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Behaviour of piled raft in pyroclastic soil

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Abstract

A piled raft is a composed foundation in which the raft is in contact with soil. The applied vertical load is transferred from the raft to the soil and to the pile heads. The load sharing between the piles and the soil is a function of the complex interaction among the raft, the soil and the pile. Considering the complexity of the problem, the best way to investigate about this interaction is to perform physical model tests at field scale. Vertical load tests on different types of foundations (single pile, unpiled raft, pile group with a free-standing cap and a piled raft composed by 5 piles) in pyroclastic soil have been performed. The raft settlement and the axial load distribution along the pile shaft were monitored during all the tests.

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Keywords: piled raft; vertical load test

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1. Introduction

Usually the project of a foundations works is based on the analysis of the interaction between the soil and the structural elements of either a shallow or a deep foundation. The conventional and somewhat out of date assumption when using deep foundations is that total load coming from the superstructure is entirely supported by piles with a little and generally neglected contribution of the connecting cap; there is an increasing trend in more up to date

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approaches to consider the piles only as settlement reducers when the bearing capacity of the cap is large enough to carry the total load with an adequate safety factor.

The piled raft is an alternative approach that combines both part of foundation (shallow and deep). The resistance and stiffness of a piled raft and load sharing mechanism between the raft and the piles are governed by complex raft-soil-pile interaction [1-4]. While the behavior of pile raft foundations on silt and clay soils is rather known, there are not many works on the application of this kind of foundation on granular soil [4]. For this purpose an experimental work was performed to analyze the behavior of pile raft foundations on pyroclastic soil; static load tests were performed on medium scale instrumented foundations.

2. Test site and subsoil investigations

The experimental field is located in Pascarola, a locality of Caivano municipality, in the north province of Naples (Fig. 1a). The subsoil is characterized by layered pyroclastic soils overlying a typical bedrock consisting of the ancient soft yellow tuff. The profile is a typical geological sequence in this area. The geotechnical characterization was based on site (CPT) and laboratory (triaxial and oedometer tests) tests. The experimental results are briefly summarized together with the proposed geotechnical model in Figure 1c,d and Table 1 [5].

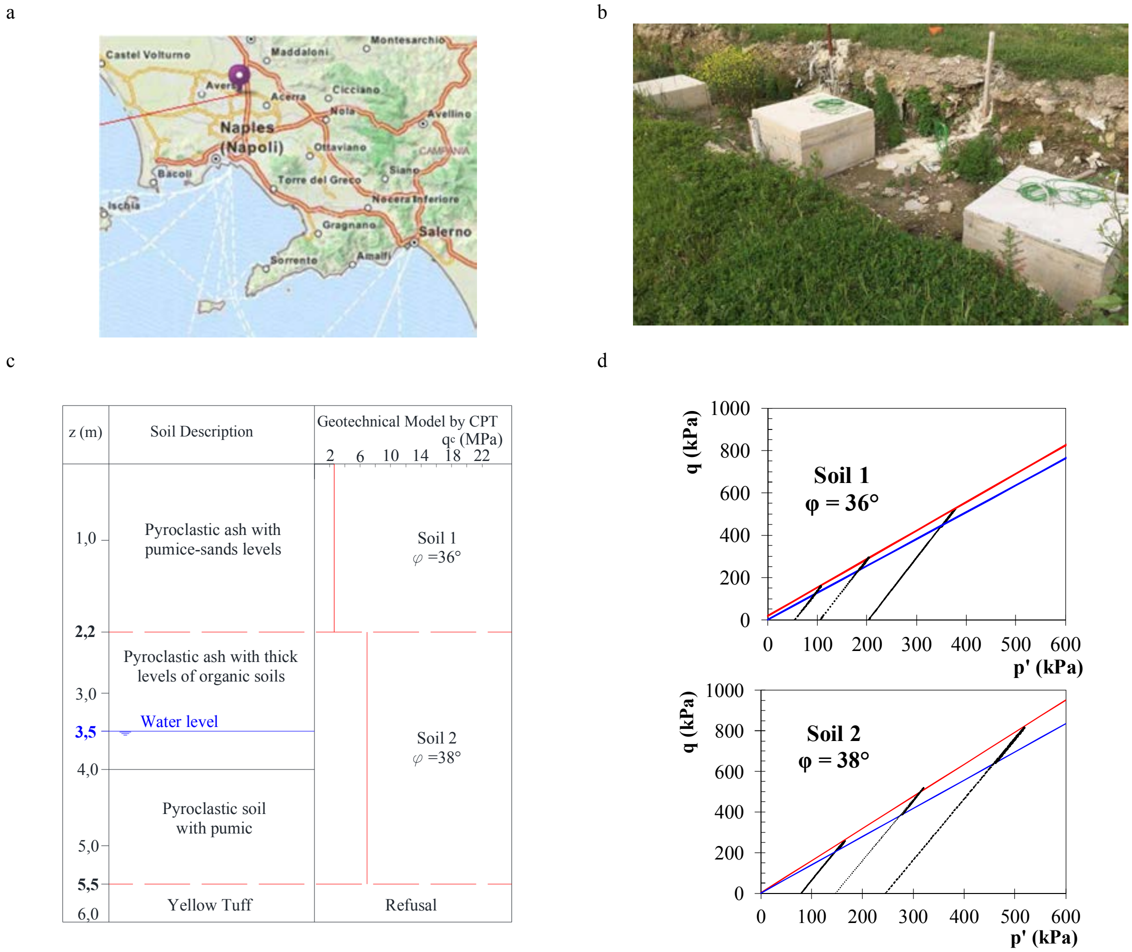

Fig. 1. (a) Test site, (b) Tested foundations, (c) Soil profile and CPT results, (d) Result of Triaxial test.

Table 1. Geotechnical Model

Soil	z (m)	γ (kN/m^3)	φ (°)	E (MPa)
1	0-2.2	15	36	3.1
2	2.2-4.2	15	38	10.9

In the test site four foundation models were realized (Fig. 1b); a single pile, an unpiled raft, a group of 5 piles connected at the top and a piled raft foundation. The piles have a diameter of 0.15 m and a length of 4.0 m, with spacing between piles of 4d (Table 2). For the pile group the raft is not in contact with the soil, while in the pile raft foundation also the plate transfers load to the soil (Fig. 2a).

To monitor the shaft load transfer along the piles, strain gauges at the top, in the middle and at pile tip were installed. The scheme of load measurement in the experimental load test is shown in Figures 2b,c.

Table 2. Geometrical features of the tested prototype

Geometric dimensions			
l_{pile}	4 m	s_{pile}	0.6 m
d_{pile}	0.15 m	L_{raft}	1.2 m
n_{pile}	5	H_{raft}	0.7 m

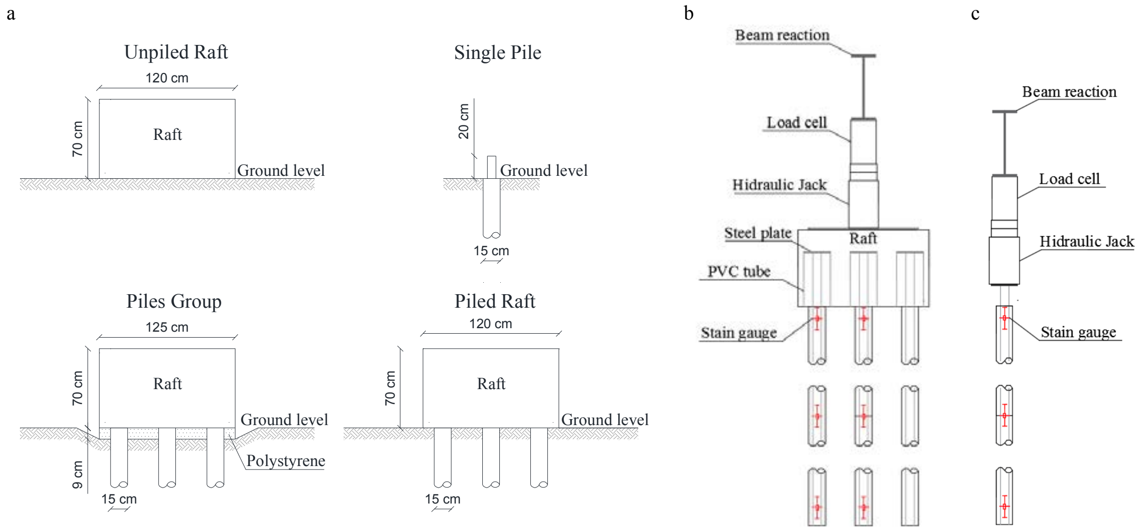

Fig. 2. (a) Types of foundation, (b) Instrumentation scheme of pile group, piled raft, (c) single pile.

3. Experimental result

3.1. Load tests

The load-settlement curves of the single pile [6,7], of the 5 piles group and of the piled raft are shown in Figure 3a. The programmed load test on the unpiled raft was temporary delayed and for this reason is not reported herein. In the Table 3, the bearing capacity of foundations are plotted as a function of two different settlement range: in the literature is typically suggested that the ultimate loading conditions may be considered conventionally as those corresponding to a settlement ranging from 0.1d to 0.25d.

For the single pile, it was possible to separately determine the shaft (S) mobilized resistance and the base (B) one just making proper used of the strain gauges measurements (Fig. 3b).

As clearly shown by the load settlement curves the shaft resistance is nearly fully mobilized for very small settlement; after this initial stage the total load has only minor increments which are fundamentally absorbed by the mobilization of the tip resistance (see Table 3).

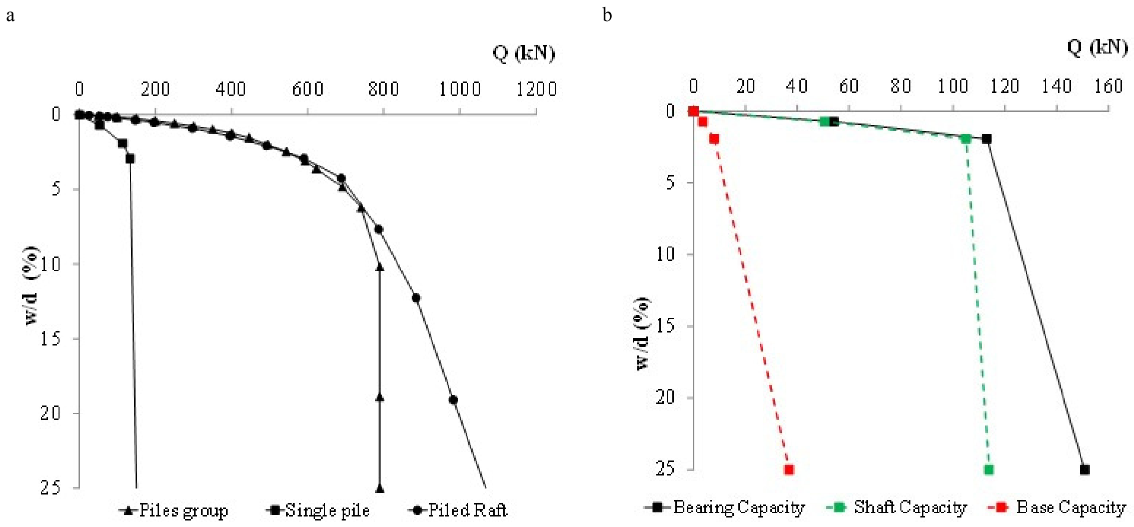

Fig. 3. Load-settlement curves of foundations: (a) Total load of different foundation, (b) Total, shaft and base load of single pile.

Table 3. Values of load at different settlement level

Types of foundation	w/d (%)	Q (kN)	S (kN)	P (kN)
Single pile	10	125.77	108.01	17.73
Piles group		787.74	-	-
Piled raft		837.37	-	-
Single pile	25	149.47	113.59	35.87
Piles group		789.50	-	-
Piled raft		1067.62	-	-

The bearing capacity of the pile group Q_G, is generally expressed in relation with the bearing capacity of the single pile Q_P. It is generally assumed as proportional to the number of pile n in the group and to a coefficient of *"efficiency "η* of the group according to the equation [1]:

$$Q_G = \eta \cdot n \cdot Q_P \tag{1}$$

In recent literature the coefficient η is defined at different load or settlement level and is not only associated to the ultimate bearing capacity. As such it was found that the efficiency is close to 1 at large displacement and decreases with increasing settlement (Table 4). The increase of bearing capacity of the piled raft system due the beneficial contact between the raft and the soil maybe expressed by the ratio between the bearing capacity of the piled raft Q_{PR} and that of the pile group Q_G following equation [2]:

$$\zeta_{PR} = \frac{Q_{PR}}{Q_G} \tag{2}$$

In the present experiment the contact between raft and soil produces an increase of the bearing capacity slightly exceeding 1/3 of the bearing capacity of the free standing pile group. For settlement lower than one tenth of the pile diameter, on the other hand, the contact of the raft is practically ineffective (Table 4).

Table 4. Values of increase of bearing capacity from single pile to piled raft

w/d (%)	η (-)	ζ_{PR} (-)
10	1.25	1.06
25	1.06	1.35

3.2. Evaluation of the load sharing among the piles in the group

During the load test on the free standing piles group the total load applied on the floating cap is of course known. To obtain the load transferred on each pile, it is necessary to define some hypothesis:

1) In the hypothesis of load perfectly centred on the raft and piles with same axial stiffness, it is possible to express the condition of vertical equilibrium with the following equation:

$$Q = EA \cdot \varepsilon_{central} + 4 \cdot EA \cdot \varepsilon_{corner} \tag{3}$$

where ε is the deformation at the top of different piles and EA is the axial pile stiffness. The equation (3) is used to determine the EA values, which in turn allow to calculate the load on top of the corner and the central pile. In Table 5 the obtained experimental value of EA is reported together with the nominal one.

Table 5. Values of medium and nominal stiffness of piles (EA)

	EA (kN)
Medium	$2.55 \cdot 10^5$
Nominal	$3.91 \cdot 10^5$

2) With the aim of using the info obtained during the experiment in terms of differential settlement at the four corner of the plinth, the following equation representing again the vertical equilibrium maybe written:

$$Q = k \cdot \sum_{1}^{n=5} w_i \tag{4}$$

This equation hold true only if there is no interaction between the piles and they behave as independent springs (Winkler model). In Figure 4a the load settlement curves for both the central and the corner pile of the group obtained with the hypothesis 1 are plotted together with the load–settlement curve obtained simply by dividing the total load applied to the group for 5.; the figure shows that the central pile is less loaded of the corner piles [4] as it could be expected beneath a rigid cap.

In Figure 4b the load-settlement curves obtained in the hypothesis 2 are plotted. It is clearly shown that the central pile is behaving as the average pile in the group while the monitored corner pile is absorbing lower load compared to the central pile, due to a possible eccentricity of the applied load on the raft.

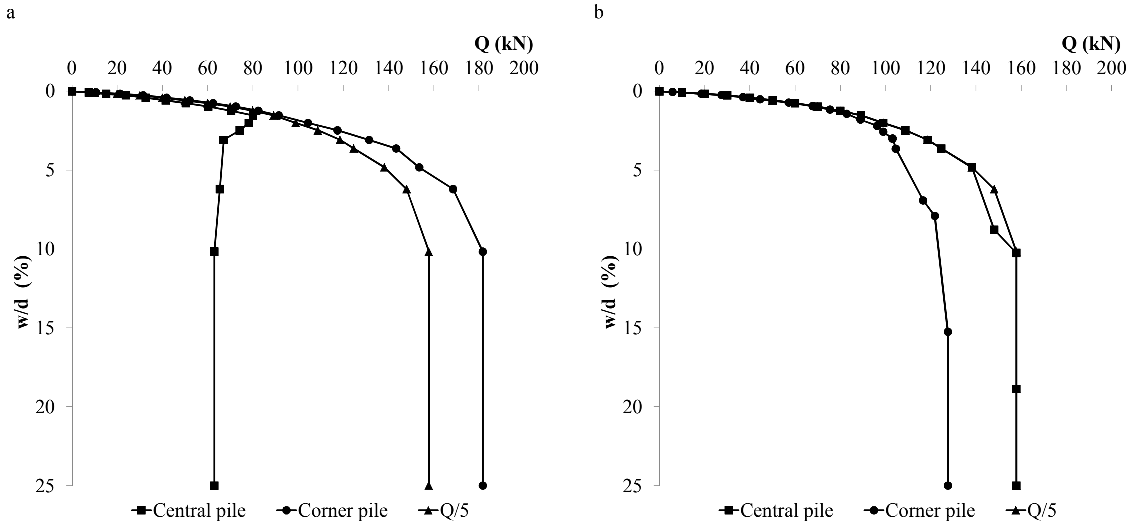

Fig. 4. Load-settlement curves: (a) Hypothesis 1, (b) Hypothesis 2.

4. Conclusion

Tests were carried out on different foundations layout with the aim to investigate the mechanisms governing the load-settlement behaviour and the load sharing for piled raft systems. Only preliminary interpretations have been carried out for the present paper. The load sharing mechanism between piles and raft depend on the loading stage; at the initial stage the load is mainly absorbed by the piles that are stiffer then the surrounding soil. Almost complete mobilization of their capacity occurs at settlement of about 0.1d. Only when the bearing capacity of the pile group is fully mobilized the raft start transferring load directly to the soil [8]. The further test on the unpiled raft and the evaluation of the real load applied on the instrumented piles, obtained by the calibration of the load cells constituted by the top pile section containing the strain gauge, will be able to supply more information useful for a better evaluation of the real distribution of the load among the piles. The full back-analysis of the various tests will be carried also by appropriate computer codes [9,10].

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