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Investigation of Shear Walls Openings on the Performance of Seismic Loads for irregular Reinforced Concrete Structures on sloped terrain

M. Y. Laissy[1,*]

[1] Civil Engineering Department, Faculty of Engineering, University of Prince Mugrin, Saudi Arabia.

* Corresponding Author e-mail address: laissy99@gmail.com, m.laissy@upm.edu.sa

Abstract:

Shear walls are very stiff and have high strength, making them helpful in many structural engineering applications, particularly for sustaining significant horizontal and weight loads. Shear walls in the context of irregular reinforced concrete constructions might include openings such as windows and doors to meet appropriate functional needs. The ETABS software was used in this study to evaluate ground storey plus ten typical storeys with shear walls, with and without opening. Seismic research was performed on numerous models to determine factors such as shear forces, drift, and storey displacement. According to dynamic analysis, models with no openings outperformed others, which is consistent with previous research in the subject. The displacement of models with openings at the roof level was 24.852 mm, whereas that of models without openings was around 5.151 mm. As a result, it is critical to examine effect of the opening on the seismic behavior of shear walls during the design process.

keywords: seismic Loads; shear walls; opening; Response spectrum analysis; ETABS, Sloped terrain.

1. Introduction

RC structures can sustain significant vertical and horizontal loads. Wind and seismic loads, Shear walls are typically designed to withstand seismic loads and wind which are among the most frequent types of lateral forces experienced by buildings (Aly and Galal 2020)

Shear walls give the necessary strength to resist seismic forces and are recognized as the most effective and simple option to withstand lateral stresses [(Ahmadi, Aghakouchak et al. 2021, Ali 2022, Hamed, Samadi et al. 2022, Najm, Ibrahim et al. 2022)]. Shear walls provide lateral support to buildings and have the shape of a box on the outside. Shear walls contribute to the stiffness and strength of the structure in the lateral direction [(Krishna and Arunakanthi 2014, Hassan and Pal 2017, Hassan and Pal 2018, Lukacs, Björnfot et al. 2019, Pal, Hassan et al. 2019)]. Because shear-walls carry high lateral loads, the effects overturn is important and should be carefully considered during structural design. The symmetrical positioning of shear-walls in RC structures is favored to mitigate the negative impacts of twisting [(Thearith 2019, Faraone 2021, Kechidi and Iuorio 2022)].

Shear walls are suggested to be symmetrically placed in both or one direction of the structure layout. Shear-walls normally considered more effective in strengthening the structure's resistance to twisting when installed on the external perimeter [(Mosoarca 2014)].

Shear wall behavior is governed by a number of parameters, including the used material, wall thickness, wall length, wall position, and structure. Shear-walls therefore are chosen in the construction of high-rise buildings in sensitive seismic loads areas due to their bearing capacity, rigidity, as well as their ductility [(Lou, Gao et al. 2021, Abualreesh, Tuken et al. 2022, Broberg, Shafaei et al. 2022)]. Because of the large change in displacement observed for shear walls with opening, shear wall opening in-plane loads are crucial than the shear-wall without opening out-of-plane [(Najm, Ibrahim et al. 2022)].

Shear walls are important in building construction due to their capacity to support loads such as wind and earthquakes. As a result, a number of research projects were conducted to examine the structural shear-walls behavior under various situations and load instances. Zhang and Wang [(Zhang, Wang et al. 2020)] investigated the performance seismic loads for the reinforced prefabricated masonry shear-walls having joint connections. Meanwhile, Choi et al investigated fragility the columns in a piloti-type retrofitted structures due to seismic with respect to adding more shear walls [(Sohn, Choi et al. 2022)].

The behavior of masonry retrofitted walls with FRP vertical rebars was explored in a report by Coccia et al. According to their findings, traditional seismic retrofitting procedures used on masonry walls have an effect on the performance of seismic loads of elements, that is frequently altered in the bending behavior out-of-plane [(Coccia, Di Carlo et al. 2020, Saeed, Najm et al. 2022)]. Furthermore, Jeon et al. examined fragility of the reinforced concrete shear-walls to seismic loads to coupling beams and discovered that high-rise regular RC shear walls with ground motion components of seven pairs and an amplification factor of shear force of 1.2 or higher met the FEMA P695 collapse margin ratio and collapse probability requirements [(Jeon and Park 2020, Budak, Sucuoğlu et al. 2023)].

When building reinforced concrete buildings with L-shaped shear walls, architects can gain various advantages, including the capacity to create wider open areas and increased design adaptability [(Wang, Shi et al. 2016, Zhang and Mueller 2017, Alih and Vafaei 2019)]. Extensive experimental studies and numerical models are required for shear walls L-shaped to ensure safety restrictions compliance specified by various code standards. Nonetheless, L-shaped concrete shear-walls are often utilized in high-rise buildings which need high levels of deformability and resistivity due to their ability to resist lateral loads and absorb seismic energy. Furthermore, these walls provide architects with greater flexibility when constructing structures with bigger open areas [(Husain, Eisa et al. 2019, Wang, Su et al. 2022, Chen, Mohammed et al. 2023)].

Shear-walls openings may be required for a variety of reasons, including remodeling demands or municipal rules for the location of elevators, windows, doors, and staircases [(Mosallam and Nasr 2017, El Ouni, Laissy et al. 2018)]. Adding apertures to shear walls affects the overall capacity of the structure and wall integrity and can result in stress concentration around the openings [(Rahim, Mohammed et al. 2020)]. The fundamental goal of this research is to understand the behavior of openings under seismic load, and then evaluate the effectiveness of several types of openings under various loading situations.

2. Description of Models

An 11 RC structure story with shear wall elements was chosen for this study in order to reduce analysis time. The study's goal was to look into the behavior of shear walls with apertures for irregular RC structures located in the Madinah Zone. This study considers the shape of a (L) shaped shear wall without and with openings, rather than the influence of the building's length. Tables 1-3 show the applied loads, model data, and seismic loads data, whereas Figures 1-4 show the model plan and geometry.

Table 1. Models' data.

Stories	11
Column	(500 * 500) m m
Beam	(300 * 500) m m
Thickness of Slab	150 m m
Thickness of Shear Wall	250 m m
opening Size	(2 * 1.0) m
Height of Storey	3.0 m
Support	fixed
Concrete Grade	M30
Steel Grade	Fy 420

Table 2. Model Loads

Concrete	**25 kN/m^3**
D.L.	3.0 kN/m^2
L.L.	2 kN/m^2
Wall Load	11.5 kN/m

Table 3. Seismic Loads

Zone	**1**
(Z) factor	0.075
Type of Soil	B
Damping Ratio	5.0 %
Response modifier factor (R)	5.0
Importance factor (I)	1.0

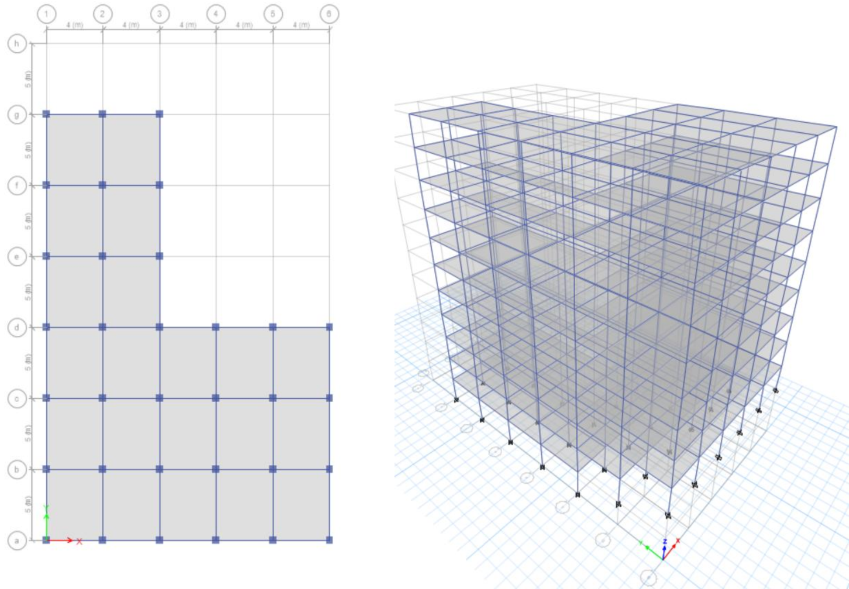

Figure 1. The structure geometry 3D model with no shear-walls.

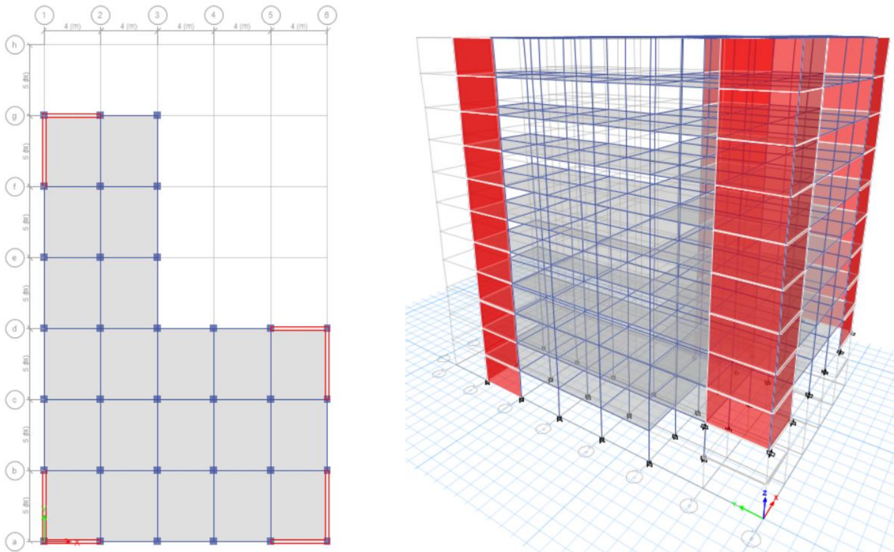

Figure 2. structure geometry 3D model with shear-walls.

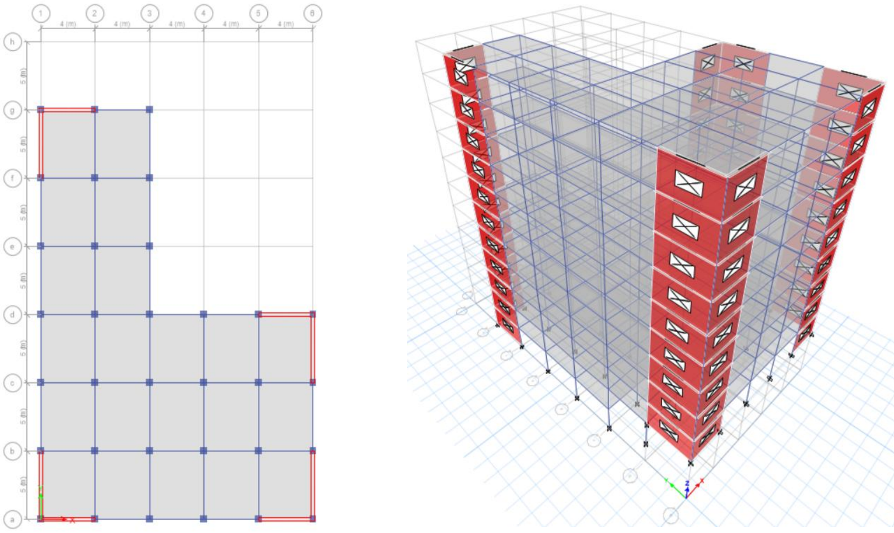

Figure 3. The structure geometry 3D model with shear-walls and opening.

Seismic analysis was performed in this study utilizing the response spectrum function. As shown in Fig. 4, it is a graphical depiction of the max. amplitude response (velocity, displacement) with respect to the time period for multiple linear SDOF oscillators under a specified ground motion component. which can be used for choosing the any linear single degree of freedom oscillator response based on the time period of oscillation. It is frequently used to assess the maximum responsiveness of structures to ground motions. Peak of the ground acceleration (PGA), that reflects the greatest point of the max. acceleration ground motion spike, is typically the data given in earthquake record.

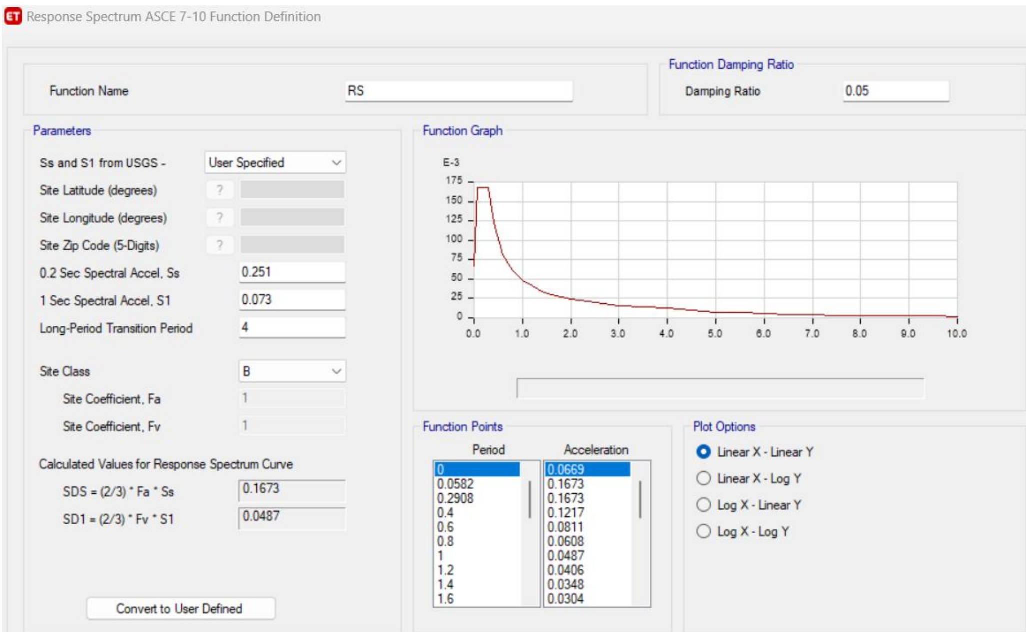

Figure 4. definition of Response spectrum analysis function.

This study focused on a structure with an irregular plan that includes shear walls with openings. The building has a floor area of 420 square meters and is modeled with 5 bays in x-axis and 6 bays in y-axis.

3. Modeling and Analysis

Three models for irregular building on sloped terrain were studied in this work. The first model displays structure with no shear walls (Fig. 1), while the other model depicts structure with shear-walls but no openings (Fig. 2). Fig. 3 depicts the last model, which consists of shear-walls with openings.

4. Results & Discussion

4.1 Storey Displacement

The max. displacement of the equivalent static analysis (ESA) for (EX and EY) is shown in Tables 4 and 5, as well as Fig. 5 and 6. The structure with no shear walls caused a displacement of approximately 24.852 mm on the top floor, whereas the structure with shear-walls caused 4.246 mm, resulting in a 17.1% reduction in the displacement of the storey of the X-direction. The vertical openings displayed a storey displacement of approximately 5.15 mm. On the top level, the building without shear walls caused 20.68 mm of displacement, whereas the structure with shear-walls caused 2.595 mm, 12.5%. The storey displacement for the openings is 2.956 mm. Tables 6 -7 and Fig. 7 -8 show the displacement storey for response spectrum analysis (RSA).

The displacement of the structure with no shear walls was approximately 42.006 mm, but the displacement of the structure with shear-walls was 28.938 mm, also a 31% decrease in X-direction and a 33% decrease in Y-direction. The storey displacement of shear-walls with opening is 29.283 mm for X-direction and 29.434 mm for Y-direction openings.

Table 4 shows a comparison of storey displacements for the ESA X directions (millimeters)

Storey	**No Shear Walls**	**Shear Walls No Openings**	**Shear Walls No Openings**
Storey11	24.852	4.246	5.151
Storey10	23.917	3.757	4.568
Storey9	22.527	3.257	3.967
Storey8	20.683	2.75	3.356

Storey7	18.45	2.245	2.744
Storey6	15.904	1.753	2.147
Storey5	13.115	1.29	1.584
Storey4	10.151	0.873	1.075
Storey3	7.091	0.52	0.643
Storey2	4.073	0.249	0.311
Storey1	1.408	0.071	0.095
Base	0	0	0

Table 5. shows a comparison of storey displacements for the ESA Y directions (millimeters)

Storey	**No Shear Walls**	**Shear Walls No Openings**	**Shear Walls No Openings**
Storey11	20.68	2.595	2.956
Storey10	19.866	2.272	2.6
Storey9	18.569	1.94	2.232
Storey8	16.796	1.604	1.857
Storey7	14.615	1.27	1.482
Storey6	12.106	0.95	1.12
Storey5	9.353	0.655	0.782
Storey4	6.45	0.399	0.484
Storey3	3.643	0.198	0.244
Storey2	1.686	0.066	0.081
Storey1	0.521	0.006	0.01
Base	0	0	0

Buildings without shear walls display larger storey displacement than other types, according to the studies. Shear walls with openings move more than those with vertical openings or no holes at all in terms of displacement. A shear wall with no openings, on the other hand, outperforms ones with vertical openings. Marius [(Marius 2013)] earlier reached the same conclusions in published literature. Finally, we can say that the shear-walls existence in buildings, regardless of whether they have openings or not, significantly improves their seismic response.

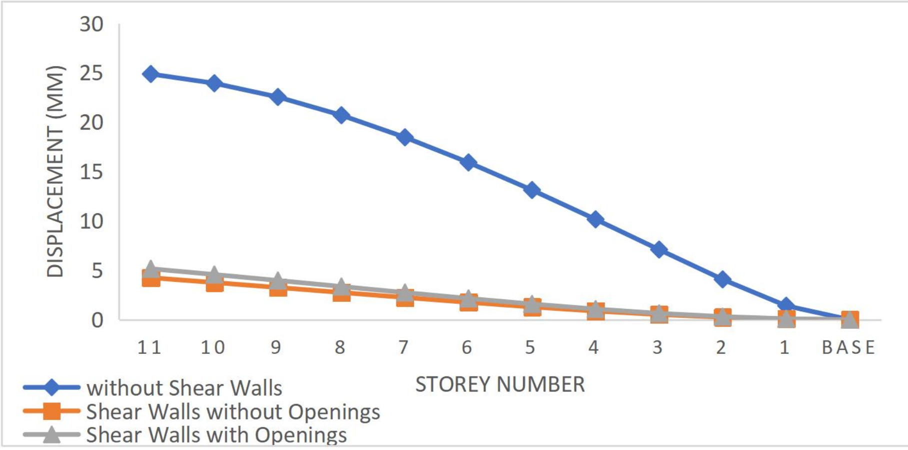

Figure 5. Storey displacements, ESA in X-direction

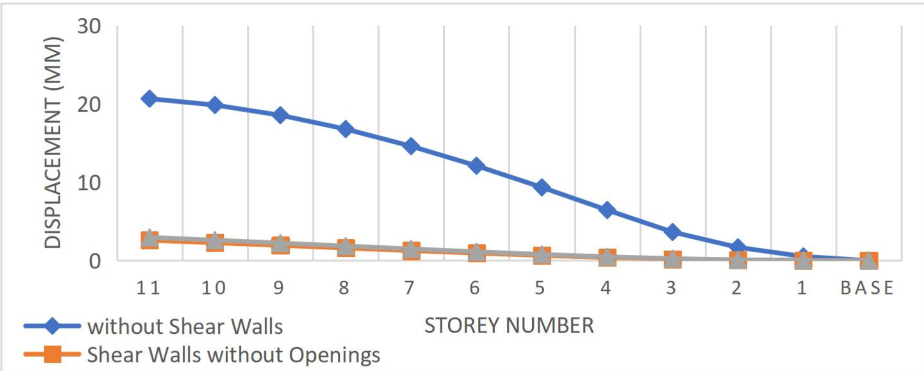

Figure 6. Storey displacements, equivalent static analysis in Y-direction

Table 6. Storey displacements comparison, response spectrum, X-direction (millimeters)

Storey	**No Shear Walls**	**Shear Walls No Openings**	**Shear Walls No Openings**
Storey11	33.829	4.049	4.592
Storey10	32.622	3.574	4.063
Storey9	30.846	3.092	3.521
Storey8	28.479	2.607	2.974
Storey7	25.561	2.128	2.434
Storey6	22.144	1.666	1.912
Storey5	18.274	1.234	1.422
Storey4	14.036	0.844	0.978
Storey3	9.666	0.511	0.598
Storey2	5.547	0.251	0.299
Storey1	1.954	0.075	0.098
Base	0	0	0

Table 7. Storey displacements comparison, response spectrum, Y-direction (millimeters)

Storey	**No Shear Walls**	**Shear Walls No Openings**	**Shear Walls No Openings**
Storey11	14.752	2.176	2.724
Storey10	14.206	1.897	2.387
Storey9	13.364	1.612	2.04
Storey8	12.217	1.326	1.69
Storey7	10.783	1.045	1.345
Storey6	9.091	0.777	1.015
Storey5	7.169	0.533	0.708
Storey4	5.058	0.323	0.439
Storey3	2.929	0.158	0.222
Storey2	1.425	0.052	0.074
Storey1	0.488	0.009	0.014
Base	0	0	0

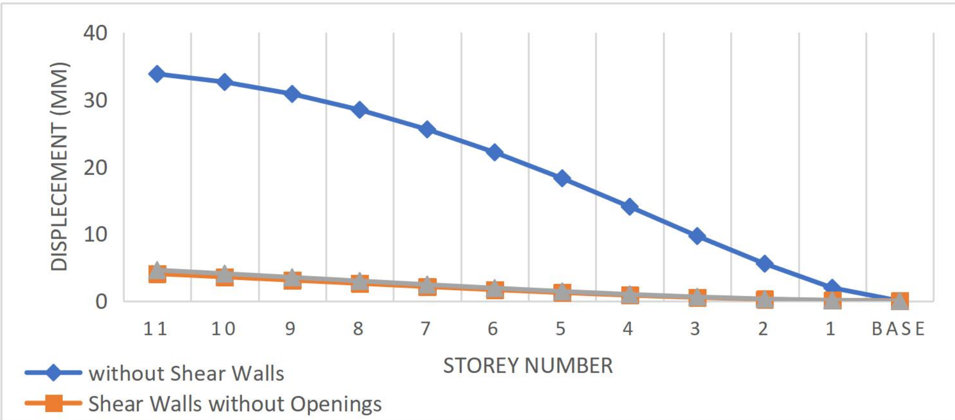

Figure 7: storey displacement for response spectrum analysis models in X-direction.

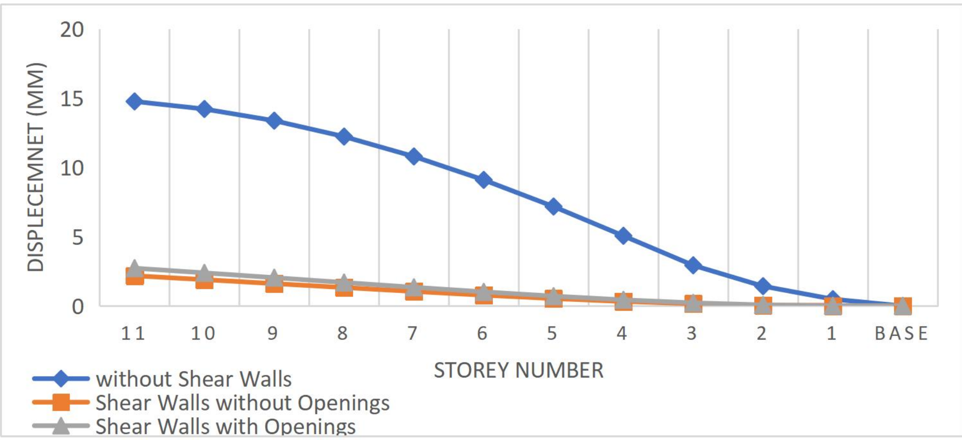

Figure 8. storey displacement for response spectrum analysis models in the X-direction.

4.2 *Storey Drift*

The storey drifts determined using ESA (EX&EY) are shown in Tables 8 and 9, as well as Figures 9 and 10. In the absence of shear walls, the maximum drift on the fourth floor is 4.895 mm for x-direction, also 5.121 mm for the Y-direction, according to the data. Maximum drift is observed on the eighth floor for buildings without shear-walls value is 3.274 mm. The values in X-direction are 3.323 mm, 3.344 mm for shear-walls with and with no openings, and it is 3.358 mm for buildings without shear-walls, 3.405 mm, 3.425 mm for shear-walls having openings in Y-direction.

Tables 10 and 11, as well as Fig. 11 and 12, show the storey drifts in both the X and Y directions in response spectrum analysis (RSA). According to the data, the fourth level has the greatest drift of 1.52 mm in X-direction and 1.04 mm in Y-direction according to the lack of shear walls. Structures with shear walls without and with opening had the greatest drift on the ninth story, with values of 0.17 mm and 0.19 mm for X-direction, respectively. Without shear walls, the Y-direction storeys have a value of 0.57 mm, whereas those with shear walls without and with openings have values of 0.10 mm and 0.12 mm, respectively.

According to the data, storey drift increases from the second level and continues to grow, with a tendency to decrease at the top storey. Shear walls with openings have higher drift values than shear walls without openings. Furthermore, buildings with no shear walls have higher drift values [(Varma and Kumar 2021, Saeed, Najm et al. 2022)].

Table 8. Storey drift comparison static analysis, X-direction (millimeters)

Storey	**No Shear Walls**	**Shear Walls No Openings**	**Shear Walls No Openings**
Storey11	0.000312	0.000163	0.000194
Storey10	0.000463	0.000167	0.000201
Storey9	0.000615	0.000169	0.000204
Storey8	0.000744	0.000169	0.000204
Storey7	0.000849	0.000164	0.000199
Storey6	0.00093	0.000154	0.000188
Storey5	0.000988	0.000139	0.00017
Storey4	0.00102	0.000118	0.000144
Storey3	0.001006	9.1E-05	0.000111
Storey2	0.000888	6E-05	7.2E-05
Storey1	0.00047	2.6E-05	3.2E-05
Base	0.000312	0.000163	0.000194

Table 9. Storey drift comparison static analysis, Y-direction (millimeters)

Storey	No Shear Walls	Shear Walls No Openings	Shear Walls No Openings
Storey11	0.000286	0.00011	0.00012
Storey10	0.00045	0.000113	0.000125
Storey9	0.000612	0.000115	0.000127
Storey8	0.000752	0.000115	0.000128
Storey7	0.000864	0.000112	0.000125
Storey6	0.000947	0.000104	0.000118
Storey5	0.000992	9.2E-05	0.000105
Storey4	0.000987	7.4E-05	8.7E-05
Storey3	0.001185	4.8E-05	6.4E-05
Storey2	0.000554	2E-05	2.4E-05
Storey1	0.000175	4E-06	0.00012
Base	0.000286	0.00011	0.000125

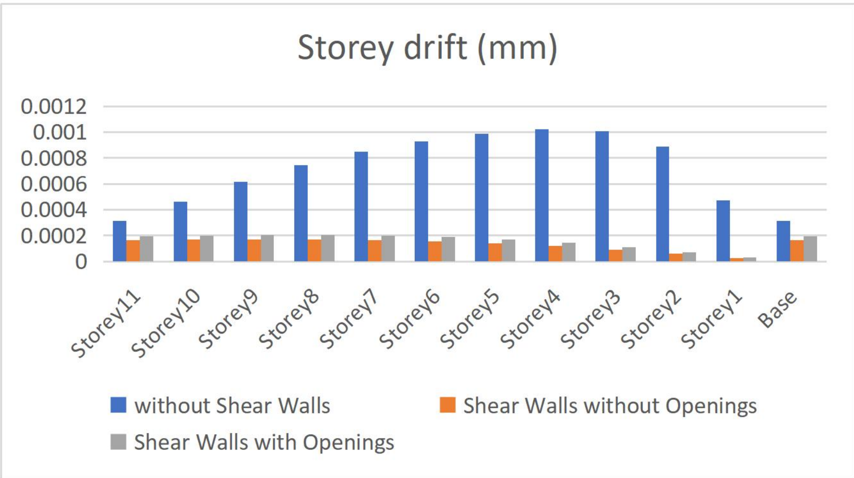

Figure 9. Story drift for static analysis models in the X-direction.

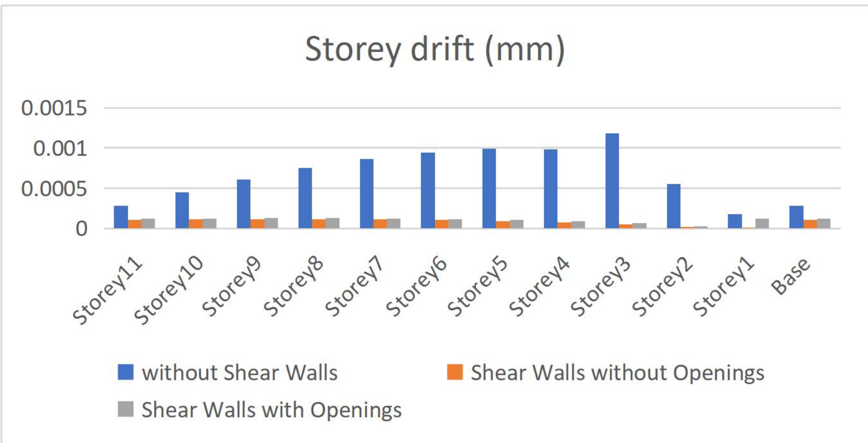

Figure 10. Story drift for static analysis models in the Y-direction.

Table 10. Storey drift comparison, response spectrum, X-direction (millimeters)

Storey	No Shear Walls	Shear Walls No Openings	Shear Walls No Openings
Storey11	0.00059	0.000161	0.00018
Storey10	0.000808	0.000165	0.000187
Storey9	0.000988	0.000166	0.000188
Storey8	0.001144	0.000163	0.000186
Storey7	0.001281	0.000157	0.000179
Storey6	0.0014	0.000147	0.000167
Storey5	0.001496	0.000132	0.000151
Storey4	0.001515	0.000112	0.000129
Storey3	0.001403	8.7E-05	0.0001
Storey2	0.001204	5.9E-05	6.8E-05
Storey1	0.000652	2.8E-05	3.3E-05
Base	0.00059	0.000161	0.00018

Table 11. Storey drift comparison, response spectrum, Y-direction (millimeters)

Storey	No Shear Walls	Shear Walls No Openings	Shear Walls No Openings
Storey11	0.000347	9.7E-05	0.000117
Storey10	0.00047	0.0001	0.000122
Storey9	0.000568	0.0001	0.000123
Storey8	0.00066	9.9E-05	0.000121
Storey7	0.000741	9.4E-05	0.000116
Storey6	0.000811	8.7E-05	0.000108
Storey5	0.000862	7.6E-05	9.6E-05
Storey4	0.000885	6E-05	7.9E-05
Storey3	0.001035	4E-05	5.9E-05
Storey2	0.000483	1.6E-05	2.1E-05
Storey1	0.000166	1.1E-05	9E-06
Base	0.000347	9.7E-05	0.000117

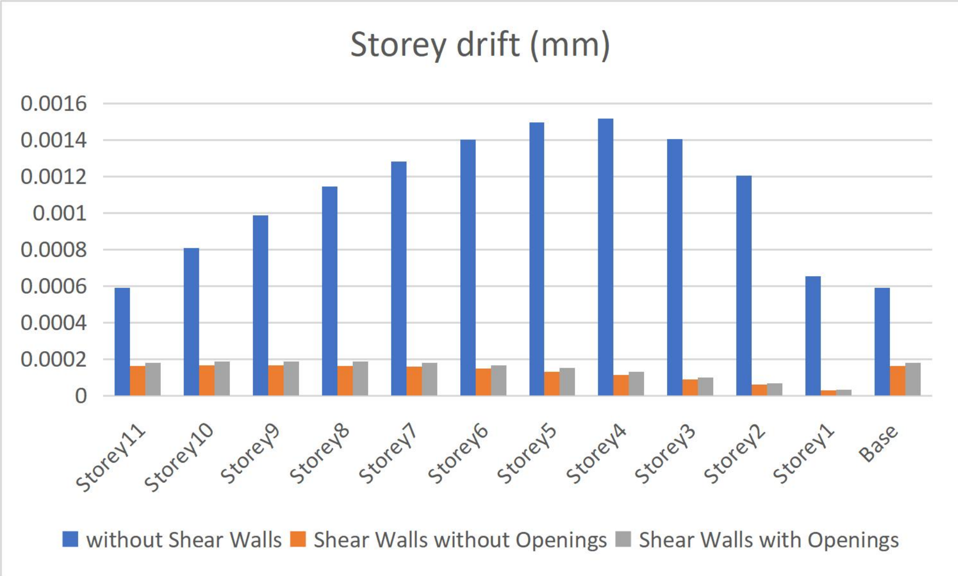

Figure 11. Story drift for response spectrum models in X-direction.

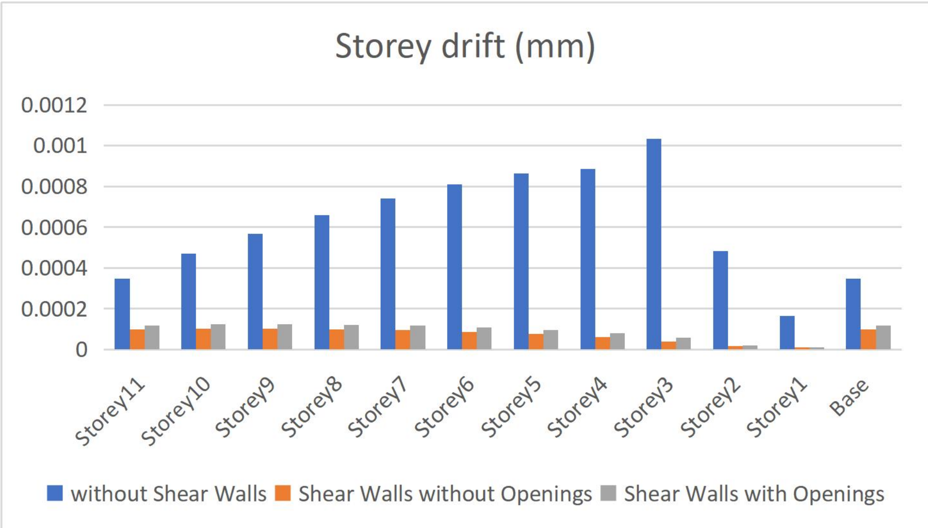

Figure 12. Story drift for response spectrum models in Y-direction.

4.3 Story Forces

In terms of the response spectrum, the first-floor storey force values for the model without shear-walls and with shear walls are 351.018 kN, 323.5231 kN respectively, and 276.572 kN for shear-walls with openings (Fig. 13 - 16). Structures without shear walls have a reduced percentage of around 21.2% of the first-floor story force value when compared to structures with shear walls. The story drift and displacement of the structures are affected greatly by the structural element height. When compared to the story forces, shear wall openings have a minor effect on these mechanical parameters. The weight of the building, on the other hand, has a considerable influence on the distribution of lateral pressures on the building. As a result, shear-walls openings decrease weight and rigidity for the structures, and therefore increase lateral forces.

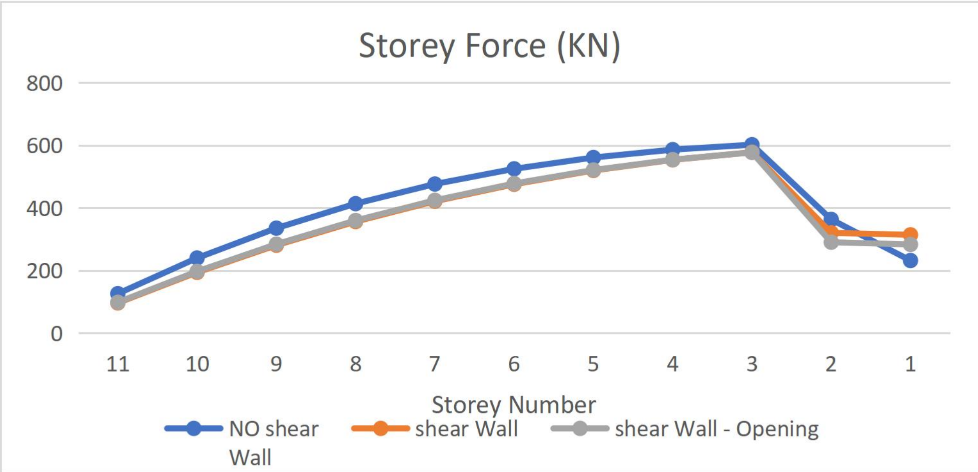

Figure 13. Story forces for models, static analysis, X-direction analysis

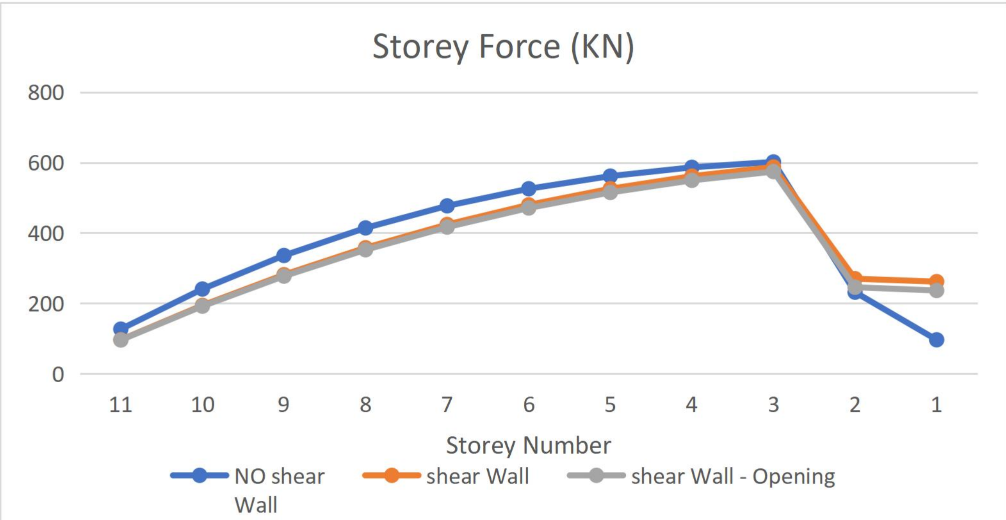

Figure 14. Story forces for models, static analysis, Y-direction analysis

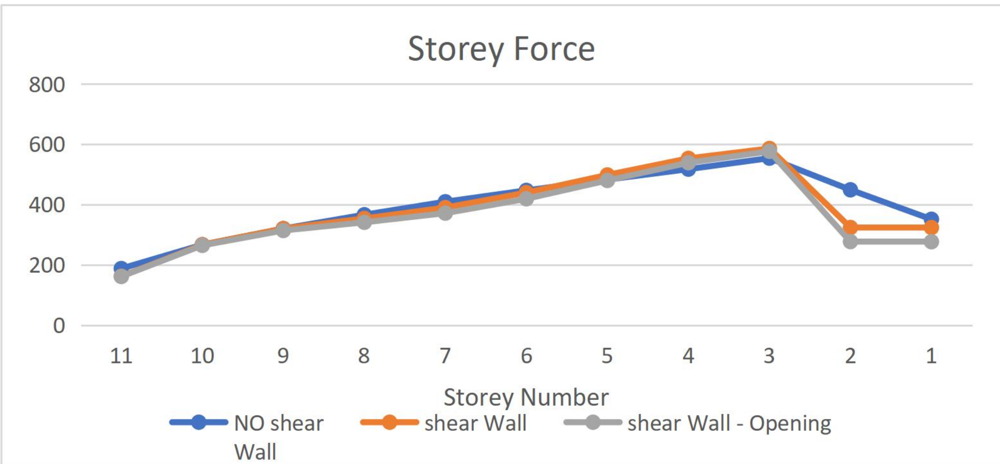

Figure 15. Story forces for models, RSA, X-direction.

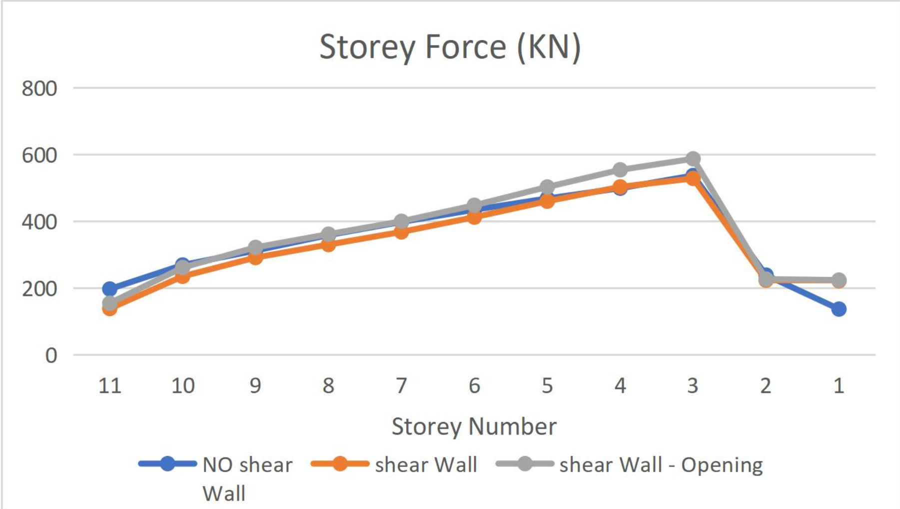

Figure 16. Story forces for models, RSA, Y-direction.

4.4 Time Period

As seen in Fig. 17, mass increase is proportional to the time period of the structure. The existence of a shear wall reduces the time period, which is minimal for the use of shear-walls on the structure's edges. The structures with shear-walls have a shorter time-period than the structures with no shear-walls. Furthermore, the structure with shear-walls and opening (Fig. 17).

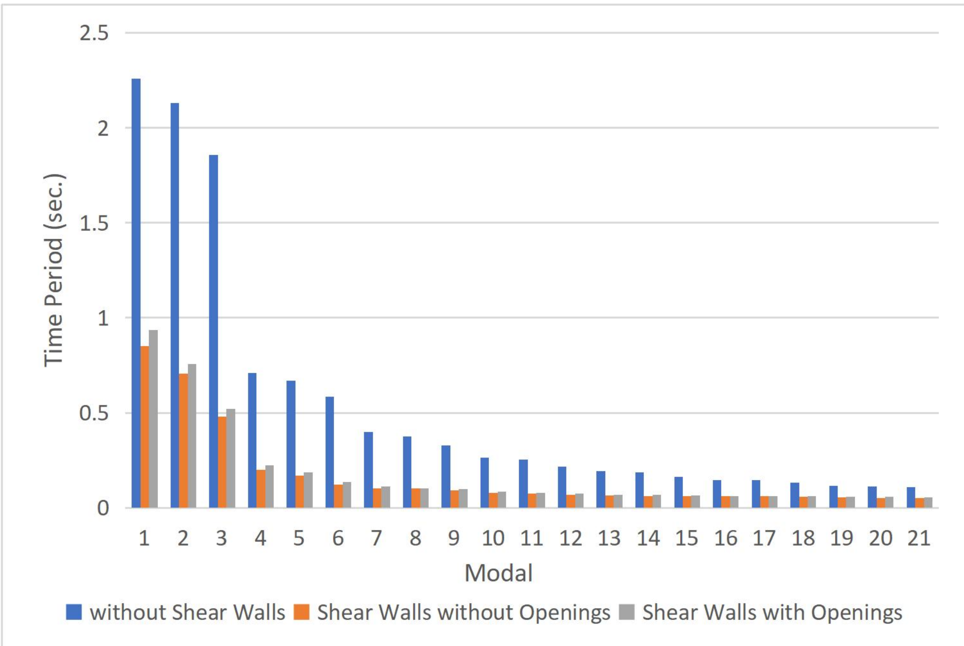

Figure 17. time period of models.

Several researchers have conducted studies on solving structural and material problems using finite element modelling, as reported in literature [(Najem and Ibrahim 2018, Parvez, Shen et al. 2019, Khan, Cao et al. 2020, Ahmed, Mohammed et al. 2022, Ahmed, Mohammed et al.

2022, Faraj, Ahmed et al. 2022, Saeed, Najm et al. 2022)]. These studies have shown similar findings.

5. Conclusions

The drawn results of the analytical examination of impact of shear-walls openings and seismic performance of it are:

1) Based on ESA approach, models with shear-wall perform better with respect to the reduction of the displacement. Structures with no openings in their shear-wall performs better in terms of reduction of the displacement.

2) When comparing buildings with and without shear walls, the response spectrum analysis found a 21.2% decrease in the value of storey force of the first floor in structures with no shear-walls. Similarly, structures with shear-walls having opening are 17.3% lower storey force value than structures with shear-walls. This result was also consistent across time history study.

3) According to the findings, using shear walls minimizes storey drift and movement in both X and Y dimensions.

4) In most cases, the highest story drift is observed on the seventh floor.

5) The investigation of the methodologies utilized (equivalent static analysis and response spectrum analysis) demonstrates that models without shear wall openings exhibit less displacement than the other model.

6) The investigation also demonstrated that utilizing shear walls without openings leads to less drift than other models. As a result, it emphasizes the critical importance of employing these models.

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