Engineering Geology 178 (2014) 15–27

Contents lists available at ScienceDirect

Engineering Geology

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

Dewatering of a deep excavation undertaken in a layered soil

Estanislao Pujades [a,b,*], Enric Vàzquez-Suñé [a], Jesus Carrera [a], Anna Jurado [a,b]

[a] GHS, Institute of Environmental Assessment and Water Research (IDAEA), CSIC, Barcelona, Spain
[b] GHS, Dept. Geotechnical Engineering and Geosciences, Universitat Politècnica de Catalunya, UPC-BarcelonaTech, Barcelona, Spain

ARTICLE INFO

Article history:
Received 25 November 2013
Received in revised form 27 May 2014
Accepted 6 June 2014
Available online 19 June 2014

Keywords:
Pumping well
Deep excavation
Dewatering
Diaphragm walls
Settlements
Groundwater

ABSTRACT

In order to carry out deep excavations under the water table in urban environments, the safety of the work site and of the adjacent buildings is a major cause for concern. One of the most common and effective methods of undertaking these excavations involves combining the cut and cover method with a dewatering system. The success of a construction depends on the stability of the excavation bottom, the effects produced outside the excavation by dewatering (soil movements) and/or the state of the enclosure (defects in the diaphragm walls). This study proposes a realistic multidisciplinary procedure to address these issues. The work emphasizes the importance of soil characterisation and underlines the need to perform a Watertightness Assessment Test (WTAT) before the excavation stage. The procedure was applied to the excavation of a deep shaft of the High Speed Train (HST) tunnel in Barcelona. An earlier geological characterisation at large scale ruled out the use of deep pumping wells. However, a subsequent hydrogeological characterisation, which involved borehole logging, grain size analyses, Natural Gamma Ray and pumping tests, revealed the presence of thin transmissive layers inside the low hydraulic conductivity materials. The dewatering system was designed by considering different model scenarios and the safest design was selected for the excavation. Depths of the enclosure and of the pumping wells differed in accordance with the scenarios. The impacts (settlements due to pumping) and the stability in each scenario were computed. The state of the enclosure underwent a WTAT before the start of the excavation, but after constructing the enclosure, to verify its low permeability. The test consisted in pumping inside the enclosure and monitoring the groundwater behaviour outside the enclosure. Numerical interpretation of this test showed a defect in the diaphragm walls below the excavation bottom. Since this defect was not repaired because of its location (below the bottom of the excavation), the dewatering system had to be redesigned to ensure safety. Surface settlements, which were also a source of concern, were small. They were computed using coupled hydro-mechanical models.

1. Introduction

Underground constructions in urban environments must be sufficiently deep so as to avoid existing structures (tunnels, car parks, basement and/or foundation of buildings) (Li and Yuan, 2012). They are therefore built below the water table at locations where the groundwater is not too deep, which could give rise to problems (El-Nahhas, 1999). As a result, it is essential to apply procedures that ensure the safety of the excavation works in the presence of groundwater. A number of underground constructions are the vertical shafts that are used for maintenance during tunnel construction or as emergency or ventilation exits during the operation of tunnels (Ni and Cheng, 2011).

A variety of techniques are used to undertake deep excavations under the water table. The optimal choice depends on the characteristics of the soil and on the hydrogeology of the site (Stille and Palmström, 2008). Incomplete characterisation complicates the prediction of the response of the medium to the construction and, therefore, the design stage (Jurado et al., 2012). An efficient method consists in combining the "cut and cover" method (Gulhati and Datta, 2005) with deep pumping wells (Powers et al., 2007). Diaphragm walls avoid lateral groundwater influx and ensure the verticality of the excavation walls (Xanthakos et al., 1994) whereas deep pumping wells prevent water from entering the excavation bottom, ensuring stable conditions. Bottom uplift or liquefaction events are therefore averted (Pujades et al., 2012a). However, deep pumping wells are not recommended when the excavation is undertaken in a low hydraulic conductivity soil (Cashman and Preene, 2001). In such cases, alternatives include eductor wells, wick drains (when low rates of water must be extracted) or excavation under undrained conditions (when the pressure drop caused by the unloading of the soil ensures stable conditions) (Preene et al., 2004; Powers et al., 2007). Nevertheless, these alternatives may pose a risk if the soil has not been adequately characterised. Unexpected transmissive layers within the low hydraulic conductivity materials may lead to instability at the bottom of the excavation (Moore and Longworth, 1979; Ramaswamy, 1979; Davies, 1984). A detailed hydrogeological

* Corresponding author at: GHS, Institute of Environmental Assessment and Water Research (IDAEA), CSIC, Barcelona, Spain. Tel.: +34 93 400 61 00; fax: +34 93 204 59 04.
E-mail address: estanislao.pujades@gmail.com (E. Pujades).

http://dx.doi.org/10.1016/j.enggeo.2014.06.007
0013-7952/

characterisation is therefore essential. Borehole logging is the most commonly used tool. However, fine layers of coarse sediments may not be detected for various reasons: 1) coarse sediments tend to be loose and may not be recovered from the core, 2) fine sediments of upper layers may be dragged during drilling and may accumulate on the outside of the core, concealing coarse sediments of deeper layers and/or 3) fine layers of coarse sediments may be overlooked by the geologist. Geophysical techniques (e.g. Ground Penetrating Radar, Electrical Resistivity Tomography, Natural Gamma Ray,..), grain size analyses and pumping tests should therefore be used for hydrogeological characterisation. Soil characterisation also plays an important role in determining the overconsolidation ratio (OCR) of the soil, which is used to predict the shear strength and the pumping settlements during dewatering. These settlements are small and elastic in overconsolidated soils (Pujades et al., 2014). Moreover, a satisfactory characterisation facilitates the setup of adequate numerical models to select the most suitable dewatering system considering both the stability of the bottom of the excavation and the impacts outside the enclosure (e.g. pumping settlements).

A thorough assessment of the state of the enclosure is crucial to a successful outcome of the excavation since diaphragm walls may suffer from defects (Bruce et al., 1989; Knight et al., 1996; Pujades et al., 2012a; Vilarrasa et al., 2012). Defects in the enclosure (gaps or open joints) hamper the dewatering process giving rise to adverse consequences (Pujades et al., 2012a). Defects located above the excavation may cause inflows that drag sediments, leading to the formation of sink holes outside the enclosure. However, if defects are located below the excavation level, the water pressure will not be low enough, resulting in unstable conditions. These situations pose serious risks that can be significantly reduced by testing the enclosure. The test must be performed before excavation since the defects can be repaired by injecting sealing substances or the dewatering system can be redesigned. However, if they are detected during the excavation stage, repair is more difficult and costly since pumping cannot be interrupted (Pujades et al., 2012a). The existence of defects can be determined by performing a Watertightness Assessment Test (WTAT), which involves pumping inside the enclosure, monitoring the groundwater behaviour and comparing the measured and the predicted drawdowns. Defects can be detected by: 1) observing the changes in flow behaviour as a result of pumping (Pujades et al., 2012a), 2) applying drawdown type curves (Vilarrasa et al., 2012) or 3) using numerical modelling.

The above discussion suggest that many factors such as characterisation, dewatering design, stability, impacts and assessment of the enclosure, which may be overlooked, must be taken into account during deep excavations in urban environments. These factors were borne in mind when undertaking a deep excavation in Barcelona (Spain) during the construction of the High Speed Train (HST) tunnel (Figure 1a). The excavation was undertaken at the crossroads of the Mallorca and Trinxant streets, the site for the construction of one of the ventilation and emergency circular shafts which were constructed every 700 m along the tunnel. The tunnel was constructed by using a Tunnel Boring Machine (TBM) and since the shaft was also used to carry out the maintenance works of the TBM, it was excavated before the construction of the tunnel. Two main problems arose during the excavation of this shaft. The first problem concerned the dewatering technique since an earlier geological characterisation of the site (not sufficiently detailed) suggested that the soil located at the bottom of the excavation had a low hydraulic conductivity. The second difficulty concerned the state of the enclosure since this suffered from a defect that was detected

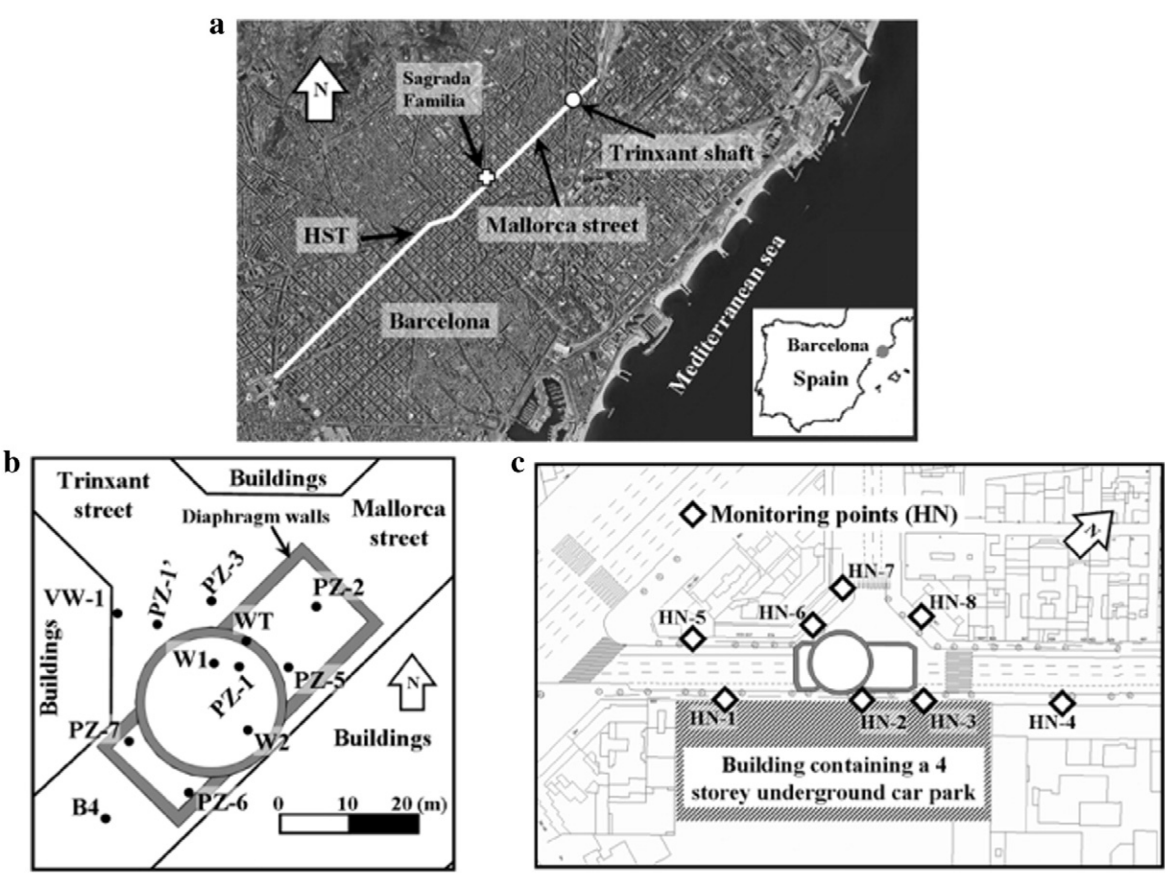

Fig. 1. a) Geographical location of the study site. Plan views of the site, including the enclosure and the location, b) piezometers and pumping wells and, c) soil movement monitoring points.