Determination of the Ultimate Bearing Capacity of a Single Barrette Wall using FEA and Cubic Nonlinear Regression

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Received: 6 September 2024 | Revised: 1 November 2024 | Accepted: 3 November 2024

 DOI: https://doi.org/10.48084/etasr.8938

ABSTRACT

This study analyzes the mechanical behavior of barrette walls under various load levels, a critical issue in the design and construction of structures subjected to large loads. The primary objective of the research is to determine the nonlinear relationship between load and settlement of barrette walls, as well as to assess the maximum load-bearing capacity of the walls under diverse loading conditions. The finite element analysis method was employed to simulate the detailed interaction between the barrette wall and the soil, combined with cubic and linear regression analysis techniques to establish the model of the relationship between load and settlement displacement. The research results reveal a nonlinear relationship between load and settlement of the wall, with an inflection point occurring at a load level of approximately 12,000 kN, where the change in settlement becomes more pronounced. The cubic regression equation achieved a coefficient of determination R^2 = 0.999, demonstrating the high accuracy of the model. The maximum load-bearing capacity of the barrette wall was determined to be 15,745.59 kN, providing a clear scientific basis for evaluating the load-bearing capacity of structures. The conclusions from this study affirm the importance of using finite element simulations in soil mechanics analysis and the design of structures subjected to large loads. The achieved results not only enhance understanding of the behavior of Barrette walls but also contribute to the development of new technical solutions and design methods, with the potential for wide application in the construction and geotechnical engineering sectors.

Keywords-finite element analysis; ultimate capacity; barrette wall; cubic nonlinear regression

I. INTRODUCTION

During the recent years, the study and optimization of solutions for constructing large load-bearing structures have become a significant challenge in the fields of construction engineering and geotechnical engineering. Barrette walls, a type of load-bearing wall commonly used in deep foundation projects, have demonstrated superior advantages in bearing both horizontal and vertical loads, particularly under complex geological conditions [1-4]. However, a detailed understanding of the mechanical behavior of barrette walls under different load levels remains limited, especially in determining the nonlinear relationship between load and settlement, a critical factor in structural design and assessment [5-9].

Previous studies have focused on analyzing the behavior of barrette walls through field experiments and soil mechanics modeling methods [10-13]. Although these studies have contributed valuable insights into the stability and load-bearing capacity of the walls, they often limit their scope to describing the linear relationship between load and settlement. These limitations fail to fully capture the complex nature of the interaction between barrette walls and the soil, particularly when the load reaches higher levels. Therefore, this research aims to address this gap by using the finite element analysis method to simulate in detail the load-bearing behavior of barrette walls under various loading conditions. The objective of this study is to better define the nonlinear relationship between load and settlement of barrette walls and to evaluate their maximum load-bearing capacity under different load levels. By employing the finite element analysis method, this study will develop a 3D model simulating the interaction between the barrette wall and the soil, thereby providing a solid scientific basis for designing and evaluating large load-bearing structures.

The finite element analysis method was chosen due to its ability to accurately and precisely simulate the complex interactions between structural elements and their surrounding environment [14, 15]. Through this method and the cubic nonlinear regression method, we aim to provide a deeper understanding of the load-bearing mechanisms of barrette walls and identify the key factors affecting the stability and safety of the structures. This research is significant not only in enhancing the understanding of the mechanical behavior of barrette walls but also in contributing to the development of new design and construction methods that optimize the cost and performance of large load-bearing structures. The results achieved from this study can be widely applied across many fields, from civil and industrial construction to large-scale infrastructure development projects, opening up new directions for future research and application.

II. MATERIALS AND METHODS

The soil sample used in this study is sandy clay, a common soil type in the Ho Chi Minh City area (Table I). This sandy clay has a high proportion of sand particles, with a small portion containing clay and organic matter, resulting in mechanical properties suitable for construction foundations. The main characteristic of this soil type is its good drainage capability, but the weak cohesion between particles leads to low compaction when subjected to large loads.

The barrette wall in this study measures 1 m in width and 5 m in length and is made from B35 concrete—a high-strength concrete suitable for structures subjected to large loads with a designed load-bearing stress of 10,000 kN. The construction process of the barrette wall involves excavating a deep trench according to the required dimensions, followed by the installation of a steel reinforcement cage and pouring concrete using the Tremie method to prevent voids and enhance structural durability [16-18]. The barrette wall is constructed directly on the natural soil foundation.

TABLE I. DESCRIPTIVE PARAMETERS OF SOIL LAYERS

Property	Symbol	Unit	Layer 8
Soil type			Sandy Clay
Natural void ratio	e		0.585
Unit weight	γ_{unsat}	kN/m^3	20.20
Saturated unit weight	γ_{sat}	kN/m^3	20.60
Direct shear test	C'	kN/m^2	4.3
	φ'	Deg.	30.8
Average SPT			190

The simulation process was carried out in a manner similar to a two-dimensional static compression test in field compression experiments (Figure 1) [19]. A 3D model of the barrette wall and the surrounding sandy clay environment was created to simulate the loading process (Figure 2). Finite element analysis was used to simulate the interaction between the barrette wall and the soil under various load levels [20], ranging from 0 to 40,000 kN (Table II). This model will calculate and compile the settlement values of the barrette wall at each specific load level. This method enables more accurate predictions of the mechanical behavior of the wall under various loading conditions.

Fig. 1. View of the test setup.

The data analysis process (Figure 3) begins with analyzing the data from experiments and simulations using cubic regression (Figure 4) to develop a model of the relationship between load and settlement displacement of the barrette wall [21]. The inflection point on the relationship model is then identified to determine the load level at which the change in settlement starts to accelerate rapidly. Once the inflection point is determined, linear regression is applied to both sides of this inflection point to establish the maximum load-bearing capacity of the Barrette wall, identified through the abscissa of the intersection of the two linear regression equations [21, 22].

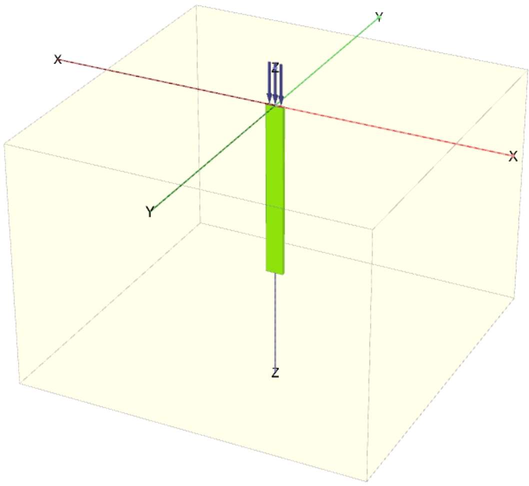

Fig. 2. 3D simulation model.

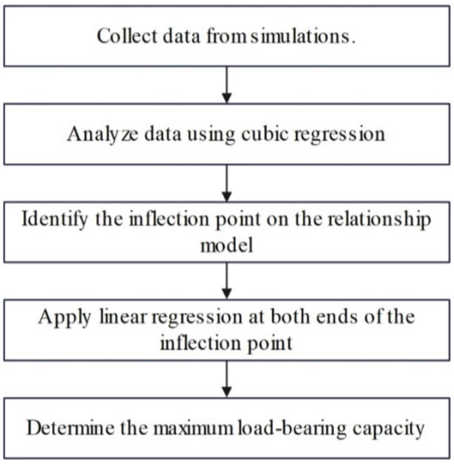

Fig. 3. Data analysis procedure.

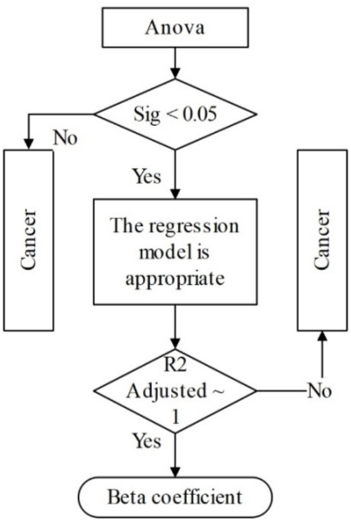

Fig. 4. Cubic regression analysis process.

TABLE II. DESCRIPTION OF LOAD LEVELS WITH CORRESPONDING TIME

Cycle	Load (kN)	Load holding time (min)
1	0	0
	2000	60
	4000	60
	6000	60
	8000	60
	10000	360
	5000	60
2	0	60
	5000	60
	10000	60
	12000	60
	14000	60
	16000	60
	18000	60
	20000	360
	15000	60
	10000	60
	5000	60
3	0	60
	2000	60
	4000	60
	6000	60
	8000	60
	10000	360
	12000	60
	14000	60
	16000	60
	18000	60
	20000	360
	22000	60
	24000	60
	26000	60
	28000	60
	30000	360
	35000	60
	40000	360

III. RESULTS

The results from the detailed simulation of settlement displacement changes of the barrette wall under different load levels, ranging from 0 to 40,000 kN, for Cycle 1 and Cycle 2 are presented in Table III, and for Cycle 3 are presented in Table IV. The 3D finite element model used accurately simulated the settlement process, indicating that the settlement gradually increases with the load levels, with a more pronounced increase at higher loads. The simulation data demonstrate a nonlinear relationship between load and settlement displacement, characterized by a sudden change in the slope of the load-settlement curve (Figure 5). The load-settlement relationship chart in the field static load test simulation for cycle 1 and cycle 2 can be seen in Figure 6. The cubic regression equation has effectively described the nonlinear relationship between the variables, with a high coefficient of determination ($R^2 = 0.999$), indicating a good fit of the model to the experimental and simulation data (Table V). The cubic regression curve demonstrated that at certain points, the settlement changes increase significantly, suggesting the occurrence of an inflection point.

TABLE III. SIMULATED COMPRESSION RESULTS (CYCLE 1 AND CYCLE 2)

Cycle	Load (kN)	Load holding time (min)	Settlement (m)
1	0	0	
	2000	60	-0.01168
	4000	60	-0.02347
	6000	60	-0.03579
	8000	60	-0.04974
	10000	360	-0.06734
	5000	60	-0.03814
2	0	60	-0.00808
	5000	60	-0.03748
	10000	60	-0.06792
	12000	60	-0.11087
	14000	60	-0.19172
	16000	60	-0.29364
	18000	60	-0.42627
	20000	360	-0.59861
	15000	60	-0.56906
	10000	60	-0.53878
	5000	60	-0.50359

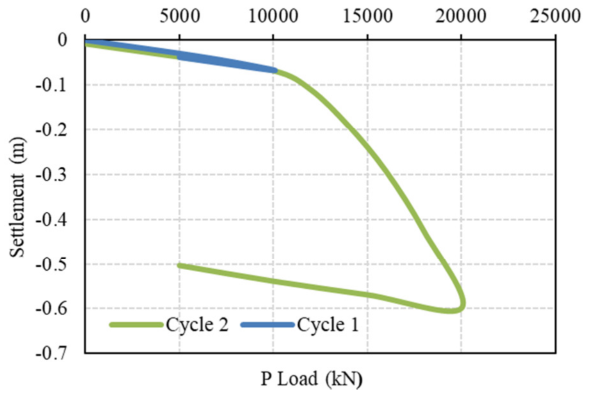

Fig. 5. Results of the field static load test simulation.

TABLE IV. RESULTS OF THE STATIC LOAD TEST SIMULATION (CYCLE 3)

Load (kN)	Load holding time (min)	Settlement (m)
2000	60	-0.011684094862
4000	60	-0.023470401842
6000	60	-0.035794390731
8000	60	-0.049739545508
10000	360	-0.067338264830
12000	60	-0.110562364952
14000	60	-0.191543074000
16000	60	-0.292858777000
18000	60	-0.426091959000
20000	360	-0.598480222111
22000	60	-0.809223220296
24000	60	-1.049828966765
26000	60	-1.315855878979
28000	60	-1.605990506680
30000	360	-1.914133270119
35000	60	-2.765036788381
40000	360	-3.714503967293

TABLE V. MODEL SUMMARY

R	R^2	Adjusted R^2	Std. estimation error
1.000	0.999	0.999	0.033
The independent variable is P load (kN).			

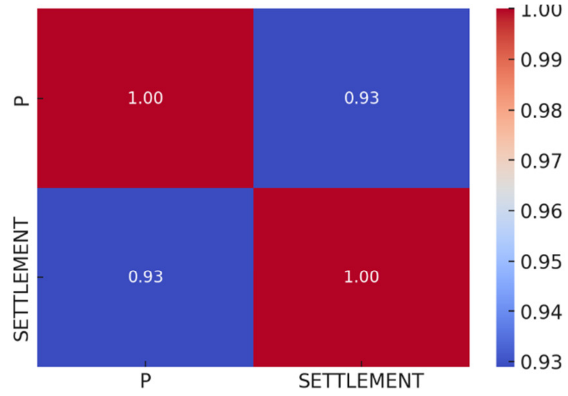

Fig. 6. Correlation matrix (load and settlement).

TABLE VI. ANOVA

	Sum of squares	df	Mean square	F	Sig.
Regression	18.640	3	6.213	5687.663	0.000
Residual	0.014	13	0.001		
Total	18.654	16			
The independent variable is P load (kN).					

In Table VI, the ANOVA results show that the Sig. value is 0, which is less than 0.05, indicating statistical significance and suitability for use in regression. The regression equation for the load-settlement relationship (Table VII) is:

$$Uz = 7E^{-15}x^3 - 4E^{-09}x^2 + 5E^{-05}x - 0.1465 \quad (1)$$

where: Uz is the settlement (m) and x is the load (kN).

TABLE VII. COEFFICIENTS

	Unstandardized coefficients		Standardized coefficients	t	Sig.
	B	Std. Error	Beta		
P load	4.707E-5	0.000	0.481	6.247	0.000
P load ** 2	-3.721E-9	0.000	-1.577	.	.
P load ** 3	7.443E-15	0.000	0.122	.	.
(Constant)	-0.146	0.037		-3.988	0.002

The inflection point on the regression model (Figure 7) occurs at a load level of P = 12,000 kN. The linear regression equations on both sides of the inflection point are in the form y = ax + b. The equation on the left has an R^2 of 0.9929, and the equation on the right has an R^2 of 0.9702, indicating that the model's accuracy is very high (Figure 8).

The ultimate bearing capacity is determined by solving for the x-coordinate of the intersection point of these two linear regression lines. The equation representing this intersection can be expressed as:

$$a_1x + b_1 = a_2x + b_2 \quad (2)$$

where a_1 and b_1 are the slope and intercept of the first linear regression line (left) and a_2 and b_2 are the slope and intercept of the second linear regression line (right).

Solving the system (2) yields P_{max} = 15,745.59 kN.

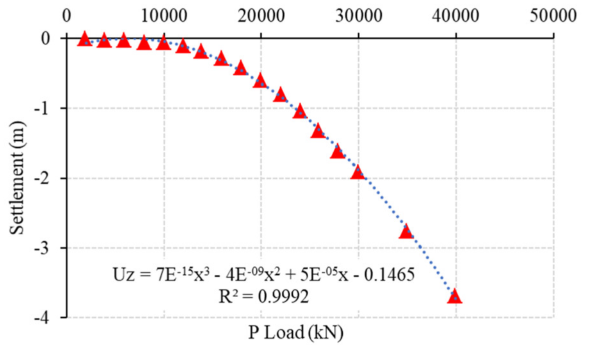

Fig. 7. Regression model of the relationship between load and settlement.

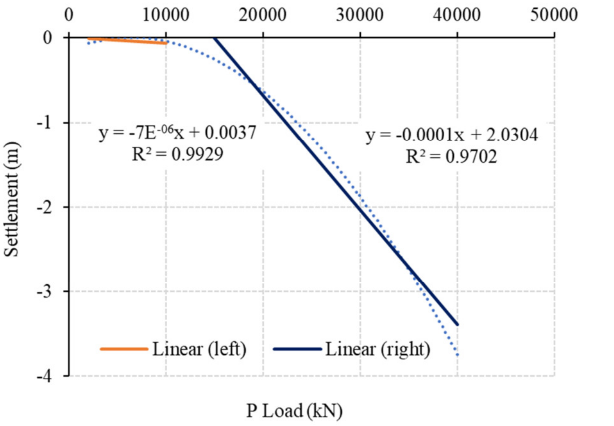

Fig. 8. Linear regression equations on both sides of the inflection point.

IV. DISCUSSION

The determination of the inflection point and influencing factors plays a crucial role in assessing the load-bearing capacity of the barrette wall. The inflection point is identified when there is a significant change in the slope of the load-settlement relationship curve, indicating a change in the mechanical properties of the foundation under different loading conditions. Factors such as soil compaction, water saturation, and construction methods can significantly affect the load-bearing capacity of the barrette. In our study, the inflection point was determined at a load level of 12,000 kN, indicating that under this load, the barrette wall begins to show significant changes in settlement.

When compared to previous studies, our results show high consistency with field static load test simulations, particularly in terms of the increase in settlement under higher load levels. This consistency suggests that the nonlinear regression analysis method used in our study can accurately simulate the load-settlement behavior of barrette walls and help determine the maximum load-bearing capacity to optimize the design.

Although the research results have provided deep insights into the mechanical behavior of barrette walls, some limitations still need to be considered. For example, the simulation test conditions do not fully reflect the actual variables present in the construction environment, such as soil layer heterogeneity and climatic factors. Furthermore, this study does not include dynamic or lateral loads, which could significantly impact the performance and stability of the barrette wall. To continue improving understanding and practical application, future research should focus on various loading scenarios and the impact of environmental factors on the barrette wall, along with incorporating 3D digital modeling and practical testing methods to enhance the accuracy of predictions and optimize foundation design.

V. CONCLUSIONS

The study has identified a nonlinear relationship between load and settlement, showing that settlement gradually increases with load, with a significant change in the slope of the curve at the inflection point corresponding to a load of approximately 12,000 kN. The cubic regression equation, with a coefficient of determination R^2 = 0.999, demonstrates the model's fit, validating the accuracy of the applied method. The inflection point on the curve describing the load-settlement relationship plays a crucial role in determining the maximum load-bearing capacity of the barrette wall. Notably, the initial design load capacity of the barrette pile was 10,000 kN, but through simulation, we determined that with this design, the actual load-bearing capacity could reach up to 15,745.59 kN, which is approximately 150% of the originally designed load capacity.

The results of this study clarify the nonlinear relationship between load and settlement of Barrette walls and identify the critical inflection point during the loading process. The novelty of this research lies in the use of cubic nonlinear regression combined with finite element analysis to accurately simulate the interaction between the barrette wall and the soil, enabling a more precise assessment of the ultimate bearing capacity. Compared to previous studies that primarily focused on linear relationships or isolated field tests, this study provides a more comprehensive perspective on the mechanical behavior of barrette walls under high loads. The findings not only enhance the understanding of load-bearing capacity but also offer a scientific basis for optimizing foundation design, improving efficiency, and ensuring safety in future large-scale construction projects. Additionally, these results open new avenues for research in improving simulation models and soil mechanics analysis. Specifically, the accuracy of these models can be enhanced by optimizing input parameters, strengthening the predictive capabilities of nonlinear algorithms, and integrating real-world factors such as changing environmental conditions or groundwater effects.

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