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Full-scale experimental assessment of the dynamic horizontal behavior of micropiles in alluvial silty soils

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ABSTRACT

The paper deals with an extensive experimental campaign of dynamic tests performed on full-scale vertical injected and not injected micropiles embedded in alluvial soils. The experimentation includes ambient vibration and impact load tests to investigate the dynamic behaviour of the soil-micropile system in very small and small-medium strain ranges, as well as snap back tests to investigate the evolution of the post-elastic response of the system. Micropiles are instrumented with strain gauges along the shaft, accelerometers and displacement transducers at the head. Modalities and results of the different performed tests are presented, focusing on the role of high pressure injections on the dynamic behaviour of the system, on the development of non-linear soil-pile phenomena, and, finally, on the evaluation of effectiveness of the different testing procedures to capture the dynamic response of soil-micropile systems.

Ambient vibration test revealed to be a versatile method to identify the dynamic properties of soil-micropile systems, although it requires demanding post-processing techniques of data. Impact load test is faster to perform and easier to post process. Free vibration test proved to be relatively simple to perform and able to catch the dynamic non-linear behaviour of soil-micropile systems.

1. Introduction

In the last 50 years many developments have been achieved in the research field of dynamic soil-pile-structure interaction, from both a theoretical and experimental point of view. With reference to the soil modelling, available methods for the investigation of the problem can be roughly classified into three main typologies: *i)* analytical solutions of continuum formulations, in which the soil is considered as an elastic medium [1–3]; *ii)* Winkler-type methods, which allow the linear and non-linear (p-y curves) soil-pile and pile-to-pile interactions be captured avoiding the direct modelling of the soil (exploiting both analytical or numerical approaches) [4–9] and *iii)* finite element, boundary element or finite differences methods, available in both frequency [10–12] and time domain, which are able to account for the soil non-linear behaviour [13–15]. All these approaches require a proper validation and are based on parameters that need to be properly calibrated. Experimental tests are therefore essential to increase their reliability.

The most of dynamic experimental tests currently available in the literature consists of small-scale laboratory tests (likely centrifuge and shaking table tests), carried out -under controlled and repeatable conditions, in which the seismic loading can be also simulated. As an example, the experimental tests of Meymand [16], Escoffier et al. [17] and Durante et al. [18] can be mentioned. On the other hand, in-situ full-scale tests have the advantage of accounting for the real interface and boundary conditions, as well as the effective soil and pile characteristics. Examples of full-scale (free vibration and forced vibration) tests on piles with small-to-large diameters can be found in the works of Alpan [19], Petrovski and Jurukovski [20], Novak and Grigg [21], Scott et al. [22], Blaney and O'Neill [23,24], Sa'don et al. [25] and Dezi et al. [26,27]. Moreover, in-situ tests are potentially able of capturing the effects of actual installation and executive procedures on the static and dynamic response of the system [28].

The last point is of great significance for micropiles, i.e. small-diameter cast-in-situ bored piles formed by cement grout injections and equipped with lost, steel reinforcement elements. Many different typologies of micropiles with progressively improved performances have been developed starting from the original *Radice* micropiles or root piles, in which, after drilling and positioning the reinforcement bar (a single bar or a small steel cage), a cement slurry is pumped from the bottom of the hole. The *Tubfix* micropile is one of the most common typology in Europe, in which a steel tube, equipped with no return valves (*valves a manchèttes*) and with a bottom plug at the tip, is

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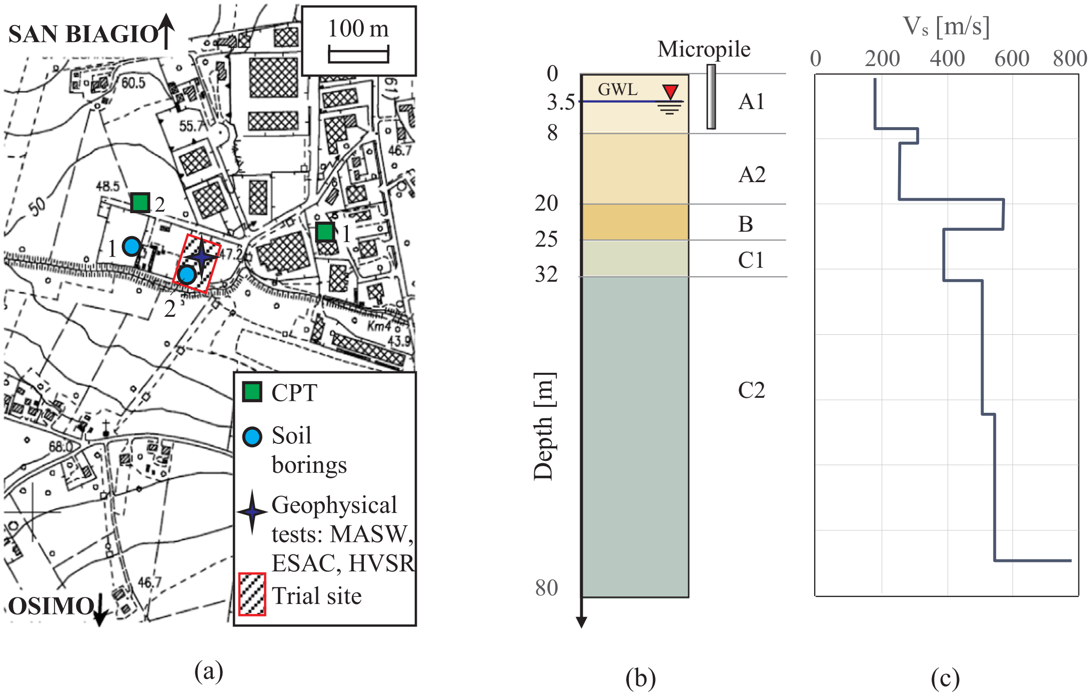

Fig. 1. (a) Position of the test site and geotechnical surveys; (b) geotechnical model; (c) shear wave velocity profile from geophysical tests.

positioned in the drilled hole; a primary neat cement grout fills the annular space between the bar and the soil; before the hardening of the primary grouting, high-pressure injection is realized through the bottom plug, in order to obtain a bulb at the micropile tip, and several (even repeatable, if necessary) high pressure injections are realized at predefined depths throughout the valves a manchèttes placed along the steel bar. Injections, performed by means of a double effect piston at a pressure ranging from 2 to 8 MPa, are supposed to break the sheath formed by the primary grouting, enlarging the section of the micropile while displacing and compacting the surrounding soil. Thanks to their simplicity of execution and their capacity to be installed in low-headroom and narrow places, micropiles are increasingly used as foundations of new constructions and to strengthen foundations of existing structures in seismic areas. Despite the growing use of micropiles, results from static and cyclic lateral load tests on micropiles are limited [29], as well as dynamic test on small-scale prototypes, i.e. [30–32], and dynamic field tests data on micropiles are lacking in the scientific literature.

The present paper deals with an experimental campaign of dynamic tests carried out on full-scale micropiles embedded in alluvial soils. The aim of the study is the investigation of the dynamic response of soil-micropile systems under horizontal loading in different range of deformation (in the linear and non-linear field). Different typologies of tests are carried out on two single vertical micropiles characterized by different executive techniques, injected and not injected. The advantage of these full-scale in-situ tests on micropiles is to provide experimental data obtained accounting not only for the full-scale dimensions of the components and the actual soil fabric and structure, but also for the actual soil modification due to adopted installation procedures and the resulting soil-micropile interface conditions. These data can be precious for the validation of advanced models of the dynamic response of micropiles and for the evaluation of the predictive capacity of simplified soil-pile interaction models when applied to micropiles. Moreover, such tests can also be useful in the design procedure of structures for which dynamic soil-structure interaction plays a significant role. For instance, in such cases, the designer could consider the usefulness of executing specific field tests (i.e. by realizing a real scale trial micropile) to evaluate the dynamic response of the foundation element in the soil of interest. In-situ dynamic tests on micropiles could also be useful for the seismic retrofitting of existing structures (both buildings and bridges) when new micropiles are installed in adjacency to the existing foundation system. In fact, tests on the added foundation elements can be carried out in a specific test field or, when possible, on the new micropiles before connecting them with the existing foundation. In this case, dynamic in-situ tests carried out on the micropiles can be useful to obtain specific indications on the real dynamic response of the foundation element in the examined soil and to allow an accurate modelling of the retrofit intervention able to take into account seismic soil-foundation-structure interaction considering both the existing and the new foundation.

In this paper, ambient vibration tests are preliminary carried out to investigate the dynamic behaviour of soil-micropile systems in the very small strain range produced by the ambient noise; then, lateral impact loading tests are executed to investigate the response in the small to medium strain range; finally, snap back tests, performed by progressively pulling the micropiles up to a force inducing the sudden failure of a calibrated steel pin, allowed the evaluation of the non-linear response of the soil-micropile system during its free oscillations. The effectiveness of the different testing procedures, pioneering adopted to capture the dynamic response of soil-micropile systems, is also discussed.

2. Site description

The test site is located in the industrial area of San Biagio - Osimo (a town of the Marche region in Central Italy), which, from the geomorphological point of view, is a wide almost flat area with low altitudes set at almost 50 m above the mean sea level. With reference to Fig. 1, the geological configuration of the site is constituted by two main formations: a Plio-Pleistocene marine deposit prevalently composed of Pleistocene marly clays (weathered in the first part, C1, and intact with depth, C2) underlying a recent continental covering soil that mainly consists of Quaternary (Pleistocene-Holocene) eluvial-colluvial (silty sands and clayey silts, A1) and Plio-Pleistocene alluvial (mainly clayey silts and clays, A2) deposits. Locally, above the Plio-Pleistocene clayey substratum, lenses of gravels and sands in clayey-silty matrix can be found (B). Before the execution of the experimental campaign, data