Study on Anti-Seismic Analysis of High-Rise Diaojiaolou Considering Pile-Soil Interaction

Ning Xu\textsuperscript{1*}, Chuanguo Jia\textsuperscript{2}, Pu Yang\textsuperscript{2}, Qingzhang Zhang\textsuperscript{3} and Jianli Zhao\textsuperscript{1}

\textsuperscript{1}China MCC20 Group Corp. Ltd., Shanghai, 201999, China
\textsuperscript{2}College of Civil Engineering, Chongqing University, Chongqing, 400044, China
\textsuperscript{3}College of Civil Engineering, Henan University of Technology, Zhengzhou, 450001, China
Email: 123xn@tongji.edu.cn

Abstract. High-rise Diaojiaolou in mountainous areas have poorer seismic performance than flat high-rise structures due to their large structural loads and irregularities. Spring elements of equivalent stiffness are used to simulate the effect of nonlinear interaction between the piles and soil of high-rise Diaojiaolou. Research shows that the spring elements of equivalent stiffness can accurately simulate the seismic performance of high-rise Diaojiaolou. It is the most unfavorable state that the soil covers part of the long side of the Diaojiao plane, and the hanging legs exposed for a long time, which should avoid. The state of the soil covering the oblique angle part of the hanging legs has good lateral force stiffness.

Keywords. Diaojiaolou, high-rise, anti-seismic analysis, pile-soil interaction, spring element.

1. Introduction
Diaojiaolou is a special structural form in mountainous construction [1]. The columns (or piles) with different lengths are used for erecting a platform on the slope [2]. In terms of seismic design of high-rise stilts, due to the irregular vertical direction and uneven stiffness distribution of high-rise stilts, grounding on different planes will inevitably have a certain impact on the seismic response of the structure. At present, there is no specific seismic code for mountain structures, especially high-rise Diaojiaolou design. The design method of flat structure can not be directly applied to mountain building structure [3, 4]. The earthquake damage investigation of the Wenchuan earthquake showed that there are certain hidden safety hazards in the seismic design of mountain building structures, and there are special problems different from flat structures under the action of the earthquake [5, 6].

This paper considers the seismic analysis of the pile-soil interaction, and obtains useful conclusions, which will provide a reference for the application of similar projects in the later period.

2. Anti-Seismic Analysis of High-Rise Diaojiaolou
In order to simplify the design process, the current seismic design methods assume that the foundation is a rigid foundation [7], which separates the three components of the building system: superstructure, foundation, and foundation for individual analysis and calculation. When the difference between the stiffness of the foundation and the stiffness of the superstructure is not large, the analysis of rigid foundation will produce a large error. Therefore, it is very meaningful to consider the subject of pile-soil structure interaction when conducting structural seismic design and seismic evaluation.
2.1. Pile-soil Interaction
In this section, the method of concentrated plastic hinge system model is used to analyze the seismic performance of the structure. Seismic analysis of a 21-story high-rise Diaojiaolou was carried out by Sap2000 software. The project is Wanshuo Jiangcheng project, which is located in Chongqing [8]. The spring element of equivalent stiffness is used to simulate the nonlinear interaction between the pile and the soil under the action of the earthquake, and the dynamic analysis is carried out. The spring damping element is used to simulate the nonlinear dynamic interaction between the pile and the soil.

2.2. Anti-Seismic Analysis
Assuming that the lower part of High-rise Diaojiaolou is fixed, the anti-seismic analysis is calculated according to the rigid foundation. The calculation results are described as follows. Figure 1 shows the model of Diaojiaolou using Sap2000 software. Figure 2 shows the calculation results of rigid foundation, and modal 7, modal 8 and modal 9 are the middle three modals.

2.3. Anti-seismic Analysis Considering Pile-soil Interaction
Using the spring element to simulate the effect of the soil around the pile on the pile body, considering the different slope coverage of the slope, the calculation is divided into three different situations. Pile element and its simulation are described as figure 3.

Among them, considering the foundation of the pile-soil structure linear interaction system, the frame beam element is used to simulate the pile foundation, and the spring element is used to simulate the linear action of the soil around the pile on the pile (JGJ94-2014).

Consider 3 situations separately for specific analysis.
Figure 3. Pile element and its simulation.

Situation 1: The slope is covered along the short side of the building structure base plane, as shown in the following figure 4 and figure 5.

Figure 4. Situation 1.

Figure 5. Deformation map of Situation 1 (the middle three modals).

We can see from figure 5 that the deformation of in each modal is large, no matter bending deformation and torsion deformation.

Situation 2: The slope is covered along the long side of the building structure base plane, as shown in the following figure 6 and figure 7.
We can see from figure 7 that the deformation of in each modal is small compared with the results in figure 5, no matter bending deformation and torsion deformation.

Situation 3: The slope is covered along the corners of the building structure base plane, as shown in the following figure 8 and figure 9.

We can see from figure 9 that the deformation of in each modal is the smallest compared with the results in figure 5 and figure 7, no matter bending deformation and torsion deformation.
3. Conclusions
The seismic analysis of three embedded Diaojiaolou under the combined action of pile and soil can be seen:

(1) The use of spring elements can better describe the nonlinear relationship between pile and soil;
(2) The seismic response of the system under different embedded areas (soil-covered areas) of the suspension legs of high-rise stilted buildings is different;
(3) The most unfavorable state is when the soil covers part of the long side area of the suspension feet plane and the suspension feet are exposed for a long time;
(4) The oblique angle part of the plane of the sling covered by the soil has a good stiffness against lateral force.

Acknowledgments
This work is supported by the Technology Fund of Company (20170310). The author thanks the project management team named “Wanshuo Jiangcheng” in Chongqing for their hospitality, time and opinions.

References
[1] Wu W and Zhao L 2020 Inspiration of traditional Diaojiaolou construction techniques based on the concept of ecological architecture *Architecture & Culture* **10** 235-236.
[2] He H C 2018 Thinking on the traditional Diaojiaolou to the modern mountain *Building Residence* **3** 189-192.
[3] Lai B J, Xiao C A and Fu B 2009 Analysis of seismic torsional effect on high-rise building structure of unequal-height fixed on slope land *Journal of Guizhou University* **5** 121-124.
[4] Wang F and Yang Z 2001 Research on the structure design of multistory building on the hillside *Journal of Central South University of Technology* **3** 72-75.
[5] Li G B, Xu H J and Guo H P 2015 Seismic performance analysis and seismic structure research of Diaojiao Building in Southwest Hubei *Huazhong Architecture* **33** 76-82.
[6] He M 2019 Development of virtual simulation system for Miao Nationality Diaojiaolou Structure *Digital Communication World* **8** 93,163.
[7] Elnashi A S 2001 Advanced inelastic static (pushover) analysis for earthquake applications *Journal of Structural Engineering* **12** 51-69.
[8] Xu N 2018 Study on pushover analysis for high-rise Diaojiaolou on multi-grade steep slope *Advances in Engineering Research* **163** 1554-1557.