Study of Bored Pile Retaining Wall Using Physical Modeling

Amin Eslami, Jafar Bolouri Bazaz

***Abstract*—**Excavation and retaining walls are of challenging issues in civil engineering. In this study, the behavior of one important type of supporting systems called Contiguous Bored Pile (CBP) retaining wall is investigated using a physical model. Besides, a comparison is made between two modes of free end piles (soft bed) and fixed end piles (stiff bed). Also a back calculation of effective length (the real free length of pile) is done by measuring lateral deflection of piles in different stages of excavation in both aforementioned cases. Based on observed results, for the fixed end mode, the effective length to free length ratio (L_{eff}/L_0) is equal to unity in initial stages of excavation and less than 1 in its final stages in a decreasing manner. While this ratio for free end mode, remains constant during all stages of excavation and is always less than unity.

***Keywords*—**Contiguous Bored Pile Wall, Effective Length, Fixed End, Free End, Free Length.

I. Introduction

EXCAVATION and supporting retaining walls have been always encountered as a challenging issue in civil engineering works. Nowadays, there are a wide range of excavation stabilization methods each of which has its own advantages and disadvantages. The choice of each method is influenced by numerous factors such as geotechnical conditions, water table, soil layering, maximum retained height, the surrounding structures and importance, sensitivity, and economy of the project [1]. One of the widely used methods for stabilization of excavation is Contiguous Bored Pile Wall (CBP). This system provides both lateral and vertical bearing capacity and can avoid excessive bulk excavation, help to control ground movement, be installed in restricted working spaces and be cost effective when combined with capping beam in comparison with other similar methods. Execution of this system summarily consists boring the shaft piles, putting the armatures, concreting the piles and excavating the soil in front of piles, respectively. Besides, a capping beam is performed in order to keep unity of piles as a unit wall and prevent bulking of piles [2].

In this study, physical modeling of this type of retaining wall is performed to make a comparison between two modes of free end (soft bed) and fixed end (stiff bed). Furthermore, the ratio of effective length to free length (L_{eff}/L_0) is discussed with measuring lateral deflection of piles and back calculation of effective length.

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II. History of Physical Modeling

Physical modeling has an old background in Geotechnical engineering. Wen was the first who reported using model piles to study batter and vertical piles [3]. Numerous researchers have used small scale physical modeling and reached valuable results. Matlock and Ripperger worked on lateral loading of piles in cohesive soil using this method [4]. Prakash in his PhD dissertation performed static and cyclic tests to one groups of model piles embedded in sand and concluded that group effect were negligible for spacing greater than 8d (pile diameter) [5]. Davisson and Sally performed lateral load tests on lateral and vertical model piles to develop design criterions for foundations for rocks and dams for U.S. Army Corps of Engineers [6]. Park published a comprehensive study of seismic performance of steel encased concrete piles with focus on the structural behavior of these composite members under lateral loading [7]. And also there are other numerous studies in this field in the literature which their description is out of order for this article.

III. The Model Description

The model discussed is a steel box with length, width and height of 1.5, 1 and 0.8 m, respectively, filled with Firoozkooh[1] sand in order to model some piles with length of 80 cm and specifications listed in Table I. Also Soil properties are listed in Table II.

TABLE I
THE MODEL PILE PROPERTIES

Material	Elasticity Modulus (Gpa)	length (mm)	Outer diameter (mm)	Inner diameter (mm)	Thickness (mm)
Poly Propylene	2	800	32	21.2	5.4

TABLE II
SOIL PROPERTIES

Soil Type	Dry unit weight (kN/m^3)	Internal Friction angle (Degree)	Coefficient of lateral earth pressure
Firooz kooh sand	14.5	39	0.217

Fig. 1 shows the modeling system schematically. The test procedure was in such a way that execution and servicing of a CBP in the field could be modeled. In this study, investigation of two modes of free end and fixed end is carried out. In the case of fixed end, a plate with some welded bars for providing fixity in the end of model piles was used. The box was filled after placing the fixed piles. Then the soil in front of piles was

[1] A place in the North of Iran

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excavated gradually in 7 levels of 10 cm to the depth of 70 cm from the top of the box and the lateral deflection of piles were measured simultaneously in each stage of excavation. A wooden raft also was used as the cap beam to make the piles united and balanced. The procedure was the same for the mode of free end piles except that no fixity mechanism was used for end of the piles.

To measure the lateral deflection of piles during excavation, a number of 4 gauges with accuracy of 0.01 mm were installed to the central pile via some wires with the spacing of 15 cm from top to toe of the pile. Fig. 2 illustrates the gauges installing positions.

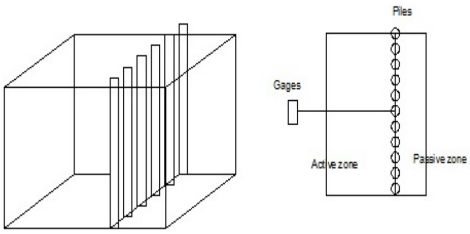

Fig. 1 Scheme and plan of the physical model

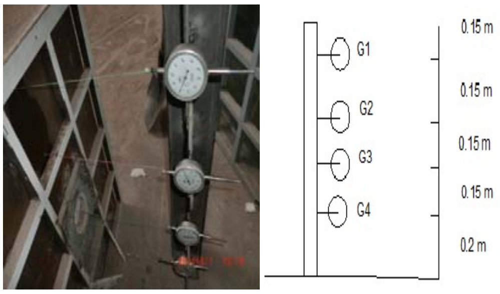

Fig. 2 Position of measurement gauges

IV. RESULTS

Figs. 3 (a)-(f) present the depth-horizontal displacement curves resulted from reading of gauge G1 in all 7 stages of excavation in both fixed end and free end modes. The curves are presented in order of excavation proceeding percentage.

As it can be observed, up to excavation stage of 25% of pile height, no lateral displacement is seen neither in fixed end nor free end modes. Reaching 37.5 % level the lateral deflection is started in fixed end mode, but still there is no deflection for free end mode. Proceeding excavation, the lateral deflection increases for both cases, but generally it can be said that despite the fact that the displacement in the case of *free* end piles starts later and slower, its increment ratio is faster and also its final displacement is more than the other case. Besides, cantilever behavior is clear in fixed end case as expected.

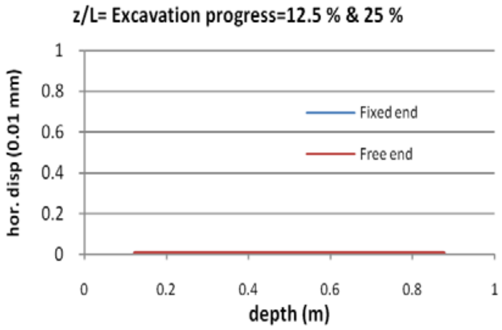

Fig. 3 (a) Excavation progress = 12.5 & 25 %

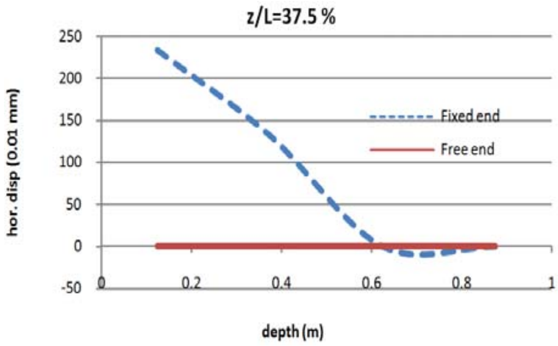

Fig. 3 (b) Excavation progress = 37.5 %

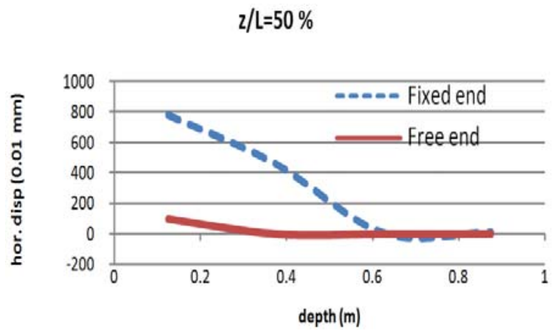

Fig. 3 (c) Excavation progress = 50 %

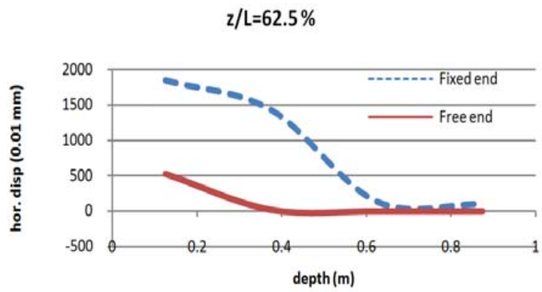

Fig. 3 (d) Excavation progress = 62.5 %

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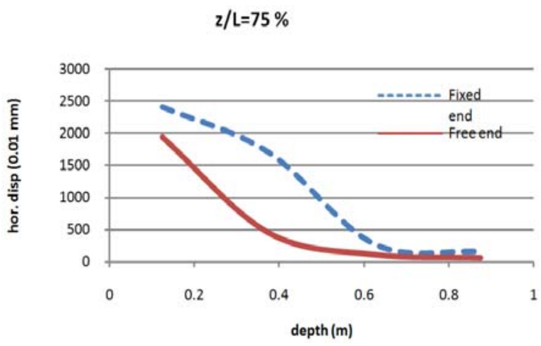

Fig. 3 (e) Excavation progress = 75 %

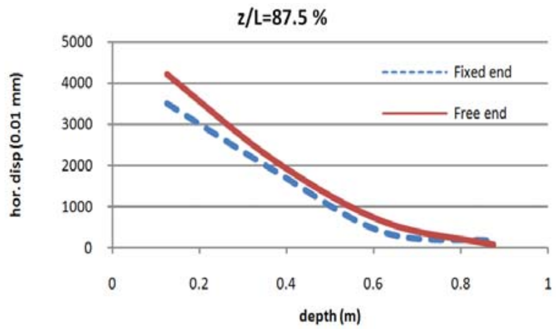

Fig. 3 (f) Excavation progress = 87.5 %

V. Discussion and Analysis - Effective Length

As it is known, the deflection of a cantilever beam under triangular extended loading (Fig. 4) is estimated by (1). [8]

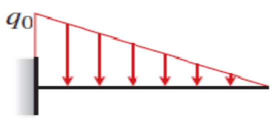

Fig. 4 Cantilever beam under triangular extended loading [8]

$$\delta_A = \frac{q_0 L^4}{30EI} \quad (1)$$

where δ, q_0, L and EI are deflection, load intensity, beam length and flexural rigidity respectively. On the other side, retaining wall behavior is similar to cantilever beam behavior due to similarity in loading and deflection nature. So it can be possible to estimate pile head deflection using (1).

The key point to be mentioned here is that in the case of piles of CBP, free length and fix length of piles are not exactly distinguishable because of the *soil* existing around the piles and *not* providing *absolute* fixity for piles by the soil. And that is where the effective length phenomenon stems from. The effective length (the real free length of pile) can be estimated with measuring pile head lateral deflection and back calculation using (1).

Fig. 5 illustrates the concept of free and effective length schematically.

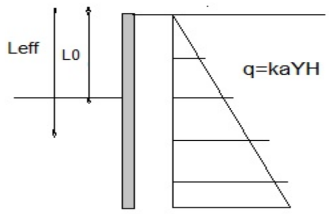

Fig. 5 Concept of effective length (L_{eff}) and free length (L_0)

Table III presents values of lateral deflection, free length, effective length and ratio of effective to free length (L_{eff}/L_0) in the last 4 stages of excavation.

The effective length is estimated using the measured deflection in each stage of excavation and putting into practice (4) with back calculation. It must be noted that in (2), ka, γ and L are lateral earth pressure coefficient, soil specific weight and pile length, respectively.

$$q = k_a \gamma L \quad (2)$$

$$\delta = \frac{k_a \gamma L . L^4}{30EI} \quad (3)$$

$$L_{eff} = \sqrt[5]{\frac{30EI\,\delta}{k_a \gamma}} \quad (4)$$

TABLE III
Effective Length And Free Length

Excavation progress		50 %	62.5 %	75%	87.5 %
*free length (cm)		25	35	45	55
** Lateral deflection (mm)	Fixed end	4.5	18.5	23	39
	Free end	3	7	20	43
***Effective Length (cm)	Fixed end	32	42	44	49
	Free end	20	28	36	45
L_{eff}/L_0	**Fixed end**	**1.28**	**1.21**	**0.99**	**0.90**
	Free end	**0.814**	**0.820**	**0.821**	**0.818**

* length of pile which it's front soil is excavated, subtracted by spacing from pile top to gage G1 (which is 15cm).
** Reading of gage G1 which is located in distance of 15 cm from pile top.
*** back calculated using (4)

The results show that in the mode of *fixed* end piles, the effective length is more than free length in initial stages of excavation (approximately 20%), but with advancing excavation this ratio decreases in such a way that these two lengths will be equal in final stages of excavation.

In *free* end case, the ratio of L_{eff}/L_0 remains constant and is always less than unity with value of 0.8. This happens due to the *non*-absolute fixity of soil as the support for piles and seems rational.

This shows that in *fixed* end mode, in initial stages of excavation the fixity of piles is mostly provided by the surrounding soil rather than the end fixity; therefore as a result of not being fixed absolutely, the effective length would be more than the free length.

On the other hand, by progressing the excavation the effect of end fixity increases (i.e. it is approaching the ideal condition for (1)) and effective length will be as equal as free length.

It is worthy to note that, in *free* end mode, with excavation progress, no change is seen in ratio of L_{eff}/L_0. This happens because in this mode, simply there is no change in fixity or supporting conditions for piles during all stages of excavation. So the ratio of L_{eff}/L_0 remains constant in this mode.

Vice versa, for *fixed* end mode, there is a dramatic change in fixity or supporting conditions from non-absolute fixity (in initial stages of excavation the supporting is provided by the soil) to absolute fixity (in the final stages of excavation the supporting is provided by the end fixity) during stages of excavation. That is why there is a change in ratio of L_{eff}/L_0 in this mode.

VI. Conclusion

- In this study, the behavior of Contiguous Bored Pile Retaining wall was investigated using physical modeling and a comparison was made between two modes of fixed end (stiff bed) and free end (soft bed) piles.
- Generally, displacement in the case of free end piles was initially less than fixed end case, but with proceeding excavation, displacement increment ratio increases in free end case and also the final lateral deflection for this case is greater.
- The pile effective length (the real free length of pile) was estimated with measuring lateral deflection and back calculation using present equations and also was compared with free length. In *fixed* end case, the value of effective to free length ratio (L_{eff}/L_0) was more than unity in initial stages of excavation and less than unity in the its final stages in a decreasing manner. While in the *free* end case, this ratio remained constant due to not having any changes in supporting/fixity conditions during all stages of excavation. In this case, the value of this ratio was always less than unity and approximately equal to 0.8.

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