 4, with displacements rising to 53.083 mm (34%), 61.306 mm (55%), and 61.313 mm (55%), respectively. At mid-levels such as Storey 15 and Storey 10, the trend of increasing displacement becomes even more prominent. In Storey 15, displacement increased by 47% in Model-2, 58% in Model-3, and 77% in Model-4, whereas in lower-level soft storey models (5–8), the increases were modest, around 18–19%. Storey 10 followed a similar pattern with displacement rising by 48%, 53%, and 84% for Models 2, 3, and 4 respectively, compared to 30–33% in Models 5 to 8. Model-5 which has a soft storey at the ground floor exhibited an extreme displacement increase of 603%.

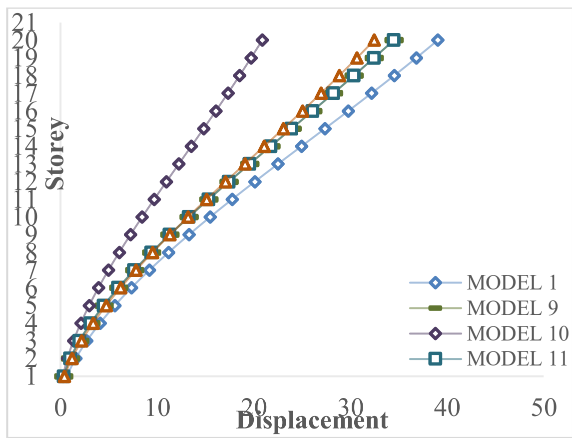

Fig. 5. Shear wall Displacement X – Direction

From table 4, at the top storey (Storey 20), displacement in the reference Model-1 is 39.04 mm, which is significantly reduced in all shear wall models. The most effective reduction is seen in Model-10 (Type 2) with a 47% decrease, lowering the displacement to 20.877 mm. Model-12 (Type 4) follows with a 17% reduction, while Models 9 and 11 (Types 1 and 3) show a 12% decrease. At Storey 15, Model-10 again shows the highest reduction at 46%, decreasing the displacement from 27.359 mm to 14.806 mm. Other models show moderate reductions: 13% in Models 9 and 11, and 16% in Model-12. Storey 10 exhibits similar trends, with Model-10 showing the largest displacement reduction of 45%.

Table 2. Soft storey Displacement (mm) Y- Direction

Storey	Model - 1	Model -2	Model -3	Model -4	Model -5	Model- 6	Model- 7	Model -8
	Disp. (mm)	Disp. (% inc.)	Disp. (% inc.)	Disp. (% inc.)	Disp. (% inc.)	Disp. (% inc.)	Disp. (% inc.)	Disp. (% inc.)
Storey 20	39.551	53.083 (34%)	61.306 (55%)	61.313 (55%)	44.725 (13%)	44.935 (14%)	44.762 (13%)	44.639 (13%)
Storey 15	27.808	40.855 (47%)	44.064 (58%)	49.355 (77%)	32.731 (18%)	33.081 (19%)	32.927 (18%)	32.819 (18%)
Storey 10	15.79	23.415 (48%)	24.168 (53%)	29.084 (84%)	20.479 (30%)	20.972 (33%)	20.836 (32%)	20.744 (31%)
Storey 5	5.8	9.824 (69%)	10.087 (74%)	10.292 (77%)	10.262 (77%)	10.877 (88%)	10.758 (85%)	10.694 (84%)
Storey 1	0.688	0.62 (-10%)	0.623 (-9%)	0.611 (-11%)	4.836 (603%)	0.8 (16%)	0.648 (-6%)	0.662 (-4%)

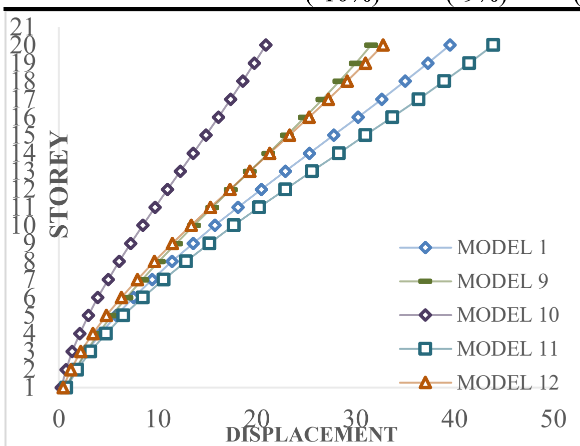

Fig. 6. Shear wall Displacement Y – Direction

From table 3, at the storey 20 Model-10 most effective performance with a 47% reduction in displacement from 39.551 mm to 20.941 mm, indicating excellent control over lateral deflection. Model-9 Type 1 also shows improvement, reducing displacement by 20%. Model-11 unexpectedly increases the displacement by 11%, Model-12 achieves a 17% reduction. At Storey 15, Model-10 maintains superior control with a 47% reduction in displacement. Model-9 and Model-12 also perform well, reducing displacements by 17% and 16%, respectively. Model-11 again shows an increase in displacement 12%. At Storey 10 Model-10 with a 46% reduction, Model-12 (15% reduction) and Model-9 (13%). Model-11 shows a 12% increase, at Storey 5 Model-10 achieves the highest reduction of 49%, Model-12 and Model-9 follow with reductions of 17% and 7%, respectively. and, Model-11 records a 13% increase in displacement.

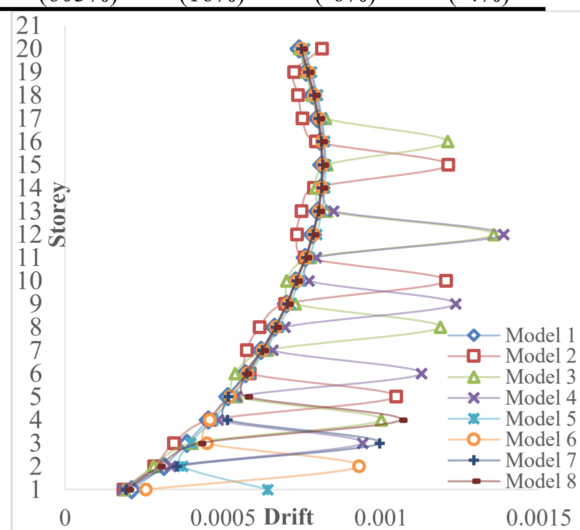

Fig. 7. Soft storey Drift X – Direction

From table 5, At the storey 20 the drift values across all models remain very close to the baseline Model-1 value of 0.000741, Model-2 showing a marginal increase to 0.000813, corresponding to a 0.0024 % increase. The other models, such as Model-3 through Model-8, show negligible variations within the 0.0001% to 0.001% range. At Storey 15 Model-2 shows drift of 0.001213, which is a -0.013% increase. All other models maintain close proximity to the reference drift of 0.000812, with percentage increases ranging from 0.0001% to 0.0006%. at Storey 10 At Storey 5, Model-2, which has a soft storey at this level, experiences the highest drift value of 0.001048.

Table 3. Shear wall Displacement Y – Direction

Storey	Model -1	Model -9	Model -10	Model -11	Model -12
	Disp. (mm)	Disp. (% inc.)	Disp. (% inc.)	Disp. (% inc.)	Disp. (% inc.)
Storey 20	39.551	31.586 (-20%)	20.941 (-47%)	43.934 (11%)	32.781 (-17%)
Storey 15	27.808	23.057 (-17%)	14.86 (-47%)	31.017 (12%)	23.33 (-16%)
Storey 10	15.79	13.674 (-13%)	8.48 (-46%)	17.7 (12%)	13.372 (-15%)
Storey 5	5.8	5.368 (-7%)	2.977 (-49%)	6.527 (13%)	4.803 (-17%)
Storey 1	0.688	0.718 (4%)	0.244 (-65%)	0.768 (12%)	0.414 (-40%)

From table 6, At Storey 20 model-1, maximum drift is 0.000742. Model-2, shows the highest drift at this level 0.001054, Other models such as Model-3 to Model-8 show negligible increases ranging from 0.0001% to 0.001%, at Storey 15. Model-2 again records the highest drift 0.00276, translating to a 0.065% increase from the model-1 0.000819. the other models exhibit very minor variations up to 0.001%, At Storey 10, Model-2 continues to show the highest drift 0.002031. Model 3 shows slight decrease -0.001%.

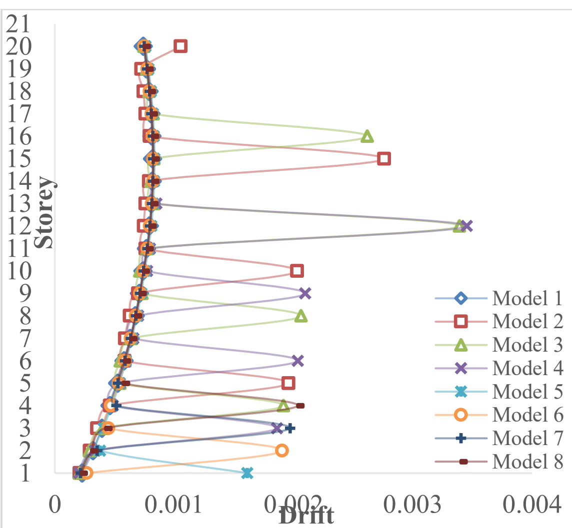

Fig. 8. Soft storey Drift Y – Direction

From table 7, At Storey 20, Model-1 shows a drift of 0.000741. Model-10 shows reduction, with a drift of 0.000386, Model-9 and Model-11 show similar reductions of −0.002%, while Model-12 achieves −0.005% decrease. At Storey 15, the drift value of 0.000812 in Model-1 drops to 0.000427 in Model-10, Models 9 and 11 show similar performance with drift reductions of −0.003%, while Model-12 also records a drift decrease of −0.003%. At Storey 10, Model-1 records a drift of 0.000729, Model-10 maintains the lowest drift 0.000403, a −0.011% reduction, followed closely by Model-12 with a −0.004% change. Models 9 and 11 both exhibit reductions of −0.002%.

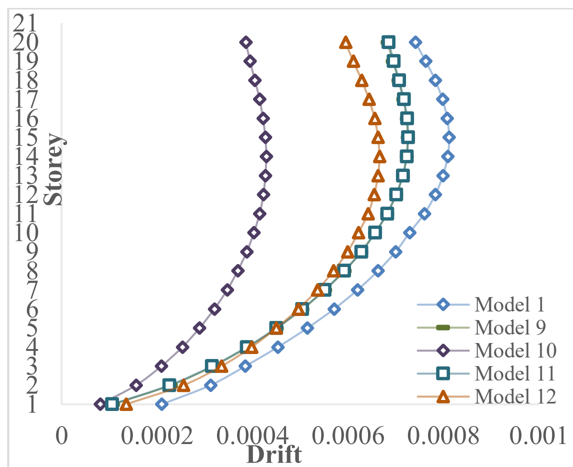

Fig. 9. Shear wall Drift X – Direction

From table 8, At the top storey (Storey 20**)**, Model-1 records a drift of 0.000742. Model-10 achieves the greatest reduction, with a drift of 0.000387, Model-9 and Model-12 also show significant drift reductions of −0.007% and −0.005%, At Storey 15, Model-1 has a drift of 0.000819. Model-10 shows the largest reduction, with a drift of 0.000428, Model-9 and Model-12 moderate decreases of −0.007% and −0.002%, At Storey 10, Model-1 drift is 0.000738. Model-10 drift is reduced of 0.000405, Model-9 shows a −0.005% decrease, while Model-12 achieves a −0.004% reduction. At the storey 5 Model-1 shows a drift of 0.000525. Model-10 remains drift of 0.000290, Model-11 records increase in at 0.002%.

Table 4. Shear wall Displacement X – Direction

Storey	Model -1	Model -9	Model -10	Model -11	Model -12
	Disp. (mm)	Disp. (% inc.)	Disp. (% inc.)	Disp. (% inc.)	Disp. (% inc.)
Storey 20	39.04	34.501 (-12%)	20.877 (-47%)	34.48 (-12%)	32.46 (-17%)
Storey 15	27.359	23.934 (-13%)	14.806 (-46%)	23.891 (-13%)	23.056 (-16%)
Storey 10	15.471	13.295 (-14%)	8.444 (-45%)	13.249 (-14%)	13.187 (-15%)
Storey 5	5.624	4.488 (-20%)	2.961 (-47%)	4.451 (-21%)	4.718 (-16%)
Storey 1	0.63	0.324 (-49%)	0.242 (-62%)	0.318 (-50%)	0.404 (-36%)

Table 5. Soft Story Drift (mm) X – Direction

Storey	Model -1	Model -2	Model -3	Model -4	Model -5	Model- 6	Model- 7	Model -8
	Drift.	**Drift. (% inc.)**	**Drift. (% inc.)**	**Drift. (% inc.)**	**Drift. (% inc.)**	**Drift. (mm)**	**Drift. (% inc.)**	**Drift. (% inc.)**
Storey 20	0.000741	0.000813 (0.0024%)	0.000743 (0.0001%)	0.000757 (0.001%)	0.000758 (0.0006%)	0.000749 (0.0003%)	0.000748 (0.0002%)	0.000747 (0.0002%)
Storey 15	0.000812	0.001213 (-0.013%)	0.000829 (0.0006%)	0.000822 (0.0003%)	0.000825 (0.0004%)	0.000816 (0.0001%)	0.000815 (0.0001%)	0.000814 (0.0001%)
Storey 10	0.000729	0.001206 (-0.016%)	0.000701 (-0.001%)	0.000772 (0.001%)	0.000742 (0.0004%)	0.000733 (0.0001%)	0.000732 (0.0001%)	0.000731 (0.0001%)
Storey 5	0.000515	0.001048 (-0.018%)	0.000543 (0.001%)	0.000542 (0.001%)	0.000529 (0.0005%)	0.000523 (0.0003%)	0.000517 (0.0001%)	0.000574 (0.002%)
Storey 1	0.00021	0.000185 (-0.001%)	0.000186 (-0.001%)	0.000182 (-0.001%)	0.000641 (0.014%)	0.000256 (0.002%)	0.000193 (-0.001%)	0.000197 (0.000%)

Table 7. Shear wall Drift (mm) X – Direction

Storey	Model -1	Model -9	Model -10	Model -11	Model -12
	Drift.	**Drift. (% inc.)**	**Drift. (% inc.)**	**Drift. (% inc.)**	**Drift. (% inc.)**
Storey 20	0.000741	0.000683 (-0.002%)	0.000386 (-0.012%)	0.000685 (-0.002%)	0.000595 (-0.005%)
Storey 15	0.000812	0.000725 (-0.003%)	0.000427 (-0.013%)	0.000726 (-0.003%)	0.000663 (-0.003%)
Storey 10	0.000729	0.000657 (-0.002%)	0.000403 (-0.011%)	0.000657 (-0.002%)	0.000622 (-0.004%)
Storey 5	0.000515	0.000451 (-0.002%)	0.000289 (-0.008%)	0.00045 (-0.002%)	0.00045 (-0.010%)
Storey 1	0.00021	0.000108 (-0.003%)	0.000081 (-0.004%)	0.000106 (-0.003%)	0.000135 (-0.020%)

Table 6. Soft Story Drift (mm) Y – Direction

Storey	Model -1	Model -2	Model -3	Model -4	Model -5	Model- 6	Model- 7	Model -8
	Drift.	**Drift. (% inc.)**	**Drift. (% inc.)**	**Drift. (% inc.)**	**Drift. (% inc.)**	**Drift. (mm)**	**Drift. (% inc.)**	**Drift. (% inc.)**
Storey 20	0.000742	0.001054 (0.010%)	0.000745 (0.0001%)	0.000758 (0.001%)	0.000759 (0.0006%)	0.00075 (0.0003%)	0.000749 (0.0002%)	0.000748 (0.0002%)
Storey 15	0.000819	0.00276 (0.065%)	0.00083 (0.0004%)	0.000832 (0.0004%)	0.000835 (0.001%)	0.000825 (0.0002%)	0.000824 (0.0002%)	0.000823 (0.0001%)
Storey 10	0.000738	0.002031 (0.043%)	0.000712 (-0.001%)	0.000773 (0.001%)	0.000753 (0.000%)	0.000744 (0.0002%)	0.000743 (0.0002%)	0.000742 (0.0001%)
Storey 5	0.000525	0.001958 (0.048%)	0.000545 (0.001%)	0.000544 (0.001%)	0.000541 (0.001%)	0.000535 (0.0003%)	0.000529 (0.0001%)	0.000575 (0.002%)
Storey 1	0.000229	0.000207 (-0.001%)	0.000208 (-0.001%)	0.000204 (-0.001%)	0.001612 (0.046%)	0.000267 (0.001%)	0.000216 (0.000%)	0.000221 (0.000%)

Table 8. Shear wall Drift (mm) Y – Direction

Storey	Model -1	Model -9	Model -10	Model -11	Model -12
	Drift.	**Drift. (% inc.)**	**Drift. (% inc.)**	**Drift. (% inc.)**	**Drift. (% inc.)**
Storey 20	0.000742	0.000519 (-0.007%)	0.000387 (-0.012%)	0.000814 (0.002%)	0.000597 (-0.005%)
Storey 15	0.000819	0.000622 (-0.007%)	0.000428 (-0.013%)	0.000905 (0.003%)	0.000668 (-0.002%)
Storey 10	0.000738	0.000601 (-0.005%)	0.000405 (-0.011%)	0.000824 (0.003%)	0.000629 (-0.004%)
Storey 5	0.000525	0.000457 (-0.002%)	0.00029 (-0.008%)	0.00059 (0.002%)	0.000457 (-0.010%)
Storey 1	0.000229	0.000239 (-0.000%)	0.000081 (-0.005%)	0.000256 (0.001%)	0.000138 (-0.020%)

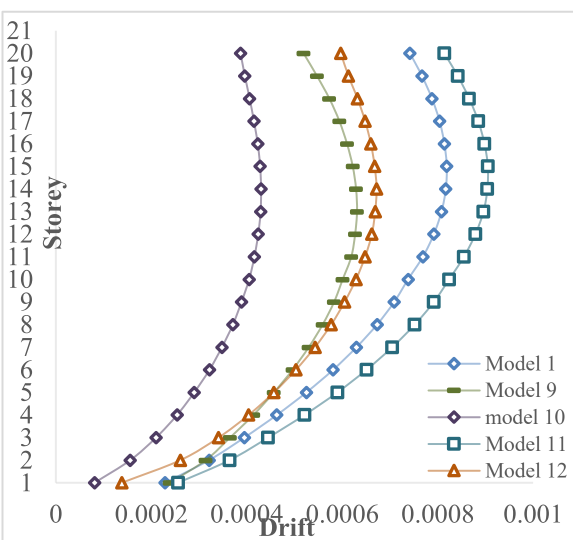

Fig. 10. Shear wall Drift Y – Direction

VII. CONCLUSION

The present comparative study of 12 structural models reveals that soft storey buildings generally exhibit higher displacements and drifts, especially in the Y-direction, indicating increased seismic vulnerability. Model 2, with soft storeys at upper levels, showed the highest drift values, emphasizing the detrimental effect of vertical irregularities on seismic performance. Models 3 to 8 also reflected elevated displacements compared to the infill frame Model 1, though the severity reduced in models with soft storeys located at lower levels. Further, models incorporating shear walls Models 9 to 12 significantly reduced both displacement and drift, with Model 10 demonstrating the best performance, achieving the lowest values in both directions. However, Model 12, while slightly higher in displacement than Model 10, exhibited the highest lateral stiffness, confirming the effectiveness of shear walls in enhancing structural rigidity. Overall, the findings highlight that shear wall systems greatly improve seismic response, while soft storey designs need careful evaluation to prevent excessive lateral movement and ensure structural safety.

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