Horizontal displacement of high-rise buildings with and without basement shear walls

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Abstract: Without rigid basement shear walls, high-rise buildings will be weaker, especially when subjected to earthquakes, water, and ground pressure. Designing a basement-filled building increases its rigidity. Research must also analyze basements without shear walls in some buildings. In this paper, the author analyzes the modeling of high-rise buildings and the impact of solid basement shear walls on the top displacement of the building. The study compares buildings with and without solid basement shear walls, considering both the same basement height and different basement heights. The research investigated the performance of the structural system, specifically focusing on the horizontal displacement at the top. Additionally, a numerical analysis was conducted using Etabs software to determine the bending moment, shear force, and axial force at the base of the column. This analysis was performed for a pair of cases: one with shear walls in the basement and another without. Furthermore, the study also considered differences in the height of the basement.

Keywords: basement wall, high-rise building, displacement, rigid walls, modeling

1. Introduction

Exploiting and making efficient use of underground space in cities is a natural part of urban growth. Underground structures, such as subways, parking lots, and other underground systems, are affected by the same things that happen to structures that are above ground. They are also affected by the environment around them, which can be bad for them—subsidence, damage, destruction, or making construction unsafe, which slows down or stops the work.

The study of the basement changes the calculations for high-rise buildings compared to similar high-rise buildings with basements that change in height and the structure of the basement when determining how to fight wind, earthquakes, and other loads.

Three main types of internal forces can appear in a building when there is a horizontal load: bending moment, horizontal shear force, and torsional moment (when the horizontal load is at an angle to the rigid center of the building). Before we can set it up correctly, we need to see how the objects are affected by forces inside them.

Look at the stiffness and cross-section of basement wall structures to choose a type of structure and cross-section that makes reason and works well. The way to build basement wall structures that work for all kinds of projects has been studied and explained by Vuong (2015), Nghia (2015), Minh (2015), Tan (2015), Khanh (2015), Thanh (2016) and Tung (2019). Additionally, Chen and Zhang (2005) wrote about dynamic calculation models of high-rise building designs with basements and looked at how basements affect high-rise buildings around the world. Tunc and Khayyat conducted a study on the dynamic behavior of basement rigid walls (Tunc and Khayyat, 2015). Ahmad and Riaz investigated the impact of geology on high-rise buildings with basements (Ahmad and Riaz, 2020). Chen et al. (2023) proposed a basement design to minimize vibration in high-rise buildings Lee and Kim (2001) developed a seismic analysis method for high-rise buildings that takes into consideration the presence of a basement. Tehranizadeh and Barkhordari (2018) examined the influence of peripheral wall openings in the basement and the number of basement floors on the base floor of a braced frame pipe system. In recent decades, civil engineering structures such as high-rise buildings have been increasing in size and becoming thinner. These structures are often exposed to significant dynamic loads, such as strong winds and earthquakes, over their lifespan. Harsh conditions have the potential to cause structural deterioration. Chen and his colleagues have conducted numerous studies on the displacement effects in high-rise buildings. One notable study is their research on the vision-based displacement testing method for shaking table testing of high-rise buildings (Chen et al., 2015).

Zhang et al. (2023) introduced the dynamic deformation laws of super high-rise buildings and visualization using GB-RAR and LiDAR technology. Zhou et al. (2022) studied the estimation of horizontal displacement in high-rise buildings by...

However, there are many unresolved topics related to the horizontal displacement of tall buildings, particularly those with or without shear walls in the basement, which necessitate further investigation. This paper examines the impact of shear walls in the basement of high-rise buildings on the horizontal displacement of these structures. The study specifically compared the effects of basements with shear walls to those without shear walls in six different case studies. The basement has shear walls that are 2.8 meters, 3.0 meters, and 3.2 meters in height. There are no shear walls in the basement with heights of 2.8 meters, 3.0 meters, and 3.2 meters.

2. Materials and Methods

The building consists of 16 floors and 1 basement. Each floor has a height of 3.6 meters. However, please note that the height of the basement is subject to change. The brick wall is constructed using beams and has a thickness of 0.2 meters. The dead load of the layers on the floor is 1.5 kN/m². The floor live load is 2.4 kN/m², while the roof floor live load is 0.9 kN/m². The brick wall has a dead load of 10.5 kN/m² on the beam. The dimensions of the different sections are as follows: the floor has a thickness of 0.15 m, the beam has dimensions of 0.3 m by 0.6 m, and the rigid wall is 0.2 m thick. The structure consists of a reinforced concrete frame utilizing Grade B25 concrete and AII steel group. Vietnamese standards such as TCVN 5574:2018 “Design of concrete and reinforced concrete structures” and TCVN 2737:2023 “Loads and actions” included in this study.

The column sizes of the stories are given in Table 1.

<table>
<thead>
<tr>
<th>Stories</th>
<th>Sizes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base ÷ Story 3</td>
<td>800×800</td>
</tr>
<tr>
<td>Story 4 ÷ Story 6</td>
<td>700×700</td>
</tr>
<tr>
<td>Story 7 ÷ Story 9</td>
<td>600×600</td>
</tr>
<tr>
<td>Story 10 ÷ Story 12</td>
<td>500×500</td>
</tr>
<tr>
<td>Story 13 ÷ Story 15</td>
<td>400×400</td>
</tr>
<tr>
<td>Story 16 ÷ Story 17</td>
<td>300×300</td>
</tr>
</tbody>
</table>

The plan and elevation of the building are presented in Figure 1.

Etabs software was used to survey the following 4 cases:
- Case 1: The high-rise building has basement shear walls that are 2.8 meters in height.
- Case 2: The high-rise building is without shear walls in its basement, which has a height of 2.8 meters.
- Case 3: The high-rise building has basement shear walls that are 3.0 meters in height.
- Case 4: The high-rise building is without shear walls in its basement, which has a height of 3.0 meters.
- Case 5: The high-rise building has basement shear walls that are 3.2 meters in height.
- Case 6: The high-rise building is without shear walls in its basement, which has a height of 3.2 meters.

Wind loads are assigned to the geometric center of the building, as shown in Figure 2.

The values of the wind load in the X direction and Y direction are shown in Figure 3.
Figure 1 The plan and 3D modeling of the building (unit: mm).

Figure 2 Geometric center of the building.

Figure 3 Value of wind load in the X direction and Y direction.
3. Results and Discussion

Case 1: Value of the top displacement of the building, bending moment and axial force diagrams at axis 2, shown in Figure 4.

![Diagram](https://www.malque.pub/ojs/index.php/msj)

a) Value of the top displacement of the building.

b) Bending moment diagram at axis 2.

c) Axial force diagram.

**Figure 4 Case 1.**
Case 2: Value of the top displacement of the building, bending moment and axial force diagrams at axis 2, shown in Figure 5.

a) Value of the top displacement of the building.

b) Bending moment diagram at axis 2.

c) Axial force diagram.

Figure 5 Case 2.
Case 3: Value of the top displacement of the building, bending moment and axial force diagrams at axis 2, shown in Figure 6

a) Value of the top displacement of the building.

b) Bending moment diagram at axis 2.

c) Axial force diagram.
Case 4: Value of the top displacement of the building, bending moment and axial force diagrams at axis 2, shown in Figure 7.

- a) Value of the top displacement of the building.
- b) Bending moment diagram at axis 2.
- c) Axial force diagram.

**Figure 7 Case 4.**
Case 5: Value of the top displacement of the building, bending moment and axial force diagrams at axis 2, shown in Figure 8.

Figure 8 Case 5.

a) Value of the top displacement of the building.

b) Bending moment diagram at axis 2

c) Axial force diagram
Case 6: Value of the top displacement of the building, bending moment and axial force diagrams at axis 2, shown in Figure 9.

Figure 9 Case 6.

a) Value of the top displacement of the building.

b) Bending moment diagram at axis 2

c) Axial force diagram
3.1. Comparison of research results:

We surveyed the horizontal displacements at floors in the X direction and Y direction for a total of 6 cases, as shown in Figure 10.

![Figure 10](image1.png)

In Figure 10, after conducting calculations for basements with heights of 2.8 m, 3.0 m, and 3.2 m in high-rise buildings, both with and without shear walls in the basement, the results suggest that we observe the same type of wind load. The presence of shear walls in the basement of high-rise buildings significantly reduces horizontal displacement at the floors and top of the building. This reduction applies to both the X and Y directions. The difference in displacement between buildings with shear walls in the basement and those without is 5.8%.

After conducting calculations on basements with varying heights of 2.8 m, 3.0 m, and 3.2 m and assuming the presence of shear walls in the basement, the results indicate that in cases 1, 3, and 5, where the wind load is consistent, there is no significant change in horizontal displacement between floors. Additionally, the top displacement remains unchanged in high-rise buildings with shear walls in the basement. In the situation where there are no shear walls in the basement, cases 2, 4, and 6 additionally show no significant differences in horizontal displacement values, as shown in Figure 10.

The values of the bending moment and axial force at the base of the 2nd floor column of axial 2 are shown in Figure 11.

![Figure 11](image2.png)

In Figure 11a, it is observed that the bending moment value at the base of the 2nd floor column is relatively small in cases 1, 3, and 5 when compared to cases 2, 4, and 6. It is worth noting that the base of the 1st floor column, being a shear wall, is not taken into consideration in this analysis. The difference value is 7 percent.

In Figure 11b, it can be observed that the axial force value at the base of the 2nd floor column is 1% lower in cases 1, 3, and 5 than in cases 2, 4, and 6.
4. Conclusions

Based on the results of the study, the following conclusions are drawn:

Under the influence of both static and wind loads, there is no significant difference in the mass distribution on the floors between the three cases with shear walls in the basement and the three cases without shear walls in the basement.

1. When high-rise buildings have shear walls in the basement, horizontal motion is much less at the top than when high-rise buildings do not have shear walls in the basement.

2. When it involves load-bearing, deformation, and even usage, the design of the basement in a high-rise building is advantageous.

3. The research results currently focus on just one basement. To gain a clearer understanding of the effects of horizontal displacement at the top of the building and the internal force values in the frame, it is necessary to continue the research with multibasement buildings.

Acknowledgment

The data used to support the findings of this study are included within the article.

Ethical considerations

Not applicable

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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