ASPS Conference Proceedings 1: 725-730 (2022)

Proceedings of

12th Structural Engineering Convention-An International Event (SEC 2022)

Available at https://asps-journals.com/index.php/acp

Effect of Openings in Shear wall on Seismic Behaviour of RC Buildings

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Paper ID - 060237

Abstract

Shear walls along the exterior perimeter of buildings increase the efficiency of buildings to resist seismic forces. In some conditions, the locations of shear walls are very critical because of the demand of architectural openings like doors and windows in the exterior face of the buildings. The literature has revealed that stiffness and seismic response of the structure is affected by the size of openings and location of openings in shear walls. This paper demonstrates effect of static and dynamic actions on 15 storey RC building having shear walls with openings. 32 building models have been prepared in commercial software STAAD for various inline and staggered openings in shear walls. Seismic coefficient method and Response spectrum method are used for seismic analysis. The analysis is carried out for the seismic zones III and IV for hard and medium soil conditions. The paper compares the response of these building models having shear wall with and without openings on parameters of time period, base shear, storey displacement, storey drifts and surface stress distribution. Uniform stress distribution was observed in shear wall with staggered opening as compared to inline openings.

Keywords: Earthquake, Shear wall, Lateral Load, Staggered opening. In-line openings.

1. Introduction

Shear walls are vertical structural elements for resisting the lateral loads that may be induced by the effect of wind and earthquakes. Entire resistance to horizontal loading is provided by shear walls. Introduction of shear walls in a building is a structurally efficient solution to stiffen the building because they provide the necessary lateral strength and stiffness to resist horizontal forces. They are generally provided along both length and width of the building and are located at the sides of the buildings or arranged in the form of core. Shear walls may have one or more openings for functional reasons such as doors, windows, and other types of openings in shear wall. The size and location of openings may vary depending on purposes of the openings. The size and location of shear walls is extremely critical. Properly designed and detailed buildings with shear walls have shown good performance in past earthquakes. Shear walls in high seismic regions require special detailing. However, in past earthquakes, even buildings with sufficient number of walls that were not specially detailed for seismic performance (but had enough well distributed reinforcement) were saved from collapse. Shear walls are efficient, both in terms of construction cost and effectiveness in minimizing earthquake damage in structural and non-structural elements (like glass windows and building contents). Finite element analysis and experimental was conducted by C.Y. Lin and C.L. Kuo [1] to study ultimate strength of shear wall with opening under lateral load. The test results indicated the shear strength contributed by diagonal reinforcement around opening reached 40% of its yield strength, while the shear strength contributed by the rectangular arrangement reached 20% of its yield strength. Also, for three walls out of four modelled with door openings experience a shear-compression failure in the first story adjacent to the door opening at average drift ratios near 1.5% [2]. Yanez F [3] concluded on six reinforced concrete walls with opening of different size of arrangement were tested under reserved cyclic lateral loading. The vertical reinforcement ratio was 0.5% in all the walls tested. The results indicate that appropriately designed walls with staggered opening can demonstrate the same behaviour and ductility as walls with regular openings.

Wu H. and Li B. [4] stated that the sizes and positions of openings can decrease the strength, stiffness, and ductility level of walls with opening. However, the walls could perform satisfactorily if the opening areas were limited within certain levels and the walls were well detailed to ensure the force-transferred mechanisms in the walls could function. Matsui T. [5] carried parametric study and concluded compressive diagonal struts transferring shear forces were formed in each wall element and their shape depended on the

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Proceedings of the 12th Structural Engineering Convention (SEC 2022), NCDMM, MNIT Jaipur, India| 19-22 December, 2022

Published online: December 19, 2022
doi:10.38208/acp.v1.574

wall panel length, regardless of opening layouts and loading directions. Mosoarca M. [6] presented the results of the theoretical and experimental tests on failure modes of three types of reinforced concrete shear walls with staggered openings which were compared to those obtained from walls with vertical ordered openings as far as the seismic response was concerned. Muthukumar G. and Kumar M. carried study [7] on displacement of wall and observed that the large number of small openings resulted in better displacement response. Sharma R., and Amin J. modelled 30 storey building and investigated and critically assess the effects of various size of openings in shear walls on the responses and behaviours of multi-storey buildings.

With understanding the response of the In-Line opening and staggered opening Structural System of Reinforced Concrete buildings for different terms such as Base Shear, Time Period of Structure, Top Storey Displacement, Storey Drift, Maximum Shear Stress in Shear Wall, the present study has been carried out with following objectives –

(i) To compare static and dynamic action in conventional and staggered opening shear wall for RC building.

(ii) To analyse staggered opening shear wall in Actual on-going project with Indian seismic zone III and IV from IS1893:2016 and two soil conditions namely Hard and Medium and compare results with conventional shear wall for RC building

A 15- storey irregular building is modelled which is

i) Bare Frame Structure

ii) Structure with Solid Shear Wall

iii) Structure with Solid Shear Wall with In-Line Openings

iv) Structure with Solid Shear Wall with Staggered Openings

Further, the openings with seizes of 1.65m x 0.8m, 1.65m x 1.2m, 1.65m x 1.65m are introduced for both In-Line and Staggered openings and structure is analysed.

2. Building Configurations –

A comparison has been shown between a structural system designed with stiffness approach and strength approach.

Table 1: Frame Section properties of Structures – Zone III – Hard Soil

ZONE III						
Sr.No.	Description		Bare Frame	Solid Shear Wall	Shear Wall In-Line Openings	Shear Wall Staggered Openings
HARD SOIL						
A	Building Properties					
1	Plan Dimensions		34550 x 16750			
2	Column Sizes	Red Marked	300 x 750	300 x 750	300 x 750	300 x 750
		Yellow Marked	350 x 750	350 x 750	350 x 750	350 x 750
3	Beam Sizes	Main	230 x 600 & 230 x 750	230 x 600 & 230 x 750	230 x 600 & 230 x 750	230 x 600 & 230 x 750
		Toilet Secondary	230 x 450	230 x 450	230 x 450	230 x 450
4	Lift Wall Thickness		230	230	230	230
5	Shear Wall		230	230	230	230

Table 2: Frame Section properties of Structures–Zone III–Medium Soil

ZONE III						
Sr.No.	Description		Bare Frame	Solid Shear Wall	Shear Wall In-Line Openings	Shear Wall Staggered Openings
MEDIUM SOIL						
A	Building Properties					
1	Plan Dimensions		34550 x 16750			
2	Column Sizes	Red Marked	300 x 750	300 x 750	300 x 750	300 x 750
		Yellow Marked	350 x 750	350 x 750	350 x 750	350 x 750
3	Beam Sizes	Main	230 x 600 & 230 x 750	230 x 600 & 230 x 750	230 x 600 & 230 x 750	230 x 600 & 230 x 750
		Toilet Secondary	230 x 450	230 x 450	230 x 450	230 x 450
4	Lift Wall Thickness		230	230	230	230
5	Shear Wall		230	230	230	230

Table 3: Frame Section properties of Structures –Zone IV-Hard Soil

ZONE IV						
Sr.No.	Description		Bare Frame	Solid Shear Wall	Shear Wall In-Line Openings	Shear Wall Staggered Openings
HARD SOIL						
A	Building Properties					
1	Plan Dimensions		34550 x 16750			
2	Column Sizes	Red Marked	300 x 750	300 x 750	300 x 750	300 x 750
		Yellow Marked	350 x 750	350 x 750	350 x 750	350 x 750
3	Beam Sizes	Main	230 x 600 & 230 x 750	230 x 600 & 230 x 750	230 x 600 & 230 x 750	230 x 600 & 230 x 750
		Toilet Secondary	230 x 450	230 x 450	230 x 450	230 x 450
4	Lift Wall Thickness		230	230	230	230
5	Shear Wall		230	230	230	230

Table 4: Frame Section properties of Structures–Zone IV–Medium Soil

ZONE IV						
Sr.No.	Description		Bare Frame	Solid Shear Wall	Shear Wall In-Line Openings	Shear Wall Staggered Openings
MEDIUM SOIL						
A	Building Properties					
1	Plan Dimensions		34550 x 16750			
2	Column Sizes	Red Marked	350 x 750	300 x 750	300 x 750	300 x 750
		Yellow Marked	400 x 850	350 x 750	350 x 750	350 x 750
3	Beam Sizes	Main	230 x 600, 230 x 750 & 230 x 700 Ht. From 9.6 M to 32 M	230 x 600, 230 x 750 & 230 x 750 Ht. From 9.6 M to 28.8 M	230 x 600, 230 x 750 & 230 x 680 Ht. From 12.8 M to 28.8 M	230 x 600, 230 x 750 & 230 x 680 Ht. From 12.8 M to 28.8 M
		Toilet Secondary	230 x 450	230 x 450	230 x 450	230 x 450
4	Lift Wall Thickness		230	230	230	230
5	Shear Wall		230	230	230	230

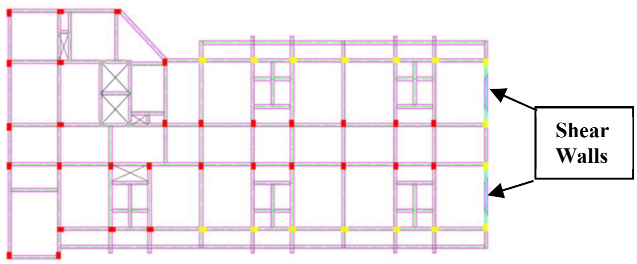

Fig. 1 Column and Beam Framing

3. Analysis of Structures –

The procedure and formulae suggested in the literature for strength and stiffness criteria are examined and the application for the two approaches for the design of 15 storey building, carried out for different opening patterns, gives the opportunity of discussing the relative influence of strength and stiffness on the design outcomes. Three

variations of openings are considered and edge distances are kept constant along the height of the structure,
a) 1.65m x 0.8m b) 1.65m x 1.2m c) 1.65m x 1.65m

Analysis of structure is carried out with following classification of models –
Model No. 1 - Bare Frame
Model No. 2 - Structure with Shear Wall
Model No. 3 - Structure with Shear Wall – In-Line openings 1.65m x 0.8m
Model No. 4 - Structure with Shear Wall – In-Line openings 1.65m x 1.2m
Model No. 5 - Structure with Shear Wall – In-Line openings 1.65m x 1.65m
Model No. 6 - Structure with Shear Wall – Staggered openings 1.65m x 0.8m
Model No. 7 - Structure with Shear Wall – Staggered openings 1.65m x 1.2m
Model No. 8 - Structure with Shear Wall – Staggered openings 1.65m x 1.65m

3.1 Results and Discussions –

A 15-Storey building is analysed for the mentioned seismic zones and soil conditions with sizes obtained using strength and Stiffness Criteria and the corresponding sample results are presented in following table 5 to table 8 and fig. 2 to fig. 7.

Table 5: Base Shear Comparison

BASE SHEAR COMPARISON in kN										
Zone	Soil Condition	Direction	Bare Frame	Solid SW	SW In Line Openings 1.65m x 0.8m	SW In Line Openings 1.65m x 1.2m	SW In Line Openings 1.65m x 1.65m	SW staggered Openings 1.65m x 0.8m	SW staggered Openings 1.65m x 1.2m	SW staggered Openings 1.65m x 1.65m
Zone III	Hard	X	2989.63	3041.3	2541.95	2532.29	2534.95	2541.95	2532.29	2534.95
		Z	2067.18	2141.6	1756.95	1755.46	1732.01	1756.95	1755.46	1732.01
	Medium	X	4049.52	4065.9	3457.07	3450.23	3446	3457.07	3450.23	3446
		Z	2810.05	2811.36	2391.96	2385.66	2382.74	2391.96	2385.66	2382.74
Zone IV	Hard	X	4452.57	4562.96	3812.92	3808.4	3799.49	3812.92	3808.4	3799.49
		Z	3078.72	3100.77	2635.43	2631.24	2630.59	2635.43	2631.24	2630.59
	Medium	X	6291.28	6264.95	5296.48	5262.17	5253.26	5296.48	5254.62	5253.26
		Z	4353.11	4346.13	3647.72	3641.88	3639.59	3647.72	3633.3	3639.59

Table 6: Dynamic Time Period Comparison

DYMANIC TIME PERIOD COMPARISON in Seconds										
Zone	Soil Condition	Direction	Bare Frame	Solid SW	SW In Line Openings 1.65m x 0.8m	SW In Line Openings 1.65m x 1.2m	SW In Line Openings 1.65m x 1.65m	SW staggered Openings 1.65m x 0.8m	SW staggered Openings 1.65m x 1.2m	SW staggered Openings 1.65m x 1.65m
Zone III	Hard	X	2.819	2.847	2.862	2.862	2.861	2.862	2.862	2.862
		Z	3.283	2.574	2.602	2.608	2.616	2.608	2.615	2.620
	Medium	X	2.818	2.847	2.862	2.862	2.861	2.862	2.862	2.861
		Z	3.283	2.574	2.608	2.608	2.616	2.608	2.615	2.623
Zone IV	Hard	X	2.818	2.847	2.862	2.862	2.862	2.862	2.862	2.862
		Z	3.283	2.574	2.608	2.608	2.616	2.608	2.615	2.616
	Medium	X	2.470	2.527	2.696	2.483	2.695	2.696	2.695	2.488
		Z	2.888	2.358	2.478	2.696	2.490	2.482	2.490	2.697

Table 7: Maximum Top Displacement Comparison

MAXIMUM TOP DISPLACEMENT COMPARISON in mm										
Zone	Soil Condition	Direction	Bare Frame	Solid SW	SW In Line Openings 1.65m x 0.8m	SW In Line Openings 1.65m x 1.2m	SW In Line Openings 1.65m x 1.65m	SW staggered Openings 1.65m x 0.8m	SW staggered Openings 1.65m x 1.2m	SW staggered Openings 1.65m x 1.65m
Zone III	Hard	X	109.77	107.16	95.173	95.35	95.44	95.17	95.44	95.70
		Z	102.72	76.64	66.805	66.69	66.51	66.50	66.35	66.20
	Medium	X	148.209	145.632	128.569	128.733	128.816	128.572	128.837	129.095
		Z	139.162	101.37	87.941	87.78	87.537	87.583	87.381	87.186
Zone IV	Hard	X	163.52	160.59	141.56	141.72	141.80	141.56	141.83	142.08
		Z	153.46	110.99	96.16	95.98	95.71	95.78	95.56	95.42
	Medium	X	171.81	179.04	172.83	173.02	173.11	172.86	173.15	173.43
		Z	163.45	132.62	120.96	120.72	120.36	120.58	120.30	119.99

Table 8: Shear Stress Comparison

SHEAR STRESS COMPARISON in MPa									
Zone	Soil Condition	Bare Frame	Solid SW	SW In Line Openings 1.65m x 0.8m	SW In Line Openings 1.65m x 1.2m	SW In Line Openings 1.65m x 1.65m	SW staggered Openings 1.65m x 0.8m	SW staggered Openings 1.65m x 1.2m	SW staggered Openings 1.65m x 1.65m
Zone III	Hard	N.A.	0.861	0.758	0.756	0.745	0.752	0.748	0.742
	Medium	N.A.	1.025	0.893	0.884	0.876	0.883	0.879	0.872
Zone IV	Hard	N.A.	1.264	1.022	0.945	0.924	0.965	0.916	0.899
	Medium	N.A.	1.462	1.236	1.082	0.992	1.194	0.986	0.983

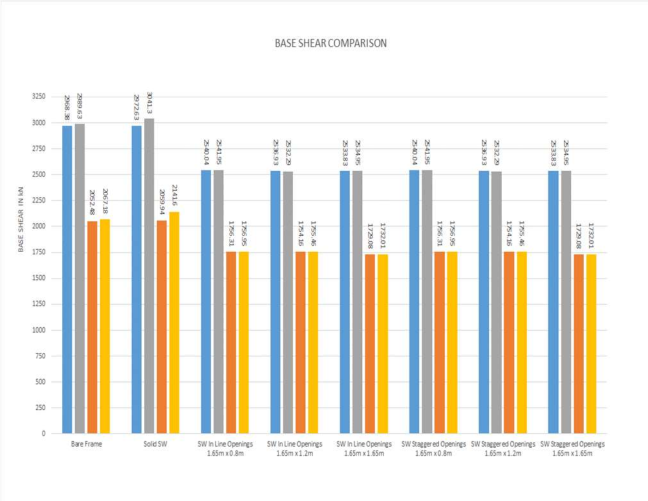

Fig. 2: Base Shear - Zone III – Hard Soil Condition

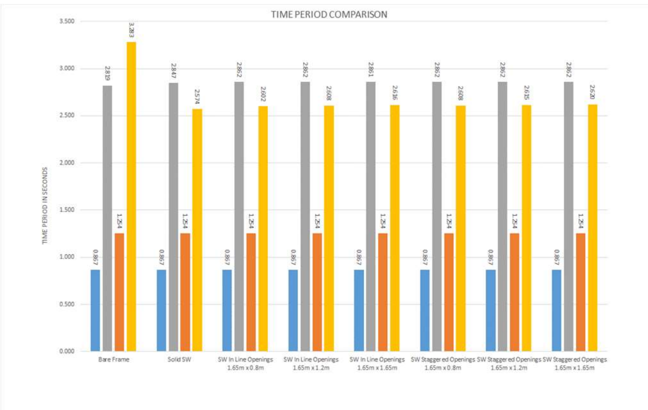

Fig. 3: Time Period - Zone III – Hard Soil Condition

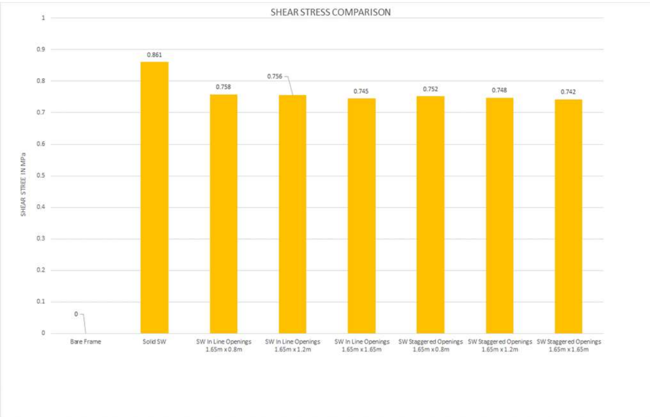

Fig. 4: Shear Stress - Zone III – Hard Soil Condition

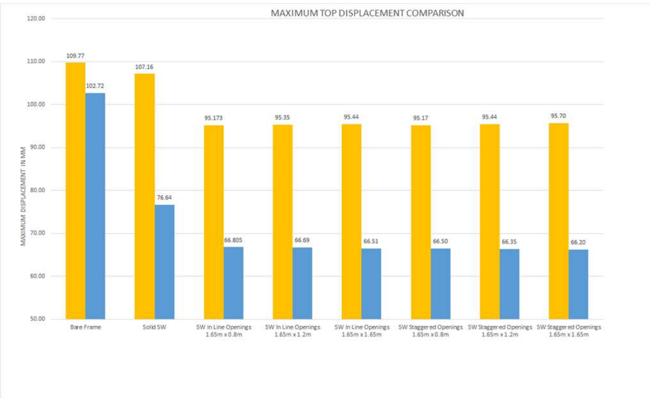

Fig. 5: Maximum Top Displacement - Zone III–Hard Soil Condition

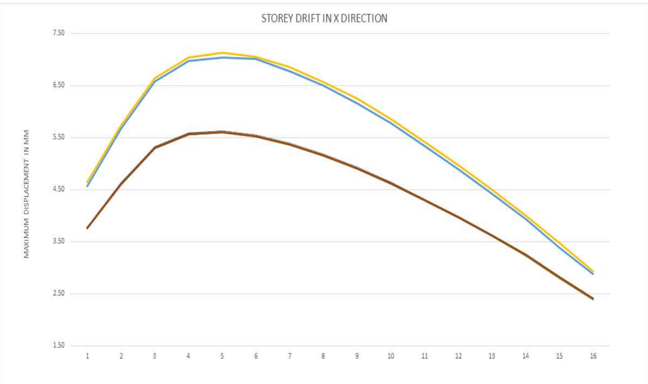

Fig. 6: Storey Drift X- Direction - Zone III–Hard Soil Condition

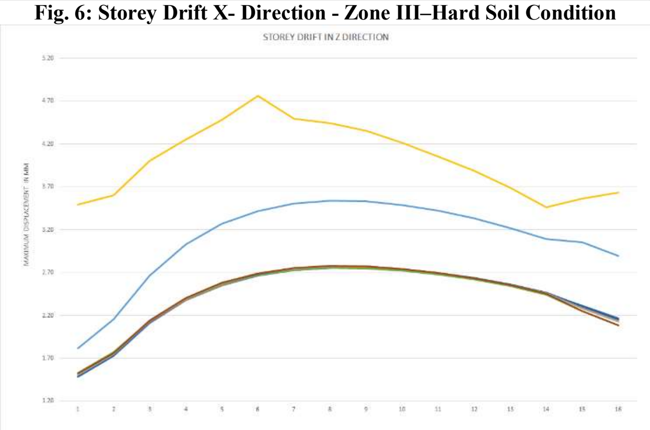

Fig. 7: Storey Drift Z- Direction - Zone III–Hard Soil Condition

A) Result Comparison for Zone III – Hard Soil Condition –

(i) It is observed from Table 5, as the opening sizes are minutely changes, base shear of Model 3,4,5,6,7 and 8 are in same range.

(ii) As compared with Model 1 and 2, base shear of Model 3,4,5,6,7 and 8 reduced with 14.53% and 14.65% respectively in X-Direction (Fig.2).

(iii) Compare (Fig.2) to Model 1 and 2, base shear of Model 3,4,5,6,7 and 8 reduced with 14.65% and 15.21% respectively in Z-Direction.

(iv) Dynamic time period of Model 3,4,5,6,7 and 8 are increased in X-direction by 1.52% and reduced by 20.46% in Z- Direction compared to Model 1 (Fig.3).

(v) Dynamic time period of Model 3,4,5,6,7 and 8 are increased in X-direction by 0.52% and by 1.47% in Z-Direction compared to Model 2 (Fig.3).

(vi) Shear stress at base gradually decreases as the opening sizes increases in both conditions. Slight reduction in Shear stress for staggered opening is observed. But shear stress near opening are increases (Fig.4).

(vii) Max. Displacement of Model 3,4,5,6,7 and 8 are decreased in X-direction by 13.10% and 35.25% in Z-Direction compared to Model 1 (Fig.5).

(viii) Comparing with Model 1 and 2, Storey drifts are minimized in Model 3,4,5,6,7 and 8 with same specification in all soil conditions (Fig.6 and Fig.7).

(ix) From analysis, it is observed that overall results computed for 3,4,5,6,7 and 8 are in same range. But the huge difference observed in stress distribution of all different walls with opening. In Zone III and Hard soil condition, it is observed that Staggered openings up to 16% shows better results.

B) Result Comparison for Zone III–Medium Soil Condition –

(i) It is observed that, as the opening sizes are minutely changes, base shear of Model 3,4,5,6,7 and 8 are in same range.

(ii) As compared with Model 1 and 2, base shear of Model 3,4,5,6,7 and 8 reduced with 14.57% and 14.85% respectively in X-Direction.

(iii) Compare to Model 1 and 2, base shear of Model 3,4,5,6,7 and 8 reduced with 15.16% and 15.55% respectively in Z-Direction.

(iv) Dynamic time period of Model 3,4,5,6,7 and 8 are increased in X-direction by 1.53% and reduced by 20.39% in Z- Direction compared to Model 1.

(v) Dynamic time period of Model 3,4,5,6,7 and 8 are increased in X-direction by 0.51% and by 1.53% in Z-Direction compared to Model 2.

(vi) Shear stress at base gradually decreases as the opening sizes increases in both conditions. Slight reduction in Shear stress for staggered opening is observed. But shear stress near opening are increases.

(vii) Max. Displacement of Model 3,4,5,6,7 and 8 are decreased in X-direction by 13.11% and 37.07% in Z-Direction compared to Model 1.

(viii) Comparing with Model 1 and 2, Storey drifts are minimized in Model 3,4,5,6,7 and 8 with same specification in all soil conditions.

(ix) From analysis, it is observed that overall results computed for 3,4,5,6,7 and 8 are in same range. But the huge difference observed in stress distribution of all different walls with opening. In Zone III and Medium soil condition, it is observed that Staggered openings up to 16% shows better results.

C) Result Comparison for Zone IV – Hard Soil Condition –

(i) It is observed that, as the opening sizes are minutely changes, base shear of Model 3,4,5,6,7 and 8 are in same range.
(ii) As compared with Model 1 and 2, base shear of Model 3,4,5,6,7 and 8 reduced with 14.15% and 15.13% respectively in X-Direction.
(iii) Compare to Model 1 and 2, base shear of Model 3,4,5,6,7 and 8 reduced with 13.99% and 14.85% respectively in Z-Direction.
(iv) Dynamic time period of Model 3,4,5,6,7 and 8 are increased in X-direction by 1.54% and reduced by 20.43% in Z- Direction compared to Model 1.
(v) Dynamic time period of Model 3,4,5,6,7 and 8 are increased in X-direction by 0.51% and by 1.48% in Z-Direction compared to Model 2.
(vi) Shear stress at base gradually decreases as the opening sizes increases in both condition. Slight reduction in Shear stress for staggered opening is observed. But shear stress near opening are increases.
(vii) Max. Displacement of Model 3,4,5,6,7 and 8 are decreased in X-direction by 13.31% and 37.59% in Z-Direction compared to Model 1.
(viii) Comparing with Model 1 and 2, Storey drifts are minimized in Model 3,4,5,6,7 and 8 with same specification in all soil conditions.
(ix) From analysis, it is observed that overall results computed for 3,4,5,6,7 and 8 are in same range. But the huge difference observed in stress distribution of all different walls with opening. In Zone IV and Hard soil condition, it is observed that Staggered openings up to 16% shows better results.

D) Result Comparison for Zone IV–Medium Soil Condition –

(i) As models are not having same specifications, but comparing the results base shear is reduces for model 3,4,5,6,7 and 8 compared with model 1 and 2.
(ii) Dynamic time period also comparatively remains same for model 3,4,5,6,7 and 8 in both directions.
(iii) Shear stress at base gradually decreases as the opening sizes increases in both conditions. Slight change in Shear stress for staggered opening is observed. But shear stress near openings are increases.
(iv) Max. deflection of structure for model 3,4,5,6,7 and 8 are comparatively remain same.
(v) Storey drifts for all models are within limit.
(vi) From analysis, it is observed that overall results computed for 3,4,5,6,7 and 8 are in same range. But the huge difference observed in stress distribution of all different walls with opening. In Zone IV and Medium soil condition, it is observed that Staggered openings up to 10.5% shows better results.

The summary of the above all modelled structures in various conditions are as follows –

(i) From the various configurations of the opening sizes and positions considered in the present study (In-Line Openings and Staggered Openings) it is revealed that the Base Shear of structure is reduced.
(ii) The structure is found to be stiff, if opening percentages for used zones and soil conditions kept in specific range.
(iii) For all opening sizes results for strength as well as for serviceability criteria are in same range, minute changes were observed.
(iv) One of the most important parameters for the structural design of buildings having shear wall with openings is the surface stress distribution on wall area near openings.
(iv) It is revealed from the study that optimal opening percentage decreases as the zone and soil condition of the structure changes. It is varied from 10.5% to 16%.
(v) The size of the openings in shear wall with gradually changing the percentage is controlled by the location of openings. It helps designer to take advantage of arranging locations conveniently.

4. Conclusions

The Shear wall with in-line and staggered openings for various Buildings are modelled and seismic response analysis has been carried out with the help of STAAD.Pro® software and findings are presented as below -

(i) Mass distribution in the structure can be modified and adjust by providing shear wall with staggered openings to obtain minimum base shear.
(ii) Surface stress variations govern by provided opening sizes. In present study it has shown that Staggered openings shows better results with well distribution of surface stress.
(iii) In the present study it has shown base shear, time period and top displacement of the structure having same specifications can be altered by introducing Staggered openings in Shear wall.

Disclosures

Free Access to this article is sponsored by SARL ALPHA CRISTO INDUSTRIAL.

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