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Technical note

Characterising the failure pattern of a station box of Taipei Rapid Transit System (TRTS) and its rehabilitation

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ABSTRACT

The case history where flooding due to the leakage through the openings in diaphragm wall accompanied by piping in excavation bottom severely affected the construction of a station box of Taipei Rapid Transit System (TRTS) is presented. The emergency grouting adjacent to but outside the diaphragm wall was conducted following the leakage. However, injection pressure due to slow setting time of grout not only aggravated the piping but also caused the side effect deflecting the diaphragm wall toward excavation area. The severe piping quickly washed the soil into station box and the differential settling of buildings above along with propagating surface cracks forced the use of water emplacing in station to ease the piping and further ground loss; meanwhile, seal grouting and void filling grouting were undertaken to facilitate the rehabilitation of foundation construction through which the station box was opened subsequently. Based on analyzed interactive behaviour between water emplacing or injection pressure and wall deflection or brace load, the diaphragm wall and bracing system would not have functioned normally during grouting if water had not been introduced in the station. The cause of opening in the diaphragm wall is triggered by the abnormal concrete placement which can be avoided through the suggested procedure of examination. The paper discusses the insights into a review of instrument records and provides the lessons learned.

1. Introduction

Piping and hydraulic uplift are the two common failure modes of a braced excavation and can possibly lead to the invasion of groundwater, and the associated ground loss frequently damages the adjacent properties in urban areas, which not only affects construction progress but also increases public nuisance. Similar problems have been experienced during the construction of a station box in Taipei Rapid Transit System (TRTS) (Lin et al., 1997; Yang and Chao, 1997; Ju et al., 1997a,b, 1998; Chang et al., 2001a,b; Fang et al., 2006). However, developing appropriate mitigation measures to reduce the amount, rate and impact of water ingress is an ongoing challenge (Schwarz et al., 2006; Hwang and Lu, 2007). This paper describes a case history for which the leakage from the openings in diaphragm wall was initially encountered and then water with debris gushed out from excavation bottom of a station box of the Luzhou Line of TRTS. The emergency grouting adjacent to but outside the diaphragm wall was undertaken following the leakage but the setting time of the grout was not short enough and in turn the grouting pressures aggravated the leakage. The severe piping quickly washed the soil into station box and the differential settling of buildings above along with propagating surface cracks forced the use of water emplacing in the station to ease the piping and further ground loss, during which seal grouting and void filling grouting were conducted to facilitate the rehabilitation of foundation construction. The cause of piping and the reasons for the failure to seal the leakage initially were unclear. In addition, the influence of water emplacing and injection pressure on the diaphragm wall deflection and brace load change was not fully understood. This paper discusses the insights gathered from a review of instrument records and provides the lessons learned from this massive incident.

2. Site characterisation

2.1. Design and construction

The 150.6 m length, 17.5–42.3 m width station box CL802 construction of the Luzhou Line lot CL700B is part of TRTS, in which the cut-and-cover method was used for its braced excavation. Fig. 1 shows the plan view of the station box. When the excavation reached to 31.7 m below the ground surface, the 1.5-m thick, 55-m

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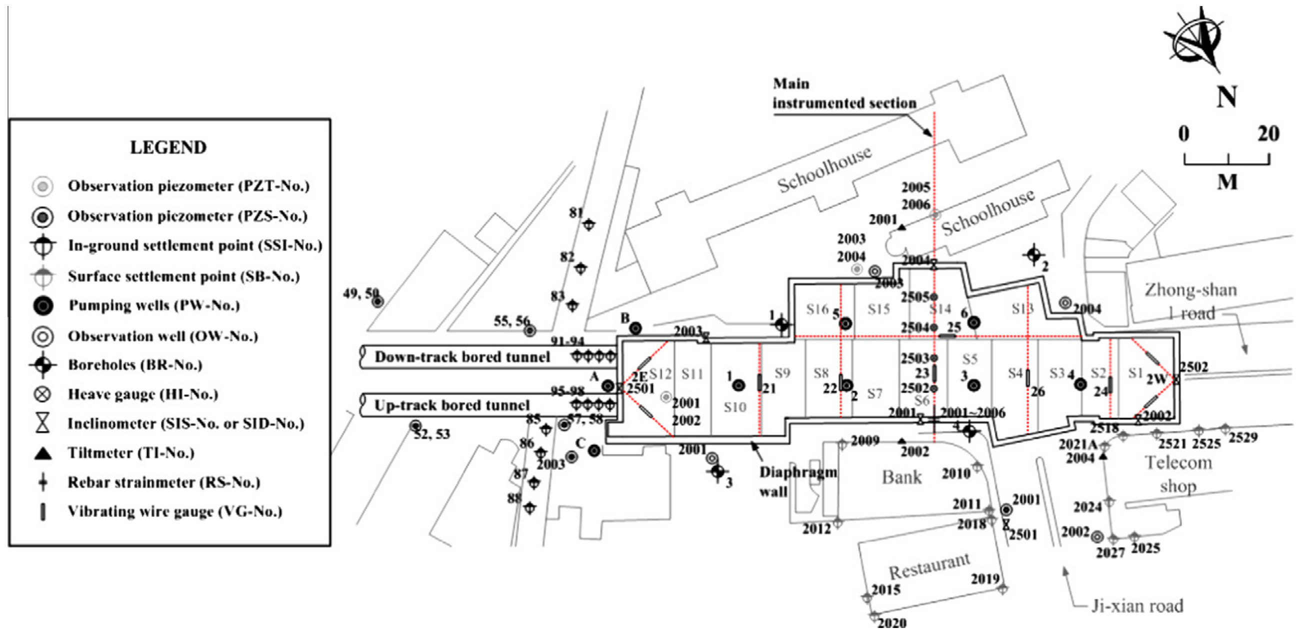

Fig. 1. Plan view of the station box and layout of monitoring instruments (after Ni and Cheng, 2011).

deep diaphragm walls, about 23.4 m penetrating into the silty sand/gravel formation, was used as the earth-retaining structure. Before the bentonite slurry trench was excavated in such soils of highly sensitive nature (Wen, 2008; Chien, 2009), a series of 25-m deep chemical churning piles (CCPs) were constructed as the guide wall to prevent slurry trench from collapsing. There were ten levels of braces. The braces supporting the diaphragm wall were installed 0.7 m above the bottom for each excavation stage. To reduce the push-in of diaphragm wall as the excavation went deeper, the jumbo min–max (JMM) method was used to construct a series of 3-m thick, 2-m wide soilcrete beams under the excavation base as shown in Fig. 2. In addition to the in-ground soilcrete beam, two 6-m thick, 1.3–2.5-m wide reinforced concrete beams under the excavation bottom were trimmed near the cross of Ji-xian road and Zhong-shan 1 road where the much greater uplift of intermediate piles than others had been experienced. Of prime importance was to reduce the possibility of hydraulic uplift during excavation. The excavation area was further divided into 16 subzones, S1–S16, shown in Fig. 1 at the beginning of final excavation.

2.2. Geological condition

Fig. 3 shows the typical soil profile derived from nearby geologic boreholes BR-1 to BR-4 (Fig. 1) drilled through a Holocene basin sediment (the Sungshan formation) of alternating silty clay (CL) and silty sand (SM) layers, of which six has been discussed by many investigators (Huang et al., 1987; Woo and Moh, 1990), into a Pleistocene basin sediment (the Chingmei gravel formation). Piezometric level in Sungshan V commonly lies 2.3 m below the ground surface (Ni and Cheng, 2011). The Taipei silty clay is of low plasticity and has a relatively larger permeability, compared with other urban soils such as Mexico City Clay and Boston Blue Clay (Cheng, 2010). However, the silty clay soil in Sungshan II is still treated as an aquiclude. Sungshan I and the underlying Chingmei formation can therefore be considered as a confined aquifer, with piezometric level some 7.4 m below the surface (Ni and Cheng, 2011). Moreover, water contents of such soils are very close to their liquid limits, so that they can easily get softened once disturbed or even washed away as subjected to large hydraulic gradients.

2.3. Monitoring programme

The station box includes eight instrumented sections designed to closely monitor the ground response to excavation activity and the interactive behaviour of brace-wall-soil system, among which the main instrumented section shown by the red dotted line in Fig. 1 includes measurements of basal heave, brace load and diaphragm wall deformation. As the excavation reached to 31.7 m depth, six pumping wells, PW-1–PW-6, screened from 65 to 70 m below the surface were installed inside the station to lower the piezometric pressure in the Chingmei formation, in which six observation piezometers, PZT-2001–PZT-2006, with various monitoring elevations of 66.4 m, 61.4 m, 41.4 m, 39.4 m, 31.4 m, and 28.4 m were used to evaluate the influence of the group-well pumping on the piezometric level in Sungshan III and Chingmei formation.

As the shield was waiting for its entrance outside the arrival shaft, the excavation in the station was still under progress. Therefore, it was decided that the shield had to be disassembled in treated soils outside the shaft, which greatly increased the possibility of water ingress being encountered during the shield disassembly (Ni and Cheng, 2011). The use of cement grouting followed by chemical grouting along with three pumping wells, PW-A, PW-B and PW-C, equipped with double-tube well screen (Ni and Cheng, 2011) rendered that the entrance of shield was achieved, during which time a series of in-ground settlement points, SSI-91–SSI-98, and observation piezometers with various monitoring elevations of 92.4 m, 83.4 m, 72.4 m and 46.4 m were utilised for characterising the settlement trough as induced by tunnelling process and the drawdown of double-well pumping. The layout of monitoring instruments is shown in Fig. 1.

3. Accident at station box, remedial actions and rehabilitation

3.1. Day one (September 7)

At 4:30 pm on September 7th 2005, a 0.5-in. wide opening at a joint between two diaphragm wall panels, located 31 m below the surface (Wen, 2008; Chien, 2009), was found by the contrac-