SEISMIC PERFORMANCE OF ASYMMETRIC HIGH-RISE RC BUILDINGS WITH AND WITHOUT INFILL WALLS

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Abstract - *This study presents a comprehensive seismic analysis of a high-rise reinforced concrete building, with a particular focus on the influence of infill walls on structural performance during seismic events. A 20-story building is modelled and analysed using ETABS software, in accordance with IS 1893 (Part-1):2016 seismic design guidelines. Three structural configurations are considered: a bare frame, a frame with AAC block infill walls, and a frame with burnt clay brick infill walls. Key parameters such as story drift and lateral displacement under seismic loads are evaluated to assess the seismic behaviour of each configuration. The results demonstrate that the presence of infill walls significantly enhances the lateral stiffness and reduces displacement, thereby improving the overall seismic performance of the structure. Comparatively, the bare frame shows increased lateral displacement and reduced stiffness. Among the infill materials, burnt clay bricks provide greater stiffness than AAC blocks. The study offers valuable insights into the role of infill walls in seismic design and highlights the importance of considering these elements in high-rise construction within earthquake-prone regions.*

Key Words: Infill walls, Push over Analysis, Seismic Structure, Story displacement, Story drift.

1.INTRODUCTION

The seismic behaviour of high-rise buildings remains a critical focus in structural engineering, especially in regions vulnerable to earthquakes. Due to their considerable height, mass distribution, and slender geometry, high-rise buildings exhibit complex responses to seismic forces. These dynamic lateral forces, if not properly accounted for, can result in severe structural damage or even collapse. Consequently, understanding the influence of various structural and non-structural components on seismic performance is essential for ensuring the safety and resilience of such buildings.

Infill walls, commonly constructed from materials such as brick or concrete blocks, are traditionally considered non-structural elements used for partitioning interior spaces. However, numerous studies have shown that infill walls can significantly affect the seismic response of buildings by contributing to lateral stiffness, strength, and energy dissipation capacity. Their presence can alter the dynamic characteristics of a structure, reducing lateral displacement and story drift during seismic events.

Despite their potential benefits, infill walls are often neglected in structural analysis, which can lead to overly conservative designs that underestimate stiffness and overestimate deformations. Conversely, incorporating infill walls in seismic analysis can provide a more realistic understanding of a structure's behaviour under earthquake loading. The type of infill material also plays a crucial role in determining the extent of these effects. Materials such as Autoclaved Aerated Concrete (AAC) blocks and burnt clay bricks differ significantly in density, strength, and stiffness, thereby influencing the overall seismic performance in distinct ways.

This study aims to investigate and compare the seismic performance of a 20-story reinforced concrete building under three different conditions: a bare frame, a frame with AAC block infill walls, and a frame with burnt clay brick infill walls. The analysis is conducted using ETABS software, following the guidelines outlined in IS 1893 (Part-1):2016. Key parameters such as base shear, story drift, and lateral displacement are evaluated using the Equivalent Static Load Method. The findings will contribute to a deeper understanding of the role of infill walls in seismic design and provide practical insights for enhancing structural safety in high-rise construction.

2. CORRESPONDING LITERATURES

The seismic performance of buildings, particularly those with masonry infill walls, has been a significant focus of research in structural engineering. Numerous studies have explored the effects of infill walls on the dynamic behavior of reinforced concrete (RC) frames, highlighting their role in enhancing structural integrity during seismic events.

C. Rajesh et.al (2014) [8] examined the seismic performance of reinforced concrete (RC) buildings with and without masonry infill walls. It uses the equivalent diagonal strut concept to model the infill walls and analyzes the buildings for seismic loads using SAP2000 software. The findings show that buildings with infill walls (strut model) are stiffer, with shorter time periods, higher base shear, and lower weight compared to bare-frame buildings. These properties make the strut model buildings safer and more resistant to earthquakes, highlighting the importance of considering infill wall stiffness in seismic design to prevent failures, as seen in the 2001 Bhuj earthquake.

Wakchaure M.R et.al (2012) [9] investigated the impact of masonry infill walls on the seismic performance of high-rise reinforced concrete (R.C.C.) buildings. Infill walls act as compression struts between columns and beams, transferring forces during an earthquake. The "equivalent strut method" is used to model these walls. A 10-story R.C.C. framed building is analyzed using ETABS software, with various infill wall configurations tested for base shear, displacement, and drift. Results show that infill walls reduce top-storey displacement, shorten response time, and increase base shear. The arrangement of the walls affects how forces are distributed, and irregularities such as soft story's can cause more damage. The study also finds that a higher slenderness ratio increases displacement and base shear. In conclusion, considering masonry infill walls is essential for accurate seismic evaluation of high-rise R.C.C. buildings.

GAYATHRI R et.al (2022) [10] focused on the analysis and design of a four-story building using ETABS software. Multi-story buildings require careful consideration of factors like cost, serviceability, and durability. The main elements of the building such as beams, columns, slabs, and footings—are analyzed and designed to ensure strength and stability. The paper discusses the analysis of a building (G+4) under the influence of shear forces and bending moments acting on beams and columns. The conclusion emphasizes that building analysis ensures safety, longevity, and economic efficiency. Using automated software like ETABS is more efficient and reliable compared to manual methods, reducing errors and improving the stability and safety of the structure.

D.Haritha et.al (2021) [11] focused on the structural analysis and design of a multi-story building using ETABS software. Structural analysis is essential to understand how different components like beams, columns, and slabs respond to various loads such as dead load, live load, and wind load. ETABS is used to perform both static and dynamic analysis, providing crucial data like shear forces and bending moments before construction, which helps in making informed design decisions regarding materials and dimensions. The building is designed according to IS codes, including IS 456-2000 for concrete and IS 875 for loads. AutoCAD is used for planning the building based on India's National Building Code. The project results include maximum shear forces and bending moments for beams and columns under different load combinations, helping to create an efficient and economical design. In conclusion, the study provides valuable insights into structural analysis and design using ETABS, ensuring safety and efficiency in the building design.

DR.K.Chandrasekhar Reddy et.al (2019) [12] analyzed a 30-story high-rise building (G+30) using ETABS 2016 software, considering seismic, dead, and live loads. The main goal is to determine the effects of lateral loads on moments, shear force, axial force, base shear, displacement, and tensile forces. The analysis compares results for seismic zones 2, 3, 4, and 5.Key findings include: Lateral displacements are highest in seismic zone 5 compared to zones 4, 3, and 2.Story shear is also greater in zone 5 than in zone 2.All structural members were designed using ETABS, and any inadequate members were identified, with suitable sections recommended by the software. The software provides improved accuracy for structural analysis. In conclusion, ETABS software offers a reliable and efficient method for analyzing and designing high-rise buildings, ensuring better accuracy in structural performance.

Kurapati Durga Prashanth Reddy et.al (2017) [13] compared the behavior of RCC buildings with and without masonry infill walls in different positions, using Response Spectrum Analysis in ETABS software. It focuses on maximum story displacement and story drift for buildings with masonry infill walls located at the center and corners. The key conclusions are: As the mode number increases, the building's time period decreases and its frequency increases. As the time period decreases, acceleration in the X and Y directions increases, stabilizing from mode-4 to mode-9. The study analyzes buildings in Zone III on medium soil (Soil Type II).The presence of masonry infill walls, whether at the center or corners, makes the building more flexible compared to a normal building in Zone III with medium soil.

Haroon Rasheed Tamboli et.al (2012) [14] examined the seismic performance of reinforced concrete (RC) frame building models, including bare frames, infilled frames, and open first-story frames, using the Equivalent Lateral Force Method. Masonry infill walls, often considered non-structural, significantly impact structural behavior during seismic events. The Equivalent Diagonal Strut method is employed to model infill panels, and ETABS software is used for analysis. The study highlights the influence of infill walls on stiffness and seismic resistance. Additionally, a short-term investigation of Muthukuda coastal waters reveals high phytoplankton productivity in the Pambanar estuary and adjacent Palk Bay, supported by mangrove vegetation and seagrass meadows. These contribute to the biogeochemistry of the region. The findings underline the need for long-term studies to understand nutrient dynamics and productivity for sustainable ecosystem management. Both studies emphasize the critical role of secondary elements in structural and ecological systems.

Hakan Dilmac et.al (2018) [15] studied one of the important factors is the infill walls in the change of the structural rigidity, ductility, dynamic and static characteristics of the structures. The infill walls are not generally included in numerical analysis of reinforced concrete (RC) structural systems due to the lack of suitable theory and the difficulty of calculating the recommended models. In seismic regions worldwide, the residential structures are generally RC buildings with infill walls. Therefore, understanding the contribution of the infill walls to the seismic performance of buildings may have vital importance. This paper investigates the effects of infill walls on the seismic performance of existing RC residential buildings by considering the requirements of the Turkish Earthquake Code (TEC). Seismic performance levels of residential RC buildings with and without walls in high-hazard zones were determined according to the nonlinear procedure given in the code. Pushover curves were obtained by considering the effect of masonry infill walls on the seismic performance of RC buildings. The analysis results showed that the infill walls beneficially affected the rigidity, roof displacements, and seismic performance of the building.

Kiran Tidke et.al (2016) [16] examined buildings with masonry infill walls are the most common type of structures used for multi-story constructions in developing countries. Masonry brick infill walls have been used in reinforced concrete (RC) frame structures as interior and exterior partition walls. Infill walls are nowadays considered to be non-load-bearing members. In the design and assessment of buildings, infill walls are usually treated as non-structural elements and are ignored in analytical models because they are assumed to be non-beneficial to the structural response. However, during wind and earthquakes, these infill walls contribute to the structural response and increase the strength and stiffness of the frame. This paper studies the effect of masonry infill walls on buildings. Dynamic analysis of buildings with different arrangements is carried out. For the analysis, a G+7 RC frame building is modeled. The width of the strut is calculated by the equivalent diagonal strut method. Analysis is carried out using SAP2000 software. Base shear, maximum story drift, and displacement are calculated and compared for all models.

K. Satya Narasimha Rao et.al (2015) [17] investigated the effect of masonry infill panels on the response of RC frames subjected to seismic action is widely recognized and has been the subject of numerous experimental investigations, with several attempts to model it analytically. In analytical analysis, infill walls are modelled using an equivalent static approach, with various formulae derived for their width. Infill behaves like a compression member between columns and beams, transferring forces from one node to another. This study investigates the effect of masonry walls on high-rise buildings. Static analysis on high-rise buildings with different arrangements is carried out. A G+9 RCC framed building is modelled, and the width of infill walls is calculated using the equivalent static method. Various cases of analysis are considered, and the analysis is conducted using STAAD.Pro software. Parameters such as axial force, shear force, storey drift, nodal displacement, and bending moment are calculated and compared for all models. The results indicate that infill walls reduce displacement and the time period while increasing base shear. Therefore, it is essential to consider the effect of masonry infill walls in the seismic evaluation of moment-resisting reinforced concrete frames.

3. MODELING AND DETAILS

The seismic analysis of a high-rise building without infill walls involves several critical parameters and considerations. The building in question is a multi-storey rigid jointed plane frame, specifically a special reinforced concrete moment resisting frame (SMRF), located in Mumbai, which falls under Seismic Zone-III. The seismic zone factor (Z) is 0.6, indicating a moderate to high seismic risk. The importance factor (I) is 1.2, reflecting the building's significance, and the response reduction factor (R) is 5, which accounts for the ductility and overstrength of the structure. The damping ratio is set at 5%, and the building is constructed on rock or hard soil (Type-I), which provides a stable foundation.

The building has a natural period of oscillation (T_a) of 1.616 seconds, which is crucial for understanding its dynamic behaviour under seismic loads. It consists of 20 storeys, with each floor having a height of 3 meters. The live load is specified as 3 kN/m^2. The structural elements include beams with a size of 350x550 mm, columns with a size of 300x700 mm, and a slab thickness of 150 mm. Additionally, the building features shear walls with a thickness of 250 mm to enhance its lateral load resistance.

The building's dimensions are 30 meters in the X-direction and 24 meters in the Y-direction. The materials used in the construction are of high strength: the concrete grade is M60 with a compressive strength of 60 N/mm^2, and the steel grade is Fe415 with a yield strength of 415 N/mm^2. The densities of the materials are as follows: AAC blocks at 9.81kN/m^3, burnt clay bricks at 20kN/m^3, concrete at 25 kN/m^3, and steel at 78.5 kN/m^3. The Young's Modulus of steel is 2 x 10^5 N/mm^2, and for concrete, it is 38729.63 N/mm^2.

This comprehensive set of parameters and specifications forms the basis for conducting a detailed seismic analysis of the high-rise building, ensuring that it can withstand seismic forces effectively despite the absence of infill walls.

Table -1: Material Properties

Description	Value
Grade of Concrete (M60) (N/mm^2)	60
Grade of Steel (Fe415) (N/mm^2)	415
Density of AAC blocks (kN/m^3)	9.81
Density of Burnt clay bricks	20
Density of Concrete (kN/m^3)	25
Density of Steel (kN/m^3)	78.5
Young's Modulus of Steel (N/mm^2)	2 x 10^5
Young's Modulus of Concrete (N/mm^2)	38729.63

Table -2: General Description of the Model Geometry

Title	Description
Type of Structure	Multi storey rigid jointed plane frame (special RC moment resisting frame SMRF)
Region	Mumbai (Zone-III)
Seismic zone factor (Z)	0.16
Importance factor (I)	1.2
Response reduction factor (R)	5
Damping ratio	5%
Soil type	Rock or hard soil (Type-I)
Natural period of oscillation (T_a) (sec)	1.616
Number of storeys	20
Live load (kN/m^2)	3
F-F height (m)	3
Beam size (mm)	350x550
Column size (mm)	300x700
Slab thickness (mm)	150
Shear wall thickness (mm)	250
Length in X-direction (m)	30
Length in Y-direction (m)	24

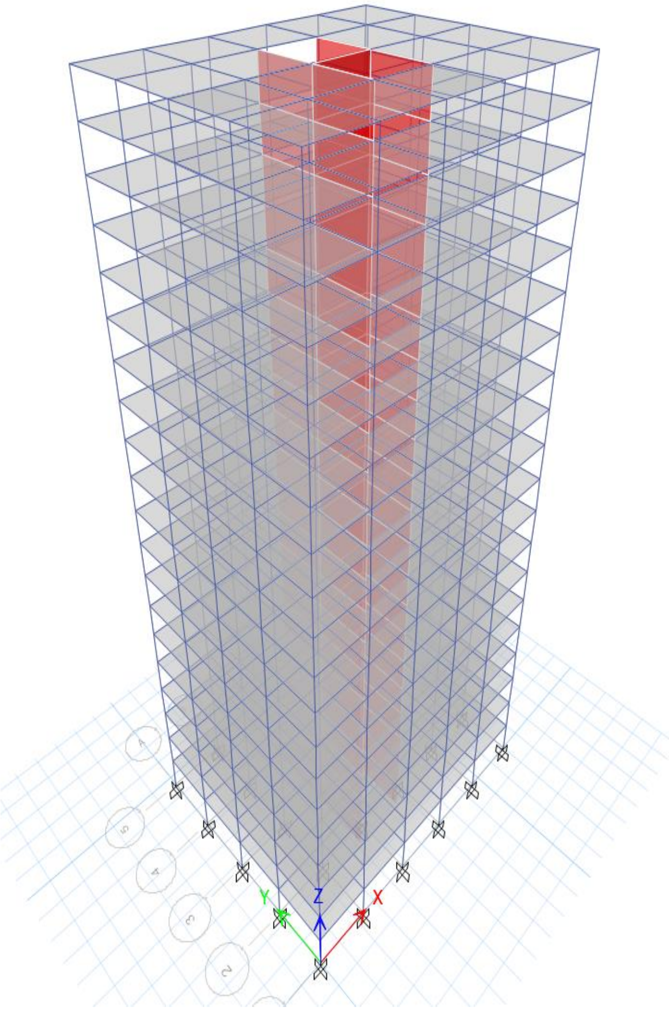

Fig -1: Structural Model without Infill Walls (3D view)

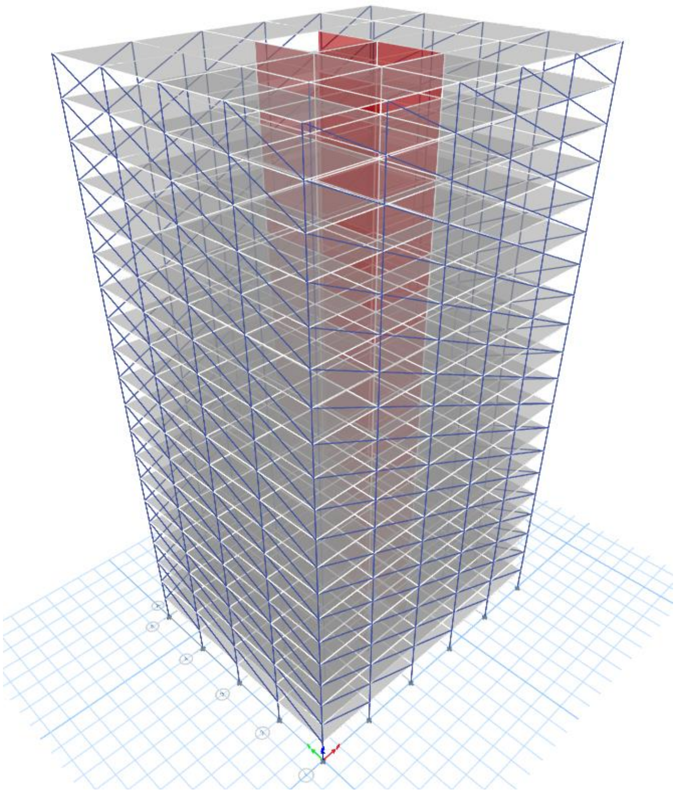

Fig -2: Structural Model with Infill Walls (3D view)

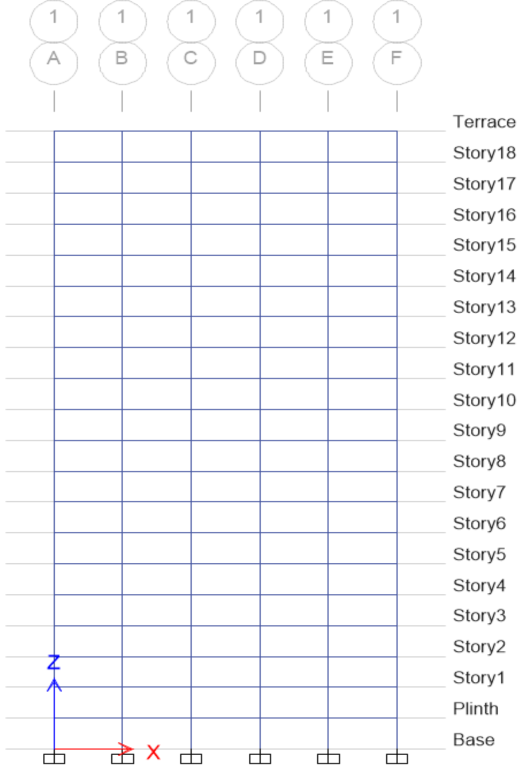

Fig -4: Structural Model without infill walls (Elevation-X)

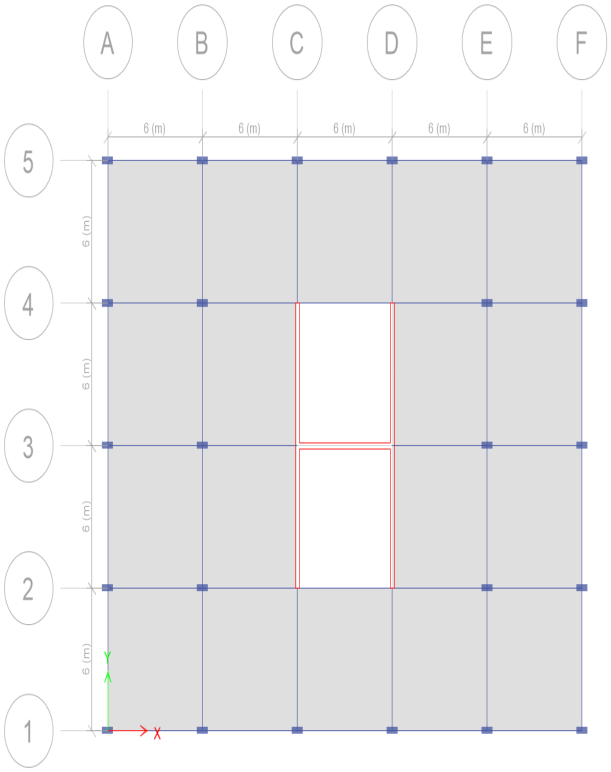

Fig -3: Structural Model (Plan view)

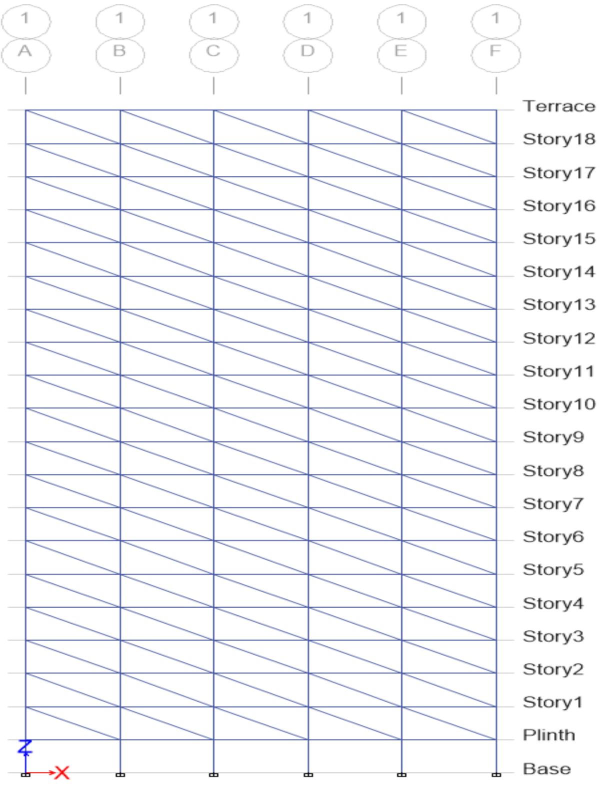

Fig -5: Structural Model with infill walls (Elevation-X)

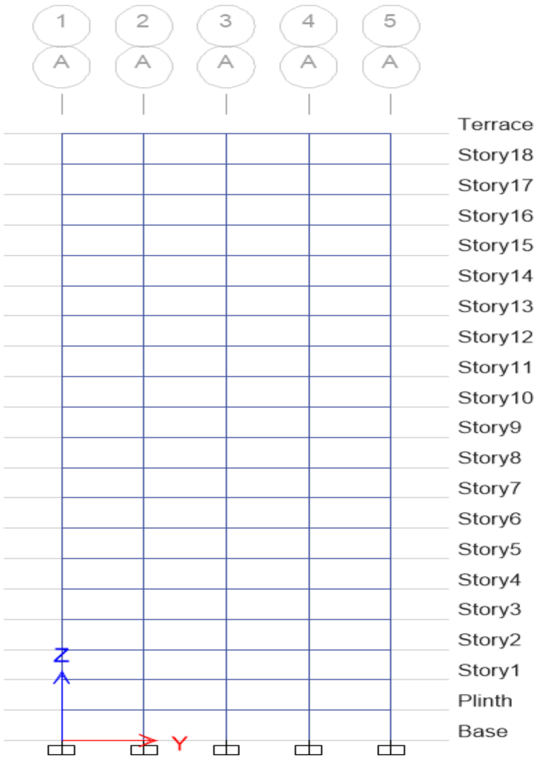

Fig -6: Structural Model without infill walls (Elevation-Y)

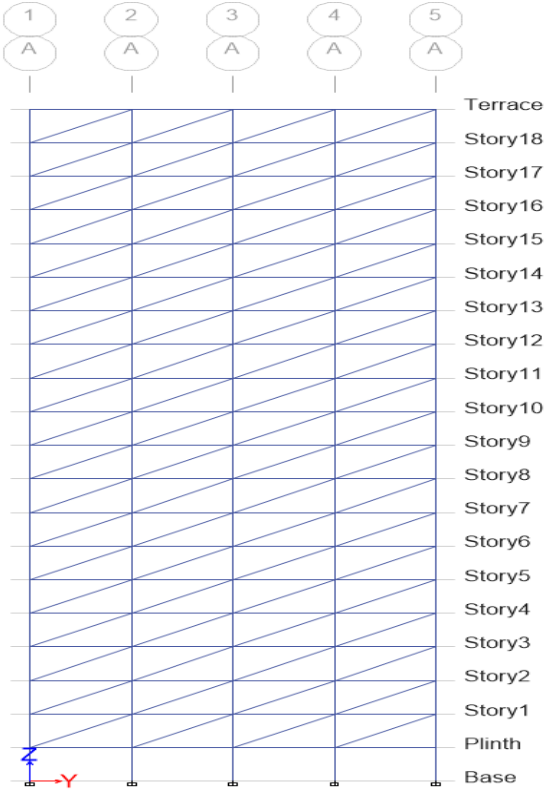

Fig -7: Structural Model with infill walls (Elevation-Y)

4. RESULTS AND DISCUSSION

4.1 Maximum Story Displacement:

4.1.1 Displacement due to vibrations in X-direction:

4.1.1.1 Displacement along X-axis:

- Load case: EQ+X
- Output type: Maximum
- Story Range: All Stories
- Top story: 20
- Bottom story: 0

The graph and the table below represents the maximum story displacement data in the X-direction for a 20-story asymmetric reinforced concrete building under the seismic load case EQ+X. It compares the lateral displacement behavior of the structure across all story levels for three different wall conditions: without infill walls (WI), with Autoclaved Aerated Concrete (AAC) infill walls, and with Burnt Clay Brick (BCB) infill walls.As expected, the displacement increases with building height for all three models, with the maximum displacement recorded at the 20th story. The bare frame without infill walls shows the highest displacements, reaching 13.988 mm at the top story, indicating reduced stiffness and increased flexibility. The inclusion of autoclaved aerated concrete blocks and burnt clay bricks infill walls significantly reduces the displacement values at each level, demonstrating their contribution to enhancing lateral stiffness. Burnt clay bricks infill walls slightly outperform autoclaved aerated concrete blocks in terms of displacement reduction at most stories, with the top story displacement being 13.345 mm for burnt clay bricks and 12.973 mm for autoclaved aerated concrete blocks.

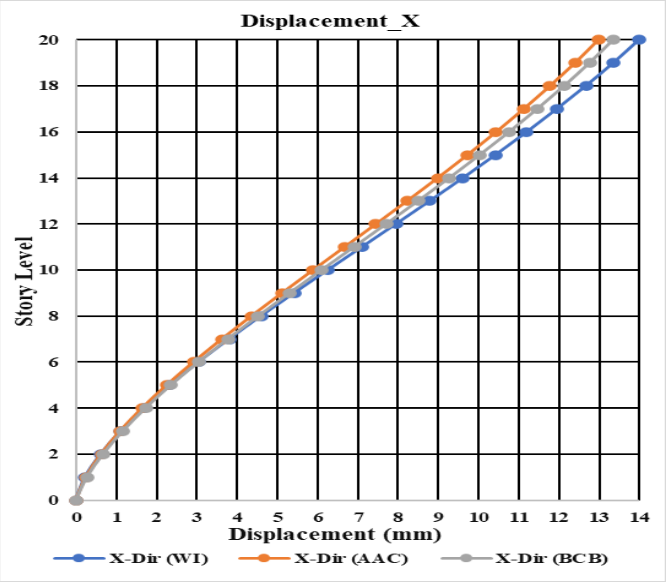

Chart -1: Story displacement along _X

Table -3: Story Response Values

Story	Elevation	X-Dir (WI)	X-Dir (AAC)	X-Dir (BCB)
	m	mm	mm	mm
20	60	13.988	12.973	13.345
19	57	13.35	12.395	12.758
18	54	12.667	11.775	12.127
17	51	11.95	11.122	11.461
16	48	11.2	10.437	10.761
15	45	10.421	9.723	10.031
14	42	9.615	8.984	9.275
13	39	8.789	8.224	8.497
12	36	7.949	7.451	7.705
11	33	7.102	6.67	6.904
10	30	6.255	5.889	6.102
9	27	5.416	5.115	5.306
8	24	4.595	4.355	4.525
7	21	3.8	3.619	3.768
6	18	3.042	2.915	3.043
5	15	2.332	2.252	2.359
4	12	1.682	1.642	1.729
3	9	1.104	1.096	1.162
2	6	0.613	0.626	0.673
1	3	0.227	0.246	0.272
0	0	0	0	0

4.1.1.2 Displacement along Y-axis:

- Load case: EQ+X
- Output type: Maximum
- Story Range: All Stories
- Top story: 20
- Bottom story: 0

The graph and the table provide the maximum story displacement in the Y-direction for a 20-story asymmetric reinforced concrete building subjected to the EQ+X seismic load case. It compares the structural performance under three different wall conditions: without infill walls (WI), with Autoclaved Aerated Concrete (AAC) block infill walls, and with Burnt Clay Brick (BCB) infill walls. As shown in the data, the displacement increases with the building height for all three configurations, with the maximum displacement occurring at the 20th story. The bare frame without infill walls shows the greatest displacement across all stories, peaking at 3.236 mm at the top, indicating lower stiffness and greater flexibility in the absence of infill walls. In contrast, the structures with infill walls exhibit significantly reduced displacements. At the same top level, the displacement for the autoclaved aerated concrete block model is 1.952 mm, and for the burnt clay brick model, it is 1.69 mm.

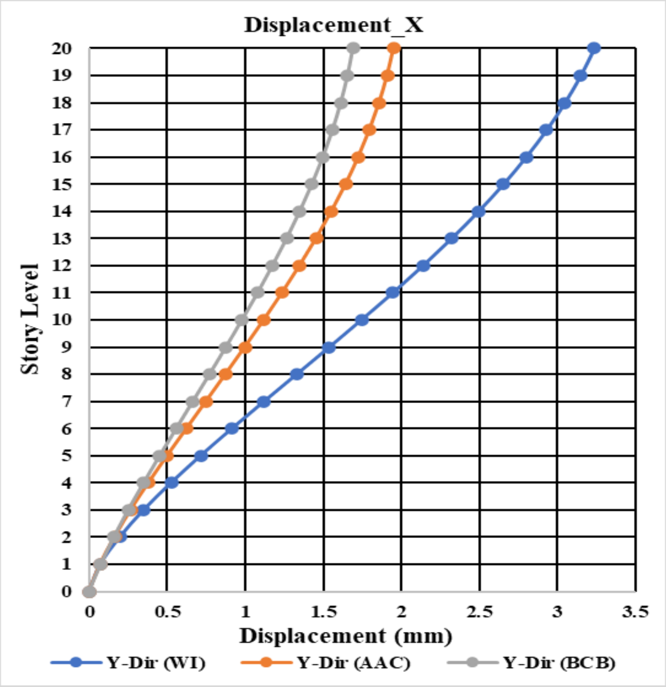

Chart -2: Story displacement along _Y

Table -4: Story Response Values

Story	Elevation	Y-Dir (WI)	Y-Dir (AAC)	Y-Dir (BCB)
	m	mm	mm	mm
20	60	3.236	1.952	1.69
19	57	3.149	1.911	1.656
18	54	3.047	1.86	1.612
17	51	2.931	1.798	1.56
16	48	2.799	1.726	1.498
15	45	2.654	1.645	1.428
14	42	2.494	1.554	1.35
13	39	2.321	1.455	1.266
12	36	2.138	1.349	1.175
11	33	1.945	1.237	1.08
10	30	1.744	1.12	0.98
9	27	1.538	0.998	0.877
8	24	1.329	0.874	0.772
7	21	1.12	0.749	0.665
6	18	0.914	0.624	0.559
5	15	0.714	0.5	0.453
4	12	0.524	0.38	0.35
3	9	0.349	0.266	0.251
2	6	0.196	0.162	0.159

1	3	0.072	0.07	0.075
0	0	0	0	0

4.1.2 Displacement due to vibrations in Y-direction:

4.1.2.1 Displacement along X-axis:

- Load case: EQ+Y
- Output type: Maximum
- Story Range: All Stories
- Top story: 20
- Bottom story: 0

The graph and the table below illustrate the maximum story displacement in the X-direction for a 20-story asymmetric reinforced concrete building under the seismic load case EQ+Y. It evaluates three structural conditions: a bare frame without infill walls (WI), a frame with Autoclaved Aerated Concrete (AAC) block infill walls, and a frame with Burnt Clay Brick (BCB) infill walls. The displacement progressively increases from the ground to the top story in all three cases, which is typical under lateral seismic loading. The bare frame without infill walls exhibits the highest displacement values throughout, reaching a maximum of 2.776 mm at the 20th story. The inclusion of infill walls, both autoclaved aerated concrete block and burnt clay brick, significantly reduces displacements at all levels. The autoclaved aerated concrete block wall configuration limits the top story displacement to 1.695 mm, while the burnt clay brick configuration shows the least displacement at 1.477 mm.

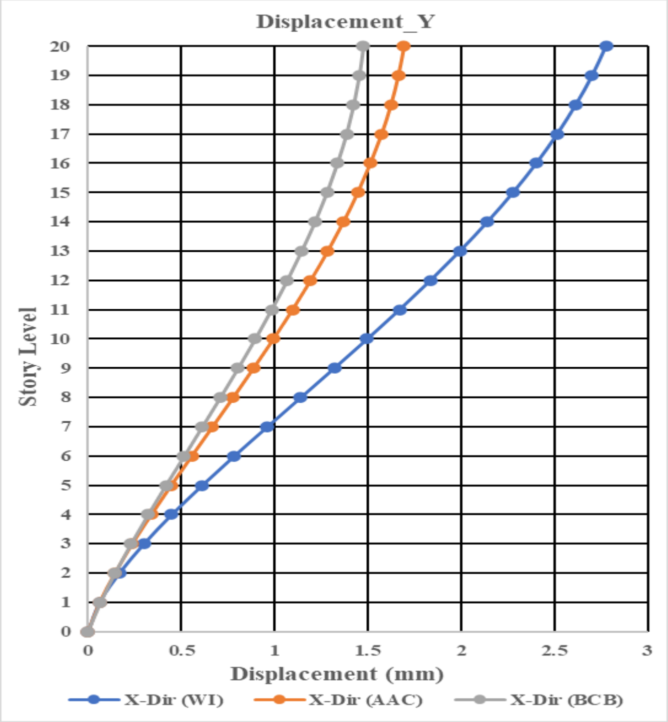

Chart -3: Story displacement along _X

Table -5: Story Response Values

Story	Elevation	X-Dir (WI)	X-Dir (AAC)	X-Dir (BCB)
	m	mm	mm	mm
20	60	2.776	1.695	1.477
19	57	2.702	1.664	1.455
18	54	2.614	1.624	1.425
17	51	2.514	1.574	1.386
16	48	2.402	1.514	1.337
15	45	2.277	1.446	1.281
14	42	2.14	1.369	1.217
13	39	1.992	1.285	1.145
12	36	1.835	1.193	1.068
11	33	1.669	1.096	0.984
10	30	1.497	0.994	0.897
9	27	1.32	0.887	0.805
8	24	1.141	0.778	0.71
7	21	0.962	0.667	0.613
6	18	0.784	0.556	0.516
5	15	0.613	0.446	0.418
4	12	0.449	0.339	0.323
3	9	0.3	0.237	0.231
2	6	0.168	0.144	0.145
1	3	0.062	0.062	0.067
0	0	0	0	0

4.1.2.2 Displacement along Y-axis:

- Load case: EQ+Y
- Output type: Maximum
- Story Range: All Stories
- Top story: 20
- Bottom story: 0

The graph and the table below summarize the maximum story displacement in the Y-direction for a 20-story asymmetric reinforced concrete building subjected to the EQ+Y seismic load case. It compares the building's displacement performance across all stories under three configurations: a bare frame without infill walls (WI), a frame with Autoclaved Aerated Concrete (AAC) block infill walls, and a frame with Burnt Clay Brick (BCB) infill walls. As the height of the building increases, the displacement in all three configurations rises progressively, with the highest displacement recorded at the top story (60 meters). The bare frame without infill walls shows the greatest lateral displacement, peaking at 13.977 mm, while the autoclaved aerated concrete blocks and burnt clay bricks infill walls reduce this to 12.879 mm and 13.344 mm, respectively. Although both infill types improve the seismic response, autoclaved aerated concrete blocks are more effective in reducing displacement in the Y-direction than burnt clay bricks in this particular case.

Chart -4: Story displacement along _Y

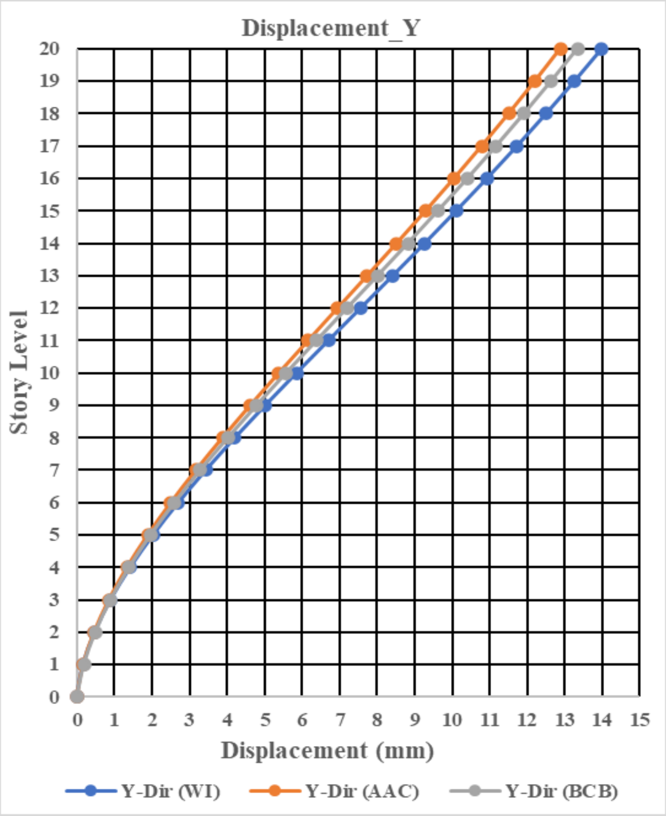

Table -6: Story Response Values

Story	Elevation	Y-Dir (WI)	Y-Dir (AAC)	Y-Dir (BCB)
	m	mm	mm	mm
20	60	13.977	12.879	13.344
19	57	13.249	12.203	12.643
18	54	12.496	11.506	11.92
17	51	11.72	10.789	11.176
16	48	10.921	10.051	10.411
15	45	10.101	9.294	9.627
14	42	9.263	8.522	8.828
13	39	8.414	7.74	8.018
12	36	7.557	6.952	7.202
11	33	6.7	6.166	6.388
10	30	5.851	5.387	5.582
9	27	5.017	4.623	4.792
8	24	4.208	3.883	4.026
7	21	3.433	3.174	3.293
6	18	2.703	2.507	2.603
5	15	2.029	1.89	1.966
4	12	1.422	1.335	1.393
3	9	0.898	0.855	0.896
2	6	0.472	0.462	0.489
1	3	0.161	0.169	0.186
0	0	0	0	0

4.2 Maximum Story Drift:

4.2.1 Drift due to vibrations in X-direction:

4.2.1.1 Drift along X-axis:

- Load case: EQ+X
- Output type: Maximum
- Story Range: All Stories
- Top story: 20
- Bottom story: 0

The graph and the table below illustrate the maximum story drift in the X-direction for a 20-story asymmetric reinforced concrete building subjected to seismic loading under the EQ+X load case. The analysis compares three structural configurations: a bare frame, a frame with Autoclaved Aerated Concrete (AAC) block infill walls, and a frame with Burnt Clay Brick (BCB) infill walls. The data shows that story drift values increase with height, reaching a peak between the 10th and 13th stories, and then gradually decreasing towards the top. This is consistent with typical seismic behaviour, where mid-height stories experience the highest inter-story deformations. Among the three configurations, the bare frame without infill walls consistently exhibits the highest drift values, indicating lower stiffness and greater lateral deformation. In contrast, the structures with autoclaved aerated concrete blocks and burnt clay bricks infill walls show reduced drift values, with burnt clay bricks generally performing slightly better than autoclaved aerated concrete blocks.

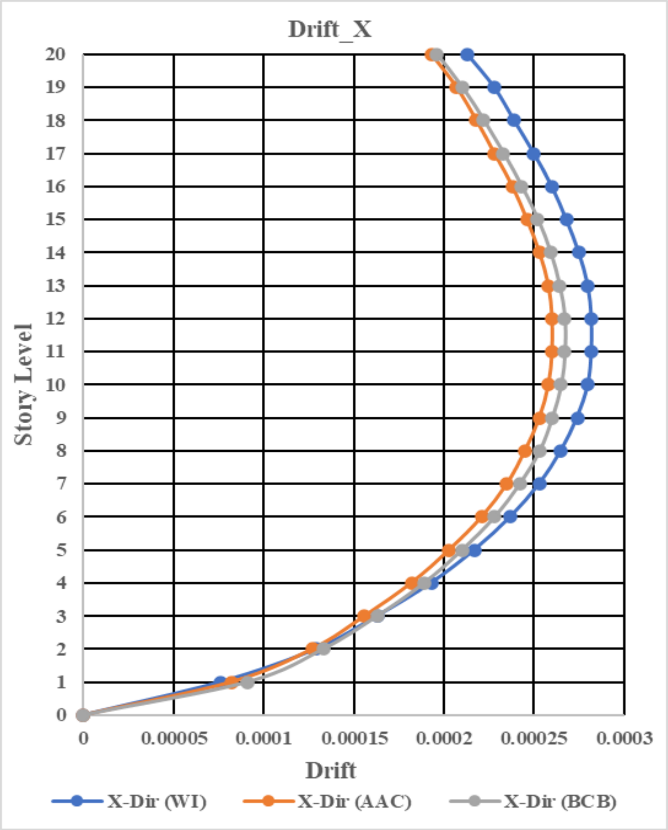

Chart -5: Story displacement along _X

Table -7: Story Response Values

Story	Elevation	X-Dir (WI)	X-Dir (AAC)	X-Dir (BCB)
	m			
20	60	0.000213	0.000193	0.000196
19	57	0.000228	0.000207	0.00021
18	54	0.000239	0.000218	0.000222
17	51	0.00025	0.000228	0.000233
16	48	0.00026	0.000238	0.000243
15	45	0.000268	0.000246	0.000252
14	42	0.000275	0.000253	0.000259
13	39	0.00028	0.000258	0.000264
12	36	0.000282	0.00026	0.000267
11	33	0.000282	0.00026	0.000267
10	30	0.00028	0.000258	0.000265
9	27	0.000274	0.000253	0.00026
8	24	0.000265	0.000245	0.000253
7	21	0.000253	0.000235	0.000242
6	18	0.000237	0.000221	0.000228
5	15	0.000217	0.000203	0.00021
4	12	0.000193	0.000182	0.000189
3	9	0.000163	0.000156	0.000163
2	6	0.000129	0.000127	0.000133
1	3	0.000076	0.000082	0.000091
0	0	0	0	0

4.2.1.2 Drift along Y-axis:

- Load case: EQ+X
- Output type: Maximum
- Story Range: All Stories
- Top story: 20
- Bottom story: 0

The graph and the table below represent the maximum story drift in the Y-direction for a 20-story asymmetric reinforced concrete building subjected to the EQ+X seismic load case. It evaluates the drift response for three structural conditions: a bare frame without infill walls (WI), a frame with Autoclaved Aerated Concrete (AAC) block infill walls, and a frame with Burnt Clay Brick (BCB) infill walls. The results indicate that drift values generally increase with height, peaking around the mid to upper stories, and then decreasing slightly towards the top. The bare frame without infill walls exhibits the highest drift values across all levels, reflecting its greater flexibility and lower lateral stiffness in the absence of infill walls. In comparison, autoclaved aerated concrete blocks and burnt clay bricks infill walls effectively reduce the story drifts at every level. Notably, burnt clay bricks walls provide slightly better performance than autoclaved aerated concrete blocks, especially in the mid-height region where drift is most critical.

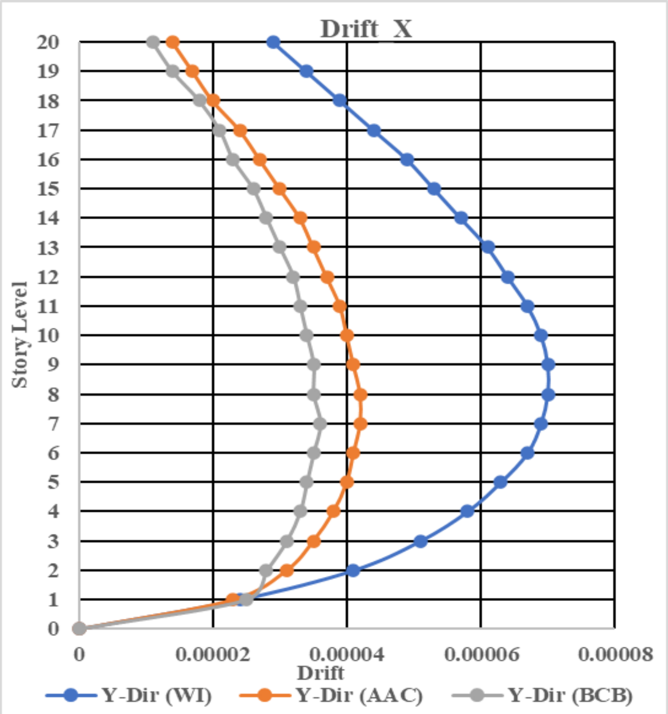

Chart -6: Story displacement along _Y

Table -8: Story Response Values

Story	Elevation	Y-Dir (WI)	Y-Dir (AAC)	Y-Dir (BCB)
	m			
20	60	0.000029	0.000014	0.000011
19	57	0.000034	0.000017	0.000014
18	54	0.000039	0.00002	0.000018
17	51	0.000044	0.000024	0.000021
16	48	0.000049	0.000027	0.000023
15	45	0.000053	0.00003	0.000026
14	42	0.000057	0.000033	0.000028
13	39	0.000061	0.000035	0.00003
12	36	0.000064	0.000037	0.000032
11	33	0.000067	0.000039	0.000033
10	30	0.000069	0.00004	0.000034
9	27	0.00007	0.000041	0.000035
8	24	0.00007	0.000042	0.000035
7	21	0.000069	0.000042	0.000036
6	18	0.000067	0.000041	0.000035
5	15	0.000063	0.00004	0.000034
4	12	0.000058	0.000038	0.000033
3	9	0.000051	0.000035	0.000031
2	6	0.000041	0.000031	0.000028
1	3	0.000024	0.000023	0.000025
0	0	0	0	0

4.2.2 Drift due to vibrations in Y-direction:

4.2.2.1 Drift along X-axis:

- Load case: EQ+Y
- Output type: Maximum
- Story Range: All Stories
- Top story: 20
- Bottom story: 0

The graph and the table below represent the maximum story drift in the X-direction for a 20-story asymmetric reinforced concrete building subjected to the EQ+Y seismic load case. It compares three structural configurations: a bare frame without infill walls (WI), a frame with Autoclaved Aerated Concrete (AAC) block infill walls, and a frame with Burnt Clay Brick (BCB) infill walls. The results show that story drift increases gradually with building height, peaking in the mid to upper levels before slightly tapering off near the top. The bare frame (WI) consistently exhibits the highest drift values, indicating greater lateral flexibility and lower stiffness. For example, the maximum drift for the without infill walls case reaches 0.00006 at the 8th and 9th stories. In contrast, the autoclaved aerated concrete block and burnt clay brick infill walls. The results show that story drift increases infill wall configurations significantly reduce these values, with autoclaved aerated concrete block showing a maximum of 0.000037 and burnt clay brick even lower at 0.000033 in the same stories. Across all levels, the burnt clay brick infill walls perform slightly better than autoclaved aerated concrete block, offering greater resistance to lateral deformation. This is likely due to the higher density and stiffness of BCB compared to autoclaved aerated concrete block. The consistent reduction in drift for the infill wall models highlights their contribution to improving seismic performance by enhancing lateral stiffness and reducing inter-story movement. Overall, the data underscores the importance of incorporating infill walls in seismic design, particularly in tall buildings where drift control is critical for structural integrity and occupant safety.

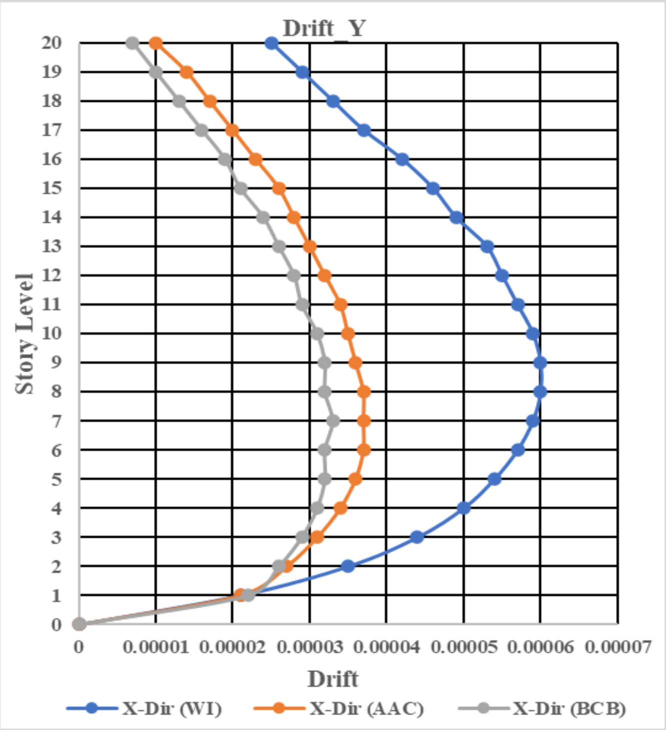

Chart -7: Story displacement along _X

Table -9: Story Response Values

Story	Elevation	X-Dir (WI)	X-Dir (AAC)	X-Dir (BCB)
	m			
20	60	0.000025	0.00001	0.000007
19	57	0.000029	0.000014	0.00001
18	54	0.000033	0.000017	0.000013
17	51	0.000037	0.00002	0.000016
16	48	0.000042	0.000023	0.000019
15	45	0.000046	0.000026	0.000021

14	42	0.000049	0.000028	0.000024
13	39	0.000053	0.00003	0.000026
12	36	0.000055	0.000032	0.000028
11	33	0.000057	0.000034	0.000029
10	30	0.000059	0.000035	0.000031
9	27	0.00006	0.000036	0.000032
8	24	0.00006	0.000037	0.000032
7	21	0.000059	0.000037	0.000033
6	18	0.000057	0.000037	0.000032
5	15	0.000054	0.000036	0.000032
4	12	0.00005	0.000034	0.000031
3	9	0.000044	0.000031	0.000029
2	6	0.000035	0.000027	0.000026
1	3	0.000021	0.000021	0.000022
0	0	0	0	0

4.2.2.2 Drift along Y-axis:

- Load case: EQ+Y
- Output type: Maximum
- Story Range: All Stories
- Top story: 20
- Bottom story: 0

The graph and the table below show the maximum story drift in the Y-direction for a 20-story asymmetric reinforced concrete building under the EQ+Y seismic load case. It compares three configurations: a bare frame without infill walls (WI), a frame with Autoclaved Aerated Concrete (AAC) block infill walls, and one with Burnt Clay Brick (BCB) infill walls. Drift values increase with height, peaking at the 13th story (39 m), where the bare frame reaches 0.000286. Autoclaved aerated concrete block and burnt clay brick reduce this drift to 0.000263 and 0.000272, respectively. The bare frame shows the highest drifts, indicating greater flexibility and lower stiffness. Infill walls significantly reduce drift, with autoclaved aerated concrete block performing slightly better than burnt clay brick in most stories. This highlights the importance of infill walls in enhancing structural stiffness and minimizing deformation. Incorporating Autoclaved aerated concrete block or burnt clay brick in seismic design improves the lateral performance of high-rise buildings and ensures better compliance with seismic safety standards.

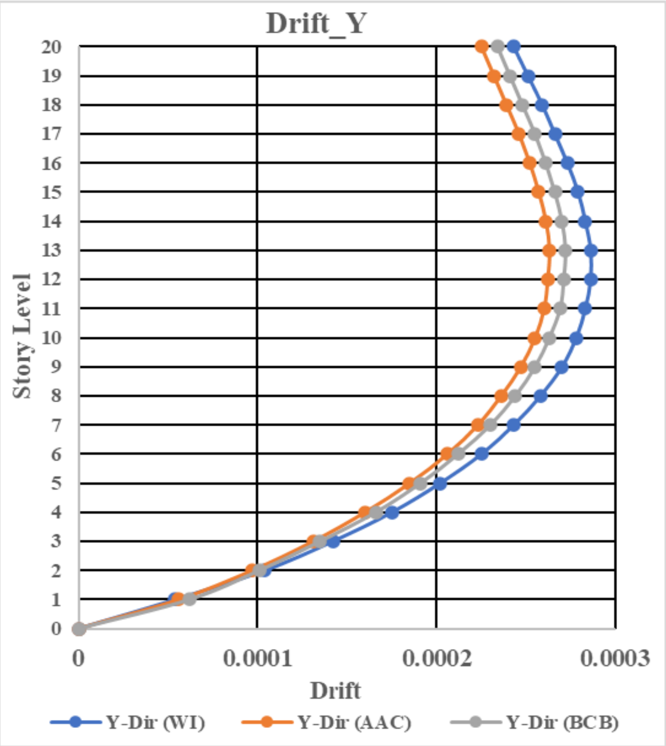

Chart -8: Story displacement along _X

Table -10: Story Response Values

Story	Elevation	Y-Dir (WI)	Y-Dir (AAC)	Y-Dir (BCB)
	m			
20	60	0.000243	0.000225	0.000234
19	57	0.000251	0.000232	0.000241
18	54	0.000259	0.000239	0.000248
17	51	0.000266	0.000246	0.000255
16	48	0.000273	0.000252	0.000261
15	45	0.000279	0.000257	0.000266
14	42	0.000283	0.000261	0.00027
13	39	0.000286	0.000263	0.000272
12	36	0.000286	0.000262	0.000271
11	33	0.000283	0.00026	0.000269
10	30	0.000278	0.000255	0.000263
9	27	0.00027	0.000247	0.000255
8	24	0.000258	0.000236	0.000244
7	21	0.000243	0.000223	0.00023
6	18	0.000225	0.000206	0.000212
5	15	0.000202	0.000185	0.000191
4	12	0.000175	0.00016	0.000166
3	9	0.000142	0.000131	0.000135
2	6	0.000104	0.000097	0.000101
1	3	0.000054	0.000056	0.000062
0	0	0	0	0

5. CONCLUSION

Based on the comprehensive seismic analysis of the 20-story asymmetric reinforced concrete building, the following conclusions can be drawn regarding the structural performance of the building with and without infill walls:

- Based on the story displacement data under seismic waves vibrating in X direction for both X and Y directions, it is evident that the presence of infill walls significantly reduces lateral displacement across all stories. In the X-direction, the top story displacement is highest for without infill at 13.988 mm, followed by burnt clay bricks at 13.345 mm, and lowest for autoclaved aerated blocks at 12.973 mm. This translates to a 7.26% reduction for autoclaved aerated blocks and 4.60% for burnt clay bricks when compared to without infill. Similarly, in the Y-direction, without infill shows a top displacement of 3.236 mm, while burnt clay bricks and autoclaved aerated blocks reduce it to 1.69 mm and 1.952 mm, representing a 47.76% reduction for burnt clay bricks and 39.68% for autoclaved aerated blocks. These findings highlight that while autoclaved aerated blocks provide the most consistent reduction across both directions due to their favorable stiffness-to-weight ratio, energy absorption, and lighter mass, burnt clay bricks perform even better in the Y-direction due to their higher stiffness despite their heavier weight. Overall, both infill types greatly enhance the building's lateral performance, but autoclaved aerated blocks are more effective in balancing stiffness and mass. These reductions highlight the vital role that infill walls play in improving seismic response by increasing lateral stiffness and reducing story drift. While material properties of the infill can influence the extent of improvement, the overall conclusion is clear structures with infill walls perform substantially better under seismic loading than bare frames, resulting in safer, more resilient buildings.
- Examining the structural response under seismic waves vibrating in Y direction reveals a notable impact of infill walls on reducing lateral displacements across both directions. In the X-direction, the maximum displacement at the top story is 2.776 mm for the structure without infill, which reduces to 1.695 mm with autoclaved aerated concrete and 1.477 mm with burnt clay bricks. This corresponds to a reduction of approximately 38.93% with autoclaved aerated concrete and 46.80% with burnt clay bricks compared to the bare frame. In the Y-direction, the top story displacement is 13.977 mm without infill, which reduces to 12.879 mm with autoclaved aerated concrete and 13.344 mm with burnt clay bricks, resulting in reductions of 7.84% and 4.53%, respectively. These results show that infill walls considerably enhance structural performance under seismic excitation, especially in the orthogonal direction (X-direction in this case), where the stiffness contribution is more pronounced. While both types of infill offer improved resistance, the key conclusion is that structures with infill walls experience substantially lower displacements than those without, underscoring the critical role of infill in enhancing seismic resilience.
- Analyzing the structural drift behavior under seismic waves vibrating in X direction reveals the important contribution of infill walls in controlling lateral deformations. In the X-direction, the maximum story drift for the structure without infill is 0.000282, which reduces to 0.00026 with autoclaved aerated concrete and 0.000267 with burnt clay bricks, resulting in a drift reduction of approximately 7.80% and 5.32%, respectively. In the Y-direction, the maximum drift without infill is 0.00007, which significantly drops to 0.000042 with autoclaved aerated concrete and 0.000036 with burnt clay bricks a substantial reduction of 40.00% and 48.57%, respectively. These results confirm that infill walls enhance lateral stiffness and effectively limit story drift, particularly in the orthogonal direction (Y-direction in this case), where the reduction is more pronounced. While both AAC and BCB show beneficial effects, the broader conclusion is that the inclusion of infill walls significantly improves drift performance, making the structure safer and more reliable during seismic excitation.
- The behavior of the structure under seismic waves vibrating in Y direction highlights the effectiveness of infill walls in reducing story drift across both principal directions. In the X-direction, the maximum story drift for the structure without infill is 0.00006, which decreases to 0.000037 with autoclaved aerated concrete and 0.000033 with burnt clay bricks. This corresponds to a percentage reduction of approximately 38.33% and 45.00%, respectively. In the Y-direction, the peak drift value without infill is 0.000286, which drops to 0.000263 with autoclaved aerated concrete and 0.000272 with burnt clay bricks, indicating a reduction of 8.04% and 4.90%, respectively. These findings emphasize the critical role of infill walls in controlling lateral deformation, especially in the orthogonal (X) direction where their contribution to stiffness is more significant. While both infill types enhance seismic performance, the broader conclusion remains that structures with infill walls demonstrate markedly better drift control compared to bare frames, ultimately leading to improved resilience and safety during seismic events.

The seismic performance assessment of asymmetric high-rise reinforced concrete (RC) buildings with and without infill walls clearly demonstrates that infill walls play a pivotal role in enhancing structural behavior during seismic events. Across all cases of seismic waves propagating in both X and Y directions, the presence of infill walls significantly reduced story displacement and drift values when compared to bare frames. Notably, the reductions were more pronounced in the direction orthogonal to the wave propagation, confirming the stiffening effect of infill walls across the frame. These results underline the substantial contribution of infill walls to lateral stiffness and seismic resistance. Overall, structures with infill walls consistently outperformed those without, showing improved stability, reduced deformation, and enhanced resilience. Therefore, incorporating infill walls in structural modeling and seismic design is essential for achieving safer and more reliable performance of high-rise RC buildings under earthquake loading.

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