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Seismic response of a pile-supported excavation on Santiago gravel

E. Sáez*, G.S. Pardo, C. Ledezma

Department of Structural and Geotechnical Engineering, Pontificia Universidad Católica de Chile, Vicuña Mackenna 4860, Macul, Santiago, Chile

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ABSTRACT

Non-secant anchored piling support is one of the most frequent earth-retaining systems for temporary deep excavations in Santiago, Chile. The main advantages of using non-secant piling support are their relatively low cost and ease of installation. This system is particularly efficient on stiff soils with deep groundwater table, conditions usually found in Santiago. This paper presents the results of a numerical investigation aimed to study the characteristics of earthquake-induced lateral pressures on a recent pile-supported excavation 26 m deep. The estimated static deformations of the piles were compared against some measurements performed during the excavation. The dynamic pressures, and their influence on the piles' internal forces, were evaluated using a synthetic Ricker wavelet in the numerical FE model. Two kinds of FE models were developed, an approximate 2D-plain strain model and a fully 3D model. The accuracy of the 2D model on predicting static and dynamic lateral pressures was also investigated.

1. Introduction

Discontinuous piling support (non-secant piling support) is one the most frequent forms of retaining systems for temporary deep excavations in Santiago, Chile (Fig. 1a). The main advantages of using discontinuous piling support are its relatively low cost and ease of installation. The system is particularly efficient in stiff soils with deep water tables, conditions usually found in Santiago. A proper design of this type of retaining system must prevent its failure and avoid damage to existing nearby structures; the latter is a crucial component of the seismic verification of temporary pile-supported excavations. Unfortunately, there are very few studies concerning the dynamic behavior of pile-supported excavations and earthquake-induced lateral pressures on non-secant piling support. This is partly due to the difficulty of properly including the arching effect, which is a 3D phenomenon that controls the mechanical behavior of this kind of discontinuous pile-supported excavations. In general terms, this effect consists on the redistribution of stresses from a yielding mass of soil to adjacent less-yielding, or restrained, portions of the soil mass.

The phenomenon of arching has been recognized for decades, but research on this topic has been sporadic and usually focused on particular problems. Probably, the most familiar application of the vertical arching effect is present in tunnel design. In the field of geotechnical engineering, one of the most important contributions was made by Terzaghi in 1943 [33], who explained the phenomenon as the pressure transfer from a yielding mass of soil to adjacent rigid boundaries through the "trap-door test". This pressure transfer phenomenon was called "arching". The trapdoor test has been extensively discussed using analytical and numerical methods (e.g., [11,12,25]). Numerical modeling has also been used to evaluate the role of the arching effect on the static lateral pressures. Most of these studies have focused on geotechnical engineering applications of the arching effect that differ from the one presented in this paper (e.g., [20,7]). On the topic of potential benefits of the arching effect on pile-supported excavations, the available literature is very scarce (e.g., [34,13]).

Regarding the specific topic of discontinuous pile-supported excavations in Santiago gravel, there is some field data available from an underpinned excavation instrumented in 1982 [6,3], and recently, some field measurements from an excavation instrumented with inclinometers in Santiago have become available [32,27] (Fig. 1b). Additionally, some numerical studies have been conducted to study the arching effect in static condition [21,10]. On the other hand, in earthquake prone countries like Chile, seismic verification of temporary pile-supported excavations is very important. Nevertheless, there are very few studies concerning the dynamic behavior of pile-supported excavations and earthquake-induced lateral pressures on soldier piles [29]. To the authors' knowledge, no experimental studies have been conducted for this problem considering dynamics loads.

The literature review shows that there is still a need for an accurate yet practical procedure for the evaluation of lateral induced pressures on discontinuous pile-supported excavation. Such a procedure will be very useful to improve the current seismic design practice. Even though there is no information concerning failures of this kind of excavation during the M_w8.8 February 27, 2010 Chile

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* Corresponding author. Tel.: +56 2 23541273; fax: +56 223544243.
E-mail addresses: esaez@ing.puc.cl (E. Sáez), gspardo@uc.cl (G.S. Pardo), ledezma@ing.puc.cl (C. Ledezma).

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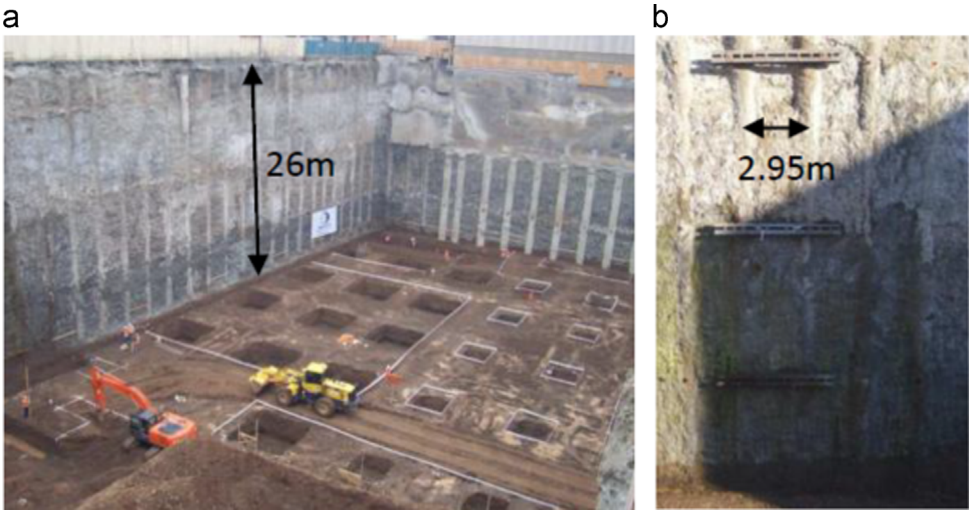

Fig. 1. Typical excavation with non-secant anchored piling support. Beauchef building in Santiago, Chile [32].

earthquake, practitioners are aware that the design approach for this type of excavation support might be overconservative due to many sources of uncertainties regarding its actual dynamic behavior. Thus, a more precise knowledge of the expected seismic response of these systems could reduce the cost of new projects, without affecting their reliability, and it may improve earthquake-engineering practice.

2. Numerical modeling

Several aspects were considered to perform this numerical analysis: (i) selection and calibration of a constitutive model able to reproduce the static and dynamic behavior of Santiago gravel, (ii) geometrical definition of a finite element model suited for the target problem, (iii) numerical simulation of the excavation sequence, and (iv) dynamic perturbation around the static equilibrium. The specifics for each one of these aspects are detailed in the following sub-sections.

2.1. Selection and calibration of the constitutive model

Santiago gravel is characterized by a fines content of about 3%, with a plastic index between 5 and 20, and coarse grains of up to 30 cm of nominal size [26]. This gravel deposit is usually overlaid by a 1.5–3.0 m thick deposit of low-plasticity clay of medium to high consistency. From the surface down to a depth of 5–7 m, the gravel contains low-plasticity silty fines, with a cohesion of about 20 kPa, and it has an angle of internal friction as high as 45°. This upper gravelly layer is known as the Second Deposition of the Mapocho River. This stratum is underlain by the First Deposition of the Mapocho River. The first deposition is denser than the second one, but it has a similar grain size distribution. The mechanical properties of this material have been studied by many authors [17,24,26,8].

The Ecole Centrale Paris (ECP)'s elasto-plastic multi-mechanism model [15] was used to represent the behavior of Santiago gravel. This effective-stress model can take into account the soil behavior in a large range of deformations [19]. The representation of all irreversible phenomena is made by four coupled elementary plastic mechanisms: three plane-strain deviatoric plastic deformation mechanisms in three orthogonal planes, and an isotropic one. The model uses a Coulomb-type failure criterion and the critical-state concept. The evolution of hardening is based on the plastic strain (deviatoric and volumetric strains for the deviatoric mechanisms, and volumetric strain for the isotropic one). A kinematical hardening, based on the state variables at the last load reverse, is used to take into account the cyclic behavior. The soil behavior is decomposed into pseudo-elastic, hysteretic, and mobilized domains.

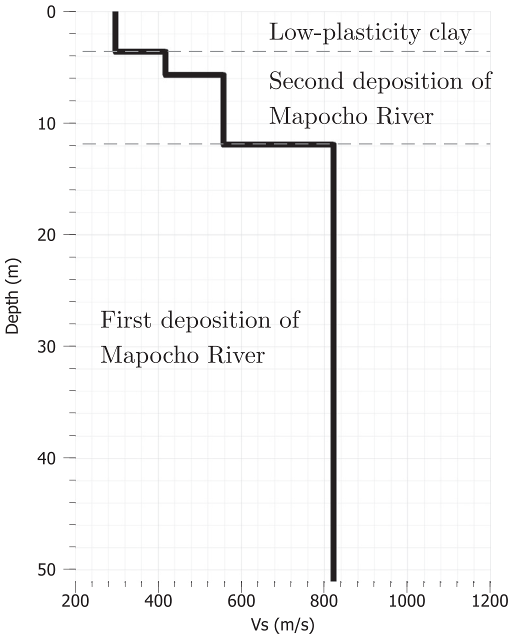

Fig. 2. Inverted shear wave profiles.

The constitutive model considers nonlinear elasticity, hence it uses a referential shear modulus G_{ref} for a mean effective stress p'_{ref} to compute the corresponding shear modulus for any arbitrary confinement p':

$$G(p') = G_{ref}\left(\frac{p'}{p'_{ref}}\right)^m \tag{1}$$

where $G(p')$ is the shear modulus for a effective confinement of p' and m is the degree of nonlinearity, usually considered as 0.5 for granular soils. A geophysical surface wave-based geophysical survey, using the F–K active and passive methods [18] and the SPAC method [1], was conducted at 300 m of the excavation under study. Combining this data, and using a global inversion method [2], a compatible shear-wave profile down to 50 m was obtained. Fig. 2 displays the best inversion. In the numerical model, the values of