Tunnelling and Underground Space Technology 64 (2017) 184–208

Contents lists available at ScienceDirect

Tunnelling and Underground Space Technology

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

# Impact of tidal level fluctuations on the structural behaviour of a segmental tunnel lining

Ken Schotte [a,*], Wim Nagy [a], Timothy Nuttens [b], Alain De Wulf [b], Philippe Van Bogaert [a], Hans De Backer [a]

[a] Ghent University – Department of Civil Engineering, Technologiepark Zwijnaarde 904, B-9052 Zwijnaarde (Gent), Belgium
[b] Ghent University – Department of Geography, Krijgslaan 281 (S8), B-9000 Gent, Belgium

ARTICLE INFO

*Article history:*
Received 18 November 2015
Accepted 23 January 2017

ABSTRACT



## 1. Introduction

An important part of the underground construction industry is based on the use of mechanised tunnelling techniques such as closed-shield tunnelling. An increasing number of tunnels is planned below busy waterways, rivers, straits or other obstacles that often leave no alternative construction method but shield tunnelling. In general, its application implies the use of segmental tunnel linings as primary or solitary load-bearing components. Defining the loads on these linings is one of the most challenging aspects of underground projects (Grübl, 2012; Ishimura et al., 2013). Naturally, tunnel linings are designed with respect to the soil and water pressures, acting along the tunnel profile, together with possible overburden loads on the surface level. These loads can mostly be considered constant in the applied design methods (Duddeck and Erdmann, 1985; ITA Working Group on General Approaches to the Design of Tunnels, 1988). However, for tunnels located below a sea or a tidal river, the water pressure continuously varies in accordance with the tidal fluctuations. In these cases, the influence of the changing tide should be taken into consideration in tunnel lining design (Lin et al., 2015).

The impact of the water level fluctuation was monitored for the Liefkenshoek rail tunnel, located in the Port of Antwerp (Belgium). The tunnel trajectory crosses River Scheldt, whose water level variation is linked to the tides of the North Sea. Apart from the constant fluctuation of stresses in the concrete lining, a vertical displacement of the tunnel was observed in response to the river tide. At the centre of the river, levelling measurements showed a decrease of the tunnel level at high tide by a value of about 10 mm with respect to low tide. In literature, only one example was found as the first rail tunnels below the Hudson River in New York City shifted with tide in the silty river bed (Hewett and Brown, 1910; Jacobs, 1910). For an average tide of about 1.50 m, the magnitude of the tunnel oscillation equalled approximately 3 mm. However, no clear explanation of the tidal movements was found, other than the statement that the increased volume of water at high tide pushed the tunnels down, and they would spring back up when the tide receded (MacLowry, 2014).

In order to obtain a clear understanding of the tidal response of the Liefkenshoek tunnel, several possible hypotheses are investigated as the causes of the vertical displacements. This paper presents the outcome of analytical settlement calculations and finite element calculations using both a beam model of the tunnel lining as well as a detailed three-dimensional (3D) model. The results are compared to the observations of the monitoring program, consisting of strain, ovalisation and levelling measurements. Consequently, the origin of the tidal oscillation of the Liefkenshoek tunnel is identified and the impact of the water level variation on the segmental lining can be evaluated. Thus the basic understanding of the behaviour of a shield tunnel lining subjected to tidal fluctuations may be improved.

## 2. Project outline and soil composition

The Liefkenshoek project, completed in 2014, was one of the largest infrastructural projects in Belgium in the last decade. It establishes a new railway connection for freight traffic between the left and right bank section of the Port of Antwerp. This new rail link has a total length of approximately 16 km, of which 6 km was constructed as a twin bored tunnel using the mix shield method (Boxheimer and Mignon, 2009). The parallel tunnels were labelled as tunnel north and south, based on their location. Both single-track tunnels with an internal diameter of 7.30 m were excavated below River Scheldt and the Port Canal. Each tunnel ring is 1.80 m wide and consists of seven concrete segments and a smaller

* Corresponding author.
*E-mail addresses:* Ken.Schotte@UGent.be (K. Schotte), Wim.Nagy@UGent.be (W. Nagy), Timothy.Nuttens@UGent.be (T. Nuttens), Alain.DeWulf@UGent.be (A. De Wulf), Philippe.VanBogaert@UGent.be (P. Van Bogaert), Hans.DeBacker@UGent.be (H. De Backer).

http://dx.doi.org/10.1016/j.tust.2017.01.014
0886-7798/

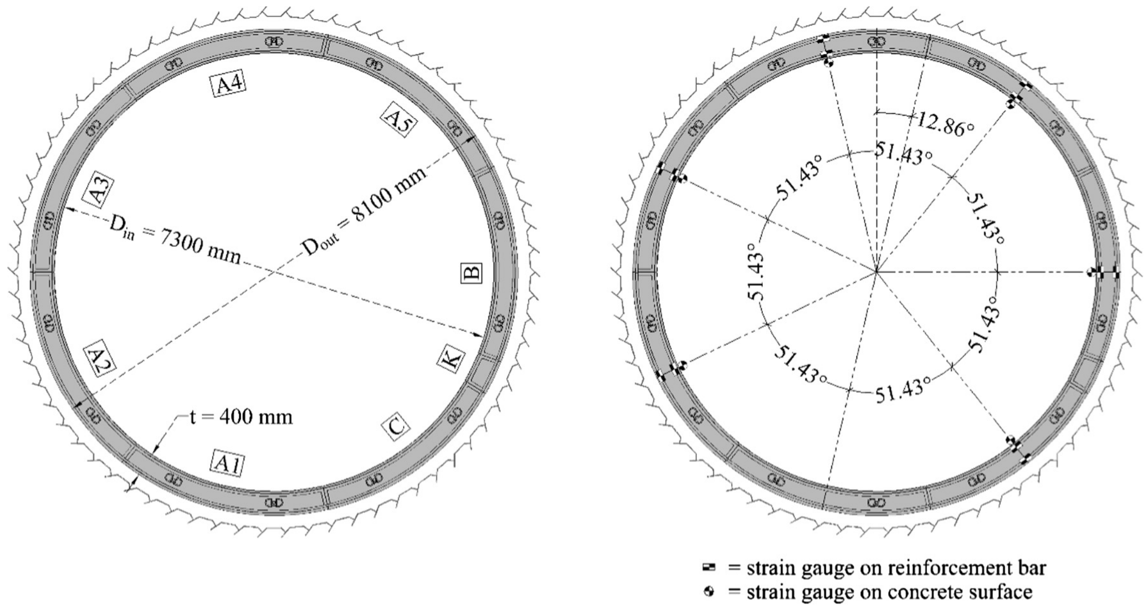


**Fig. 1.** Geometry of the Liefkenshoek tunnel and indication of strain gauge locations.

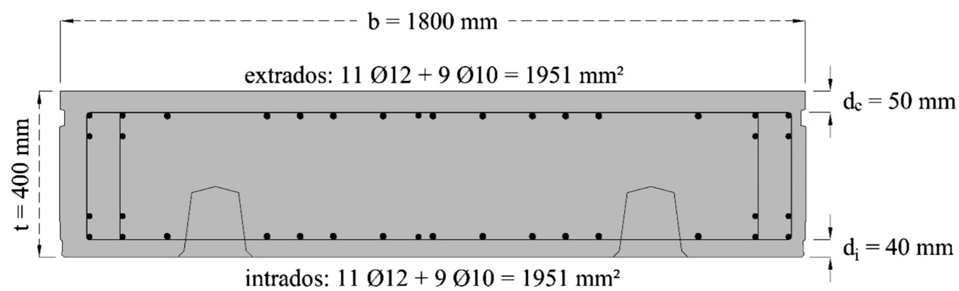


**Fig. 2.** Cross-section of a tunnel segment and positioning of reinforcement bars.

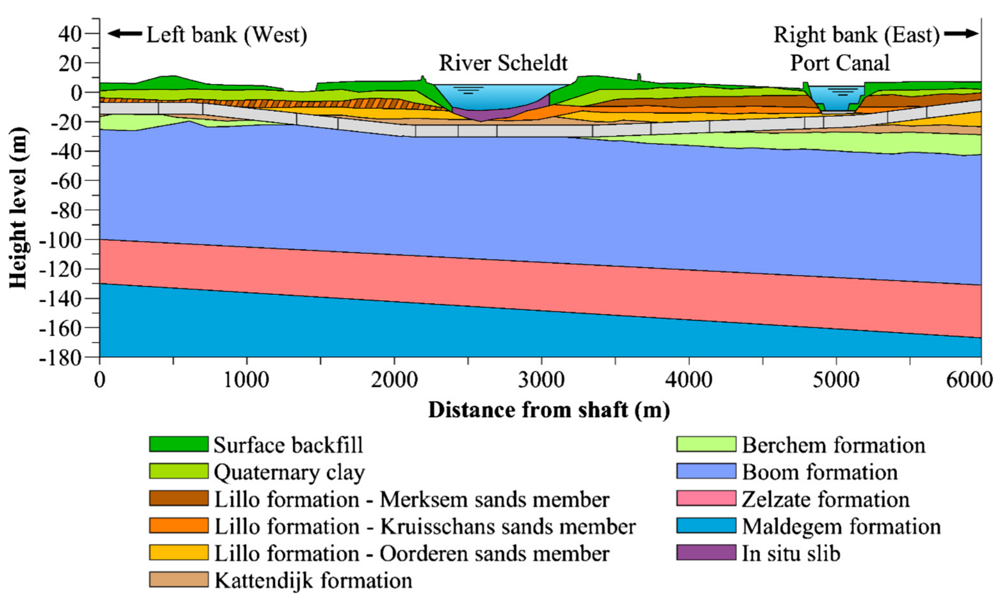


**Fig. 3.** Longitudinal profile of the Liefkenshoek tunnel with soil composition.

keystone, all in C50/60 concrete quality. Due to the large water pressures below the river, a lining thickness of 0.40 m was chosen, resulting in an outer diameter of 8.10 m. The total diameter of the TBM shield equalled 8.39 m. Consequently, an annular tail void of approximately 15 cm had to be filled with a grout mixture. The geometry of the tunnel rings is shown in Fig. 1. Fig. 2 shows the