Computers and Geotechnics 97 (2018) 62–68

Contents lists available at ScienceDirect

Computers and Geotechnics

journal homepage: www.elsevier.com/locate/compgeo

Technical Communication

Development of new prediction model for capacity of combined pile-raft foundations

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ARTICLE INFO

Keywords:
Piled raft
Rafts
Bearing capacity
Design
Finite-element modeling

ABSTRACT

The complex soil-structure interaction factors to estimate load bearing capacity of a combined pile-raft foundation (CPRF) is scarce. A new prediction method is proposed to estimate both Ultimate Limit State (ULS) and Serviceability Limit State (SLS) bearing capacity of CPRF by evaluating the pile-raft and raft-pile interaction factors. The developed model is validated with available experimental results. The simplified expressions for the evaluation of load-sharing ratio and a mobilized factor of safety of CPRF considering the serviceability requirement of the structure are also proposed. It provides a simple design solution for CPRF subjected to vertical loading condition.

1. Introduction

For foundations of high-rise structures, the conventional pile group foundation is still dominant in the current practice which does not give credence to the raft contribution in the pile group leading to over conservatism in the design. This is due to the limited understanding of how to incorporate the capacity of both raft and piles as a single unit. There may be two cases in the design philosophy, the first one, where a raft cannot provide an adequate bearing capacity and the other one, where the raft is unable to perform under the serviceability requirement of the structure. In both the cases, the piles can be introduced below the raft to improve the safety against failure or to reduce the settlement to an acceptable level. The foundation concept where piles can be used below the raft to achieve both the safety as well as the serviceability requirements, opens up the margin of the economy in the design solution, and is called a combined pile-raft foundation (CPRF) system.

Several researchers have advocated the use of piles below the raft as settlement reducers [1–4] with some available applications [5–7]. On the other hand, few researchers have supported the bearing capacity approach if flexural rigidity of the raft is very high such that differential settlement does not pose any issue [8–10] with few available applications [11,12]. However, none of them have put forward a simplified methodology that can combine both the safety and serviceability requirements in the design philosophy.

The present study proposes an expression to estimate both the Ultimate Limit State (ULS) and the Serviceability Limit State (SLS) bearing capacity of a CPRF embedded in the medium dense sand by employing finite element methodology. The proposed expression estimates the capacity of the pile and raft components of CPRF within a maximum difference less than ± 10% when compared with the measured results. Thereafter, the simple equations to predict the load-sharing response and mobilized factor of safety considering serviceability requirement of the structure are also derived.

2. Idealisation of load-bearing mechanism of CPRF

The superstructure vertical load applied on the CPRF can be expressed in terms of load-bearing capacity. It can be computed as the summation of the capacity of pile group (*written in terms of individual pile capacities*) and un-piled raft, multiplied with their interaction factors:

$$Q_{CPRF} = \alpha_{pr}\alpha_{pp}\sum_{n=1}^{n} Q_{\text{single pile}} + \alpha_{rp}Q_{unpiled\ raft} \tag{1}$$

in which, Q_{CPRF}, $Q_{\text{single pile}}$ and $Q_{unpiled\ raft}$ are the load-bearing capacity of the CPRF, single pile and un-piled raft foundation. α_{pr}, α_{pp} and α_{rp} are pile-raft, pile-pile and raft-pile interaction factors. These factors give rise to a complex load-bearing mechanism in the CPRF, as shown in Fig. 1(a). The compatibility condition of Eq. (1) lies in equal settlement of all components of the CPRF that confirms the rigidity of the system. At the design stage, the load carrying capacity of single pile and un-piled raft are only available parameters, hence, the prediction of these

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https://doi.org/10.1016/j.compgeo.2017.12.008
Received 12 October 2017; Received in revised form 7 December 2017; Accepted 15 December 2017
0266-352X/

Nomenclature

The following symbols are used in this paper:

A_p, A_s surface area and base area of the pile
D_P, B_r pile diameter and raft width
E Young's modulus
N_c, N_q and N_γ bearing capacity factors
P_s skin resistance along the pile shaft
q vertical stress at the foundation level
q_b end bearing pressure
Q_{CPRF}, $Q_{P\text{-}CPRF}$, $Q_{R\text{-}CPRF}$ load-bearing capacities of the CPRF, the piles in CPRF and raft in CPRF
$Q_{unpiled\ raft}$, $Q_{group\ piles}$ load-bearing capacities of the un-piled raft and the pile group
$Q_{single\ pile}$, $Q_{single\ pile,u}$ load-bearing and ultimate bearing capacity of the single pile
Q_r load-carrying capacity of the raft component of the CPRF
S pile spacing
w settlement
α_{CPRF} is the CPRF coefficient
α_{pp}, α_{pr}, α_{rp}, pile-pile, pile-raft and raft-pile interaction factors
ϕ friction angle
$\overline{\tau_s}$ average limiting shear stress down the pile shaft

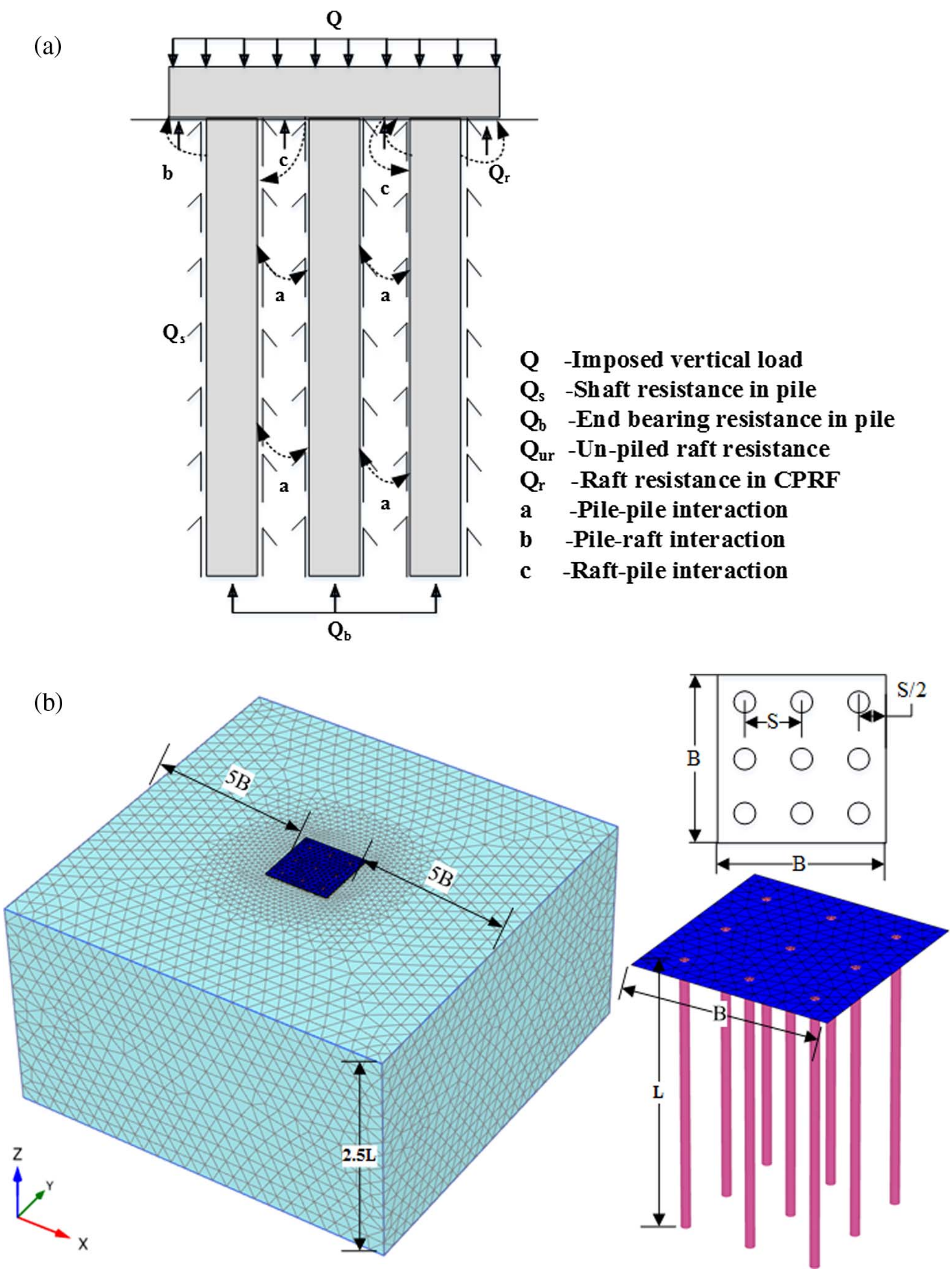

Fig. 1. Combined Pile-Raft Foundation (a) schematic representation of interaction mechanism, (b) discretised three-dimensional model.