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A mitigation technique to reduce ground settlements induced by tunnelling using diaphragm walls

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Abstract

Ground movements due to the excavation of shallow tunnels may cause damage or loss of functionality to nearby buildings: embedded diaphragm walls pre-installed between the tunnel and the building can be effective in reducing these movements thus preventing damage on existing structures. Plane strain finite element analyses are first presented in the paper in which a continuous diaphragm made by adjacent panels was modelled to evaluate the effects of different geometrical and mechanical parameters. For a limited set of these parameters, 3D FE analyses were also performed maintaining a plane strain excavation scheme to evaluate the effectiveness of an infinite diaphragm made by closely spaced piles. A 3D study is finally presented in which the horizontal diaphragm length needed to attain the same efficiency provided by an infinite diaphragm is evaluated. Completion of tunnel construction was assumed in both 2D and 3D studies.

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Keywords: tunnelling; mitigation of ground movements; diaphragm wall; three-dimensional numerical analysis

1. Introduction

The main design restriction for tunnel excavation in urban areas is the induced ground deformation when the tunnel line passes near an existing building. Both active and passive techniques have been developed to control the movements of structures affected by tunnelling. For example, site observations and laboratory investigations have

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shown the effectiveness of compensation grouting as an active mitigation technique [1,2]. In this paper, a numerical study was carried out to evaluate the possibility of reducing ground movements induced by tunnelling by pre-installing a passive protective barrier between the tunnel and the buildings exposed to potential damage, to limit the lateral propagation of displacements from the tunnel axis. Mitigation barriers of bored piles and micropiles have been used in Shanghai [3,4] and Barcelona [5,6] showing to be effective in reducing ground movements induced by tunnelling. The effectiveness of protective barriers has also been demonstrated by centrifuge tests [7] and numerical studies have been performed to investigate the role of geometrical and mechanical characteristics of the diaphragm [8,9,10].

In this study, parametrical analyses were performed using the FE codes Plaxis 2D and 3D to define the soil-structure interaction mechanisms that allow the reduction of ground movements induced by tunnel excavation. Plane strain numerical analyses were first carried out to evaluate the effects of the wall length and of the roughness at the soil-diaphragm interface. A three-dimensional study was then carried out to evaluate the efficiency of a diaphragm made by piles installed at different spacing, that is generally preferred to a continuous diaphragm wall made by adjacent panels due to the minor impact related to pile construction.

Finally, a 3D model was developed to evaluate the minimum horizontal length needed for a diaphragm to reach in a given section about the same efficiency provided by a diaphragm of infinite horizontal extension. Completion of tunnel construction was assumed in both the 2D and 3D analyses.

2. Model definition

2.1. Soil properties

Ground conditions assumed in the analyses are representative of those encountered in the historical centre of Rome, close to the *Aurelian Walls* at *Porta Asinaria*. The soil profile consists of a 17 m thick gravelly made ground (MG) overlying a slightly overconsolidated sandy silt layer, about 13 m thick, and a sandy gravel with a thickness of about 12 m which rests over a thick deposit of stiff Pliocene overconsolidated clay. In the analyses the conservative assumption of a diaphragm wall entirely installed in the sandy silt was made.

The mechanical behaviour of the MG was described using the Hardening Soil model (*HS*), while the behaviour of the sandy silt layer was described by the Hardening Soil model with small-strain stiffness (*HSsmall*) [11,12], both implemented in the code Plaxis. In addition to the features of the *HS* model, *HSsmall* model is able to describe the hysteretic para-elastic soil behaviour at very small strain. The strength and stiffness parameters of the soils were selected to reproduce data from cross-hole tests and from resonant column and triaxial tests carried out on undisturbed samples retrieved from the site. Figure 1a lists the values adopted in the analyses.

Measurements of pore water pressure show a downwards seepage in the silty soil, from the made ground towards the gravel, with the groundwater head decreasing from 26 to 17 m o.d..

2.2. Problem definition

The model layout is schematically represented in Figure 1b: the tunnel has a diameter D_t = 6.7 m and its axis is at a depth z_0 = 25 m. The offset d of the diaphragm from the tunnel axis is equal to $0.8D_t$. Four possible wall lengths were investigated: $L = z_0$, $z_0 + 0.5D_t$, $z_0 + D_t$ and $z_0 + 1.5D_t$. The diaphragm was assumed to be continuous, made by adjacent panels 0.6 m thick, or discontinuous, made by a line of piles with a diameter D_p = 0.6 m, installed at spacing $s = D_p$, $1.5D_p$ or $2D_p$. In both the 2D and 3D analyses, the vertical boundaries of the transverse section of the models were located 12 tunnel diameters away from the tunnel axis, while the meshes extended about 4 diameters below the tunnel: vertical boundaries were restrained horizontally, while the base was fixed. A horizontal width l of 7.2 m was adopted for the 3D FE mesh, that is capable to model a line of piles with 12, 8 and 6 piles installed at spacing $s = D_p$, $1.5D_p$ and $2D_p$, respectively. Drained condition of soil was considered in all the analyses.

Plaxis interface elements were used to reproduce the soil-structure contact: they are defined by the R_{int} parameter that reduces both strength and stiffness parameters of a selected soil. The interface of the diaphragm wall was assumed either partially (R_{int} = 0.7) or fully rough (R_{int} = 1.0), while it was assumed R_{int} = 0.7 for the contact between the tunnel lining and the soil.