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Research Paper

An experimental study and numerical modeling of laterally loaded regular and finned pile foundations in sandy soils

Bushra S. Albusoda[a], Anmar F. Al-Saadi[b], Abbas F. Jasim[c,d,*]

[a] Department of Civil Engineering, College of Engineering, University of Baghdad, Iraq
[b] World Bank Financed Project in M.O.E, Ministry of Education, Baghdad, Iraq
[c] Rutgers, The State University of New Jersey, Civil and Environmental Engineering Department, Piscataway, NJ 08854, United States
[d] Highway and Transportation Engineering Department, Al-Mustansiriyah University, Baghdad, Iraq

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ABSTRACT

A significant objective in the design and implementation of capable and cost-effective pile foundations is the enhancement of their lateral capacity when lateral load is applied. This study offers a nonlinear 3D analysis of pile-soil interaction. The ways that piles behave are examined in this research, with a sequence of laboratory model tests conducted to develop *p-y* curves of laterally loaded finned and regular piles in multilayered sandy soil from Karbala city in Iraq. To clarify the effects of group interaction, pile type, pile group patterns, and spacing ratios were analyzed, and from the investigational tests, *p*-multipliers values were identified.

1. Introduction

Many methods have been presented within the area of foundation engineering to determine the optimal lateral load capacity of piles. One of the principal and most complicated issues faced in this field is measuring the reaction of pile groups and individual piles to outwardly applied lateral load. The *p-y* curve method is commonly used to study this reaction; with a laterally loaded pile considered as a beam on an elastic foundation, and for the soil is replaced by an arrangement of independent narrowly spaced springs.

A succession of laboratory tests on laterally loaded model pile groups conducted by Kim and Yoon [1] examined the effects of pile groups in sand of a loose to medium density. The conclusions drawn were that pile spacing of over six times the pile diameter within a group appears to be great enough to eliminate the group effects of the pile for both loose and medium sand densities, and that each individual piles within a pile group behave identically to single pile. The *p*-multiplier factor, they concluded, offers an accurate, way of identifying the shadowing effects of laterally loaded vertical piles within a group. The *p*-multiplier factors were evaluated to be 0.84 for the lead row of the 3×1, 3×2, and 3×3 pile groups, 0.58 for the middle row, and 0.4 for the trail row. The typical *p*-multiplier factors for the middle and trail rows vary with the inconstant arrangements of pile spacing and pile groups in sand of loose and medium densities, and subject to the pile group type and its spacing.

A study by Gandhi and Selvam [2] conducted laboratory tests on aluminum pipe piles in cohesionless soil in order to investigate the behavior of fixed-head pile groups with different patterns when lateral load is applied. The behavior of bored piles was contrasted to that of driven piles, concluding that when the number of piles within a group increases, the efficiency of the particularly spaced pile group decreases, owing to the larger number of overlapped areas of active and passive wedges. As a result of the compression in a driven pile, the load factor α is greater than that of bored piles, and with spacing up to $s/d = 2$ (d = pile diameter) there is a linear increase in α for both bored and driven piles, otherwise the value of α stays fixed at 1 or thereabouts. In addition to this, the optimal spacing between group piles in regards to the maximum load capacity is found to be roughly double the comparative stiffness factor T. An experimental test on bored piles was also conducted by Franke [3], whose results demonstrated that when the spacing of the piles was less than 6d in the same load, the displacement of a group was greater than an individual pile. Whereas Yalcin and Meyerhof [4] performed experiments on small pile groups and flexible model piles in layered soil, comprising clay that overlaid sand, that were subjected to axial, lateral, inclined, and eccentric loads. They discovered that the ultimate pile capacity is reliant on the upper layer thickness to pile embedment ratio, and on the inclination and eccentricity of the load. Albusoda and Alsaddi [5] performed small scale of 25 model tests to evaluate the performance of different types of laterally loaded piles (regular, battered and finned) in layered sandy soil. Results revealed that there is a significant increase in the ultimate lateral load carrying capacity of single piles upon varying the piles type

* Corresponding author at: Rutgers, The State University of New Jersey, Civil and Environmental Engineering Department, Piscataway, NJ 08854, United States.
E-mail address: abbas.jasim@rutgers.edu (A.F. Jasim).

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Nomenclature

c	cohesion
C_C	coefficient of curvature
C_u	coefficient of uniformity
D_{10}	effective grain size
D_{30}	grain size at 30% passing
D_{50}	mean grain size diameter
D_{60}	grain size at 60% passing
d	pile diameter
D_r	relative density
EI	flexural stiffness
E_p	Young modulus of model pile
G4S3	pile groups consisting of 4 piles with spacing ratio of 3
G5S3	pile groups consisting of 5 piles with spacing ratio of 3
G4S4	pile groups consisting of 4 piles with spacing ratio of 4
G5S4	pile groups consisting of 5 piles with spacing ratio of 4
G4S6	pile groups consisting of 4 piles with spacing ratio of 6
G5S6	pile groups consisting of 5 piles with spacing ratio of 6
I_p	moment of inertia of pile cross section
L	length of pile
L_e	embedded length of pile
M_z	bending moment of pile at any depth
n_h	constant of the coefficient of horizontal subgrade reaction
P	unit soil pressure
T	stiffness factor
s/d	pile spacing ratio
y	lateral deflection of pile
$\varnothing^\circ$	angle of internal friction
δ°	angle of interfacial friction between aluminum and sand
γ_d	dry unit weight of soil
η	efficiency of ultimate lateral resistance of pile group

from regular to battered and finned.

A finned pile has been defined by Lee and Gilbert [6] as a pile with four plates that is welded at 90° to the top of a traditional monopile. Peng, Rouainia [7] offered a 3D examination of laterally loaded fin piles and asserted that the lateral load capacity of model tests on a monopile considerably increased with the introduction of fins. By measuring the lateral resistance against the displacement of the pile head, the rise in the lateral resistance when fins are applied to a pile can be revealed, and numerical analysis demonstrates that an increase in fin length leads to an increase in lateral resistance. Further to this, Nasr [8] conducted a number of tests on individual vertical and finned piles of varying sizes and shapes, concluding that when the diameter of the pile is equal to the fin width ($w_f/D_p = 1.0$) then the efficiency of the fin improved by about 75% for short piles, and 90% long piles.

This study offers a 3D computer simulation of laterally loaded regular and finned piles to examine the effect that pile type, pile group patterns, and spacing ratios have on the lateral resistance and capacity of the piles in sandy soil, using the information attained from the experimental tests to verify the results. To evaluate the possibility of fin piles decreasing foundation costs, it is important to mention that the numerical analyses were performed using the Mohr-Coulomb model.

2. Experimental setup

The small-scale model laboratory tests were performed in a testing setup that has been fabricated especially for this purpose. However, direct shear test for sand was conducted in order to obtain the angle of internal friction values for three different densities of sand representing each layer in the system. Fig. 1 shows a schematic diagram of the testing setup and direct shear test results for sand bed specimens. The testing setup consists of three main parts, which are steel tank, loading frame and raining system.

Testing tank made of mild steel consisting of four detachable sides of 4 mm thickness plates and a base of 6 mm thick plate, the tank was fabricated with internal dimensions of 1000 mm width, 1000 mm length and 800 mm height. One side of the testing container was fabricated with a square small door that can be used as a draining port for the sand inside the tank after completing the tests. An adjustable pulley arrangement was used as a lateral loading frame attached to the side wall of the steel box in which a steel wire is passed through to hold a static weight at one end while the other end is connected to the pile cap. The weights at the end of steel wire represent the lateral load acting on the piles as shown in Fig. 1(a.)

Finally, a raining system was manufactured to obtain a relatively homogeneous sand bed. Different sand relative densities could be obtained depending on the sand discharge rate and falling height. The

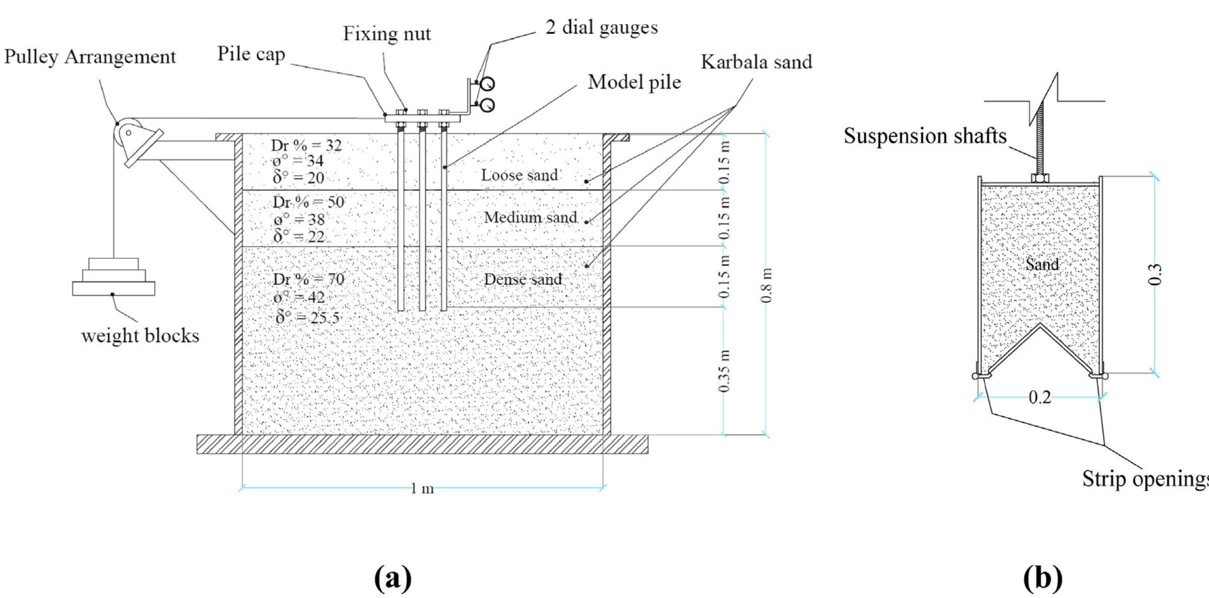

Fig. 1. Schematic diagram of (a) testing container and curtain miner hopper and (b) raining system.