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Seismic Response of Open Ground Story Reinforced Concrete Buildings, Considering with Soil-Structure Interaction

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Abstract
This study investigates the seismic behavior of open-ground story (OGS) reinforced concrete buildings with soil-structure interaction (SSI) using SAP2000. The study mainly focused on mid-rise (8-storey) and low-rise (4-storey) OGS buildings, incorporating different masonry infill materials such as brick, concrete blocks, and autoclaved aerated concrete (AAC) blocks. Selected ground motions from the Bhuj, El Centro, and Chi-Chi earthquakes were utilized to simulate varying seismic intensities and frequency content. Critical parameters such as top-story displacement and inter-story drift are analyzed to assess the structural safety and serviceability of RC buildings. The results demonstrate that both OGS coupled with SSI and masonry infill type significantly affect the displacement and drift, with mid-rise buildings showing more pronounced impacts. Furthermore, ground motion characteristics are critical in producing different response patterns. The study highlights the importance of considering SSI, infill materials, and ground motion characteristics in the design of OGS buildings to enhance earthquake resilience and reduce seismic damage.
Keywords: *Soil-Structure Interaction, Open-Ground Storey, Masonry Infill Walls, Ground Motion Characteristics.*

1. Introduction
In recent years, growing concern has emerged over the seismic performance of buildings due to the devastating impact of earthquakes on structures and human lives. Among various building types, Open Ground Story (OGS) Reinforced Concrete (RC) buildings, also known as "soft-story" structures, have shown particular vulnerability during seismic events. These buildings typically feature an open ground floor, often used for parking or commercial purposes, while the upper floors remain enclosed. Although this architectural design offers practical advantages, it introduces significant stiffness and mass distribution irregularities across the building height, resulting in poor seismic performance. The soft-story behaviour leads to concentrated deformation at the ground level, making these structures highly susceptible to earthquake collapse (Murty, Jain, Sheth, & Jaiswal, 2006). Further complicating the seismic response analysis is the role of Soil-Structure Interaction (SSI). While many building designs assume a fixed-base condition where the foundation is rigidly connected to the ground, real-world scenarios involve soil flexibility, which can significantly alter a structure’s dynamic behaviour. The interaction between the soil and structure influences both the natural frequency and vibration amplitude, which makes accounting for (Mishra & samanta, 2023) SSI effects critical, especially in OGS RC buildings. Here, the combination of structural irregularities and soil flexibility can lead to unpredictable and unsafe responses (Wolf, (1985)). Despite increasing awareness, limited research has been conducted on the seismic response of OGS RC buildings in conjunction with SSI. This study aims to address this gap by evaluating the seismic performance of these buildings with different masonry infill materials while incorporating SSI effects, with the ultimate goal of providing more accurate design recommendations for earthquake-prone areas. [1]

1.1. Masonry Infill Walls
The increasing frequency and intensity of seismic events necessitate a comprehensive understanding of the seismic response of structures, particularly those

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with open-ground stories. Open-ground stories reinforced concrete buildings are commonly employed in areas where vehicular access is prioritised, yet this design introduces vulnerabilities during seismic activities (Basu, Maiti, & Bhowmik, 2013). The absence of lateral support in the ground story can lead to significant deformation and potential collapse under seismic loads (Mondal & Tesfamarian,, 2013). Incorporating masonry infill walls can influence the overall behaviour of these buildings, acting as a critical factor in their seismic performance. Various types of infill walls—such as brick, concrete blocks, and autoclaved aerated concrete (AAC) blocks—exhibit distinct mechanical properties and bonding characteristics, which can alter the dynamic response of the structure (Borsaikia, Dutta,, & Deb, 2021). The interaction between the building and the underlying soil, known as soil-structure interaction (SSI), further complicates this relationship, as the flexibility and composition of the soil can significantly affect the seismic performance of the entire system (Wijaya, Rajeev, & Gad, 2020). This research analyses the seismic response of open ground storey reinforced concrete buildings with different masonry infill types under soil-structure interaction. The findings will contribute to a deeper understanding of how various infill materials can mitigate or exacerbate seismic risks, ultimately guiding more resilient architectural and engineering practices in earthquake-prone regions. [2-6]

2. Methodology

2.1. Structural Model Details

Table 1 Building Description

Particular	RCC Structure
Plan and Dimension	15 X 15 m
Height of Each Floor	3 m
Number of Stories	G+4 and G+8
Type of Building	RCC Building
Grade of Concrete	M30
Grade of Reinforcing Steel	Fe 550
Column Dimension	300 x 450 mm
Beam Dimension	300 x 400 mm
Slab Dimension	150 mm

The RCC structure is designed with a plan dimension of 15 x 15 meters, featuring a height of 3 meters per floor. It consists of two variations: one with G+4 storeys and the other with G+8 storeys. The building is constructed using M30 grade concrete and Fe 550 grade reinforcing steel, ensuring strength and durability. The columns have a dimension of 300 x 450 mm, while the beams are sized at 300 x 400 mm. The slabs are designed to be 150 mm thick. This configuration supports a robust structural framework suitable for various applications, providing a stable environment for occupants. The choice of materials and dimensions reflects compliance with modern construction standards. [7-11] (Refer Table 1, Table 2)

2.2. Infill Wall Diagonal Strut

Later Stafford Smith and Carter (1969) proposed a theoretical relation for the width of the diagonal strut based on the relative stiffness of infill and frame.

$$\alpha h = \sqrt[4]{\frac{E_{m\,.\,t}\ \sin 2\theta}{4.E_f.I_c.h_{inf}}}$$

- E_f = modules of Elasticity of frame
- E_m= Modulus of Elasticity of masonry infill
- t = Thickness of infill wall
- h_{inf}= Height of infill wall
- I_c=Moment of Inertia of Column

Where t, Hy, and E are the thickness, the height and the modulus of the infill, respectively, is the angle between the diagonal of the infill and the horizontal, E is the modulus of elasticity of the column, I is the moment of inertia of the columns, H is the

Table 2 Diagonal Strut Thickness

Materials	Thickness (mm)
Autoclaved Aerated Blocks (AAC)	480
Burnt Brick (BB)	590
Concrete Block (CB)	460

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Figure 1 shows Plan for G+4 and G+8, Figure 2 shows 3D View and Elevation of G+4, Figure 3 shows 3D View and Elevation of G+8.

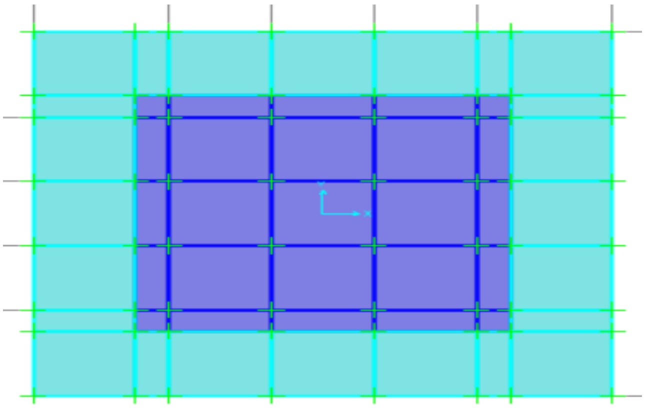

Figure 1 Plan for G+4 and G+8

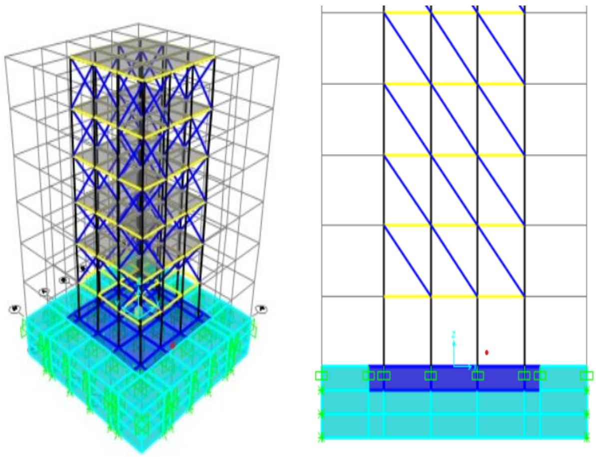

Figure 2 3D View and Elevation of G+4

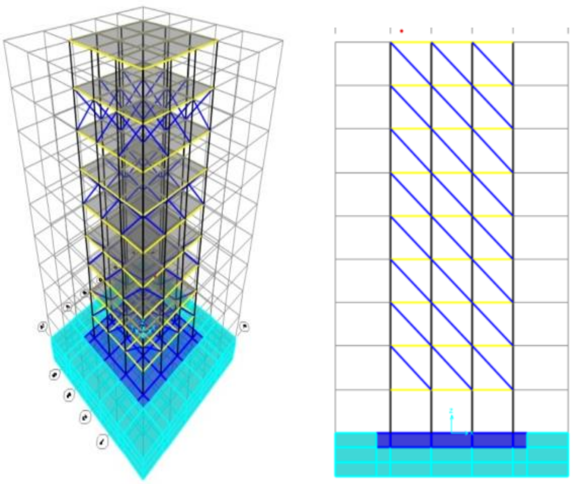

Figure 3 3D View and Elevation of G+8

3. Results and Discussion

3.1. Results

3.1.1. G+4 Story Displacement

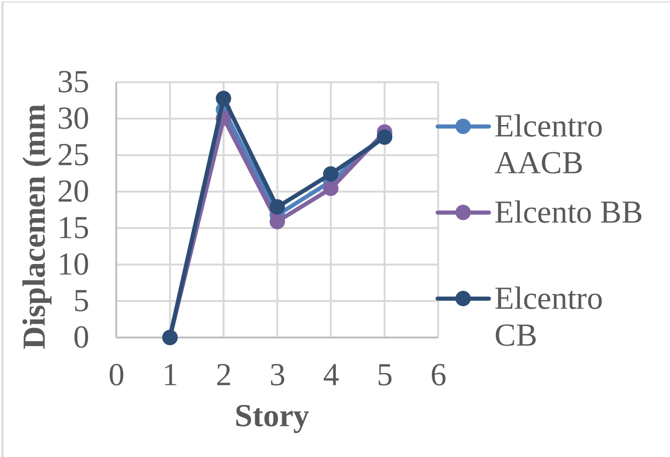

Figure 4 Story Level Versus Story Displacement-Elcentro

In figure 4, the graph shows that concrete block (CB) has the highest displacement at 32.78 mm, while Burnt brick (BB) and Autoclaved aerated concrete block (AACB) exhibit more moderate and closely aligned displacements.

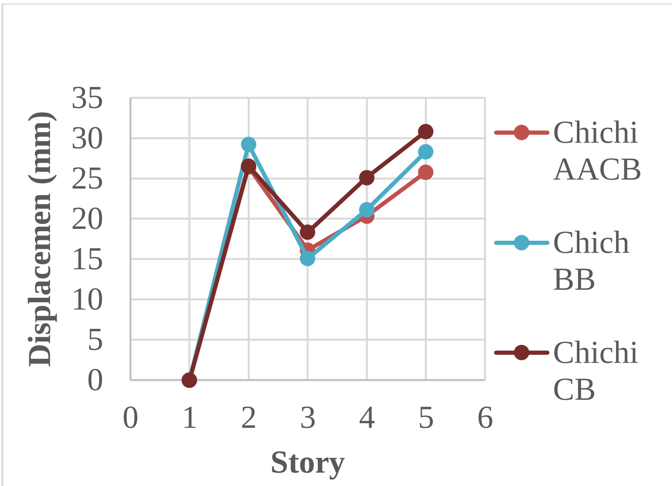

Figure 5 Story Level Versus Story Displacement-Chichi

In figure 5, the graph shows that Burnt brick (BB) has the highest displacement of 29.23 mm, while concrete block (CB) and Autoclaved aerated concrete block (AACB) exhibit more moderate and closely aligned displacements.

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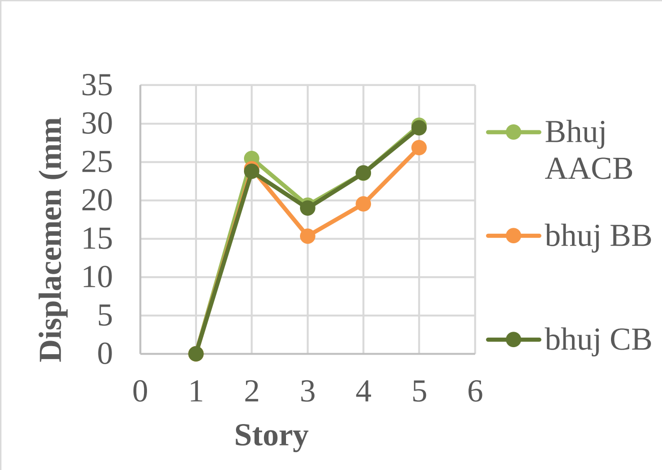

Figure 6 **Story Level Versus Story Displacement-Bhuj**

In Figure 6, the graph shows that Autoclaved aerated concrete blocks (AACB) have the highest displacement of 25.45 mm, while Burnt brick (BB) and concrete blocks (CB) exhibit more moderate and closely aligned displacements.

3.1.2. G+8 Building Story Displacement

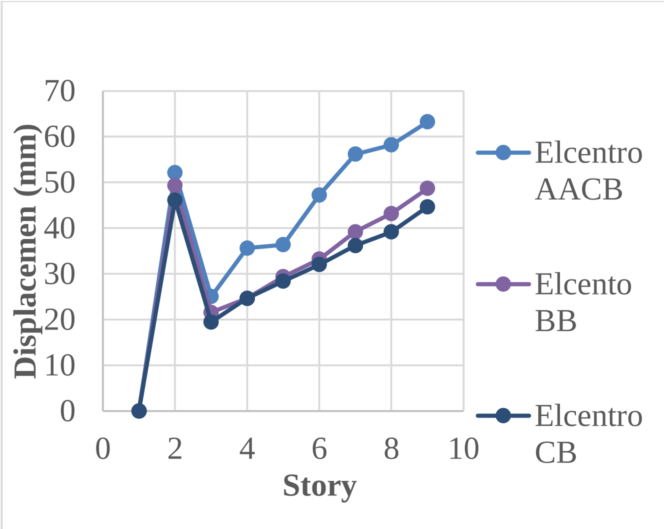

Figure 7 **Story Level Versus Story Displacement-Elcentro**

In figure 7, the graph shows that Autoclaved aerated concrete block (AACB) has the highest displacement across all stories, peaking at 63.24 mm at the top story, while Burnt brick (BB) and concrete block (CB) exhibit slightly lower but similar trends.

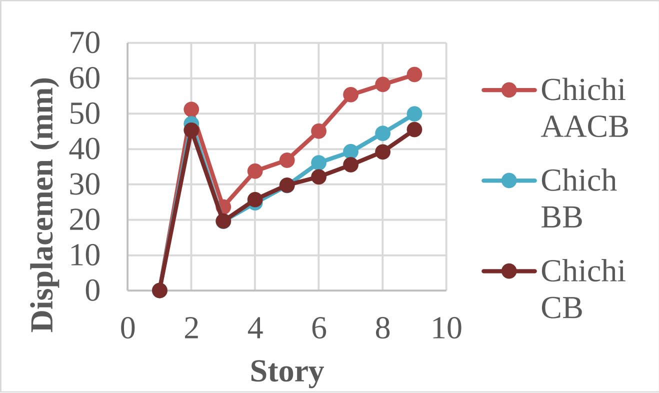

Figure 8 **Story Level Versus Story Displacement-Chichi**

In Figure 8, the graph shows that Autoclaved aerated concrete block (AACB) results in the highest displacement of 61.02 mm, while Burnt brick (BB) and Concrete block (CB) follow similar but slightly lower displacement patterns across all stories.

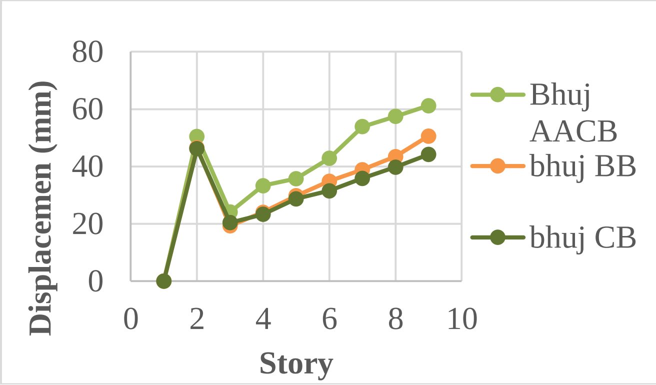

Figure 9 **Story Level Versus Story Displacement-Bhuj**

In Figure 9, the graph shows that Autoclaved aerated concrete block (AACB) has the highest displacement of 61.22 mm, while Burnt brick (BB) and concrete block (CB) exhibit more moderate and closely aligned displacement.

3.1.3. G+4 Building Inter Story Drift

In Figure 10, the graph shows that Burnt brick (BB) results in the highest drift ratio of 0.1039 %, while autoclaved aerated concrete block (AACB and Concrete block (CB) follow similar but slightly lower drift ratio patterns across all stories.

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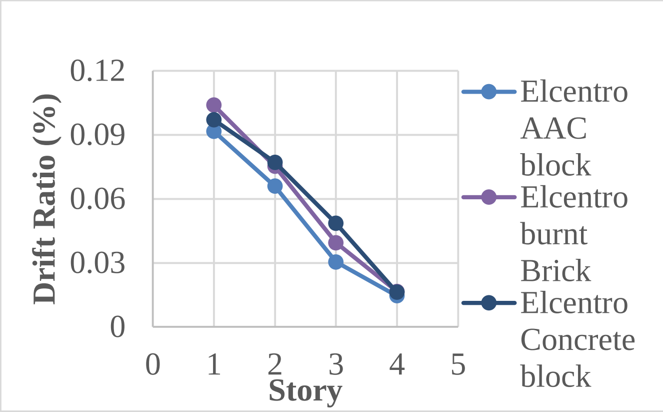

Figure 10 **Inter Story Drift Ratio G+4-Elcentro**

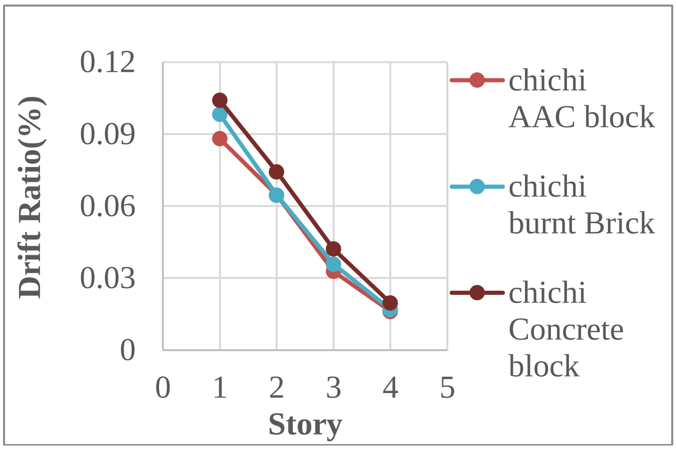

Figure 11 **Inter Story Drift Ratio G+4- Chichi**

In Figure 11, the graph shows that Concrete block (CB) results in the highest drift ratio of 0.1041 %, while autoclaved aerated concrete block (AACB) and Burnt brick (BB) follow similar but slightly lower drift ratio patterns across all stories.

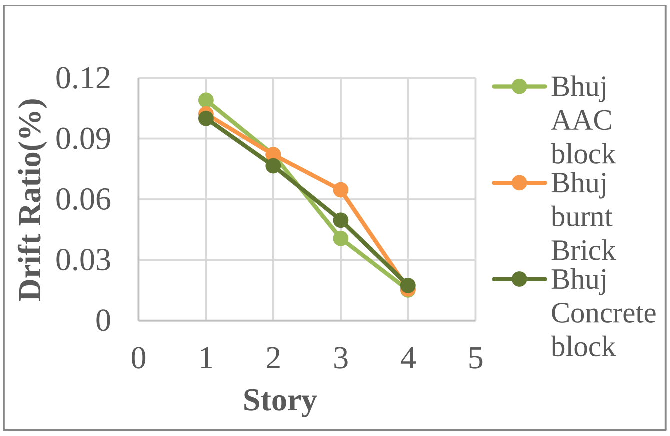

Figure 12 **Inter Story Drift Ratio G+4-Bhuj**

In Figure 12, the graph shows that autoclaved aerated concrete block (AACB) results in the highest drift ratio of 0.1091 %, while concrete block (CB) and Burnt brick (BB) follow similar but slightly lower drift ratio patterns across all stories.

3.1.4. G+8 Building Inter Story Drift

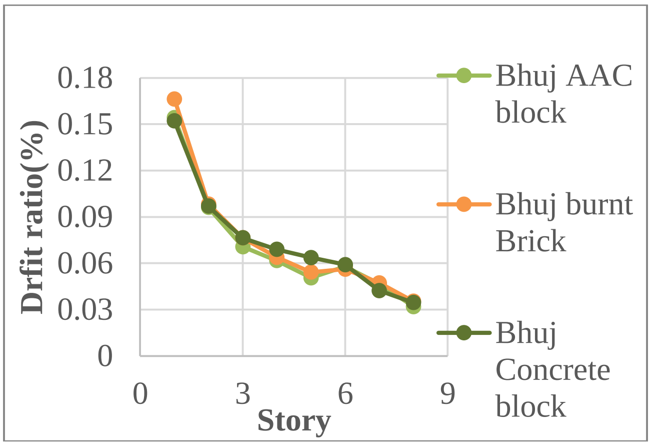

Figure 13 **Inter Story Drift Ratio G+8-Bhuj**

In Figure 13, the graph shows that Burnt brick (BB) results in the highest drift ratio of 0.1663 %, while concrete block (CB) and autoclaved aerated concrete block (AACB) follow similar but slightly lower drift ratio patterns across all stories.

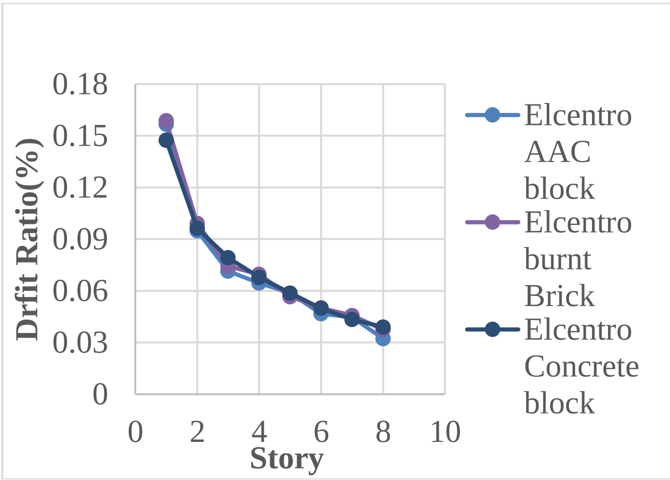

Figure 14 **Inter Story Drift Ratio G+8-Elcentro**

In Figure 14, the graph shows that autoclaved aerated concrete block (AACB) results in the highest drift ratio of 0.1567 %, while concrete block (CB) and Burnt brick (BB) follow similar but slightly lower drift ratio patterns across all stories.

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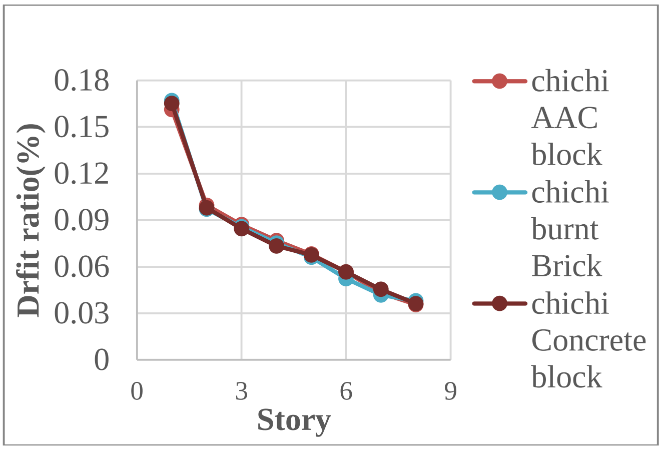

Figure 15 Inter Story Drift Ratio G+8-Chichi

In Figure 15, the graph shows that Burnt brick (BB) autoclaved aerated concrete block (AACB) results in the highest drift ratio of 0.1671 %, while concrete block (CB) and autoclaved aerated concrete block (AACB) follow similar but slightly lower drift ratio patterns across all stories. [12-16]

3.2. Discussion

The displacement patterns for different wall materials indicate that Autoclaved Aerated Concrete Block (AACB) consistently shows the highest displacements, especially in figures 7-9, which peaks above 61 mm across stories. Concrete Block (CB) and Burnt Brick (BB) generally exhibit lower and closely aligned displacements, with slight variations across different figures. These findings suggest that AACB, while advantageous in weight and insulation, may require additional structural considerations due to its higher displacement behaviour under loads. Burnt Brick and Concrete Block show more stable but similar performance in terms of displacement. The drift ratio patterns across the figures reveal that Autoclaved Aerated Concrete Block (AACB), Burnt Brick (BB), and Concrete Block (CB) exhibit varying dominance in different scenarios, with each material peaking at different times. AACB generally shows higher drift ratios in figures 12 and 14, while BB leads in figures 10 and 12. CB occasionally shows the highest drift ratio, indicating that no single material consistently outperforms the others. This variation suggests that all three materials respond differently under different conditions, requiring tailored design approaches for structural stability. [17-20]

Conclusion

The displacement patterns for the G+4 building (Figures 4 to 6) show that Concrete block (CB), Burnt brick (BB), and Autoclaved aerated concrete block (AACB) alternate in dominance, each having the highest displacement in different figures. In contrast, the G+8 building (figures 7 to 9) consistently shows AACB with the highest displacement, reaching 61-63 mm, suggesting greater deformation under load compared to BB and CB. Drift ratio patterns for the G+4 building (figures 10 to 12) highlight BB, CB, and AACB as having the highest ratios in separate instances. For the G+8 building (figures 12, 14, and 15), BB again shows the highest drift ratio of 0.1663%, with AACB closely following at 0.1567%. Overall, BB and AACB exhibit higher drift ratios than CB across both building types.

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