Automation in Construction 69 (2016) 11–20

Contents lists available at ScienceDirect

Automation in Construction

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

# Automatic pressure-control equipment for horizontal jet-grouting

Yao Yuan [a], Shui-Long Shen [a,*], Zhi-Feng Wang [b], Huai-Na Wu [a,*]

[a] State Key Laboratory of Ocean Engineering and Collaborative Innovation Center for Advanced Ship and Deep-Sea Exploration (CISSE), Department of Civil Engineering, Shanghai Jiao Tong University, 800 Dong Chuan Road, Minhang District, Shanghai 200240, China
[b] School of Highway, Chang'an University, China

ARTICLE INFO

Article history:
Received 18 October 2015
Received in revised form 16 May 2016
Accepted 22 May 2016
Available online 2 June 2016

Keywords:
Horizontal jet grouting equipment
Pressure-control
Spoil discharge
Vertical displacement

ABSTRACT

A new horizontal jet grouting equipment is proposed to eliminate the harmful effect on the surrounding environment due to the injection of large amount of water and/or grout under high jetting pressure. The components of the proposed equipment and the construction procedures are introduced. During horizontal jet grouting by the proposed equipment, the inner pressure of the soil stratum can be monitored automatically, the generated spoil can be transported out, and the impact on surroundings (such as ground upheaval and lateral displacement of the subsoil) can be mitigated. A field test involving the installation of five horizontal jet grout columns was conducted in Shanghai to demonstrate the applicability of the new equipment. In addition, monitoring instruments were installed to observe the vertical displacement of the ground surface. The measured maximum value of the ground surface upheaval was as low as 9.4 mm, which verifies that the new equipment performed as per expectations. Finally, the in-situ quality of jet grouted columns was found to be very good based upon the results of field cone penetration and unconfined compressive strength tests.



## 1. Introduction

Jet-grouting is a soft soil improvement technology, which is initially invented based on jetting cut technology in coal mining [1] and grouting [2] in soft soil engineering in early 1970s [3]. After jet-grouting technology was invented, it is widely used in many construction projects, e.g. deep excavations to seal the joints of diaphragm wall to prevent leakage [4], improvement of stability shaft entrance [5], improvement of bottom stability of excavation [6], stabilization of micro-tunneling route [7], tunnel canopy construction [8], recovery of collapsed tunnel [9], improvement of soft subsoil of embankment [10], marine [11] or on-land foundations [12]. In some circumstance, jet grouting was also applied to improve soft rocks, e.g. in Athens Metro project [13] and remediation of existing shield tunnel [14]. The first patent of jet grouting was applied in 1968, as the 'Chemical Churning Pile' (CCP) method [1], which is the forerunner of the single fluid system [15]. Recently with developments in construction technology, the double fluid system (involving grout and air) [16], and the triple fluid system (grout, water and air) [17] have been used for different geological conditions [18]. During jet grouting, high velocity fluids shrouded by a compressed air are ejected from small diameter nozzles to erode the soil and to mix it with the grout to form a soil-cement column [16]. The shear strength of the cemented column can reach several MPa [19].

Based on construction direction of the rod for jet grouting machines, jet grouting technology can be classified as: 1) vertical jet grouting systems [17]; 2) inclined jet grouting systems [20]; and 3) horizontal jet grouting systems [21]. Fig. 1 depicts the in-situ stress state and mechanism of stress transferring in ground during horizontal jet-grouting construction. Before jet grouting, the in-situ overburden pressure $p$ (shown in Fig. 1) can be expressed as follows:

$$p = \gamma h \tag{1}$$

where $\gamma$ = unit weight of the overburden soils; and $h$ = overlying thickness of the soil above the construction site.

Fig. 1(a) shows the longitudinal profile of the ground movement during conventional jet grouting process. The conventional jet grouting operation is a two stage process. Stage I is the ground movement during drilling. As shown in Fig. 1(a), the ground heave at this stage is generally small, which is induced by the friction between the drilling rod and the surrounding soils. Stage II is the ground movement during jet grouting process. When the slurry ejects from the monitor, the inner stratum pressure around the drilling rod will increase and the ground surface will be upheaval, which is induced by the expansion of the grouting slurry and the spoil soils (Fig. 1(b)). The subsequent injection of large volumes of high pressurized fluids into the soil stratum can lead to ground upheaval and lateral movement of the surrounding soils.

To solve the ground expansion problems, some modifications of jet grouting were conducted [21]. In 1995, Nakashima and Nakanishi [20]

* Corresponding authors.
E-mail addresses: slshen@sjtu.edu.cn (S.-L. Shen), zhifeng.wang@chd.edu.cn (Z.-F. Wang).

http://dx.doi.org/10.1016/j.autcon.2016.05.025
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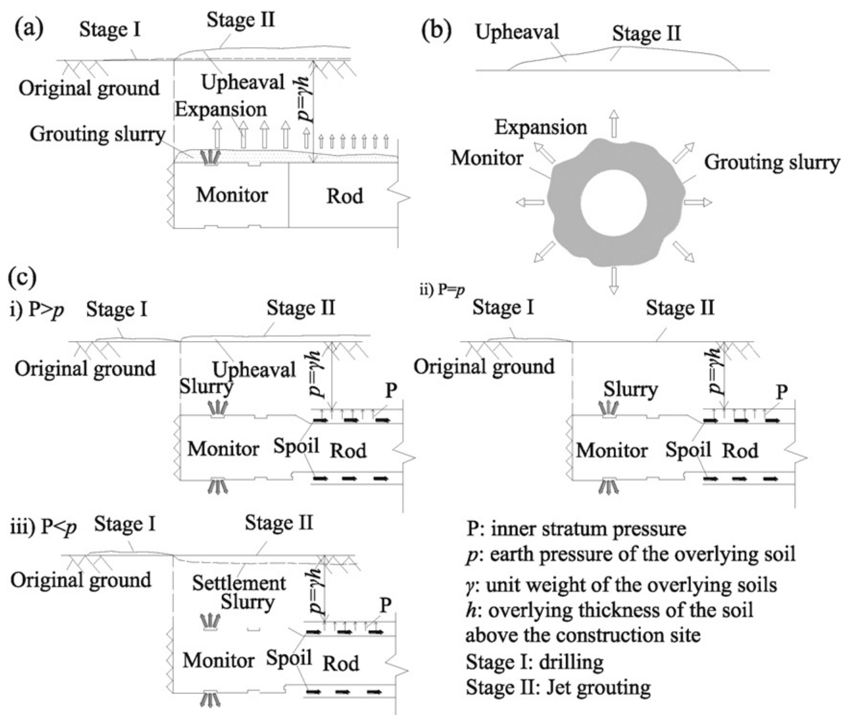


**Fig. 1.** Mechanism of load transferring during jet grouting: a) longitudinal view of the ground movement; b) Sectional view of the ground upheaval due to grouting slurry; c) ground movement model of the horizontal jet grouting construction.

developed a jet-grouting technology to make the balance of jetting pressure with surrounding earth pressure and this system is named as Metro Jet System Technology (MJS). MJS technology utilizes the negative pressure induced by highly pressurized water to remove the spoil [20]. Fig. 2a shows a sectional view of compound pipe used in MJS technology. The different pipes function as follows: (1) for injecting the high pressure grout (grout pipe), (2) for injecting high pressure water to erode soil (water pipe I), (3) for spoil generating water (water pipe II), (4) for injecting compressed air (air pipe), (5) for the cable set that link the sensor to measure the earth pressure during jet-grouting (cable pipe), (6) for transporting the additive (additive pipe), and (7) for transporting out the spoil induced during jet grouting (spoil pipe). The equipment required for MJS makes the rod pipe large and heavy. In addition, the existence of earth pressure measuring cable prevents the rod from continuous 360 degree rotation and the pipe can only swing action during construction, resulting in reduced construction efficiency.

In order to overcome the drawbacks of the MJS system, Shen et al. [21] introduced a new horizontal jet grouting technique called the 'Composite-Pipe Method' (CPM). Fig. 2b shows the sectional view of compound pipe used in CPM technology. In CPM, the high pressure water generates a vacuum state temporary in the entrance of spoil pipe to remove the spoil generated during construction. This CPM equipment, which can be regarded as the simplified version of MJS, can help reduce the inner pressure of the stratum during jet grouting. However, when the overburden soil for jet grouting construction is very thin, the pressure of the jet grouting fluids may have a major effect on the surrounding environment, and the volume of spoil to be removed cannot be controlled automatically. Moreover, both spoil pressure and earth pressure do not be monitored during construction. This may cause obvious ground displacement around construction site during and after jet grouting (see Fig. 1(c)).

In this paper, to eliminate such impacts (e.g. outflow of the drilling fluid) and to reduce the impact on surroundings (e.g. large ground upheaval and lateral displacement), a new construction equipment for horizontal jet grouting technology named as pressure-control jet grouting technology (PCJG) is proposed. Fig. 1(c) shows the basic concept of ground movement during jet grouting process in the proposed PCJG technology. During the jetting process, the ground movement can be controlled via control of inner stratum pressure near the monitor,

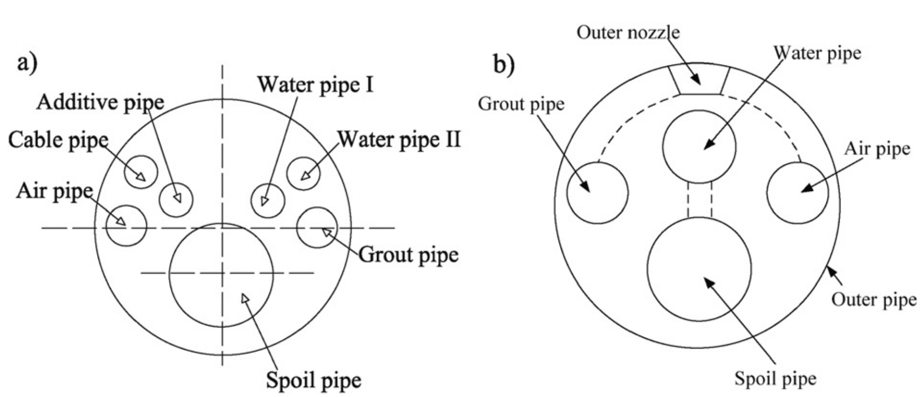


**Fig. 2.** Sectional view of composite pipes used in MJS and CPM technology, a) MJS; b) CPM (modified from Nakashima and Nakanishi [20]; Wang et al. [24]).