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APPLICATION OF HIGH-POWER ELECTRICAL SPARKS FOR DYNAMIC COMPACTION OF SOIL

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ABSTRACT

The paper describes an electrical discharge technology, applied for soil compaction around a borehole, filled with hardening grout, in operations for erection of micropiles, cast piles, soil anchors and soil nails. The technology consists in that 150-250 microsecond long electrical sparks are generated with 6-second period in borehole. The sparks have 30-40 kJ energy, which is roughly of the same order of magnitude as a pile drop hammer. But a single electrical spark has 200-250 MW because of its short duration. Such pulses compact the contact layer of soil and thus increase bearing capacity of piles, anchors or soil nails times 1.5-2.0.
Electrical spark in soil is a practically non-observable event, prohibiting any instrumentation near it, which so far can only allow its qualitative investigation in water rather than in soil. The experiments in water were staged in lab on a set-up, generating 5 kJ sparks, with electronic registration of time-dependent registration of pulse behavior. It was found that longer pulse efficiency is higher and can be increased by addition of special admixtures.
Full-size bored piles, micropiles and soil anchors were tested in-situ on construction sites, having various soil conditions. The test data yielded that pile (anchor, nail) bearing capacity could be increased times 1.5-2.0 by high-energy electrical spark treatment, as compared to conventional technology (without electrical spark treatment).

INTRODUCTION

The past two decades have seen active development of new equipment for construction of various geotechnical structures. The worldwide known companies Bauer, Casagrande, Kato, Soilmec and many others have marketed a large spectrum of dedicated drilling rigs and attachable equipment for installing piles and ground anchors in all kinds of soil and climatic environment.

However, large-diameter piles could not be reliably and effectively cast if their toes reached water-saturated sands, because at depths over 10 m the bottom hole sands were highly loosened. The amount of loosened material could be as high as several meters above the bottom hole, depending on the ground water table, water head, sand properties and the operation specific features.

In 1950-60s there was developed in the USSR a camouflet blasting technology for casting bored under-reamed piles. The holes were mainly drilled in stable soils by rotary rigs with ordinary augers to design depths. Then an explosive package was lowered to the bottom hole, equipped with a electric detonator, connected to a fuse. The borehole was grouted with liquid concrete and then the fuse was activated. Explosion of several kilograms of TNT generated a seismic wave that expanded in the borehole and produced a cavity in soil. The column of the liquid concrete pushed the explosion gases up to the surface and filled the cavity, thus forming a camouflet under-ream that highly improved pile bearing capacity, as compared to conventionally produced piles.

However, the new technology featured serious drawbacks due intensive seismic aftermath that prevented application of such piles, at least in urban environment. In the long run no piles with explosion-formed under-reams were erected either in Moscow or in any other big cities. Nevertheless, the idea of comouflet under-reammed cast piles proved to be fruitful. It was recently implemented within a framework of geotechnical electrical discharge technology (GEDT) as electro-chemical explosion (ECE) [1].

GEDT has been successfully implemented in Moscow since 1990 for installing cast piles, ground anchors and micropiles.

Electric discharge technology for geotechnical engineering and at-depth compaction of low-density sands soils is based on dynamic compaction action on soil media by pulsed electric spark, generated by high-voltage discharge unit.

Electric spark produces a shock wave and hydroflows in the vapor and gas cavity. The shock waves, followed by vapor and gas cavity action, apply multiple pulsed hydro-dynamic pressure on borehole walls. The equipment generates pulse trains with several seconds interval between them that result in multiple dynamic action of soils.

The soils react specifically to these actions, depending on many characteristics (soil properties, dynamic loading parameters, current stress-strain behavior of soil, etc.).

The procedure for such piles installation is given on Fig.1.

The effectiveness of GEDT has broadly been discussed in technical publications [2-5]. However, there are certain limits to GEDT application. It is, primarily, a limited number of GEDT units to execute big jobs, involving large-size geotechnical structures. Moreover, ECE could be preferable as compared to GEDT, as is the case of under-reamed piles, resting on high-density soil interlayer.

In order to outline the feasible application area for different types of electric discharge technology, to evaluate the seismic effect and to elaborate recommendations for ensuring integrity of existing buildings if electric discharge technology is used NIIOSP jointly with ZAO "Research Institute of Applied Physics and High Technologies" have investigated various soils compaction by GEDT and ECE method.

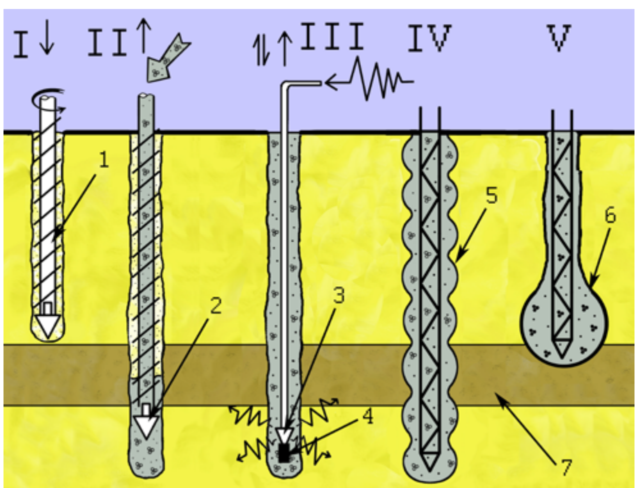

Fig. 1. I-Drilling a hole II-Filling the hole with concrete mixture. III- Electrical discharge processing of pile body. IV,V- Lowering reinforcement frame into hardening concrete mixture. Legend . 1-auger, 2-valve, 3- electrical discharge emitter, 4-cartridge filled with special paste for single-shot ECE treatment of pile toe; 5-ready reinforced pile; 6-camouflet under-ream, generated by ECE; 7- dense soil layer.

The experiments were done in a box, equipped with High-Speed Photocamera and containing a compact electric discharge unit UEG-30 (Fig.2). Full-scale tests were staged in Moscow, Moscow Region, Rostov-on-Don, Nizhny Novgorod Region, etc.

Fig. 2. UEG-30 compact option.

Electrical discharges were generated in box, filled with water and sand (Fig. 3). Battery storage capacitance was up to 5 kJ to generate a single pulse. Spark length was 40 mm.

Pulse parameters were investigated in two modes: a) with electrically explosive conductor (EEC), placed into the discharge gap; b) with cartridge, filled with aluminum powder and introduced into this gap – electrochemical explosive (ECE).

EEC mode is a particular case of GEDT with explosive conductor, placed in the discharge gap.

Fig. 3. Test box, filled with water-saturated sand.

Energy of the vapor-and-gas cavity (VGC) can be increased to get higher intensity and duration of hydroflows, which affect the object of treatment, by using electrical discharge (ED) in chemically active condensed media [6]. Such transformation process in ED channel of the capacitor electrical energy and chemical energy will be called electrochemical explosion below.

Energy, released by chemical reactions, adds up to electrical energy thus increasing the unit energy (per unit mass), introduced into VGC, of electro-hydro-pulsed devices with the capacitor overall dimensions being unchanged.

Special composition, introduced into the discharge gap (ECE mode), is not an explosive, but it can be transformed by exothermic chemical reactions at high temperatures and pressures, developed in the plasma channel.

The following typical pressure pulses were measured (Fig. 4).

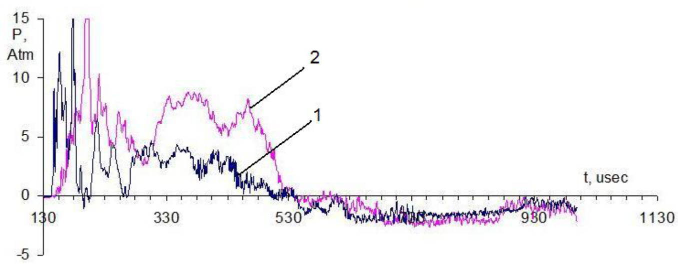

Fig. 4. Pressure pulse: 1 - EEC mode; 2 - ECE mode. Horizontal axis corresponds to microseconds; horizontal axis corresponds to pressure in bars (kgf/cm^2).

High-speed photo-imaging and VGC progress are shown on Fig.5

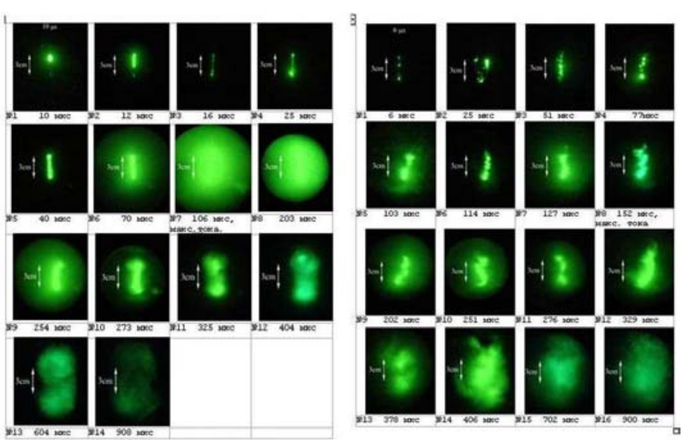

Fig. 5. Discharge formation: on the left side – mode EEC; on the right side – mode ECE.

Laboratory and field tests showed VGC dimensions, seismic effect of electrical discharge and effectiveness of electrical discharge treatment of different soils.

Special paste, fed into the discharge gap (ECE mode), multiplies VGS energy and provides for its effective control along with hydro-flows of the liquid, which act on the treated object. The pulse duration increases times 3-5 while its amplitude elongates times 1.5-2.

In [8, 9] a borehole of infinite length was simulated in infinite porous medium, saturated with liquid, the respective dynamic processes are described in it with due account of [7]. It was shown, contrary to [10], that in water-saturated cohesionless soils, subject to high-rate loading (typical for electric discharge processes), maximum soil deformations are 0.1-0.2 mm at 0.05 m distance. Also interaction of solid and liquid phases essentially affects their movement that results in attenuation of vibrations after pulsed load termination.

According to the measurements, VGC dimensions are about 8-10 cm. As per [11], the volume of liquefied soil is roughly equal to triple VGC volume. Therefore, the dimension of the liquefied soil around the pile could be 5-10 cm.

GEDT is effective in water-saturated sands that easily liquefy by passing shock wave, generated by electrical pulse, the follows hydroflows pressure, boosted by hydrostatic pressure of liquid weight in borehole that compacts soils in the contact zone.

In cohesive clay soils a different behavior is observed. Most clay soils are not liquefiable. The shock wave of an electric discharge causes mainly elastic vibrations. In such conditions VGS hydroflows action is insufficient for adequate plastic deformation of borehole walls. The essential factor herein is the pulse short duration, which is due to practical disappearance of VGS material because of vapor condensation and solution of its vapor-plasma gases. This explains low effectiveness of EEC in clay soils, which do not feature thixotropic softening, and, therefore, ECE is more effective for cohesive soils, enabling under-reams creation in cohesive soils (Fig.6).

Electric discharge treatment of piles essentially reduces boring aftermaths effect on pile bearing capacity (e.g., liquidation of bentonite crust, appearing during boring operation under bentonite slurry, compaction of the interface layer, loosened by boring, liquidation “necks”, etc.).

Special care shall be taken when applying this technology to strengthen existing footings, sitting on cohesionless soils, which are prone to dynamic softening. In such cases, the electric discharge technology is recommended outside the active zone of the footing, to be underpinned, in order to reduce the risk of additional softening of soil under the building that could lead to additional settlements.

Fig. 6. Under-reamed root piles (ECE mode) in clay.

These activities enabled development of a simple analysis for designing bored injected root piles [12] with due account of [13].

The following factors (Tables 1 and 2) were obtained to determine the increased root pile bearing capacity, improved by electric discharge treatment, on the basis of statistical assessment of pile static load test data with the account of bore-hole diameter.

Table 1. Soil service factors γ_{cR}

Pile types	Types of soil under pile toe			
	Sands	Sand loams	Clay loams	Clays
GEDT piles	2.4	2.4	1.8	1.8

Table 2. Soil service factors γ_{cf}

Pile types	Types of soils, pierced by pile			
	Sands	Sand loams	Clay loams	Clays
GEDT piles	2.4	2.4	1.9	1.9

In order to assess the proposed method, based on Tables 1 and 2, a comparative design pile load graph, derived from field tests and analytical results, was plotted (Fig.7).

Analysis of the comparative graph enables conclusion that the proposed method for pile bearing capacity analysis, allowing for the proposed service factors, gives maximum error of 15%.

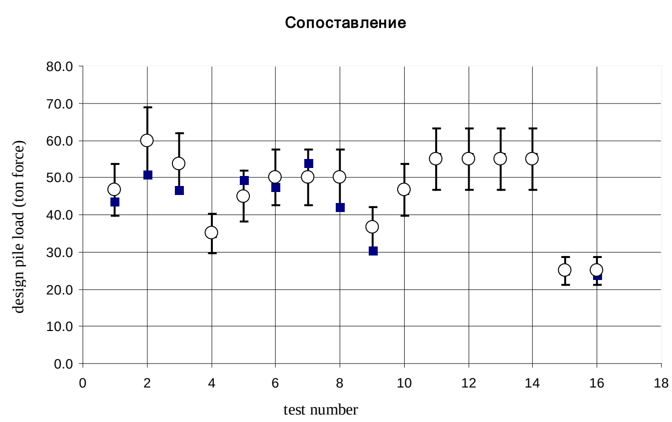

Fig. 7. Comparative graph. Square marker – design load on pile, corrected with the proposed service factors for side friction and toe resistance as per proposed approximations, tables of Construction Code SP 50-102-2003, [ton force]. Circular marker – pile design load as per static test data (ton force) with 15% scatter.

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