Engineering Structures 109 (2016) 117–125

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

3D numerical investigation of mechanized twin tunnels in soft ground – Influence of lagging distance between two tunnel faces

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ARTICLE INFO

Article history:
Received 20 April 2015
Revised 23 November 2015
Accepted 30 November 2015
Available online 17 December 2015

Keywords:
Numerical modelling
Lining response
Segmental lining
Settlement
Lagging distance
Twin tunnel

ABSTRACT

During the construction of twin mechanized tunnels, a large impact of lagging distance is expected due to the strong effects of external loads and also the time dependence of the tunnel behaviour along the direction of tunnelling. Most researches in the literature focused on the influence of the distance between the tunnels' axis and their relative position. In this study, a 3D numerical investigation was carried out of the interaction between twin mechanized tunnels excavated in a horizontally parallel section. Special attention was paid to the influence of the lagging distance between the two mechanized tunnel faces. The numerical results indicated that the critical situation in terms of the lining stability occurs when the face of the following tunnel is at the same transverse section as the preceding tunnel. The tendency in the change of the bending moment and the lining deformation in the preceding tunnel and the following tunnel are generally opposite, depending on the lagging distance.

1. Introduction

During excavation of tunnels close to each other, significant interactions between tunnels have been presented in the literature. A review of twin tunnel interaction has been given in recent works by the authors of the present work [1–4]. Accordingly, most researches have focused on the interaction between two horizontally driven tunnels using physical tests [5–7], empirical/analytical methods [8,9], field measurements [8–14], and numerical analyses [15–22]. They considered the interaction between twin tunnels in terms of the ground deformation, but not the structural forces induced in tunnel linings [2].The effect of the tunnel location in transverse section, i.e. tunnel distance or different depths of tunnels, etc., was thoroughly studied. However, less work has been devoted to the influence of lagging distance, along the tunnel advance direction, between tunnel faces on the change in structural forces, lining deformation and ground displacement.

Tunnels can nowadays be excavated using conventional methods such as the New Austrian Tunnelling Method (NATM) or mechanized methods such as shield machines, tunnel boring machines, pipe jacking, and so on. While NATM tunnels are mainly supported by shotcrete, rock bolts and steel ribs, a mechanized tunnel is however usually excavated using a shield machine, supported by segmental concrete lining. NATM method can be used in tunnel with arbitrary shape but mechanized tunnel is usually applied for circular tunnels. Then, the behaviour of twin NATM tunnels and that of twin mechanized tunnels excavated in the same condition are therefore not similar.

Ng. et al. [22] presented an interesting numerical investigation on the multiple interactions between large parallel hypothetical twin tunnels constructed in stiff soils using the NATM. This study pays special attention to the influence of the lagging distance between twin tunnel excavated faces (L_F), indicating a strong effect of L_F on the behaviour of both tunnels. It should be mentioned that the behaviour of tunnels excavated using the NATM method and the mechanized method are very different, caused not only by the tunnel shape but also by the components of the construction loading along the tunnelling direction.

Along the axis of the tunnel excavated using the mechanized method, there are some construction loads such as slurry/mud pressures on the tunnel face, jacking forces and compensation grouting pressures at the shield tail and so on. These forces have a strong effect on the behaviour of a single tunnel, not only in terms of structural forces and lining deformation, but also on the displacement of the ground surrounding the tunnel [22]. Generally, under the impact of jacking forces and grouting pressure, the greatest normal forces and longitudinal forces induced in a lining ring are reached right after their installation behind the shield tail. These two structural forces then gradually decrease as the grout

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http://dx.doi.org/10.1016/j.engstruct.2015.11.053
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hardens and the shield machine advances further away from the measured lining section. However, their values increase again due to a gradual increase in ground loads. The steady state of the tunnel lining is only reached after a tunnel advance of about $5D_{tu}$ (D_{tu} is external diameter of the tunnel).

Evidently, each of above loading components in the mechanized tunnelling method has only a certain impact range in the transverse section and also along the tunnelling direction. During the excavation of twin mechanized tunnels, the interaction between two tunnels therefore depends on both their distance and relative location in transverse section, and the lagging distance between the two tunnel faces along the tunnelling direction. Do et al. [3] conducted a series of tridimensional (3D) numerical analyses, which showed that tunnel distance had a great effect on the interaction between two tunnels. In this study, the following tunnel is excavated when the preceding tunnel has reached a steady state.

Also, using 3D numerical models of twin horizontal mechanized tunnels, Do et al. [2] focused on the effect of the tunnelling procedure in which the two tunnels are simultaneously excavated (case 1) and successively excavated when the preceding tunnel has reached a steady state before the excavation of the following tunnel (case 2). The numerical results indicated that the simultaneous excavation of twin tunnels causes smaller structural forces and lining displacement than those induced in the case of twin tunnels that are successively excavated. However, the simultaneous excavation of twin tunnels can result in a greater settlement above the two tunnels.

A detailed investigation of the influence of the lagging distance between tunnel faces on their interaction has not yet been conducted in any of the above studies. Obviously, due to the strong effects of external loads along the tunnelling direction in mechanized tunnelling and also the time dependence of the tunnel behaviour, the lagging distance can be expected to have a great impact; thus, this is the goal of the present study. A 3D numerical investigation of the interaction between twin mechanized tunnels (with varying lagging distance), using the FLAC^{3D} finite difference code [23] has been carried out. The numerical results presented in section 3 indicate that the critical situation in terms of the lining stability is when the face of the following tunnel is at the same transverse section as the shield tail of the preceding tunnel. The changes in structural forces, deformation of the tunnel linings and the displacement of the ground surrounding the tunnel, which are caused by the effect of the lagging distance, have been highlighted.

2. Numerical model

Figs. 1 and 2 show a plan view and a cross section of the 3D model used in this study. Basically, the same 3D numerical model developed in the finite difference program FLAC^{3D} [23] used in another work by the same authors [2,3] has been adopted in the present study. All the parameters used in the numerical model are the same as those applied in previous works by Do et al. [2,24,25]. Therefore, only a short description is given here.

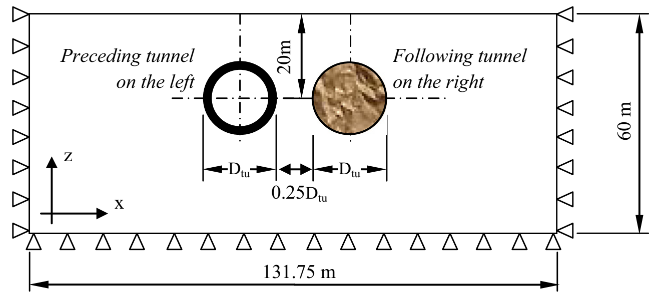

Fig. 2. A–A: typical cross section view of the twin tunnels (not scaled) (from Do et al. [2]).

2.1. Soil's constitutive model

The parameters from the Bologna-Florence high speed railway line project in Italy have been adopted for use in this study. The soil has been modelled using the Cap-Yield (CYsoil) constitutive model, which is a strain-hardening constitutive model that is characterized by a frictional Mohr–Coulomb shear envelope (zero cohesion) and an elliptic volumetric cap in the (p', q) plane [23,24]. Parameters of the soil are shown in Table 1 [4,24].

2.2. Shield machine simulation

The twin horizontal tunnels are excavated at a space distance of 11.75 m from centre to centre. The tunnels have an external excavation diameter including the lining thickness (D_{tu}) of 9.4 m and were excavated at a depth of 20 m below the ground surface.

The tunnel construction process has been modelled using a step-by-step approach [24]. The advance length of 1.5 m after each excavation has been used, which is equal to the width of a lining ring. A schematic view of the present shield machine is provided in Fig. 3.

In this 3D numerical model, most components of a shield machine have been simulated: trapezoidal distribution pressure applied from the shield chamber to the tunnel face, distribution pressure applied to the ground surface in the cylindrical void just behind the tunnel face, the shield machine and its conicity, the self-weight of the shield machine, the jacking force at the shield tail, the grouting pressure in the liquid state and the hardened grout, the tunnel linings with the joints and the back-up train (see Fig. 3).

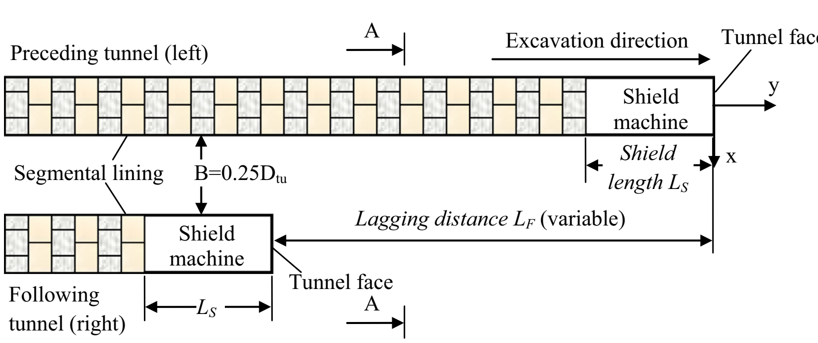

Fig. 1. Plan view of the twin tunnels (not scaled) (from Do et al. [2]).