Execution of vertical/horizontal jet grouting under crossing point of two existing MRT lines to improve Singapore marine clay

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ABSTRACT

Several cities in Asian countries are undergoing economic growth, and a lot of infrastructure projects are ongoing or under planning to upgrade and/or maintain urban functions. They are often located on soft grounds at coastal area or big river sides; geotechnical engineering surely has an important role to overcome technical difficulties and complete projects safely and economically. As a case study experiencing highly advanced geotechnical engineering, this paper deals with an expansion of an underground station for Mass Rapid Transit in Singapore to upgrade the present network system which currently has five lines in service. Focusing on tunneling works immediately under the crossing point of existing two lines, detail of construction procedure and results of massive ground improvement work are presented.

Keywords: ground improvement; jet grouting; unconfined compressive strength; shield tunnel

1 INTRODUCTION

As a Singapore's major railway system, Mass Rapid Transit (or MRT) networks have been in service over three decades, and still developing under the direction of Singapore government aiming at an environmentally advanced country (see Fig. 1). Tomson Line is one of the new lines under construction, of which T226 section is allocated at a crossing point of existing Circle Line (CCL) and North South Line (NSL) at Marina Bay Station. T226 section includes construction of a pedestrian linkway, two railway tunnels of both Woodlands and Changi bounds immediately below the crossing point. Since the two existing lines must keep the service and the construction work are deep under existing tunnels, T226 section has several challenges in terms of construction technique.

On the other hand, Singapore Marine Clay is one of typical soft soils in South Eastern Asia (Arulrajah et al. 2008). It is normally consolidated or under consolidating; ground may suffer from serious deformations following to excavation or dewatering process. The T226 section is located at a reclaimed area near coast and the new tunnels are planned in Singapore Marine Clay. To minimize the influence of the

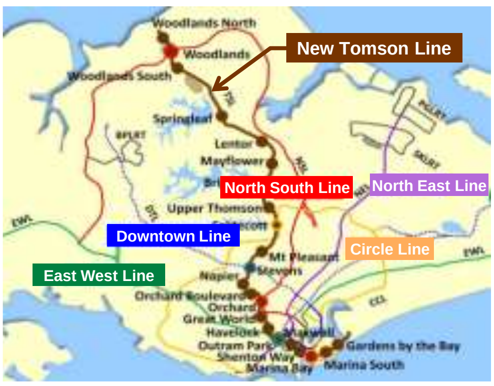


Fig. 1. MRT network in Singapore including Tomson Line.

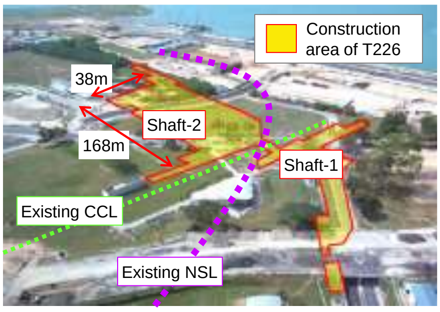


Fig. 2. Overview of T226 section.

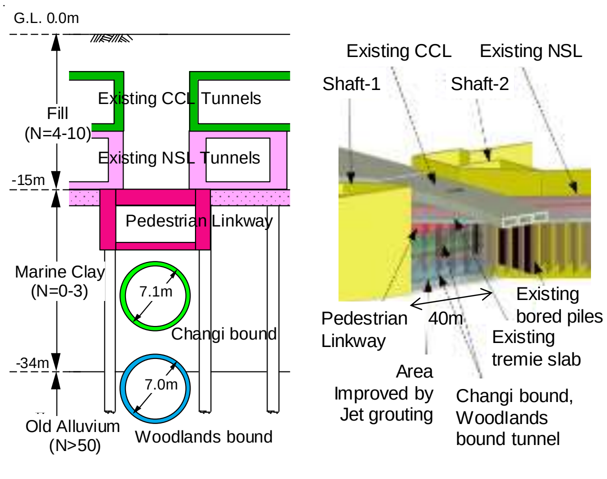


Fig. 3. Sectional view of T226 section.

construction work on the existing two lines, jet grouting was massively conducted prior to the tunneling works.

This paper reports an geotechnical engineering practice at T226 section of Tomson Line. Detail of construction procedure is overviewed and successful execution results of massive jet grouting work are presented.

2 OVERVIEW OF T226 SECTION

Fig. 2 and Fig. 3 shows the overview and sectional view of T226 construction site, respectively. The construction site is in an artificially buried area where some former construction works were suffered from ground deformations and failures (Shirlaw et al. 2006). The T226 section consists of construction of two vertical shafts which would be connected by a pedestrian linkway and two railway tunnels under the crossing point of two existing railway tunnels. These new tunnels are at the depth of -15~-40 m, where soft marine clay with the *N*-value of 0~3 dominates. Consequently, it was decided in design that the whole area would be solidified by in-situ ground improvement to prevent significant deformation of the existing tunnels during the construction. Based on the detail work assessment, jet-grouting technique in both vertical and horizontal directions was employed as shown in Fig. 4. The jet grouting works were firstly conducted from surface/subsurface of the ground in vertical direction (Fig. 4(a), (b)). These were followed by horizontal jet grouting conducted from both the vertical shafts (Fig. 4(c)). Then, the pedestrian link way was constructed using a rectangular open shield machine as explained in Fig. 5. After construction of base slab in the pedestrian link way, vertical jet grouting became possible to improve remaining area below the existing tunnels (Fig. 4(d)).

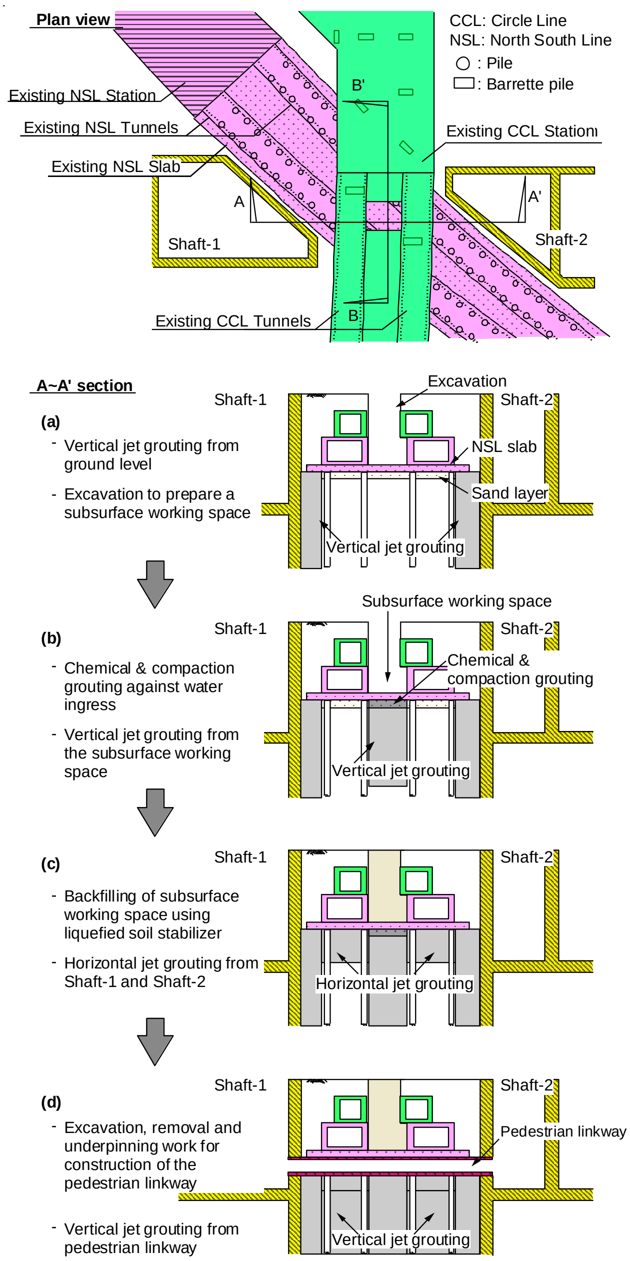


Fig. 4. Work flow of vertical/horizontal jet grouting.

3 EXECUTION OF JET GROUTING

3.1 Work detail

In comparison with horizontal jet grouting, vertical execution is conventional and there has been a lot of application for Singapore Marine Clay (Ganeshan and Yng 2009; Ng 2011). In the present work, jet grouting system using both compressed air and high pressure water was employed. Based on a test construction conducted at the site, the detail procedure was decided

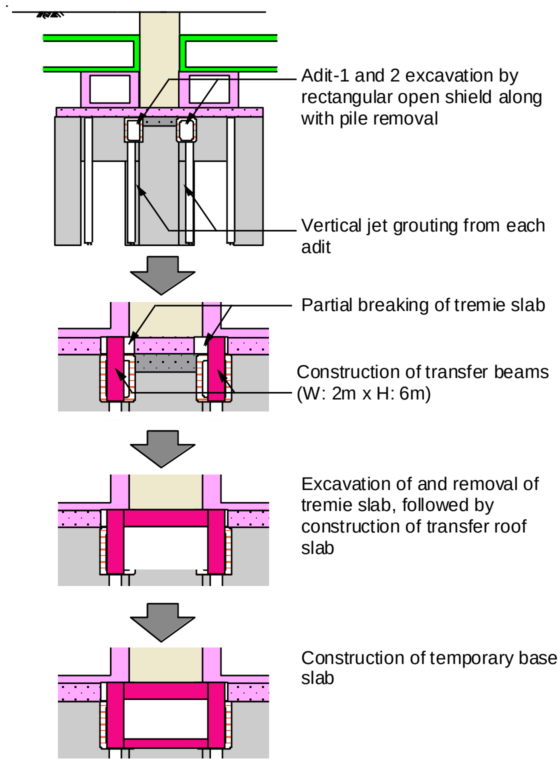


Fig. 5. Construction process of pedestrian linkway.

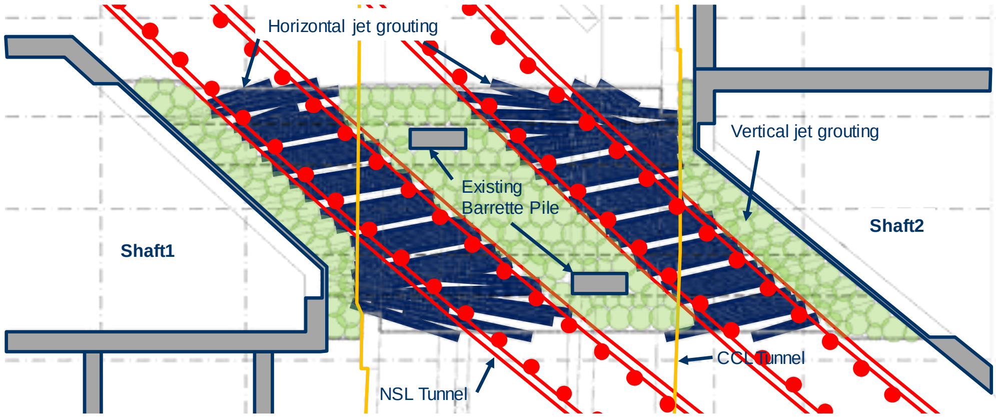


Fig. 6. Arrangement of vertical and horizontal jet grouting piles (plan view).

as the followings: i) prior to jet-grouting, in-situ Singapore Clay was loosened by applying high pressure water jet; ii) 1.1:1 cement water ratio was selected for grout mixture; iii) water , air and grout pressure were 25 MPa, 0.7 MPa and 40 MPa, respectively; iv) grout discharge rate was 170 L/min, v) the target column strength was 0.6 N/mm^2 and vi) the target diameter of the column was 1,800 mm with the spacing of 1,500 mm.

The horizontal jet grouting is not so common; the work details were decided with reference to limited published case studies (e.g., Kato et al. 2012; Claudia et al 2013). In the process: i) pre-water jetting was conducted in prior to jet-grouting to loosen the in-situ Singapore Clay, without using compressed air so as not to entrap air in the grouted bodies; ii) 1:1 cement water ratio was selected for grout mixture; iii) water and grout pressure were 20 MPa and 5 MPa, respectively; iv) grout discharge rate was 80 L/min; v) the target column strength was 0.6 N/mm^2, and vi) the target diameter of the column was 800 mm with the spacing of 600 mm.

Fig. 6 shows the arrangement in a plan view of the horizontal jet grouting piles between two shafts along with that of the vertical jet grouting piles. The lengths of horizontal jet grouting were not more than 15 m and areas behind existing piles remained inevitably unimproved. From both the shafts-1 and -2, total 360 horizontal piles with arrangement of 30 in row and 12 in stage were conducted from the top stage. To secure the working space for three sets of the grouting rig, working lifts were fabricated, as shown in Fig. 7.

Treatment of excess slurry would be a heavy task in this project because the execution place was deep under the two lines in service. The excess slurry was collected through the guide casing around the jet grouting rod implemented at the surface of the shaft wall. It was then temporarily stocked in a storage tank placed at the shaft basement, and finally pumped up to the ground surface.

3.2 Work results

After the jet grouting work, core samples were horizontally obtained and the quality of the jet grouting piles were confirmed as the followings:

(a) Working lift fabricated in vertical shafts

(b) Execution of horizontal jet grouting

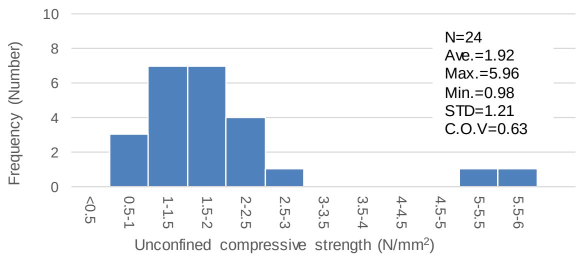
Fig. 7. Horizontal jet grouting work.

- Each core was successive, and total core recovery was found as 96-100 %.
- Sample for unconfined compressive strength (UCS) was collected from the cores and all the strengths were more than design strength, 0.6 MPa, as summarized in Fig. 8(a).
- The variation of the UCS was not more than that having been obtained by past execution in Singapore (Ng 2011), as referred to in Fig. 8(b).

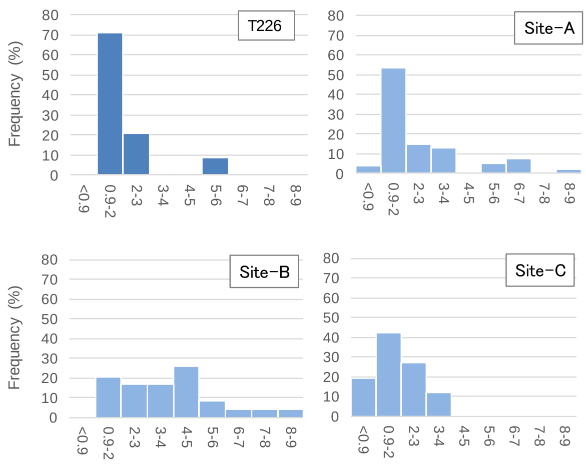
Additionally, we had an opportunity to directly observe the jet grouting piles during the adit excavation for the pedestrian linkway. A rectangular open shield machine was mobilized, which run through the improved area immediately under the existing two lines, and the jet grouting piles were directly observed at the excavation surface as shown in Fig. 9. There was no major unsolidified part and no significant water ingress, which contributed the smooth operation of the following excavation work.

4 CONCLUSION

A lot of underground work will be conducted in future Asian infrastructure projects, and they may face work difficulties against which employment of in-situ soil improvement technique will be considered. The author hopes that the present achievement will be referred to and contribute to successful operations of jet grouting at extremely weak ground like Singapore marine clay.



(a) Results obtained in T-226



(b) Comparison with other results in Singapore

Fig. 8. Unconfined compressive strength of jet-grouting piles.

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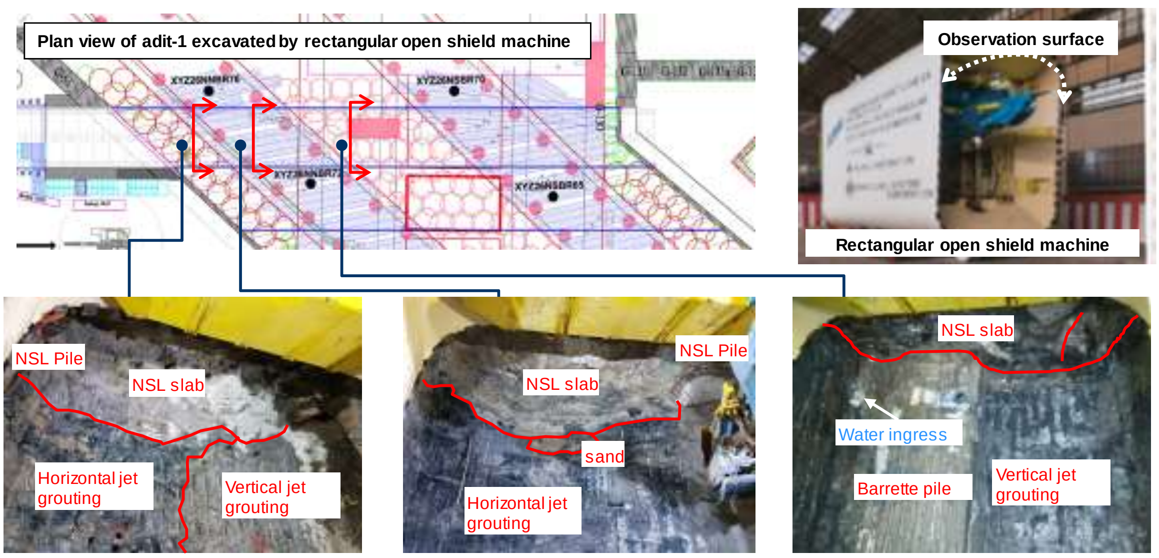

Fig. 9. Directly observed jet grouting piles at excavation surface in open shield machine.