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Studying the behavior of the structural system of a high-rise building with the structural outrigger

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Abstract: *In modern tall buildings, lateral loads induced by wind or earthquake are often resisted by a system of coupled shear walls. But when the building increases in height, the stiffness of the structure becomes more important and introduction of outrigger beams between the shear walls and external columns is often used to provide sufficient lateral stiffness to the structure. In the present paper an investigation has been performed to examine the behavior of various alternative 3D models using ETABS software. Results show that the outrigger changes the kinetic characteristic (oscillation periods decreased 30%), the optimum position of the outriggers is at mid height. The outrigger used as one of the structural system to effectively control the excessive drift displacements, shear force, bending moment and is connected with the column against the rotation of the core.*

Keywords: *Drift story, outriggers, stiffness, displacements, shear force*

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I. INTRODUCTION

In recent years, high-rise buildings have developed rapidly. Due to the limited urban land fund and high population density, the development of high-rise and super-high-rise projects is an inevitable choice. Developments in construction technology also create many challenges for structural science. High-rise buildings are getting thinner and thinner, the material strength is getting higher and higher. In particular, the use of hard floors for super high-rise buildings is more and more popular. According to statistics, 73% of super high-rise buildings in the world built from 2000 onwards use core and rigid floors to support horizontal loads. One of the important design criteria of high-rise buildings is the horizontal displacement at the top. The limit of displacement due to horizontal load is H/1000; H: house height. The use of core systems to reduce displacement due to lateral loads is very effective. However, as the height of the building increases, the core does not have enough stiffness to keep the displacement down to an acceptable limit.

Both the core and other members such as columns, walls, etc are considered to be internal transverse load-bearing structures, but the floor beams have small stiffness while the distance from the core to these members is large, so in fact most of the horizontal loads. borne by the core. This phenomenon causes the boundary members to work inefficiently. To overcome this phenomenon, on some floors we create horizontal beams or trusses (the outrigger). It has great rigidity connecting the hardcore to the outer members. The problem for the structural designer of high-rise buildings is to find solutions to increase the stiffness of the structural system. At the same time, they also need to minimize the lateral displacement at the top and the core's mounting moment under the effect of lateral loads. The outrigger structural system is considered an effective way to solve the above problems.

For the above reasons, the article analyzes the behavior of high-rise buildings with the outriggers, their position, and effects on stiffening the building, reducing horizontal displacement at the top of the building.

II. METHODOLOGY

Hard floors in high-rise buildings are usually designed as a system of very rigid horizontal beams (often called rigid beams) or the outrigger. They have the effect of connecting the core to the outer walls and columns. Accordingly, the core is usually arranged in the middle of the columns and the rigid beams develop in directions to connect the core and columns.

The research model is a 50-storey building with a core size of 8m x 8m (Figure 1). Typical floor height is 3.6m, total building height is 180m. The beams, columns, cores and the outrigger are assumed to be reinforced concrete structures. Column size is 0.75m x0.75m and girder 0.3m x 0.6m, core thickness is 0.35m.

For static analysis use wind load analysis by TCVN 2737-2020 and dynamic analysis use earthquake load by TCVN 9386-2012. Use ETABS 2016 software to analyze the model. Core walls and rigid floors have been modeled as shell elements with beams and columns modeled as bar elements.

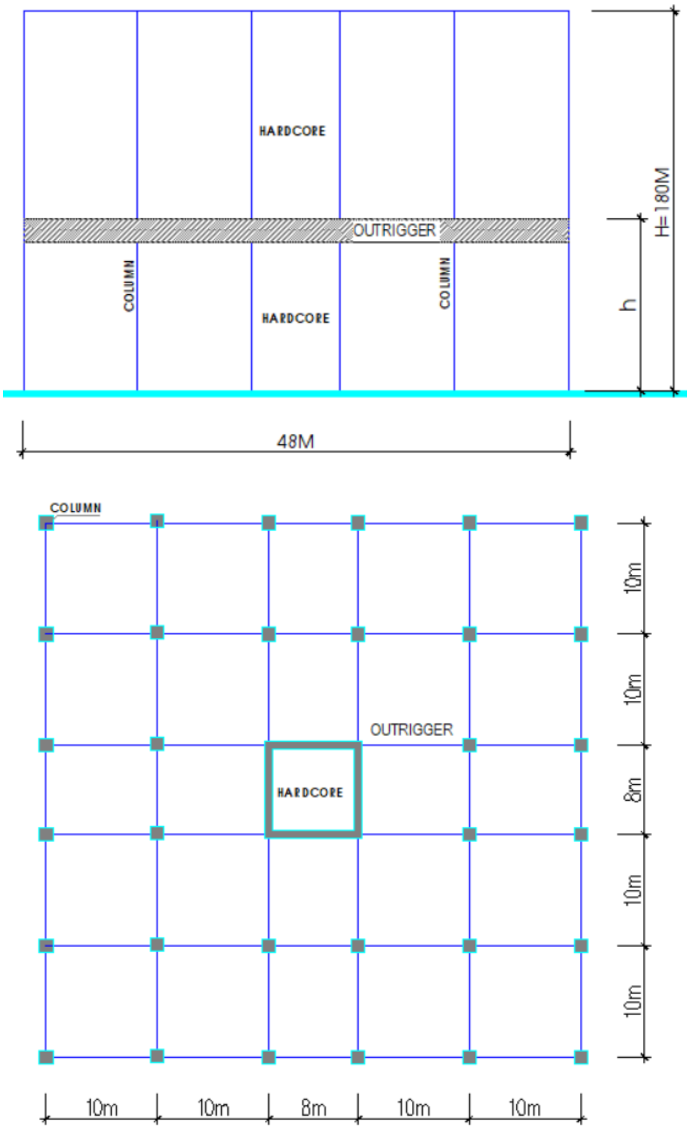

Figure 1. Analytical model

The building has only one outrigger. The distance from the foundation surface to the top surface of the the outrigger layer is h. Consider four models with the outrigger layers:

Model 1: No the outrigger
Model 2: h=0.25H
Model 3: h=0.5H
Model 4: h=0.75H
Model 5: h=H

The project is assumed to be built in Thai Nguyen, the ground has a peak acceleration a_{gR} = 0.0928g; soil type B; importance coefficient γ = 1; behavior coefficient q = 3.9. The seismic load is determined by the method of multi-vibration response spectrum. The steps to calculate earthquake load comply with the regulations of TCVN 9386-2012. Structural material using concrete B30 has R_b = 17Mpa; E_b=3.35,104 Mpa. CIII reinforcement has E_s = 20,104Mpa; R_s = 365Mpa.

The results of structural analysis according to Etabs 2016 software for five models in the case of an outrigger are shown in the diagrams.

III. RESEARCH RESULTS

Horizontal displacement is reduced by 35% when h=H and by 65% when h=0.5H. The curvature of the change graph at these outrigger positions is because the rotation of the wall is limited by the solid-column interaction (Figure 2).

The shear force is reduced at the location with the outrigger. The reduction remains nearly constant throughout the height of the shear wall under the outrigger and the total shear force remains unchanged (figure 3).

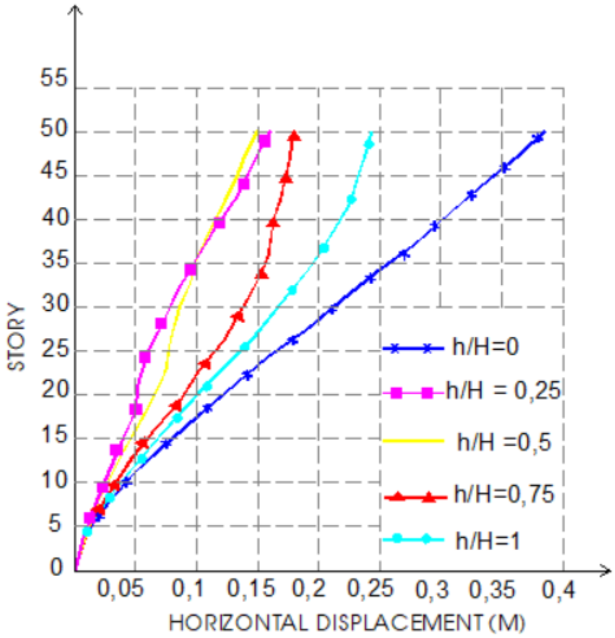

Figure 2. Horizontal displacement due to wind load

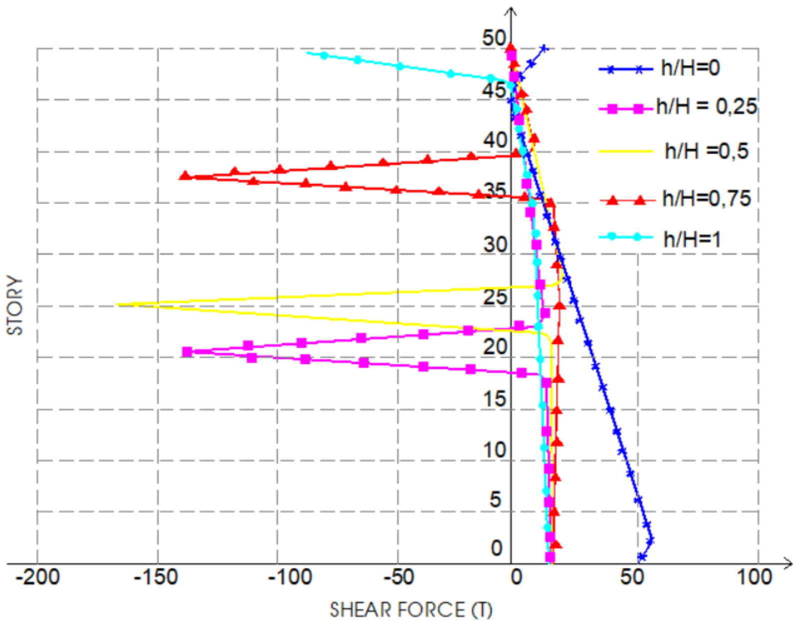

Figure 3. Core shear force due to wind load

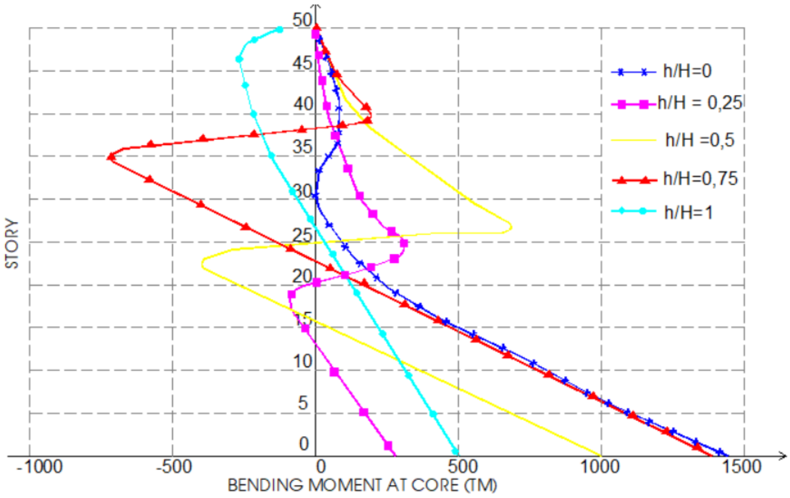

Figure 4. Bending moment at core due to wind load

The bending moment is reduced by 96% when the rigid stage is placed in the middle of the core height. Earthquake load, displacement is reduced by 33% when the the outrigger is placed at the top of the structure. And reduced by 66% when the hard floor is placed in the middle of the building (h = 0.5H) (Figure 4).

Table 1. Calculation results of oscillation

Model	**Direction**	Period of Oscillation(s)			Effective mass (%)		
		Type 1	Type 2	Type 3	Type 1	Type 2	Type 3
1	X	5.85	1.91	1.07	77.7	11.4	3.51
	Y	4.84	1.30	0.59	69.6	13.9	5.43
2	X	5.85	1.91	1.08	77.7	11.6	3.40
	Y	4.07	1.13	0.59	63.7	21.1	6.05
3	X	5.87	1.09	1.08	77.9	11.1	3.58
	Y	4.18	1.24	0.53	73.4	10.2	6.42
4	X	5.88	1.90	1.07	77.8	11.3	3.44
	Y	4.53	1.09	0.56	72.8	12.1	4.06
5	X	5.90	1.91	1.08	77.7	11.4	3.51
	Y	4.78	1.22	0.55	70.7	13.7	5.10

From the calculation results in the table, it shows that the period of oscillation: type 1 decreased by 29%; type 2 reduced by 35%; Type 3 by 50%.

Effective mass: form 1 reduced by 6%, form 2 reduced by 10%; Type 3 by 85%.

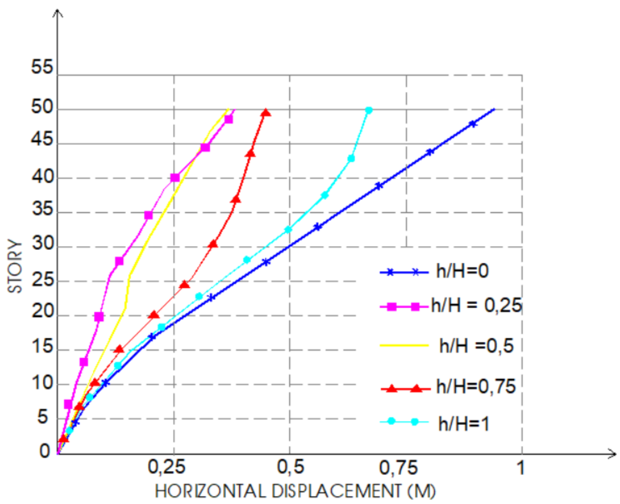

Figure 5. Horizontal displacement due to earthquake load

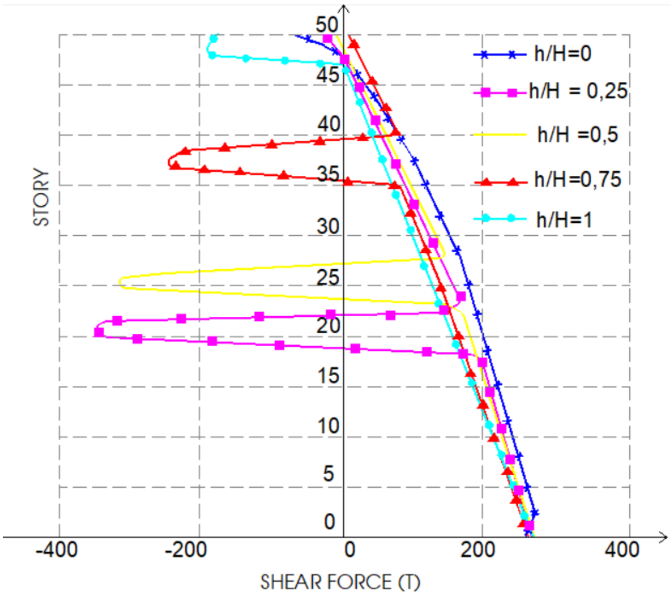

Figure 6. Core shear force due to seismic load

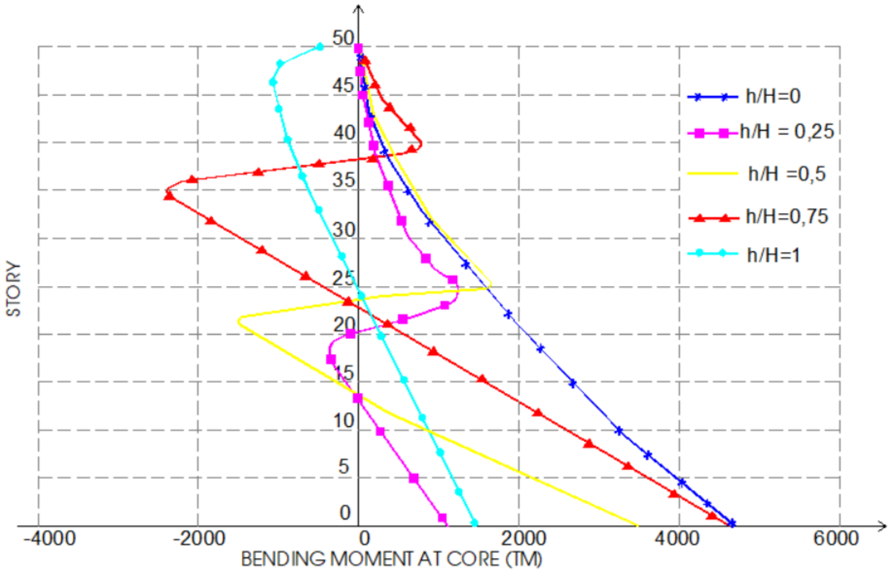

Figure 7. Core bending moment due to seismic load

The horizontal displacements, shear forces, and bending moments caused by earthquakes tend to be similar to static analysis due to wind loads. The displacement graph of the model without the outrigger is regular and continuous in height. At the position of the displaced the outrigger, there is a breakpoint. Model 3 for the smallest peak displacement, model 2 for the displacement at the smallest floors.

IV. CONCLUSION

The use of the outrigger in high-rise buildings increases stiffness and makes structural forms efficient under lateral loads. Based on the analysis results, the following conclusions were obtained:
- The outrigger changes the dynamic characteristics of the building. The basic oscillation period of the building is reduced by over 30%. The change depends on the number and location of the outrigger.
- When considering horizontal displacement in both static and dynamic analysis, the optimal outrigger position is in the middle of the building height. It reduces the peak displacement by 30%.
-The shear force and bending moment are significantly reduced when the outrigger system is added to the structure

Conflict of interest

There is no conflict to disclose.

ACKNOWLEDGEMENT

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