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A Comprehensive Study on the Effect of Regular and Staggered Openings on the Seismic Performance of Shear Walls

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Abstract: Shear walls have high strength and stiffness, which could be used at the same time to resist large horizontal loads and weight loads, making them pretty beneficial in several structural engineering applications. The shear walls could be included with openings, such as doors and windows, for relevant functional requirements. In the current study, a building of G + 13 stories with RC shear walls with and without openings has been investigated using ETABS Software. The seismic analysis is carried out for the determination of parameters like shear forces, drift, base shear, and story displacement for numerous models. The regular and staggered openings of the shear wall have been considered variables in the models. The dynamic analysis is carried out with the help of ETABS software. It has been observed that shear walls without openings models perform better than other models, and this is in agreement with the previous studies published in this area. This investigation also shows that the seismic behaviour of the shear wall with regular openings provides a close result to the shear wall with staggered openings. At the roof, the displacement of the model with regular openings was 38.99 mm and approximately 39.163 mm for the model with staggered openings. However, the model without a shear wall experienced a displacement of about 56 mm at the roof. Generally, it can be concluded that the openings have a substantial effect on the seismic behaviour of the shear wall, and that should be taken into consideration during the construction design. However, the type of opening (regular or staggered) has a slight effect on the behaviour of shear walls.

Keywords: seismic behaviour; opening shear wall; story drift; displacement; base shear

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1. Introduction

Reinforced concrete (RC) buildings considerably resist horizontal and vertical loading. Wind and seismic loads are the most common loads that shear walls are designed to carry [1]. The shear walls are the best and simplest method to sustain these lateral forces as they provide the required strength against seismic forces [2–4]. Shear walls are the components in the external form of a box that provide lateral support to the building. The shear wall provides strength and stiffness to the building in the lateral direction [5–8]. Since shear walls carry massive lateral forces, the overturn effects on them are significantly important and must be considered in the structural design. Shear walls in buildings are preferred to be symmetrical in order to mitigate the negative effects of twists [9–11]. They might be placed symmetrically along with one or both directions in the plan. Shear walls are more effective when provided on the exterior perimeter of the building; therefore, this layout will increase the resistance of the structure against twisting [12]. The shear walls behaviour depends upon the material used, wall length, wall thickness, wall position, and building frame. RC shear walls are used in the design of multi-story buildings located in seismically vulnerable areas because of their rigidity, bearing capacity, and high ductility [13–15]. Obviously, an opening in a shear wall positioned along with in-plane loading is more critical than an opening in a shear wall located along without-of-plane loading because there is a considerable change in displacement noticed after having an opening in a shear wall positioned along with in-plane loading [16].

Shear walls are considered an essential element in the construction of buildings because of their capacity to resist lateral loads such as earthquakes and wind loads. Therefore, research studies have been carried out to understand the structural behaviour of shear walls under different load cases and conditions. Zhang and Wang [17] investigated the seismic performance of prefabricated reinforced masonry shear walls with vertical joint connections, while Dang-Vu et al. [18] studied the seismic fragility assessment of columns in a piloti-type building retrofitted with additional shear walls. Coccia et al. [19] reported the behaviour of masonry walls retrofitted with vertical FRP rebars, and their study showed that the conventional seismic retrofitting techniques on masonry walls influence the seismic performance of the element, which is typically modified in an out-of-plane bending behaviour. Further, the study of Jeon et al. [20] investigated the seismic fragility of ordinary reinforced concrete shear walls with coupling beams, and their study showed that high-rise ordinary reinforced concrete shear walls designed using seven pairs of ground motion components and a shear force amplification factor ≥ 1.2 were adequate to satisfy the criteria on collapse probability and the collapse margin ratio prescribed in FEMA P695.

Reinforced concrete structures with L-shaped walls provide numerous benefits for architects that permit them to design architectures with larger open areas and a lot of versatility [21–23]. However, a lot of experimental tests and numerical models should be done for L-shaped shear walls to ensure compliance with the safety provisions obligatory by the various code standards. What is more, given the necessities of deformability and resistance, L-shaped concrete shear walls are used in multi-story buildings because they possess a high capability of resisting lateral loads and may expend an excellent amount of seismic energy if they are properly designed [24–27]. Openings in shear walls may be required because of municipality or remodeling considerations, similar to elevators, windows, doors, and the placement of staircases [28]. Providing openings in the shear walls decreases the total structural capacity and integrity of the wall, in addition to stress condensation around the openings [27].

The main aim of this study is as follows: to understand the behaviour of staggered and regular openings and to analyze the effectiveness of staggered openings to seismic load when different loads are used.

2. Model Description

A 14-story RC structure with shear wall elements and the 14 stories were selected in the model to minimize the analysis time in the software, and the behaviour of shear walls with the openings was the aim of this study and not the effect of the building's length, shape "L" of RC shear wall without opening, with a vertical and staggered opening in Seismic Zone V, has been considered in this study. Tables 1–3 illustrate the model data, applied loads on the structure, and seismic input data. The plan and geometry of the models are shown in Figures 1–4. Compared to the area of the wall in that story, the shear wall has a 5% opening.

Table 1. Models data.

Number of Stories	14
Column Size	(600 × 600) mm
Beam Size	(300 × 600) mm
Slab Depth	150 mm
Shear Wall Thickness	300 mm
Size of opening	(2 × 1.5) m
Story Height	3.5 m
Support	Fixed
Concrete Grade	M25
Steel Grade	Fe 500

Table 2. Loads.

Unit Weight of Concrete	25 kN/m^3
Dead load	3.75 kN/m^2
Live load	3 kN/m^2
Beam Load	11 kN/m

Table 3. Seismic data.

Seismic Zone	V
Zone factor (Z)	0.36
Soil Type	Medium
Damping Ratio	5%
Response Reduction factor (R)	5
Importance factor (I)	1

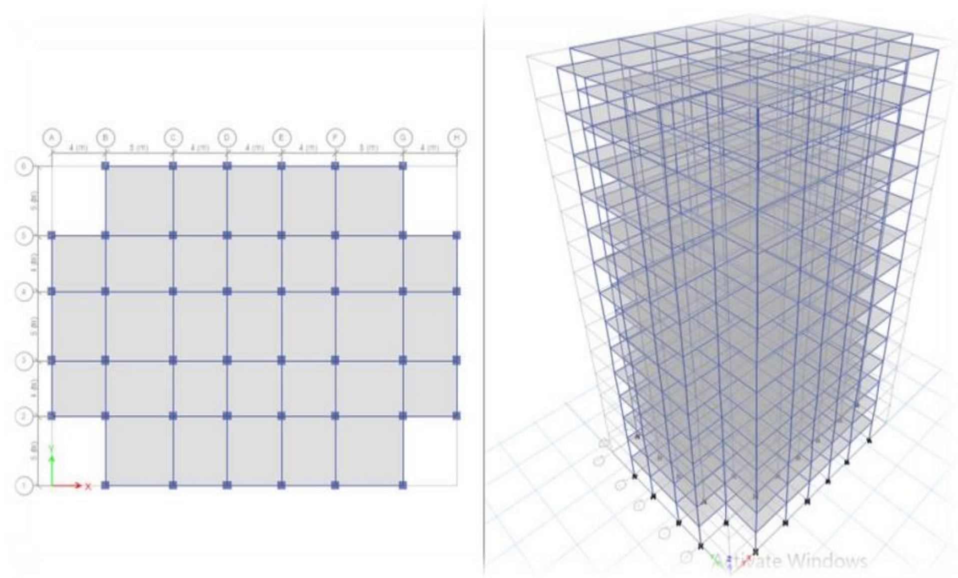

Figure 1. The geometry of the structure and the 3D of the structure without shear walls.

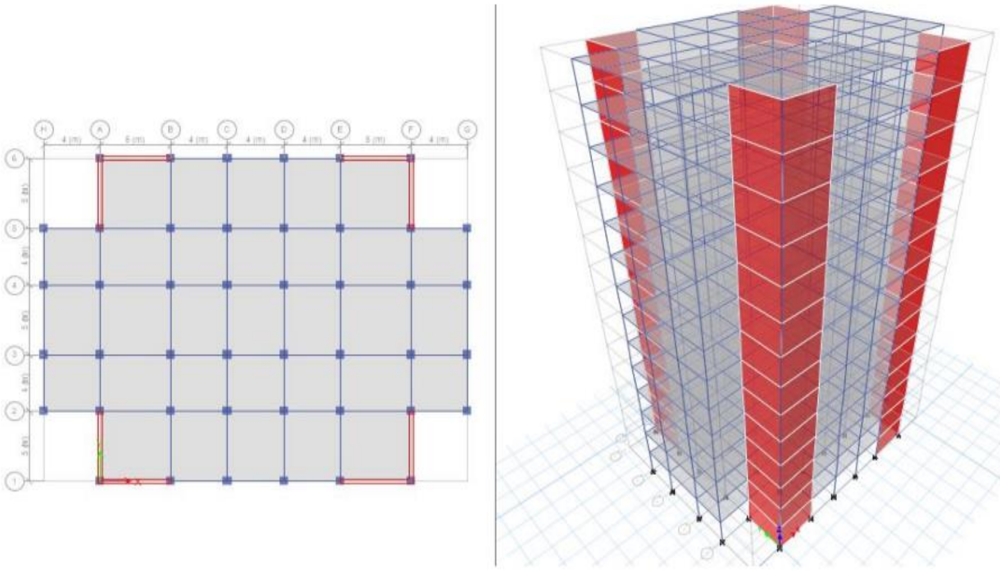

Figure 2. The geometry of the structure and 3D structure shear wall without opening.

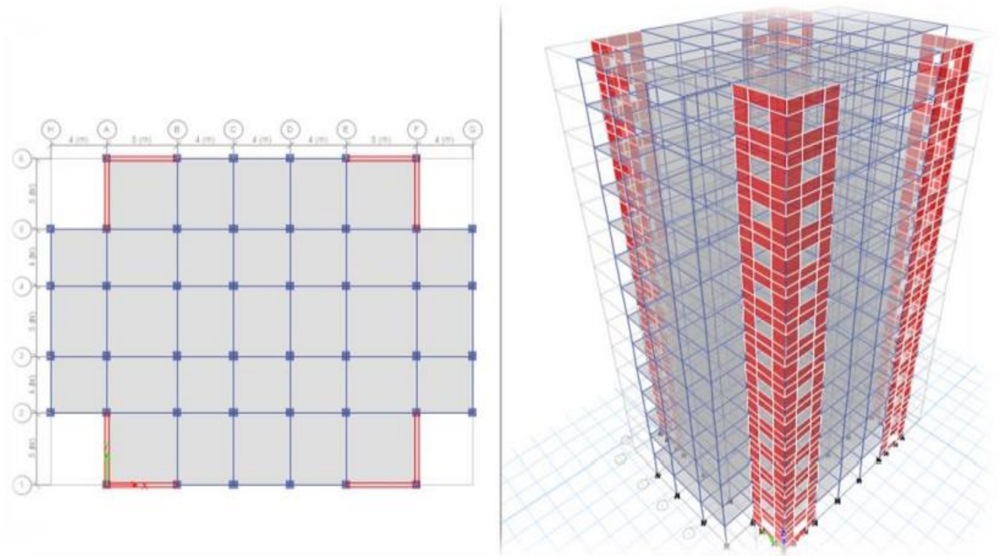

Figure 3. The geometry of the structure and 3D structure shear walls with vertical openings.

Response spectrum function and time history function (El Centro 1940) have been used in this study for seismic analysis. A response spectrum is a plot of the maximum response amplitude (displacement, velocity or acceleration) versus time period of many linear single degree of freedom oscillators to a give component of ground motion as shown in Figure 5. The resulting plot can be used to choose the response of any linear SDOF oscillator, given its natural time period of oscillation. One such use is in evaluating the peak response of structures to ground motions. The first data listed from an earthquake record are usually the peak ground acceleration (PGA), which expresses the tip of the maximum spike of the acceleration ground motion.

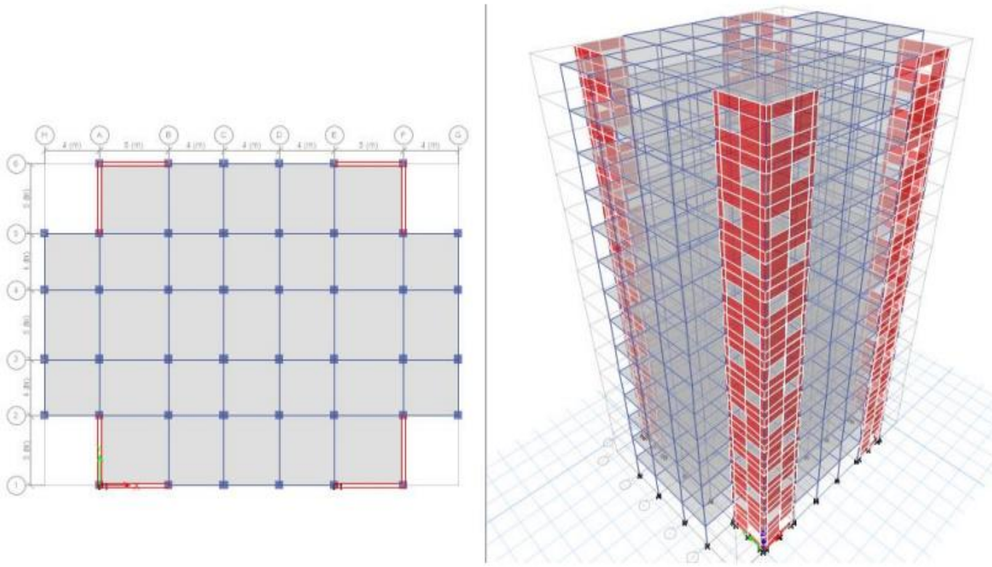

Figure 4. The geometry of the structure and 3D structure shear walls with staggered openings.

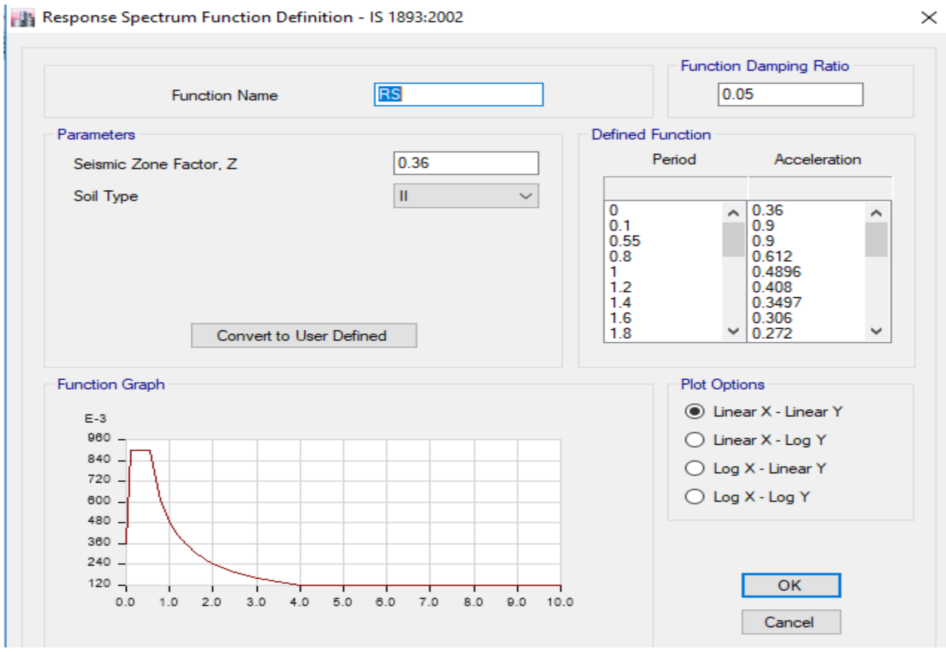

Figure 5. Response spectrum function definition.

ETABS Software handles the initial conditions of a time function differently for linear and nonlinear time-history load cases. Linear cases always start from zero, thus the corresponding time function must also start from zero and nonlinear cases may either start from zero or may continue from a previous case. When starting from zero, the time function is simply defined to start with a zero value. When analysis continues from a previous case, it is supposed that the time function also continues relative to its starting value. A long record may be broken into multiple sequential analyses which use a single function with arrival times. This prevents the need to create multiple modified functions. The time history function used in this study is shown in Figure 6.

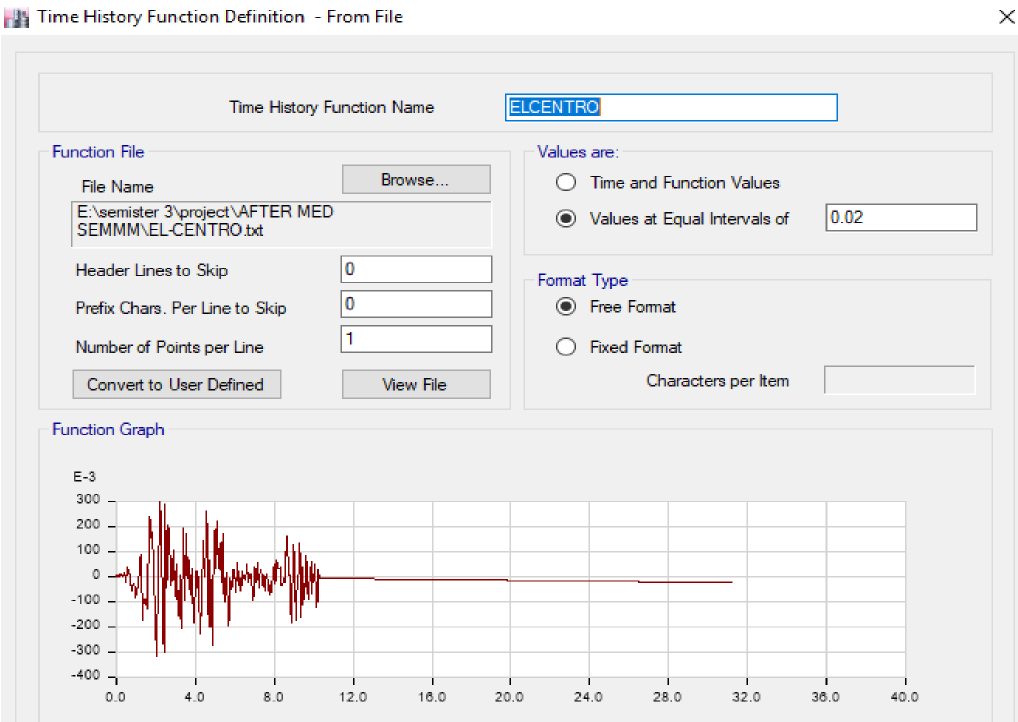

Figure 6. Time history function definition.

This study was conducted on a regular plan structure with shear walls containing vertical and staggered openings. The buildings are modelled with a floor area of 690 m^2 (30 m $\times$ 23 m) with 7 bays along a 30 m span and 5 bays along a 23 m span.

3. Modeling and Analysis

Four models have been considered in this study. The first model contains a building without shear walls (Figure 1); the second model characterizes a building with shear walls without openings (Figure 2); the third model includes shear walls with vertical openings (Figure 3). However, the fourth model includes shear walls with staggered openings (Figure 4).

4. Results & Discussion

4.1. Story Displacement

Tables 4 and 5 and Figures 7 and 8 demonstrate the maximum displacement in the case of equivalent static analysis (ESA) (EX&EY). On the top floor, the results show that the building without shear walls produced about 53.089 mm when compared to the building with shear walls produced 37.212 mm, i.e., a 30% reduction in the X-direction. It is observed that the story displacement of the vertical opening at the roof is approximately 38.032 mm and 38.173 mm for staggered openings, respectively.

Similarly, in the Y-direction, on the top floor, the results show that the building without shear walls produced 56 mm, while the building with shear walls produced 38.125 mm, a 32% difference. The displacement story of the vertical opening at the roof was also discovered to be 38.99 mm for staggered openings and 39.136 mm for unstaggered openings. The story displacement in the case of response spectrum analysis (RSA) is shown in Tables 6 and 7 and Figures 9 and 10. Results show that the building without shear walls produced about 42.006 mm while the building with shear walls produced 28.938 mm, i.e., a 31% decline in the X-direction and a 33% decline in the Y-direction. The displacement story of the vertical opening at the roof is 29.283 mm for staggered openings in the X-direction and 29.434 mm for vertical and staggered openings in the Y-direction, respectively. Tables 8 and 9 and Figures 11 and 12 demonstrate the story displacement in the case of time history analysis (THA). The results appear to show that the building without shear walls produced 45.727 mm, while the building with shear walls produced about 34.72 mm, i.e., a 24% reduction. In the X-direction, the displacement story of the vertical opening at the roof is 28.74 mm for staggered openings and 28.7 mm for unstaggered openings, 32.809 mm and 32.34 mm for vertical and staggered openings in the Y-direction respectively.

Table 4. Comparison of the story displacements, ESA and X-direction (mm).

Story	without Shear Walls	Shear Walls without Openings	Vertical Openings	Staggered Openings
Story 14	53.089	37.212	38.032	38.173
Story 13	51.742	34.488	35.436	35.552
Story 12	49.685	31.614	32.628	32.724
Story 11	46.954	28.609	29.658	29.739
Story 10	43.649	25.48	26.538	26.603
Story 9	39.87	22.259	23.3	23.348
Story 8	35.715	18.987	19.991	20.022
Story 7	31.27	15.723	16.668	16.679
Story 6	26.614	12.532	13.398	13.392
Story 5	21.817	9.489	10.258	10.232
Story 4	16.941	6.681	7.332	7.294
Story 3	12.046	4.205	4.717	4.672
Story 2	7.216	2.171	2.523	2.488
Story 1	2.725	0.707	0.876	0.865

Table 5. Comparison of the story displacements, ESA, and X-direction (mm).

Story	without Shear Walls	Shear Walls without Openings	Vertical Openings	Staggered Openings
Story 14	56.000	38.125	38.99	39.163
Story 13	54.475	35.291	36.281	36.423
Story 12	52.221	32.311	33.364	33.482
Story 11	49.275	29.203	30.287	30.389
Story 10	45.738	25.977	27.065	27.146
Story 9	41.715	22.663	23.731	23.796
Story 8	37.307	19.307	20.332	20.373
Story 7	32.606	15.965	16.927	16.952
Story 6	27.695	12.705	13.585	13.583
Story 5	22.648	9.604	10.382	10.366
Story 4	17.532	6.749	7.405	7.37
Story 3	12.411	4.237	4.752	4.716
Story 2	7.381	2.181	2.534	2.498
Story 1	2.749	0.707	0.875	0.873

The results show that buildings without shear walls have higher story displacement in comparison with other models. The shear wall with staggered openings experiences a higher displacement than vertical openings and shear walls without openings. A shear wall without openings reveals improved performance compared to shear walls with vertical and staggered openings. The same findings have been found in the published literature by Marius [29]. Overall, it can be concluded that the presences of shear walls in the buildings significantly improve the seismic response of the buildings regardless of the openings in that shear wall.

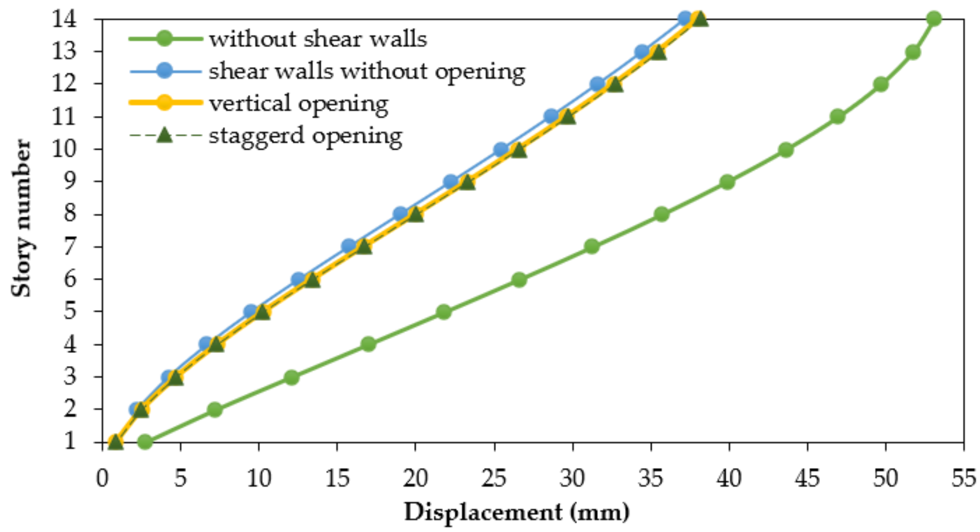

Figure 7. Story displacements, ESA in X-direction.

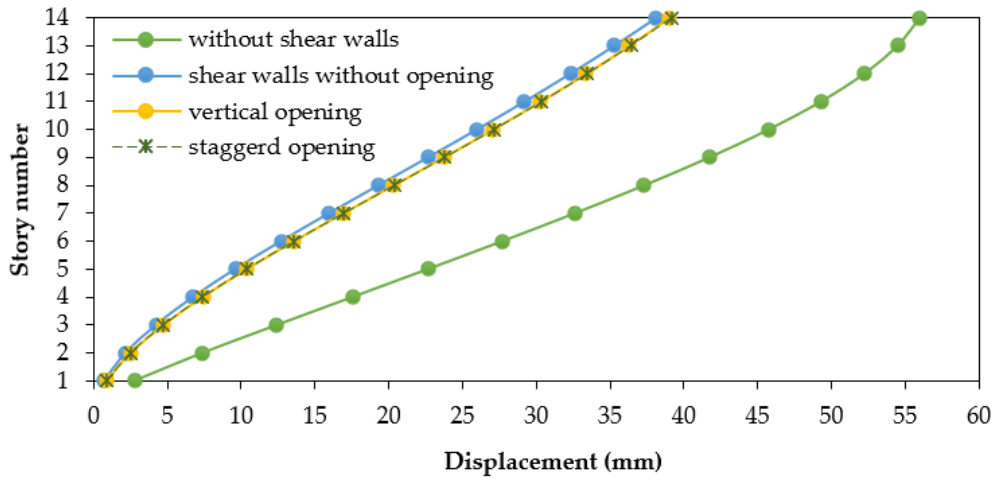

Figure 8. Story displacements, ESA in the Y-direction.

Table 6. Comparison of the story displacements, response spectrum, and X-direction (mm).

Story	without Shear Walls	Shear Walls without Openings	Vertical Openings	Staggered Openings
Story 14	42.006	28.938	29.283	29.434
Story 13	41.105	26.869	27.339	27.468
Story 12	39.745	24.699	25.251	25.361
Story 11	37.935	22.439	23.057	23.15
Story 10	35.724	20.092	20.759	20.836
Story 9	33.152	17.673	18.373	18.433
Story 8	30.252	15.206	15.924	15.964
Story 7	27.047	12.722	13.441	13.459
Story 6	23.555	10.262	10.961	10.959
Story 5	19.788	7.878	8.533	8.509
Story 4	15.758	5.634	6.216	6.178
Story 3	11.482	3.61	4.087	4.041
Story 2	7.025	1.905	2.244	2.207
Story 1	2.694	0.641	0.807	0.793

Table 7. Comparison of the story displacements, response spectrum, and Y-direction (mm).

Story	without Shear Walls	Shear Walls without Openings	Vertical Openings	Staggered Openings
Story 14	43.769	29.29	29.845	30.009
Story 13	42.743	27.159	27.822	27.96
Story 12	41.252	24.931	25.659	25.776
Story 11	39.305	22.619	23.393	23.493
Story 10	36.951	20.224	21.028	21.11
Story 9	34.23	17.764	18.583	18.648
Story 8	31.179	15.262	16.08	16.122
Story 7	27.822	12.75	13.551	13.574
Story 6	24.178	10.27	11.032	11.03
Story 5	20.264	7.872	8.572	8.554
Story 4	16.093	5.62	6.232	6.194
Story 3	11.681	3.593	4.088	4.049
Story 2	7.101	1.891	2.238	2.2
Story 1	2.688	0.634	0.801	0.796

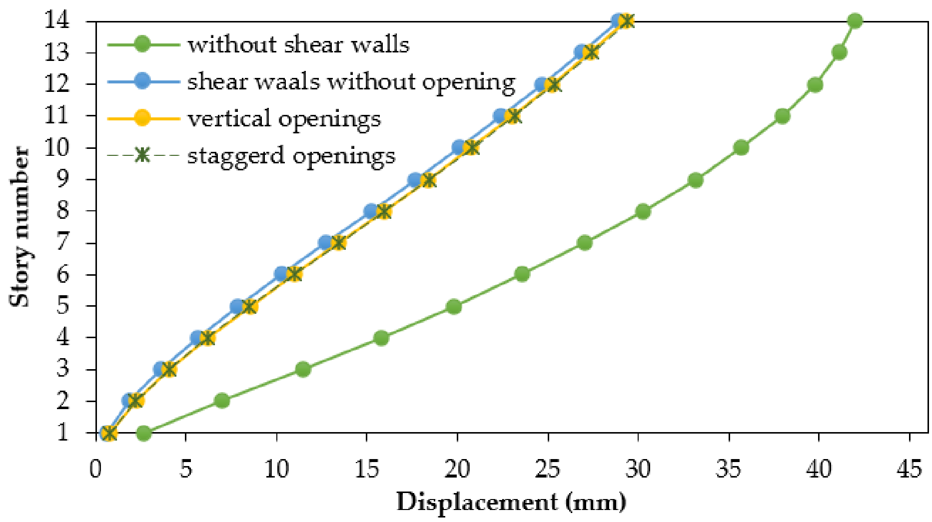

Figure 9. Story displacement of the models, response spectrum analysis in the X-direction.

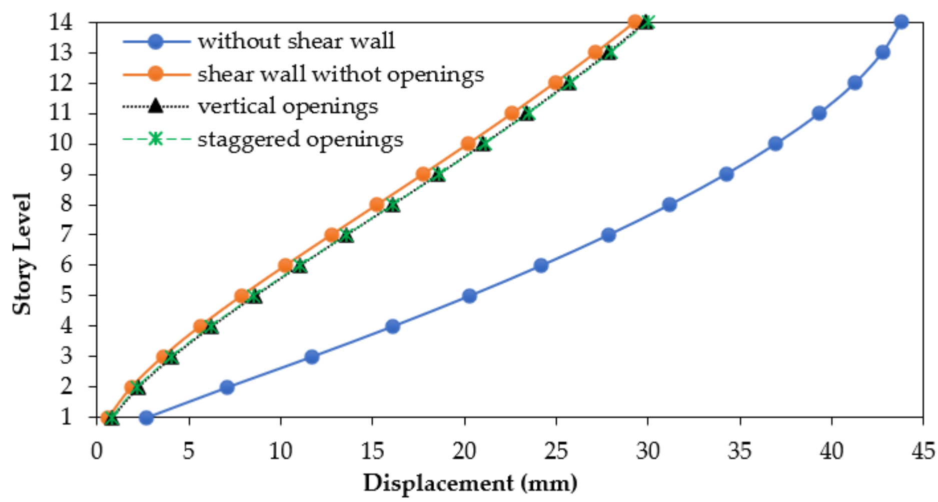

Figure 10. Story displacement of the models, response spectrum analysis, Y-direction.

Table 8. Comparison of the story displacements, time history, and X-direction (mm).

Story	without Shear Walls	Shear Walls without Openings	Vertical Openings	Staggered Openings
Story 14	45.727	34.74	28.749	28.662
Story 13	44.907	32.402	26.854	26.753
Story 12	43.659	29.935	24.805	24.699
Story 11	41.941	27.329	22.651	22.546
Story 10	39.98	24.57	20.405	20.303
Story 9	37.979	21.667	18.09	18
Story 8	35.546	18.652	15.727	15.644
Story 7	32.594	15.577	13.337	13.266
Story 6	29.044	12.511	10.942	10.87
Story 5	24.855	9.54	8.575	8.51
Story 4	20.043	6.759	6.289	6.214
Story 3	14.698	4.28	4.159	4.096
Story 2	9.009	2.224	2.292	2.23
Story 1	3.454	0.736	0.824	0.807

Table 9. Comparison of the story displacements, time history, and Y-direction (mm).

Story	without Shear Walls	Shear Walls without Openings	Vertical Openings	Staggered Openings
Story 14	46.471	32.91	32.809	32.34
Story 13	45.45	30.694	30.608	30.14
Story 12	43.937	28.363	28.24	27.777
Story 11	41.891	25.903	25.755	25.312
Story 10	39.327	23.298	23.168	22.751
Story 9	36.562	20.554	20.506	20.127
Story 8	33.959	17.697	17.795	17.457
Story 7	30.943	14.778	15.058	14.767
Story 6	27.447	11.865	12.325	12.078
Story 5	23.419	9.039	9.634	9.431
Story 4	18.849	6.397	7.043	6.882
Story 3	13.791	4.043	4.641	4.523
Story 2	8.412	2.095	2.545	2.477
Story 1	3.186	0.686	0.909	0.896

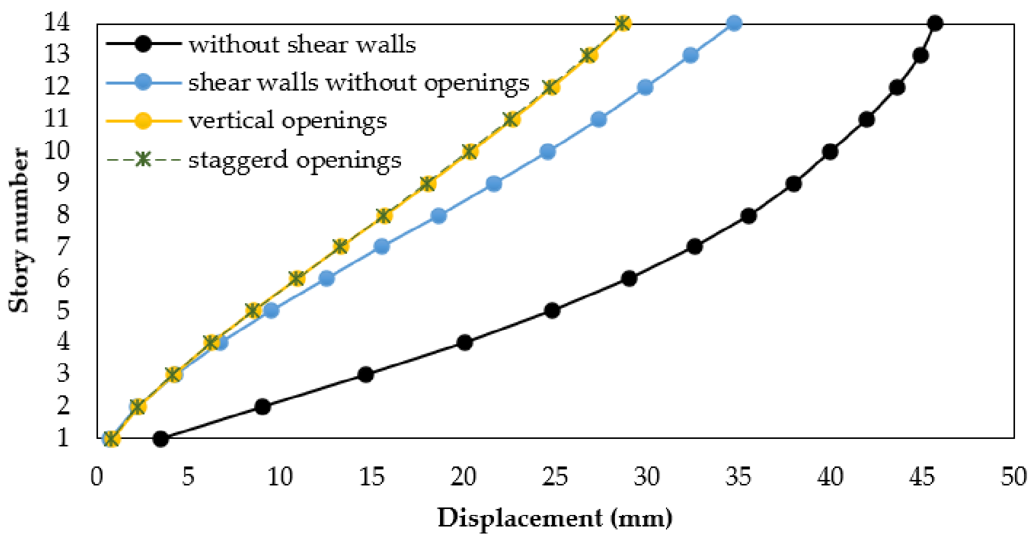

Figure 11. Story displacement of the models, time history analysis, X-direction.

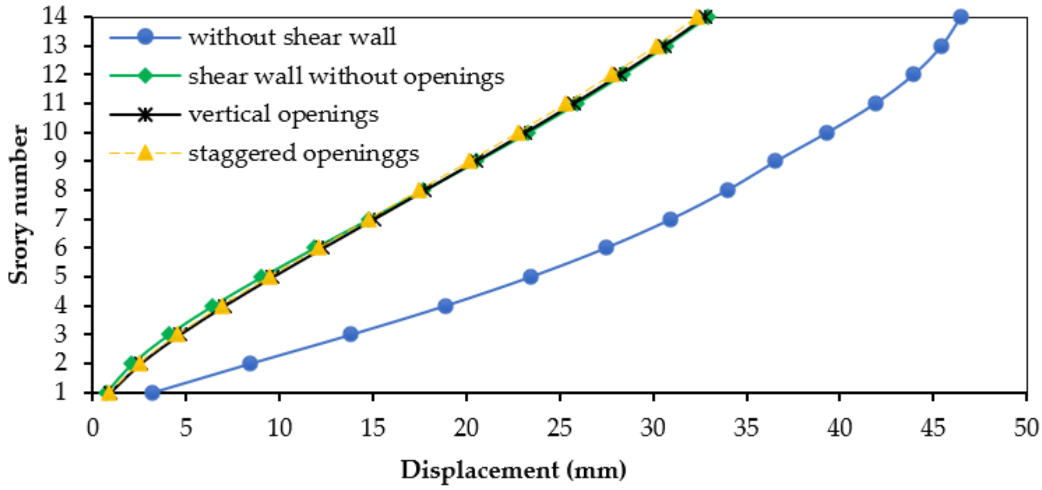

Figure 12. Displacement of the models, time history analysis, Y-direction.

4.2. Story Drift

Tables 10 and 11 and Figures 13 and 14 demonstrate the story drifts carried out by using ESA (EX&EY). The results show that the maximum drift that could be found on the fourth floor due to the buildings lack of shear walls is 4.895 mm in X-direction and 5.121 mm in Y-direction. It is also observed that the maximum drift story of the building with shear walls seen on the eighth floor is 3.274 mm, 3.323 mm, and 3.344 mm for the building's vertical and staggered openings in the X-direction, and 3.358 mm for shear walls without openings and 3.405 mm and 3.425 mm as results of shear walls with a vertical and staggered opening in the Y-direction.

Tables 12 and 13 and Figures 15 and 16 demonstrate the story drifts in the case of response spectrum analysis (RSA) in the (X&Y) direction. The results show that the maximum drift seen on the third floor due to the building without shear walls is 4.476 mm in X-direction and 4.6 mm in Y-direction. It is consequently observed that the maximum drift story of the building with shear walls seen on the eighth floor is 2.544 mm, 2.566 mm, and 2.585 mm for the building's vertical and staggered opening, respectively, in X-direction. However, shear walls without openings have a 2.573 mm thickness, while shear walls with vertical and staggered openings in the Y-direction have 2.614 mm and 2.63 mm thicknesses, respectively.

Tables 14 and 15 and Figures 17 and 18 determine the story drifts in the case of time history analysis (THA) in the (X&Y) direction. The results show that the maximum drift found on the third floor is due to the building's lack of shear walls, 5.689 mm in X-direction and 5.379 mm in Y-direction. Likewise, it was observed that the maximum drift story of the building with shear walls seen on the eighth floor was 3.075 mm, 2.397 mm, and 2.381 mm for the building's vertical and staggered opening in X-direction, respectively; 2.919 mm for shear walls with no openings, and 2.783 mm and 2.741 mm for shear walls with vertical and staggered Y-direction openings.

The results show that the story drift increases from the second story and onwards. It gradually grew and has a tendency to fall back to the top story. The model with a vertical opening and staggered opening shear wall indicates more drift value compared to the shear wall without an opening. The building without shear walls shows a high drift value. The same findings have been found in the published literature by Marius [29].

Table 10. Comparison of the measured story drift, static analysis, and X-direction (mm).

Story	without Shear Walls	Shear Walls without Openings	Vertical Openings	Staggered Openings
Story 14	1.347	2.725	2.61	2.621
Story 13	2.057	2.874	2.808	2.828
Story 12	2.731	3.005	2.97	2.985
Story 11	3.305	3.129	3.12	3.136
Story 10	3.778	3.222	3.238	3.255
Story 9	4.155	3.271	3.309	3.326
Story 8	4.445	3.274	3.323	3.344
Story 7	4.656	3.192	3.27	3.288
Story 6	4.797	3.043	3.141	3.161
Story 5	4.876	2.808	2.927	2.938
Story 4	4.895	2.476	2.616	2.624
Story 3	4.83	2.034	2.195	2.185
Story 2	4.49	1.463	1.647	1.624
Story 1	2.725	0.707	0.876	0.865

Table 11. Comparison of the story drift, static analysis, Y-direction (mm).

Story	without Shear Walls	Shear Walls without Openings	Vertical Openings	Staggered Openings
Story 14	1.526	2.834	2.722	2.74
Story 13	2.253	2.98	2.917	2.941
Story 12	2.946	3.108	3.076	3.094
Story 11	3.538	3.226	3.222	3.242
Story 10	4.023	3.314	3.334	3.352
Story 9	4.408	3.356	3.399	3.423
Story 8	4.701	3.358	3.405	3.425
Story 7	4.911	3.26	3.343	3.368
Story 6	5.047	3.101	3.204	3.22
Story 5	5.116	2.855	2.977	2.997
Story 4	5.121	2.512	2.654	2.658
Story 3	5.103	2.057	2.22	2.218
Story 2	4.632	1.474	1.659	1.631
Story 1	2.749	0.707	0.875	0.873

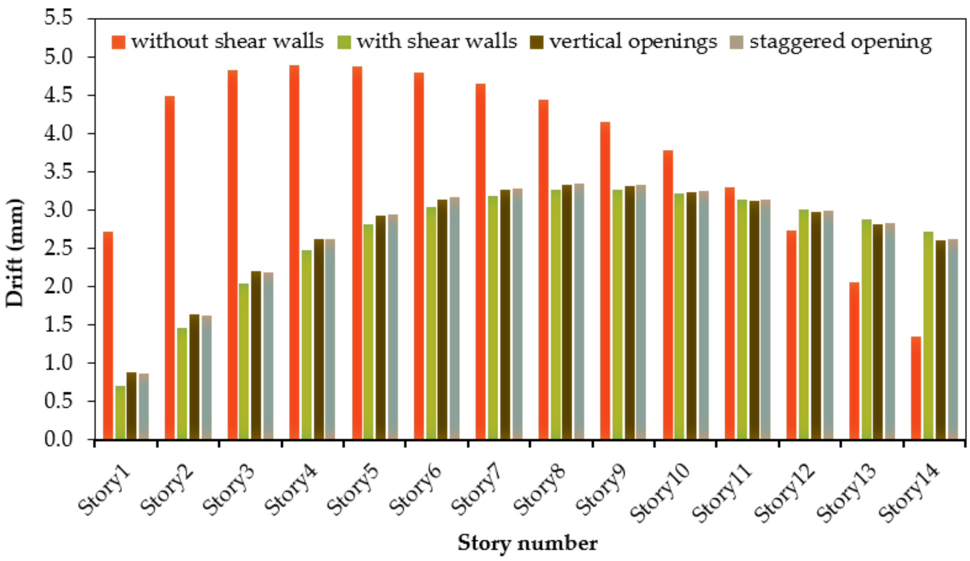

Figure 13. Story drift of the models: static analysis and X-direction analysis.

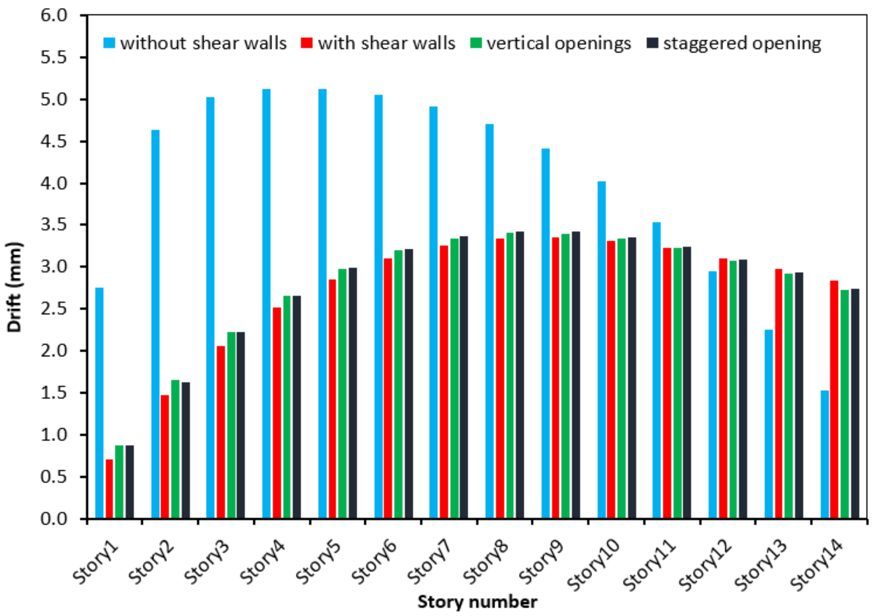

Figure 14. Story drift of the models: static analysis and Y-direction (mm).

Table 12. Comparison of the story drift, response spectrum, and X-direction (mm).

Story	without Shear Walls	Shear Walls without Openings	Vertical Openings	Staggered Openings
Story 14	1.144	2.138	2.038	2.052
Story 13	1.777	2.256	2.197	2.215
Story 12	2.318	2.355	2.318	2.334
Story 11	2.732	2.443	2.424	2.439
Story 10	3.063	2.508	2.503	2.519
Story 9	3.338	2.543	2.552	2.568
Story 8	3.572	2.544	2.566	2.585
Story 7	3.782	2.504	2.542	2.559
Story 6	3.981	2.414	2.472	2.491
Story 5	4.167	2.263	2.345	2.357
Story 4	4.342	2.035	2.145	2.153
Story 3	4.476	1.71	1.852	1.841
Story 2	4.333	1.266	1.44	1.417
Story 1	2.694	0.641	0.807	0.793

Table 13. Comparison of the story drift, response spectrum analysis, and Y-direction (mm).

Story	without Shear Walls	Shear Walls without Openings	Vertical Openings	Staggered Openings
Story 14	1.278	2.201	2.118	2.136
Story 13	1.923	2.316	2.273	2.295
Story 12	2.471	2.41	2.392	2.407
Story 11	2.889	2.493	2.493	2.511
Story 10	3.221	2.551	2.566	2.58
Story 9	3.499	2.58	2.608	2.628
Story 8	3.734	2.573	2.614	2.63
Story 7	3.945	2.526	2.582	2.605
Story 6	4.14	2.429	2.504	2.519
Story 5	4.319	2.271	2.369	2.387
Story 4	4.483	2.037	2.161	2.163
Story 3	4.6	1.707	1.859	1.857
Story 2	4.416	1.26	1.44	1.411
Story 1	2.688	0.634	0.801	0.796

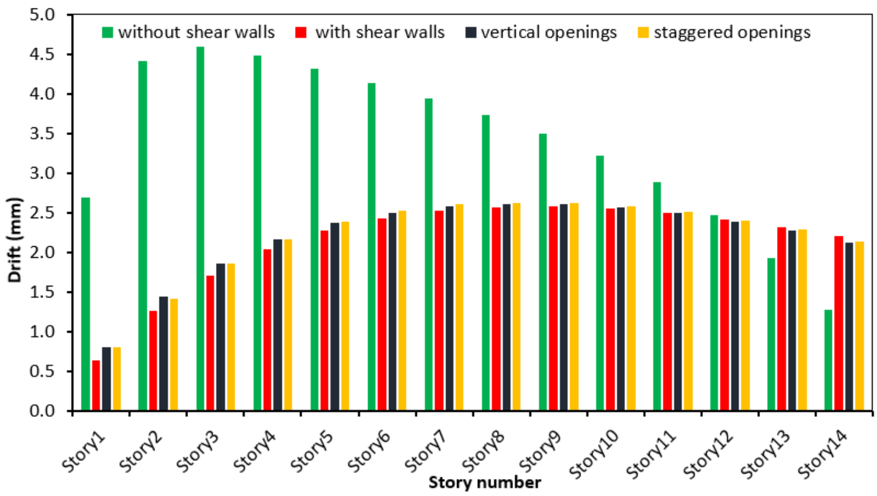

Figure 15. Story drift of the models, response spectrum analysis and X-direction.

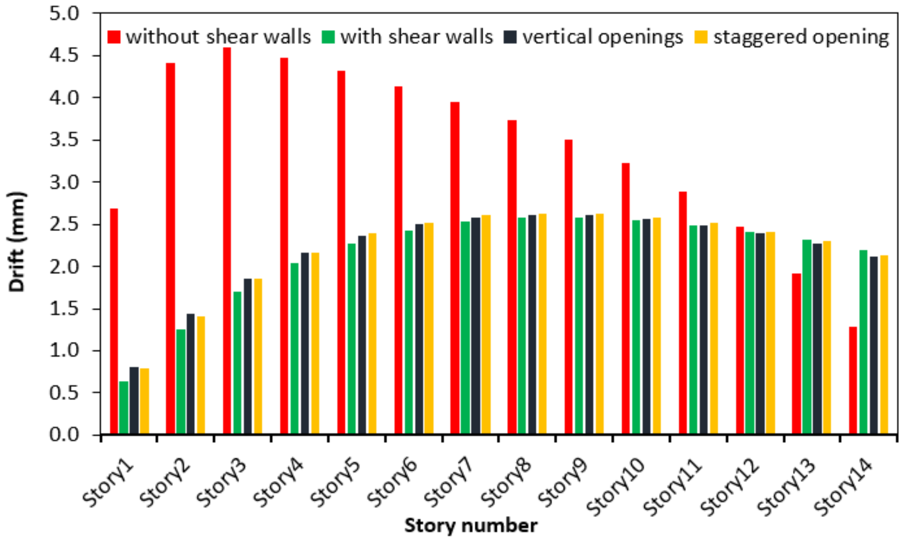

Figure 16. Story drift, response spectrum analysis, and Y-direction.

Table 14. Comparison of the story drift, time history analysis, X-direction (mm).

Story	without Shear Walls	Shear Walls without Openings	Vertical Openings	Staggered Openings
Story 14	1.04	2.338	1.907	1.909
Story 13	1.624	2.467	2.048	2.054
Story 12	2.206	2.606	2.155	2.154
Story 11	2.714	2.759	2.246	2.243
Story 10	3.123	2.903	2.315	2.305
Story 9	3.533	3.015	2.363	2.356
Story 8	3.862	3.075	2.397	2.381
Story 7	4.078	3.066	2.396	2.376
Story 6	4.233	2.972	2.367	2.364
Story 5	4.812	2.78	2.287	2.296
Story 4	5.345	2.479	2.131	2.124
Story 3	5.689	2.056	1.869	1.866
Story 2	5.555	1.493	1.47	1.43
Story 1	3.454	0.736	0.831	0.807

Table 15. Comparison of the story drift, time history analysis, Y-direction (mm).

Story	without Shear Walls	Shear Walls without Openings	Vertical Openings	Staggered Openings
Story 14	1.197	2.311	2.213	2.201
Story 13	1.817	2.432	2.368	2.363
Story 12	2.446	2.541	2.485	2.466
Story 11	2.994	2.64	2.587	2.561
Story 10	3.491	2.745	2.662	2.626
Story 9	3.913	2.856	2.727	2.679
Story 8	4.204	2.919	2.783	2.741
Story 7	4.343	2.914	2.757	2.722
Story 6	4.328	2.826	2.692	2.653
Story 5	4.57	2.642	2.591	2.549
Story 4	5.058	2.354	2.404	2.368
Story 3	5.379	1.947	2.098	2.046
Story 2	5.226	1.41	1.639	1.592
Story 1	3.186	0.686	0.909	0.896

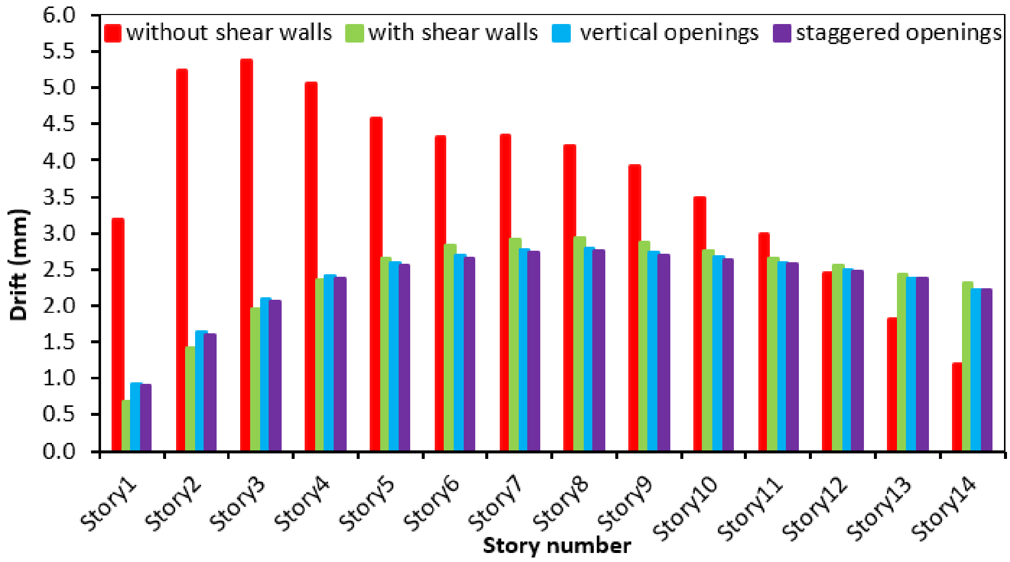

Figure 17. Story drift of the models, time history analysis, X-direction.

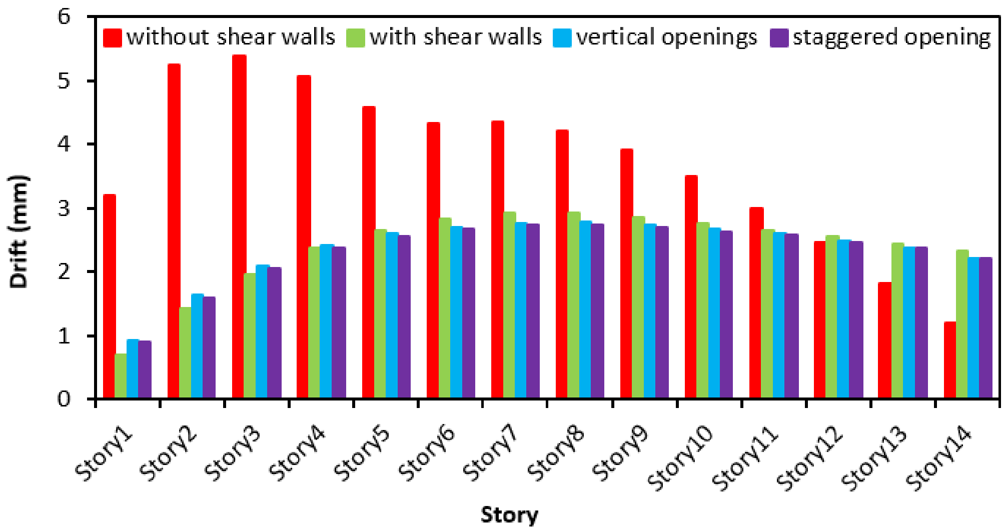

Figure 18. Story drift of the models, time history analysis, Y-direction.

4.3. Story Forces

In the case of the response spectrum, the values of story forces on the first floor are 3558.8 kN for modal without shear walls, 6295.9 kN for building with shear walls, and 5906.5 kN, 5871.6 kN for vertical opening, and staggered opening, respectively (as shown in Figures 19 and 20). As can be seen, the reduction percentage of story force value on the first floor is about 16.3% in buildings without shear walls when compared to buildings with shear walls. Figures 21 and 22 demonstrate the story forces in the case of time history analysis; the story forces on the first floor due to building without shear walls are 4491.0 kN when compared to building with shear walls, 7087.7 kN, and 5381.2 kN, 5333.9 kN for shear walls staggered and vertical openings in the case of time history, respectively. Additionally, it is noticed that the difference in story forces in the time history analysis (THA) as compared to the response spectrum analysis (RSA) results are insignificant for the same cases. Overall, it can be said that the displacement and story drift of the building significantly affected by the height of the structural element, story or building. Therefore, the shear walls openings have a slight effect on these mechanical properties as compared to the story forces. However, the distribution of the lateral forces (story forces) on the building are significantly influenced by the weight of the building. Consequently, the openings on the shear wall reduced the weight and stiffness of the building and then increased the lateral forces. Moreover, compared to other methods of analysis, time history analysis shows that the story forces are higher for all models. That might be attributed to the higher lateral forces applied on the building which generated by earthquake (El Centro).

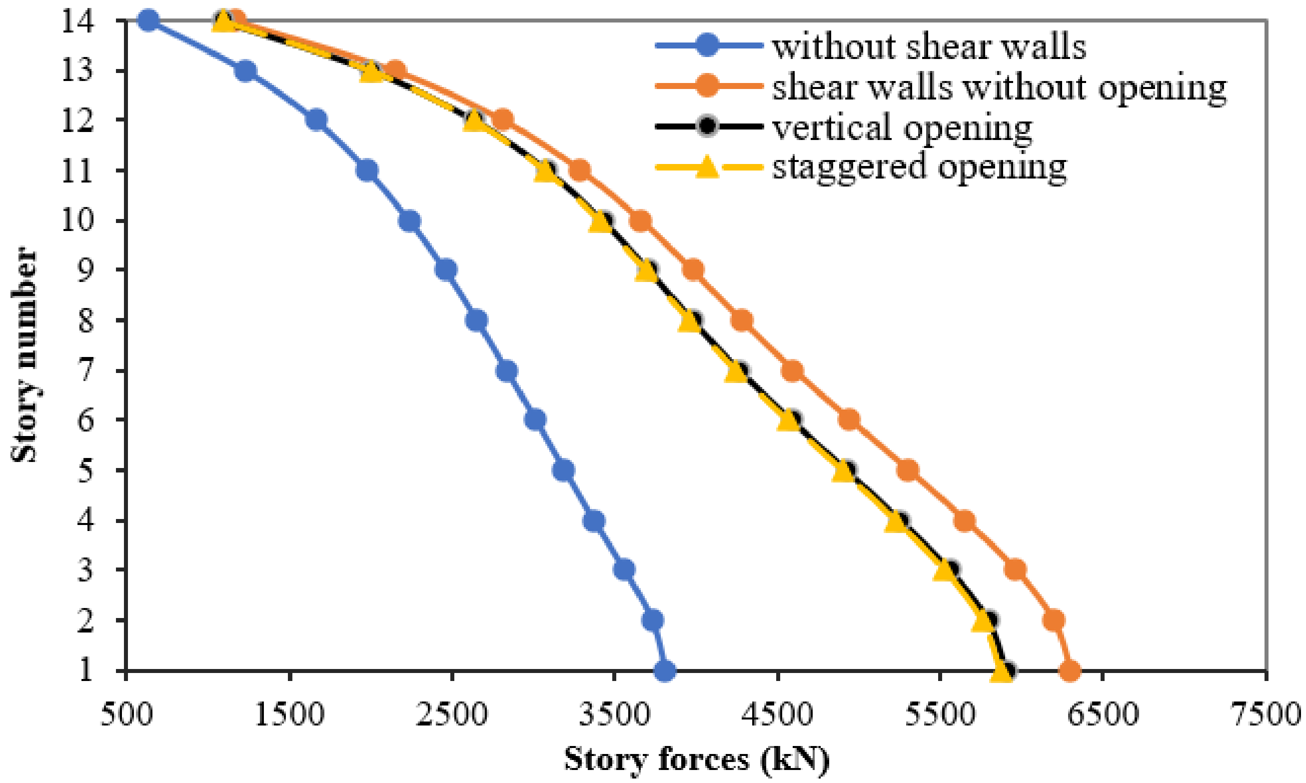

Figure 19. Story forces of the models, response spectrum analysis, X-direction.

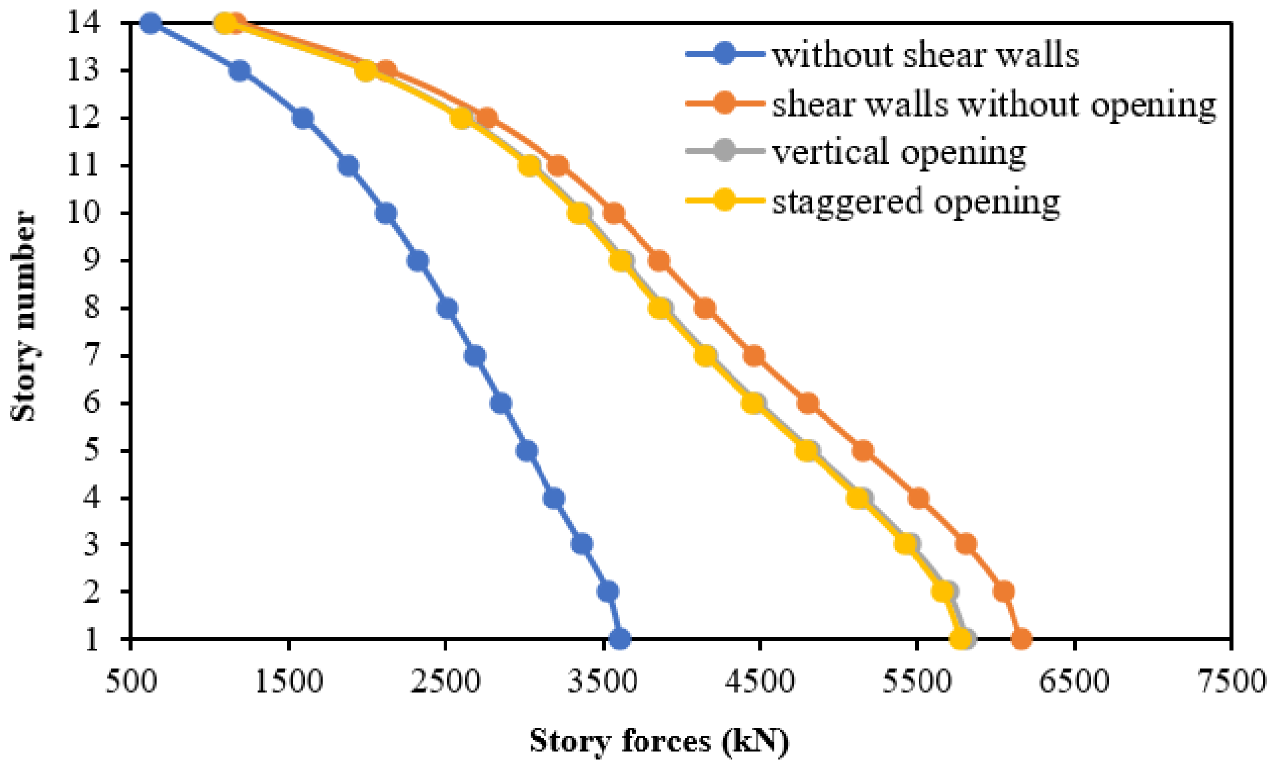

Figure 20. Story forces of the models, response spectrum analysis, Y-direction.

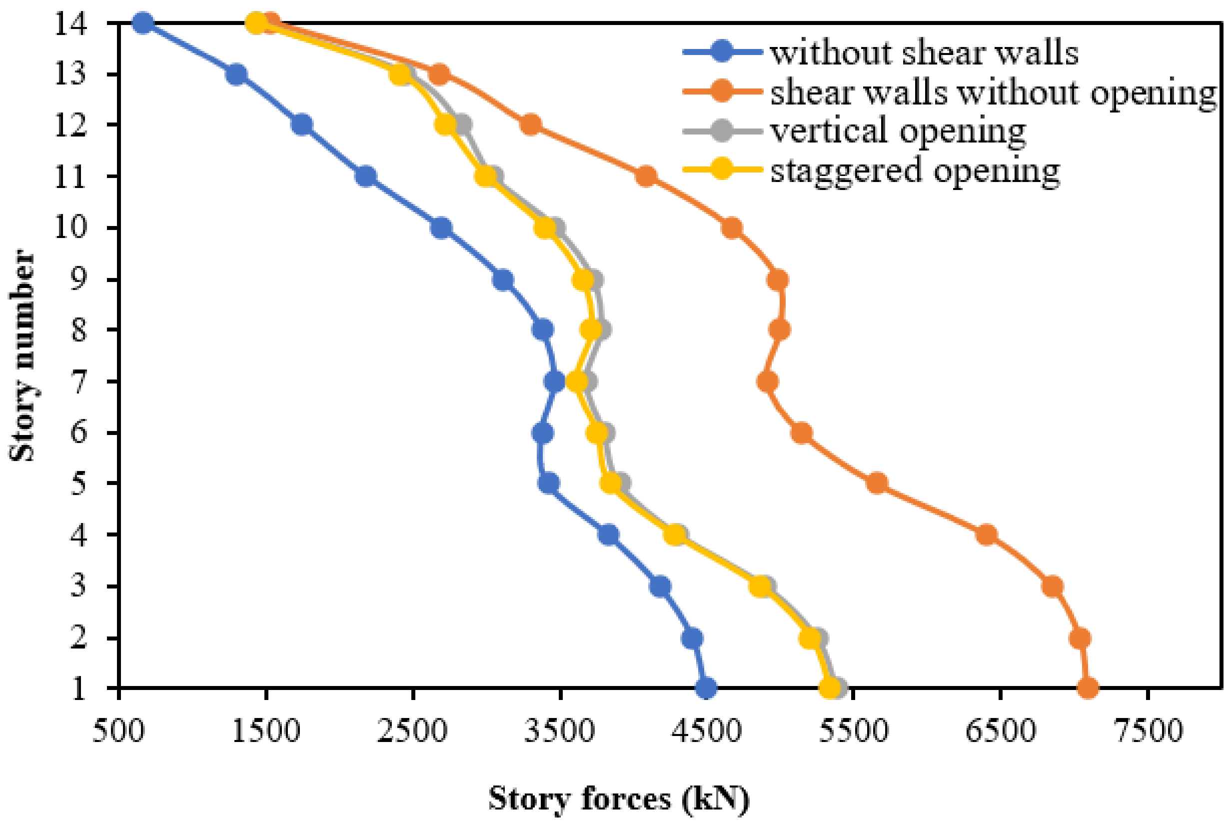

Figure 21. Story forces of the models, time history analysis, X-direction.

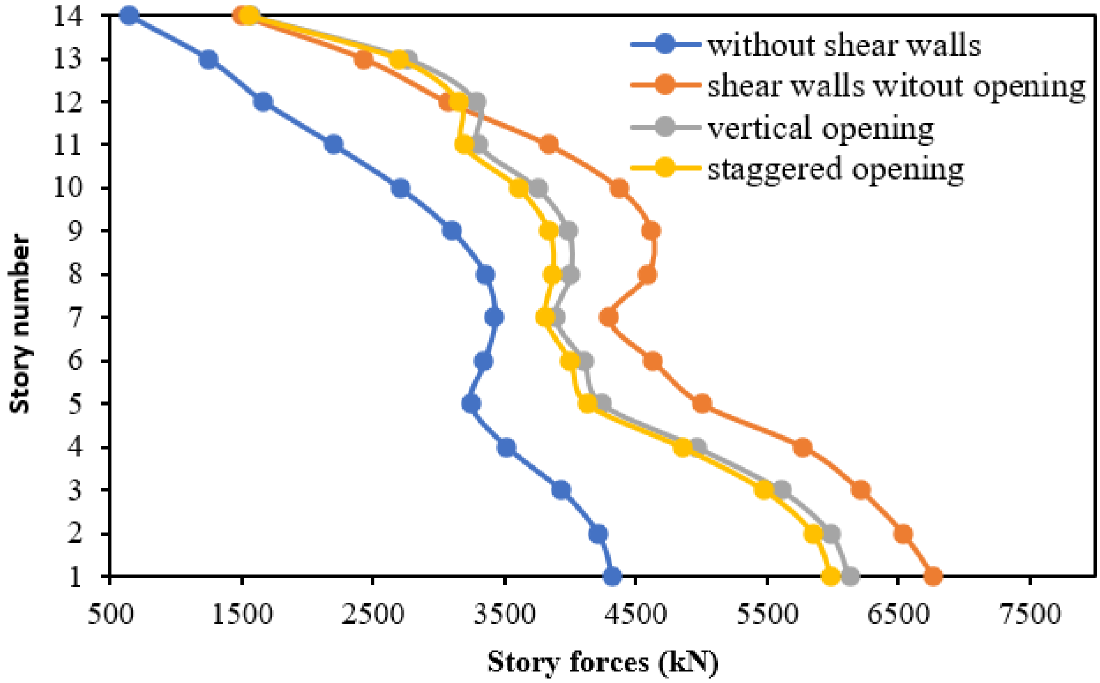

Figure 22. Story forces of the models, time history analysis, Y-direction.

The findings of this study agree with the results of the study by Mosoarca [12].

4.4. Time Period

As shown in Figure 23 the time period of the structure increases with an increase in mass. The time period decreases when the shear wall is provided and is a minimum for shear walls on the outer edges of the structure. A building with shear walls indicates that the time period reduces compared to a building without shear walls. Besides, a building with shear walls with a vertical opening, as in Figure 23, shows that the time period declines compared to a staggered opening.

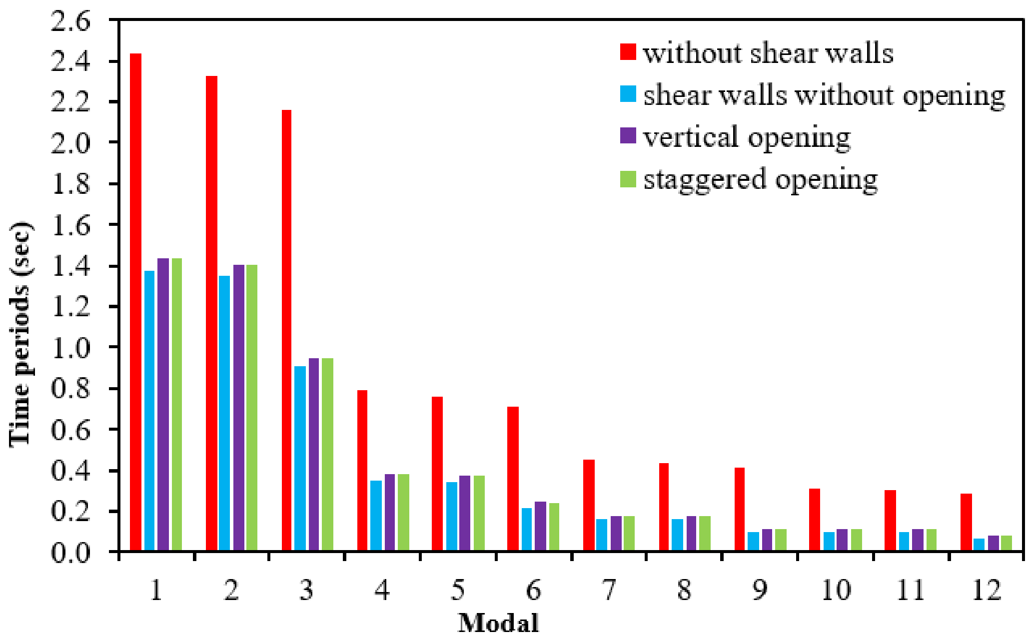

Figure 23. The time period of the models.

Finally, more or less similar behaviour of using finite element modelling in solving structures and materials problems has been conducted by several researchers, which provided by literature reports [30–37].

5. Conclusions

From the analytical study on the effect of openings on the seismic behaviour of shear walls, the following conclusions could be drawn:

1. Based on the ESA method of the models, it can be seen that the model with a shear wall showed improved performance in terms of displacement reduction. Additionally, a building with a shear wall without an opening shows better performance based on displacement reduction.
2. According to the response spectrum analysis, it is observed that the percentage reduction of story force value on the first floor is about 43% in buildings without shear walls when compared to buildings with shear walls and about 28% in buildings with shear walls when compared to shear walls with opening, equally for time history analysis.
3. From time-history analysis, it is concluded that the building with a shear wall showed good quality performance in terms of displacement reduction. Similarly, a building with a shear wall without an opening shows superior performance based on displacement reduction.
4. The results show that using shear walls cuts down on story drift and movement in the X and Y directions by a lot.
5. The maximum story drift in most of the cases produced is found on the seventh floor.
6. In all three analyses (equivalent static analysis, response spectrum, and time history analysis), the results concluded that shear walls without openings show less displacement as compared to the other models.
7. Similarly, it has been found that shear walls without openings show less drift as compared to other models. Thus, in turn, it emphasizes the vital impact of using these models.
8. Compared to other methods of analysis, time history analysis shows that the seismic story forces are higher for all models.

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