

Crosswise-loaded short and long piles in artificially cemented top sand layers embedded in lightly bonded residual soil

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Abstract

Twenty-six crosswise-loaded short (rigid) and long (flexible) piles were tested in artificially cemented top sand layers embedded in lightly bonded residual soil. The dimensions of the artificially cemented top sand layer around the piles varied from about 2 to 4 times the pile diameter and 0.1 to 0.3 times the pile length. Slope indicators were used to measure horizontal displacements in short and long piles. The field results present an important enhancement in the performance of the short and long piles under crosswise load when the artificially cemented top sand layers increase the total lateral area compressing the lightly bonded residual soil, increasing bearing capacity and reducing the maximum horizontal displacement at any given working load. At failure, a unique linear relation is observed between the crosswise load of both the short and long piles and total lateral area compressing the lightly bonded residual soil. Such finding helps to determine the foundation-residual soil interaction mechanism and provides sound normalization for test results, both considered necessary steps towards the development of a design concept for predicting the crosswise-loaded pile response.

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1. Introduction

Lightly bonded residual soils are a result of the *in situ* weathering of rocks. The interparticle bonding in residual soils is created by the crystallisation associated with the formation of mother rocks and the precipitation of mineral cells (Leroueil and Vaughan, 1990). The porous cemented structure leads to distinctive geotechnical characteristics quite different from those of transported soils with similar densities and grain size distributions. According to Consoli

et al. (1998) and Schnaid and Mantaras (2003), prestressing lightly bonded residual soils results in substantial damage to the cemented structure with a considerable reduction in initial soil stiffness. According to the same authors, it is important to notice that the result of prestressing slightly bonded residual soils is in contrast with the ordinary patterns obtained by overconsolidation, where soil stiffness is expected to increase with increasing maximum past mean consolidation stress.

The performance of short and long piles subjected to crosswise loads is controlled by the properties of the soil near the surface (Simons and Menzies, 1975; Poulos and Davis, 1980; Faro et al., 2015). It is for this reason that Simons and Menzies (1975) recommend replacing poor surface soils by compacted gravel. Poulos and Davis (1980) presented an overview of methods conceived to

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Nomenclature

A_{mob}	Area under compression mobilized at the pile shaft	L_{cem}	thickness of cement treated layer
D	diameter of pile	L_n	LVDT reading at a specified time interval t
D_{cem}	diameter of artificially cemented top sand layer	L_{n-1}	LVDT reading immediately previous to L_n
H	horizontal load	L_1	first LVDT taken just after loading application
$H_{failure}$	crosswise load failure	q_u	unconfined compressive strength
L	length of pile	V_{cem}	volume of artificially cemented top sand layer
		δ	horizontal displacement

increase the crosswise resistance of piles by increasing the dimensions and/or stiffness of the piles near the ground surface. These methods comprise the use of sand or gravel fills, the insertion of wings around the pile, concrete collars, mortar and even short piers or beams surrounding the piles.

Field-tests in crosswise loaded piles were carried out by Almeida et al. (2011) in a lateritic soil profile in order to establish values of coefficient of soil reaction. Consoli et al. (2016) subjected long piles to a transverse load in residual soil sites and found out that lightly bonded residual soil is not suited for analysis as a sedimentary fine-grained soil once the pile–soil interaction is analysed. Tomisawa and Nishikawa (2005) developed a design method to determine the horizontal resistance of piles constructed in improved ground. The study presents a rational design method in which ground improvement is conducted around piles constructed in soft ground and ground subjected to liquefaction, where the ground strength after improvement is reflected as horizontal resistance. Rollins et al. (2010) performed full-scale lateral load tests on a pile group in clay before and after the assemblage of soil mixing and the jet grouting of walls on either side of the pile group. According to the authors, both soil mixing and jet grouting resulted in a significant increase in the transverse load of pile clusters. Although these results provide important insights to pile design, there is no established method to estimate the failure crosswise load of piles surrounded by artificially cemented top sand layers embedded in lightly bonded residual soil. The response ought to take into consideration the lateral resistance of the adjacent lightly bonded residual soil, which controls the performance of the pile (Faro, 2014).

In the present research, an attempt is made to extend these early views by interpreting the results of twenty-six (26) crosswise load tests carried out in rigid and flexible piles surrounded by artificially cemented top sand layers (considering their distinctive thicknesses and diameters) embedded in lightly bonded residual soil. Different improved top layers geometries were tested under a particular diameter-to-length ratio and, based on these results, an attempt is made to normalize data in order to help the development of design methods. It follows studies of the bearing of shallow foundations in cement treated layers

(Consoli et al., 2008) and plate anchors subjected to pullout loads (Consoli et al., 2013), as well as rigid piles embedded in cement treated soils subjected to lateral load (Faro et al., 2015).

2. Soil characteristics

The present investigation reports data from crosswise loaded piles in artificially cemented top sand layers embedded in lightly bonded residual soil. Subsequent to pile execution and prior to the compaction of the cement-stabilized top sand layers, the local soil was carefully excavated to the volumetric geometry of the cement treated soil layer to be built.

Appropriate sand-cement mixing and compaction are essential factors for the suitable performance of the pile system. To permit assessment between attained field compaction and lab referential values, the field water content, density and compression strength were carefully measured. Overall, the backfill control indicated a homogenous mass with the characteristic values presented herein.

2.1. Homogeneous lightly bonded residual soil stratum

In situ cone penetration (CPT) tests were carried out to establish the main features of the studied residual soil site. The CPT profile up to 15 m depth at a testing location is shown in Fig. 1. The homogeneity of the residual soil stratum is clearly observed and slight variations in the cone tip strength (q_t) are attributed to the progression of weathering, a usual characteristic of residual soil sites. The friction ratio (R_f), expressed as a percentage of the sleeve friction (f_s) to the cone tip strength (q_t), both measured at the same depth, is around 6.0% in the whole profile. This value is typical of clayey soils. According to USCS, the residual soil was ranked as a low plasticity clay (CL). The dry unit weight was around 12.1 kN/m³ and the water table was found at about 10 meters depth. The unconfined compressive strength was 51.2 kPa (average value), varying (5 specimens tested) between 46.6 kPa (minimum value) and 59.3 kPa (maximum value). The effective friction angle of 31.8° and effective cohesion intercept of 23.8 kPa were computed after triaxial test (see Fig. 2 for typical stress-strain curves) results. It is important to note that increasing the confining

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