Pulsed High-voltage Discharge Technology Applied in Reaming

Chen Chen, Feng Xuewei, Li Dongshuang, Ji Xiaoyu, Yan Xuanchen, Chen Dayong

College of Construction Engineering, Jilin University / State Key Laboratory of Superhard Materials / Laboratory of Technology for Drilling Under Complex Condition of Ministry of Land and Resources, Changchun, China, 130026

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Abstract

Principle of pulsed high-voltage discharge technology applied in reaming, test device and relative parameter were expounded in the paper. The process of reaming is that liquid-electric effect is produced, according to discharge in the borehole filled with liquid medium, then shock wave exerted on liquid medium around the electrode radially (perpendicular to direction of discharge) is passed to stratum to compact the soil. Device of pulsed high-voltage discharge introduced from Russia was used to do this experiment, which completed reaming work for two boreholes. Using the same capacitance value, discharge was conducted at 1.5m and 2m in each borehole separately under the condition of different voltages. Boreholes' diameters were enlarged from 150 mm to 302–319 mm with different discharge times. It indicated that pulsed high-voltage discharge technology could compact and enlarge the diameter rapidly. Compared with traditional reaming technology, this new technology can improve the speed of construction and be better for complex formation, especially drilling in wet formation, in which drill pipe sticking, burying drilling, collapsing borehole and other incidents can be avoided. It's a new environmentally friendly technology with wide application prospect.

Keywords: pulsed high-voltage discharge; reaming; soil compaction.

1. Introduction

In the 20th century, pulsed high-voltage discharge technology has been carried out systematic research, even used in the production by scientists in Russia (former Soviet Union). So far, the applications in industry, science, medicine and military have been widely, what's more, application fields are expanding constantly.

In recent years, pulsed high-voltage discharge technology has been applied in pile foundations. Liquid-electric Effect produced by pulsed high-voltage discharge was used in pile foundation quality detection in our country in the end of the 20th century[1]. However, it is nearly blank with regard to pulsed high-voltage discharge technology applied in drilling and reaming. Therefore, experimental investigation in this paper has prominent engineering significance. In addition, it's new focus taking advantage of pulsed high-voltage discharge to treat with domestic and industrial wastewater, and pulse pressure waveform generated by liquid-electric effect can be used to Machining and molding. Pulse pressure waveform has been utilized in extracorporeal lithotripsy. Moreover, sparker and liquid-electric sand removal have been used in seismic prospecting and oil prospecting[2].

2. Principle and test device of pulsed high-voltage discharge

2.1 Principle of shock wave soil compaction

The process of soil compaction is that liquid-electric effect is produced, according to discharge in the borehole filled with liquid medium, then shock wave exerted on liquid medium around the electrode radially (perpendicular to direction of discharge) is passed to stratum to compact the soil. Liquid-electric effect[3] is the phenomenon turning electrical energy to sound energy and other forms of energy, when sparker discharges in liquid.

Source adopted in this paper was transmission-type land sparker. Principle that shock wave compacts soil is extremely complexity[2]: firstly, electrode begins to discharge in the borehole; then discharge channel is generated under highfield; lastly, discharge current would reach dozens of kiloampere, which is pulse pressure wave. The size of shock wave depends on voltage, energy, electrode structure, inductance and resistance of discharge circuit and so on. Pressure pulse generation and radiation are significant stage to decide formation wave, which also can be controlled.

Hereafter, shock wave acts on wall of borehole and radiate spherically outward. When pulse pressure exceeds enormously strength that soil can be supported, original structure of soil begins to destroy, and then soil is compacted. When pulse pressure spreads a certain radius, on which pulse pressure is equal to elastic limit, soil can't be destroyed. Pulse wave has turned to elastic impulse wave at this moment. Spherically elastic impulse wave keeps on expanding outward(figure 1).

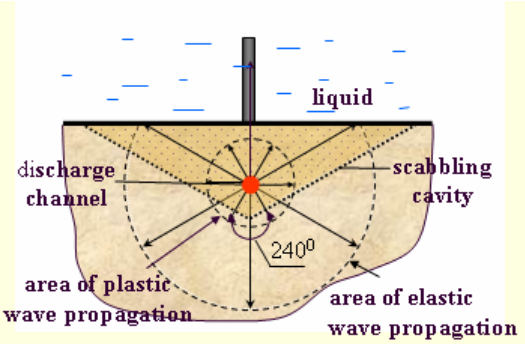

Figure 1 schematic diagram of discharging process

Electric energy stored in capacitor W_c:

$$W_c = \frac{1}{2} C U_c^2 \tag{3}$$

Discharge power N:

$$N = \frac{W_c}{T} = \frac{C U_{GK}^2}{2T} \tag{4}$$

C – capacity of capacitor; U_c – charging voltage of capacitor; T – discharge time; U_{Gk} – critical breakdown voltage

Total intensity of liquid-electric effect is proportional to capacity of charging circuit and charging voltage from (3)–(4).

2.2 Test device and parameter

The device of pulsed high-voltage discharge used in this test was newly introduced from Russia(Figure 2). As shown in figure 3, they are physical graph and schematic diagram of structure underground. Main parameters are shown in table 1. Operating temperature is range from –15°C to +30°C, and air relative humidity is not more than 95%. Moreover, it is allowed to utilize during raining and snowing.

Table 1 Technical parameter of high voltage pulse discharge device

Parameter	Supply voltage	Frequency	Power	Pulse voltage amplitude	Pulse power	Pulse frequency	Discharge capacity
Number	220/380 V	50Hz	10kW	9KV ± 10%	50KJ ± 10%	$\leq 0.2 \pm 25\% s^{-1}$	1600F ± 10%

Figure 2 Device principle layout

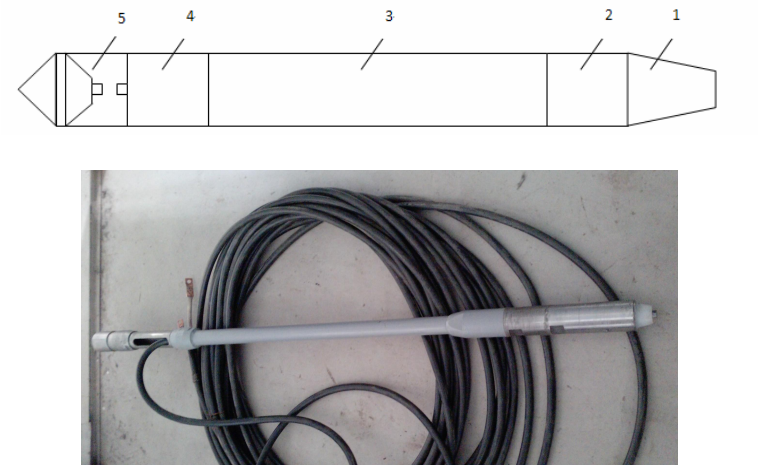

Figure 3. Physical graph and schematic diagram of structure underground
1 – bridle; 2 – charging part; 3 – capacitor energy storage part; 4 – trigger and discharge part; 5 – electrod

3. Pulsed high-voltage discharge experiment

3.1Methods and Processes of the Experiment

In order to more directly observe the level of reaming and facilitate to measure the boreholes' diameter after reaming, the experiment followed the way of injecting cement mortar into borehole to discharge in it. After pile-forming, the level of reaming was measured, and the level of the enlarging of the boreholes' diameter was the level of reaming.

Experiment Program: symbol M32.5 cement and riversand as well as tap water were used in the experiment. Since the purpose of this experiment was to verify the case of reaming, as well as taking into account the mobility of mortar and the water content on the impact of the discharge. The water-cement ratio of 0.7 was used for the preparation of cement mortar. Some Practice Base of Jilin University was chosen as the Test Site. On the same soil in the region, two holes were drilled, separately named as # 1 hole and 2 # hole. The two holes' depths were 3m and diameters were 150mm. It was discharged separately at the depth of 1.5m and 2.0m in the each hole. And discharge locations were both at the original soil.

Discharge capacitance values of 1# hole and 2# hole were both set to 750 μF . Different voltage and discharge times were used to discharge experiments. Different voltage discharges were used to discharge at the location of 1.5m of the two holes. 1 # hole was 6.5kV and 2 # hole was 7.5kV. And discharge times were 16. Two holes used the same voltage 7.0kv to discharge at the location of 2 m. Discharge times of 1 # hole were 20 and the ones were 16 of 2# hole.

Experiment steps: 1. Drilling borehole, according to the designed program plan, 3 holes were drilled as above-mentioned; 2. Preparation of cement mortar, taking into account of the conductivity and mobility of the mortar, water-cement ratio of 0.7 was used for mortar prepare; 3.The mixed cement mortar was injected into holes until filled up; 4. Electrode was placed at certain depth of holes (at the depth 1.5m of holes) to start discharge. In order to insure the density of the cement mortar at the apertures after discharge, the discharge device was raised at the interval of twice discharges so that the cement mortar could fill up with the aperture. And then the discharge device was back to the original location (1.5m depth). After per discharge, the cement mortar would produce a certain settlement. Settlement was recorded after twice electric discharges as Figure 4; 5. After data recorded, the cement mortar was poured into holes once again.

Figure 4. The situation of cement mortar before and after the discharge

3.2 Experimental results and discussion

48 hours after pile-forming, pile bodies in holes had been molding with a certain intensity. Pile bodies were dug up with manual excavation methods. The final revealed results of pile bodies were shown

in Figure 5. The pile diameter was enlarged almost two times after measurements. The data was from 302 mm to 319 mm(As Figure 6). The compactness of soil around the pile at the location of diameter enlarged was pretty good, which illustrated the technology could ensure quality while expanding the diameter of holes.

Figure 5. Pile bodies

The concrete discharge times were set by formation conditions with general 10–20 times of discharges for each location. If with too much fragmental stones in backfills or more dense of soil , the times of discharge could appropriately increase to ensure reaming effects. When the settlement of cement mortar at each location kept unchanged (the settlement of cement mortar was less than 1cm), the electrode was enhanced to the other position of the hole. Once without the influence of adjacent piles in the soil, the general first discharge settlement of mortar could be up to 40–60cm.

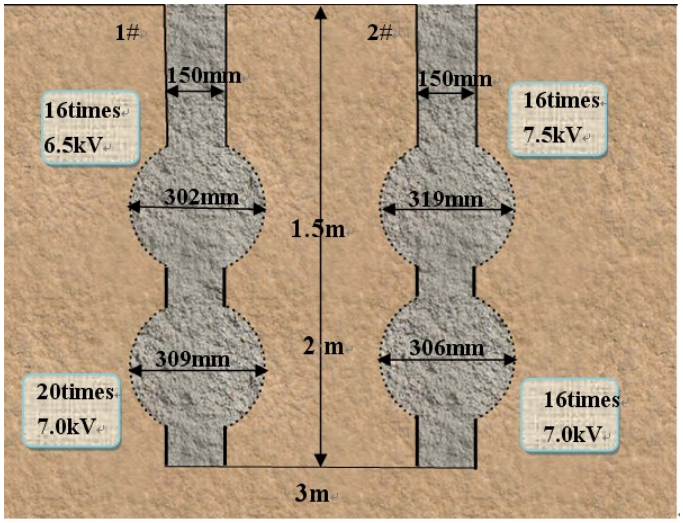

Figure. 6 Picture of the Experimental Data

According to the experimental data with the same numbers of discharge, when the discharge voltage was greater, the compaction effect of soil was more obvious. With the same discharge voltage, when the discharge times were more, the effect of soil compaction was more evident. Nevertheless, the effects caused by discharge voltage were more serious than the ones caused by the discharge times. The maximum energy released by this experiment was 21.1kJ based on equation (1). If larger capacitance and higher voltage values were selected, more energy could be obtained.

4. Conlusion

(1) The test on high voltage pulse discharge had achieved good results. It proved that this method could really expand the hole diameter and improve hole quality. Because of adopting transmission-type electric discharge source, with the hole's depth increasing, the length of the cable requires corresponding increase, resulting in energy loss growing. The cable parameters on the effect of the discharge should be further discussed.

(2) Generating the tremendous energy, this technology can also be used to burst assisted drilling or dealing with accidents in borehole. Drilling horizontal or vertical holes and other drilling construction, high voltage pulse discharge technique can be used for secondary reaming. It can avoid drill pipe sticking, burying drilling, collapsing borehole and other incidents, especially in wet formation.

(3) The soil selected in this test is single-layer and just two sets of comparative tests are done, only to analyze qualitatively. In the future, it's necessary to experimentize with different strata and different discharge parameters, which can help to research degree of reaming quantificationally.

References

[1] Li D.X. Yang B.A. (1987), Test of pile foundation using liquid-electric effect[J], *Chinese Journal of Rock Mechanics and Engineering*, Vol.6 No.1 64-68

[2] Qin Z.Y. et al. (2000), High-voltage pulsed discharge and its application[M], Beijing Industrial University Press

[3] Л.А.Yutkin(1962) , Liquid-electric Effect[M], Science Press

Анотація

У статті розглядається технологія розширення свердловини на основі імпульсного високовольтного розряду, дослідний зразок пристрою і відносні параметри. Процес розширення полягає у використанні рідинно-електричного ефекту, згідно якої розряд викликається в свердловині заповненою рідиною, потім ударна хвиля радіально рухається від електроду (перпендикулярно напряму розряду) і проходить через гірські породи і ущільнює їх. Пристрої реалізовують даний принцип були ввезені з Росії і використовувалися для розширення двох свердловин. Використовуючи аналогічну ємкість розряд був проведений на глибині 1,5 і 2 м-коди в кожній свердловині окремо в умовах різної напруги. Діаметр свердловини був збільшений з 150 мм до 302–319 мм при різному часі розряду. Показано що імпульсна високовольтна розрядна технологія дозволяє швидко збільшити діаметр. Порівняно з традиційними технологіями нова технологія може збільшити швидкість споруди і краще для складних формацій, особливо в тих, що обводнюють, які схильні до обвалення стінок і прихватів бурильної колони і запобігти ускладненням. Це екологічно дружня технологія з широкою сферою застосування..

Ключові слова: імпульсний високовольтний розряд, розширення, ущільнення грунта.

Аннотация

В статье рассматривается технология расширения скважины на основе импульсного высоковольтного разряда, опытный образец устройства и относительные параметры. Процесс расширения заключается в использовании жидкостно-электрического эффекта, согласно которой разряд вызывается в скважине заполненной жидкостью, затем ударная волна радиально движется от электрода (перпендикулярно направлению разряда) и проходит через горные породы и уплотняет их. Устройства реализующие данный принцип были ввезены из России и использовались для расширения двух скважин. Используя аналогичную емкость разряд был проведен на глубине 1,5 и 2 м в каждой скважине раздельно в условиях различных напряжений. Диаметр скважины был увеличен с 150 мм до 302–319 мм при различном времени разряда. Показано что импульсная высоковольтная разрядная технология позволяет быстро увеличить диаметр. В сравнении с традиционными технологиями новая технология может увеличить скорость сооружения и лучше для сложных формаций, особенно в обводненных, которые склонны к обрушению стенок и прихватам бурильной колонны и предотвратить осложнения. Это экологически дружественная технология с широкой областью применения.

Ключевые слова: импусный высоковольтный разряд, расширение, уплотнение грунта.