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Wind-Related Structural Stiffness and Stiffness Reduction Factors

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Abstract: One of the most important parts of a building is its columns. When columns are destroyed, it can lead to the destruction of other structures or be the major cause of the destruction of the whole structure. Building stiffness is a very important factor when looking at how structures behave because it affects how buildings vibrate and, by extension, how much horizontal wind they can handle. It is possible to be more specific about how to plan high-rise buildings that are subject to wind loads by looking at how buildings behave when their structural stiffness decreases. The objective of the study is to investigate through the effects if reinforced concrete buildings reduce stiffness and how that changes how wind affects the structure. The author of this study looks at how reinforced concrete high-rise buildings behave. The results will be used to look at changes in the horizontal displacements and internal forces in buildings so that project design suggestions can be made.

Keywords: *wind loads; stiffness; high-rise building; stiffness decreases; horizontal displacements.*

1. Introduction

According to the Vietnamese standard TCVN 9386: 2012 on the design of earthquake-resistant structures [1], a reduction of structural stiffness can be described by a single coefficient, which makes the calculation very easy. Additional standards for determining issues through, like ACI 318M-11 [2] and CSA-A23.3-04 [3], also use stiffness reduction factors. Several experimental research have been conducted to investigate the reduction of structural stiffness. Particularly, these studies include the works of D. Branson [4], Elwood and Eberhard [5], as well as Paulay and Priestley [6]. These research groups have presented out recommendations suggesting specific coefficients for reducing structural stiffness in different kinds of structures and at varying levels of load-bearing capacity. While the application of these concepts may be appropriately intricate, they are similar to the practical aspects of structural engineering. Researchers [7–17] have used the stiffness reduction coefficient to simulate how frame structures behave when they are affected by earthquake loads and made comments on the building work as a result.

There have also been a lot of experimental studies on the effects of structural displacement. For example, Jong-Han Lee and his colleagues looked at how to design high-rise buildings so that they are resistant to earthquakes when they are subjected to the effect of horizontal displacement [18]. Wei Hua Hu and his colleagues calculated the horizontal displacement of high-rise buildings due to wind load [19]. Additionally, our country has done research on the behavior of high-rise buildings that move horizontally, such as research that used a ground laser tracker to track the movement of high-rise buildings: Faro Focus3D X130 [20], Nguyen Hong Hai, and Nguyen Hong Ha used nonlinear static methods to study how high-rise buildings in Vietnam respond to vibrations in relation to displacement [21-24].

Research Significance

After searching through the above research topics, the author thinks it is important to investigate into reinforced concrete high-rise buildings with load-bearing frame and wall systems. This includes investigating into the factors that make the structure less stiff and how that affects how dynamic wind affects the structure.

Objective of the current study

The primary goal of the current study is to investigate through the effects if reinforced concrete buildings reduce stiffness and how that changes how wind affects the structure.

2. Materials

Information about the building and impact loads:

There is one basement that is 3.5 meters deep and 9 floors that are 3.9 meters high. Walls made of bricks are built on all beams and are 0.2m thick. The dead load of the layers on the floor is 1.6 kN/m^2. The floor has a live load of 2.4 kN/m^2, and the roof floor has a live load of 0.9 kN/m^2. The brick wall placed over the beam adds 11 kN/m^2 to the dead load. The section size has been chosen so far: the floor is 0.15 meters thick, the beams are 0.3 meters by 0.6 meters, and the concrete walls are 0.25 meters thick. Grade B25 concrete with C300-V reinforcements.

3. Methodology

Case 1: All floors have columns that are the same size: 0.8m×0.8m.

Case 2: The three-story column's size is changed just once, shown in Table 1

Table 1: The three-story column's size is changed just once

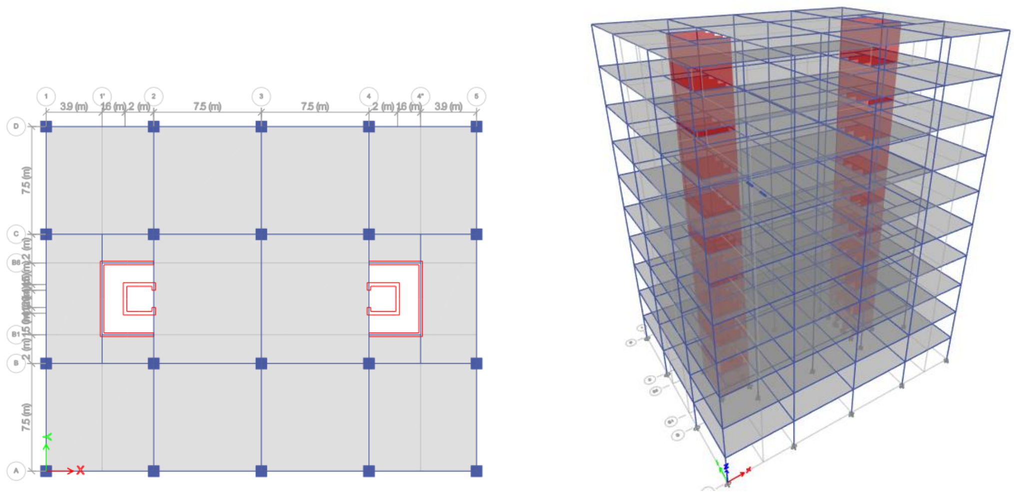
Base ÷ Story 3	Story 4 ÷ Story 6	Story 7 ÷ Story 9	Story 10
0.8×0.8m	0.7×0.7m	0.6×0.6m	0.5×0.5m

Case 3: The beams on each floor are different sizes, and the force of the wind on the building, shown in Table 2

Table 2: The beams on each floor are different sizes and the force of the wind on the building

	Sizes	Wind: OX direction (kN)	Wind: OY direction (kN)
Story 10	0.3×0.3m	229.1	279.2
Story 9	0.4×0.4m	224.2	272.8
Story 8	0.5×0.5m	218.7	265.9
Story 7	0.6×0.6m	211.2	257.2
Story 6	0.7×0.7m	203.2	247.3
Story 5	0.8×0.8m	193.8	237.0
Story 4	0.9×0.9m	182.3	223.0
Story 3	1.0×1.0m	165.8	205.1
Story 2	1.1×1.1m	146.1	181.8
Base ÷ Story 1	1.2×1.2m	0	0

The plan and 3D model of the building are shown in Fig. 1

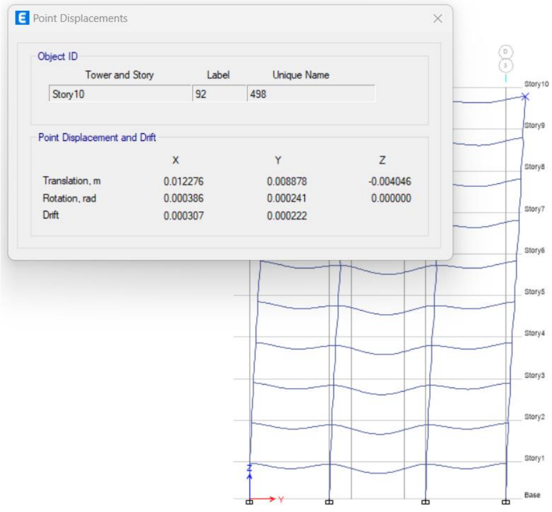


a) Plan of the building b) 3D model of the building

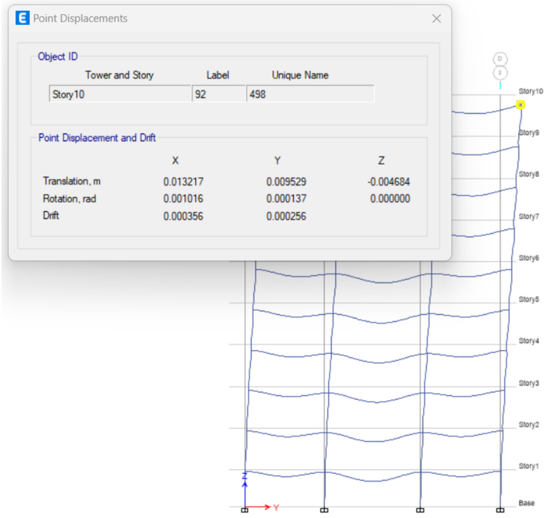
Fig. 1 The plan and 3D model of the building

4. Results and Discussions

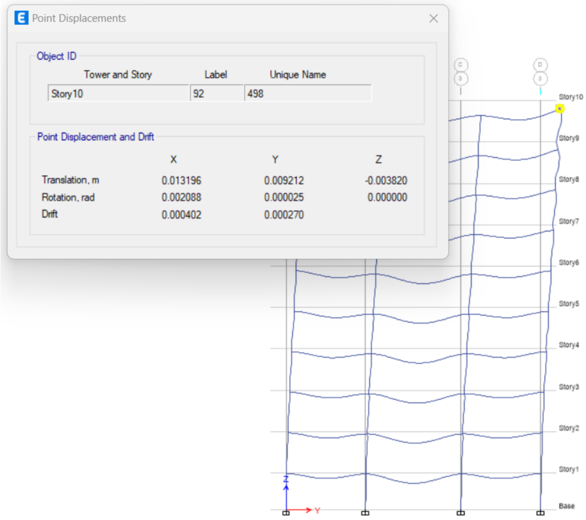
The measurement of displacement at the top point of the building at axis 3-C, shown in Fig. 2.



a) Case 1



b) Case 2

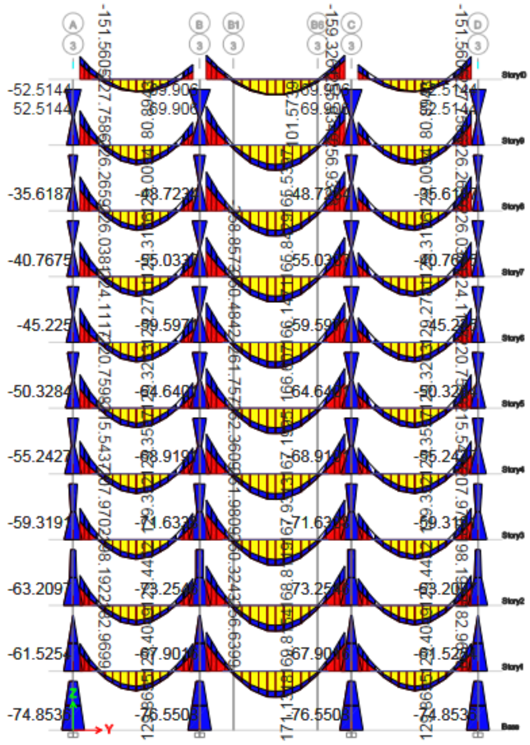


c) Case 3

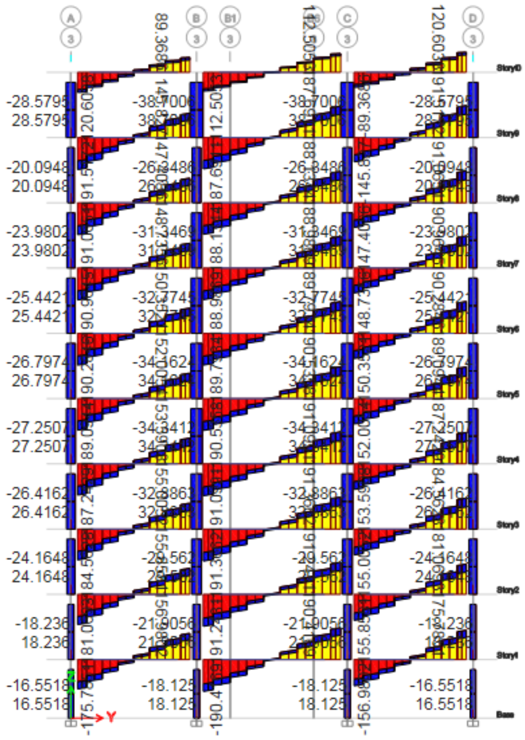
Fig. 2 The displacement at the top point of the building

This is a diagram of the bending moment, shear force, and axial force at axis 3-C:

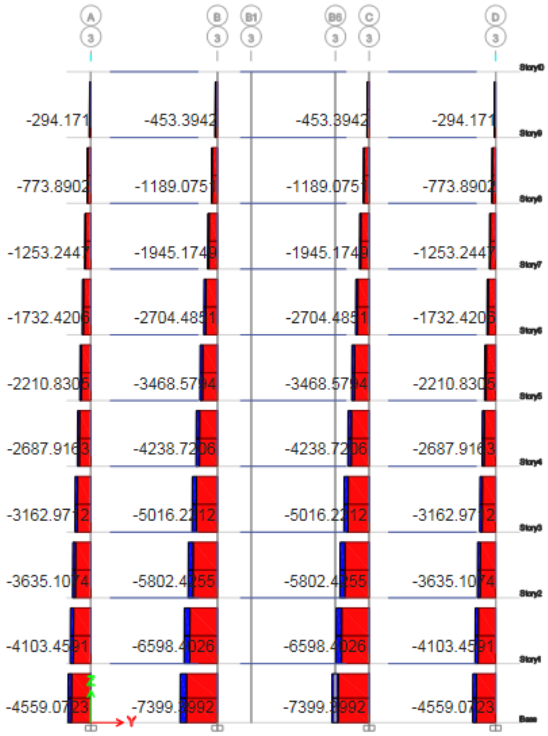
Case 1: shown in Fig. 3



a) bending moment (kNm)



b) shear force (kN)



c) axial force (kN)

Fig. 3 The diagram of the bending moment, shear force, and axial force at axis 3-C, case 1

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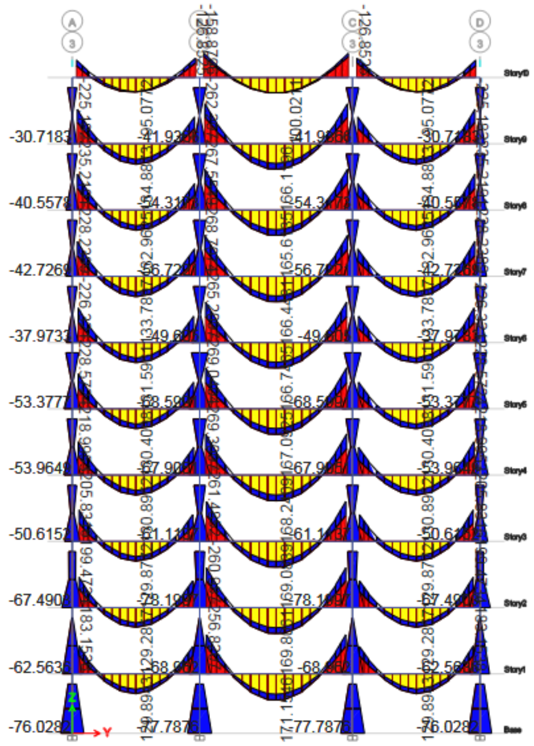
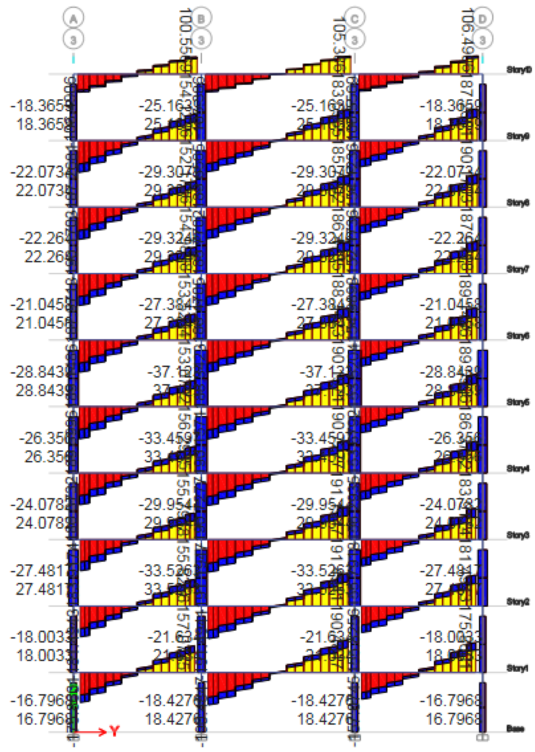
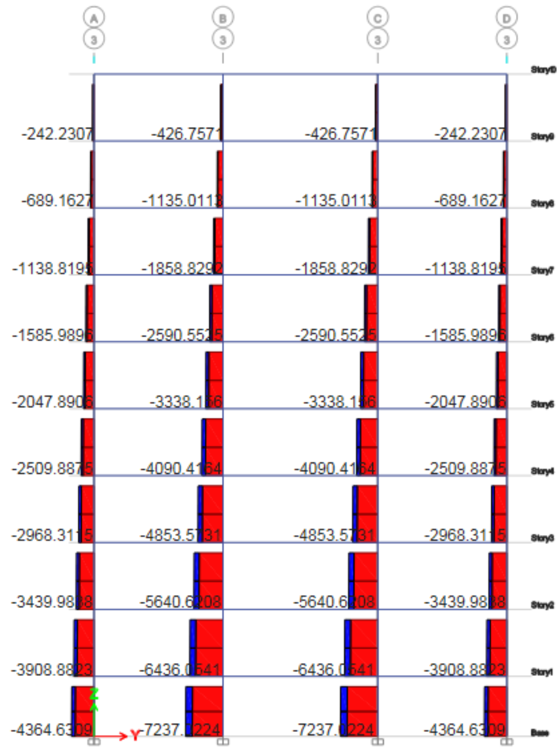
Case 2: shown in Fig. 4



a) bending moment (kNm)



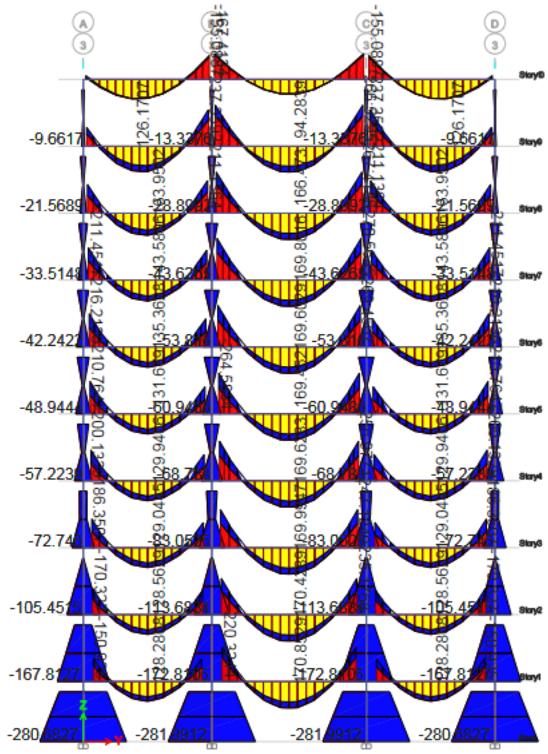
b) shear force (kN)



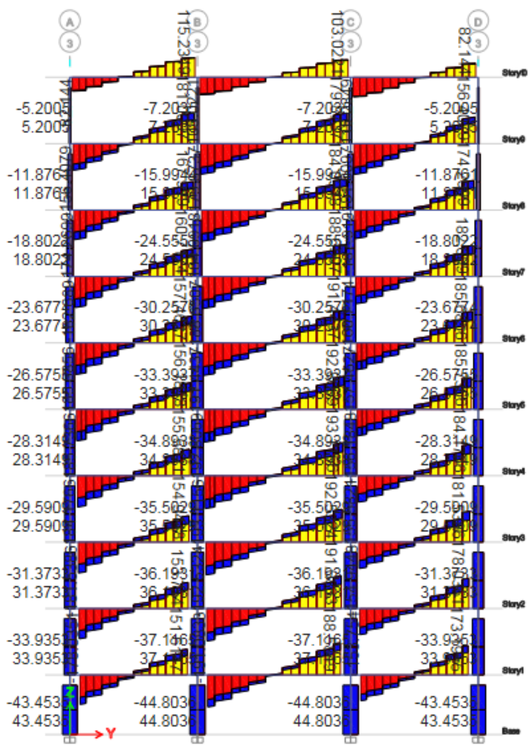
c) axial force (kN)

Fig. 4 The diagram of the bending moment, shear force, and axial force at axis 3-C, case 2

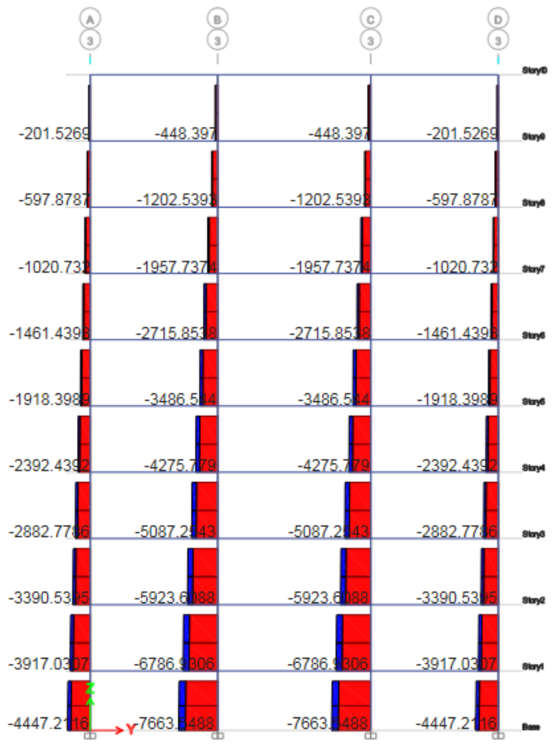
Case 3: shown in Fig. 5



a) bending moment (kNm)



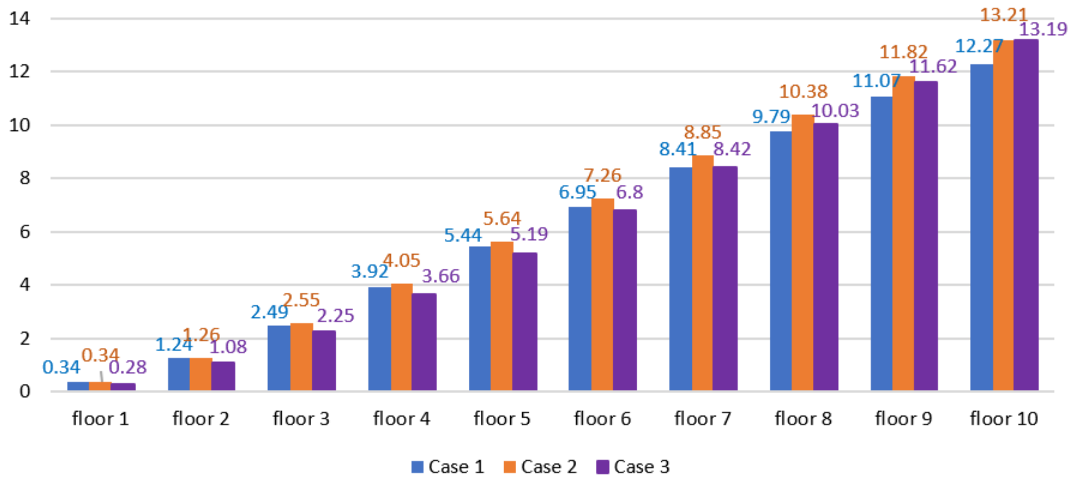
b) shear force (kN)



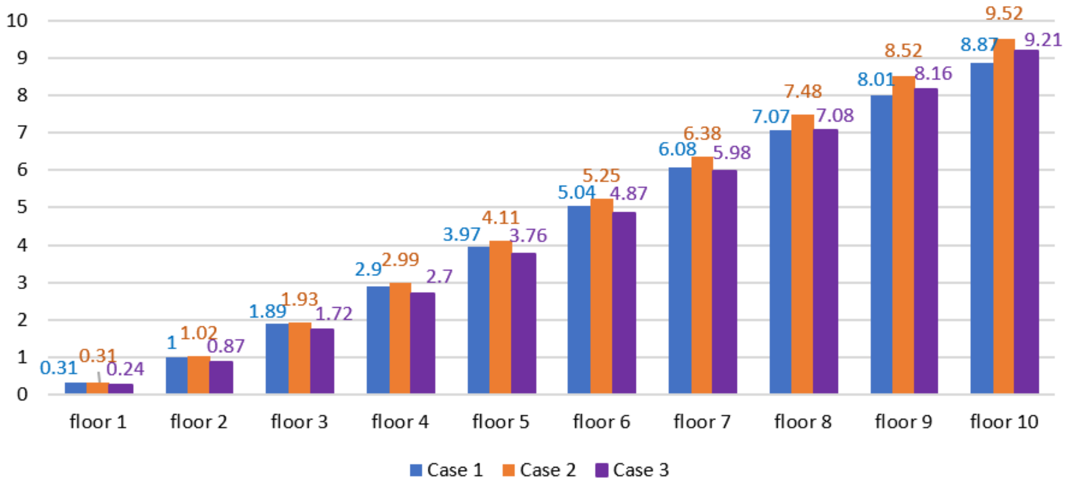
c) axial force (kN)

Fig. 5 The diagram of the bending moment, shear force, and axial force at axis 3-C, case 3

Horizontal displacement at floors in X and Y directions in 3 cases at axis 3-C (the measurement is mm), shown in Fig. 6:



a) X direction



b) Y direction

Fig. 6 Horizontal displacement at floors in X and Y directions in 3 cases

Comment: The displacements at the floors are the same in all three cases. The change in values isn't significant, and the safeguards are still the same as Vietnam's standards for horizontal displacement at the top (including the Y and X directions). On the other hand, looking at Fig. 6a and Fig. 6b, we can observe that Case 2 has the maximum displacement value at the floors (this includes the displacement at the highest point of the building). In the X and Y directions, the horizontal displacement at the floors of Case 1 is more than that of Case 3, while in the opposite direction, from floors 8 to 10, the horizontal displacement at the floors of Case 3 is higher than that of Case 1. The results of this study show that when the cross-section of the columns at the floors change, the displacements at the floors change as well. This has a significant impact on the structural integrity of the building when compared to the cases in which the cross-section is not changed or when the cross-section of the columns at three levels changes at the same time.

Axial force at column base of axis 3-C in 3 cases (the measurement is kN), shown in Fig. 7:

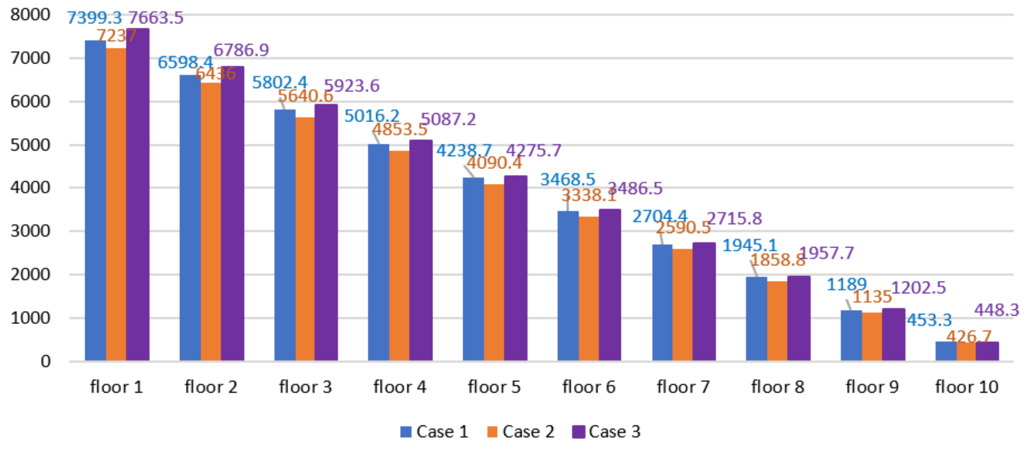


Fig. 7 Axial force at column base of axis 3 in 3 cases

Comment: The axial force observed at the base of the column in Case 3 is the highest, while the one measured in Case 2 is lowest. In spite of this, the axial force is not significantly different in all of the three cases.

The horizontal displacement in the X and Y directions can be shown in Fig. 6 and Fig. 7, respectively; however, the axial force showed at the column base doesn't change by significantly. In order to determine which case is better over the others, it is essential to take consideration both the shear force and the bending moment.

Shear force at column base of axis 3-C in 3 cases (the measurement is kN), shown in Fig. 8:

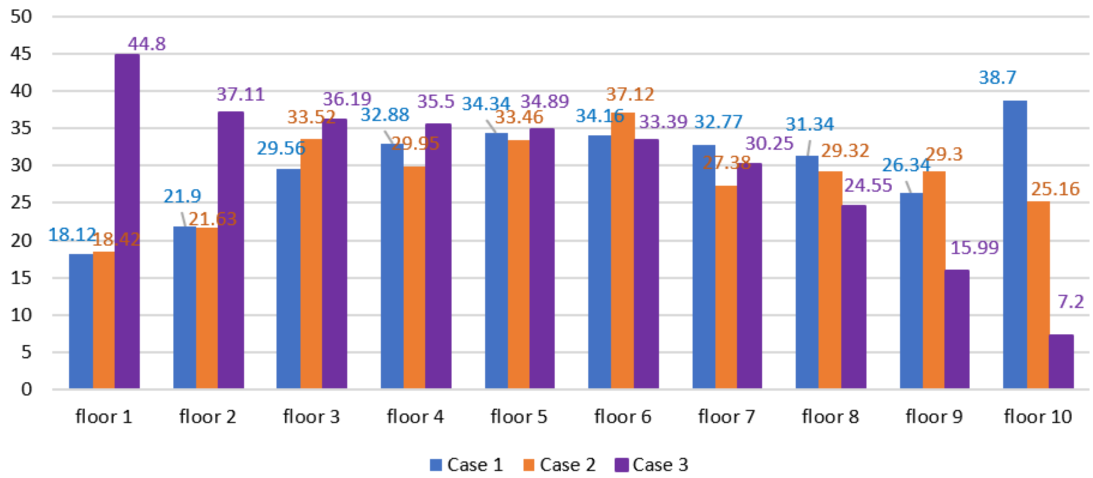


Fig. 8 Shear force at column base of axis 3-C in 3 cases

Comment: Take note in Fig. 8, the shear force demonstrated by Case 3 from the first floor all the way up to the fifth floor has the highest value. Also, the shear force showed at the first floor is twice as much as the value exerted by the other cases. The shear force drops off significantly between floors 6 and 10, as shown above. At floor 10, the shear force of Case 3 is one-fifth that of Case 1, which is a significant difference. That examples, from the first story all the way up to the fifth floor, the cross-section of each floor gets smaller, which causes the shear force to rapidly grow. In addition, the design and construction of the building present extra challenges.

Bending moment (M_{2-2}) at column base of axis 3-C in 3 cases (the measurement is kNm), are shown in Fig. 9:

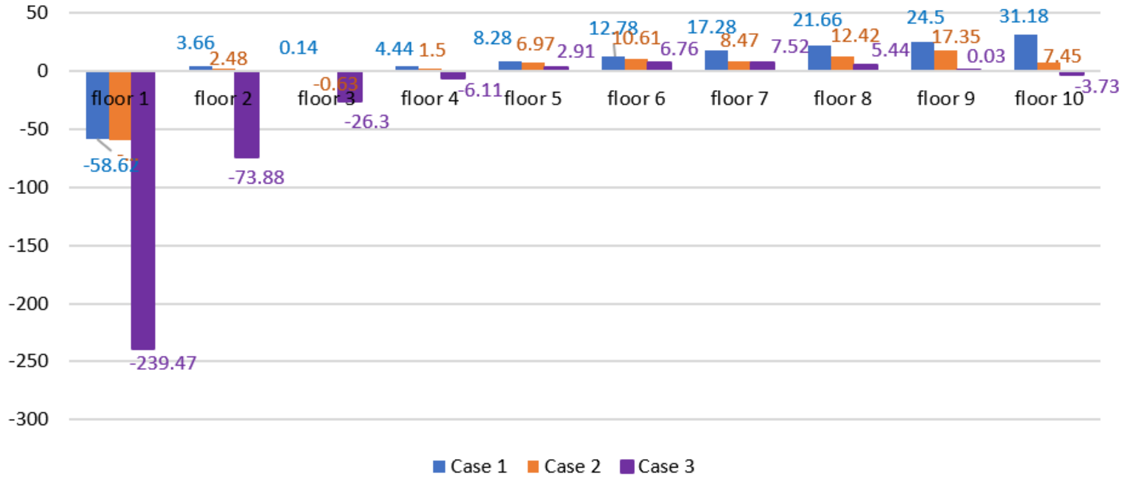


Fig. 9 Bending moment at column base of axis 3-C in 3 cases (M_{2-2})

Bending moment (M_{3-3}) at column base of axis 3-C in 3 cases (the measurement is kNm), are shown in Fig. 10:

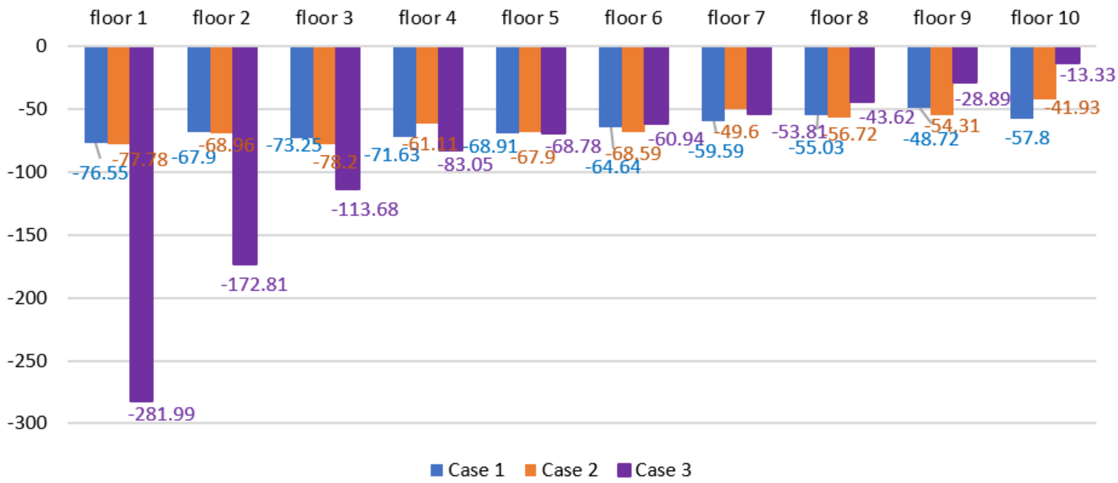


Fig. 10 Bending moment at column base of axis 3-C in 3 cases (M_{3-3})

Comment: Take a look at The value of the bending moment M_{2-2} is shown to be negative in Fig. 9 and Fig. 10, and the value of the bending moment for Case 3 of the first floor is shown to be extremely high and to be four times greater than the value of the bending moment for the other Cases. When the cross-sections of the columns on all floors are decreased, the bending moments M_{2-2} and M_{3-3} will grow by a factor of several, which will result in the building being increasingly unstable.

5. Conclusions

Based on the results of the study lead to the following conclusions:

1. Both the axial force at the column bases and the horizontal displacement in the X and Y directions are not changed by significant amounts.
2. There is a significant gap between the shear force at Case 3's first and second floors and that of the other cases; similarly, and vice versa, the shear force at Case 1's tenth level has a value that is five times more than that of Case 3. It is essential to give attention to the shear force value at the building's lowest and highest floors during the design process.
3. When the cross-section of all floor changes, particularly the lower floors like the first and second levels, the bending moments M2-2 and M3-3 demonstrate that the building is more likely to become unstable. This is especially true for the lower floors. When the cross-section changes, the existence of all floors leads to in waste, additional construction time, and...

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