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Settlement Due to Blasting Improvement in Loose Saturated Deposits; Application to 18 Case Studies

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ABSTRACT

Among various methods for modification and treatment of saturated loose deposits, Explosive Compaction (EC) can be realized as an effective and common deep soil improvement method. In this paper, 18 different sites from U.S, Canada, India, Nigeria, Poland and etc. have been studied. Explosive Compaction successfully has been performed for modifying of loose saturated soils layers with thicknesses varied from 5 to 40 m in these sites. While EC performance, volume change due to densification ranged about 2% to 10% was observed. Analysis on the compiled database focused for Powder Factor (PF) role in induced settlement due to EC. Moreover, by using nonlinear optimization, a new relation has been proposed for settlement prediction in which PF, depth of Explosive charges and number of explosion phase's factor have been considered simultaneously. This relation indicates it is required to increase used powder factor by increasing depth of charge to get an enough compaction as well as influence of first and second phases in final settlement is more than further phases .

KEYWORDS

Deep Improvement, Explosive Compaction, Settlement, Powder Factor, Charges Arrangement

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1- Brief Introductions

Due to Development of construction, importance of projects and weak problematic configuration; Soil improvement is considered as an option for treatment of projects foundation system.Usual options for treatment of deep layer at depth Include: Vibro methods (Vibro floatation and Vibro replacement), Deep Dynamic Compaction (DDC), Deep Soil Mixing (DSM), Jet Grouting and Explosive Compaction (EC).

Explosive Compaction also known as Blast Densification (BD) is a soil densification technique that uses the energy released by completely contained detonations of explosives within loose, saturated, cohesionless soil to rearrange the particle into denser configuration and expel the water from the pore spaces. This method doesn't need special equipment and can identify as a fast, easy and costly method among various deep treatment methods. Inexpensive and readily transportation of energy source, simple and small-scale equipment, ability to work in confined conditions make EC an attractive method. Unlike other methods Blast Densification has ability to treat the problematic layer directly and improve deposits bottom-up.

EC involves placing a charge at depth in a borehole in loose soil (generally sands to silty sands or sands and gravels), and then detonating the charge. Several charges are fired at one time, with delays between each charge to enhance cyclic loading while minimize- in peak acceleration. Often several charges will be stacked in one borehole with gravel stemming between each charge to prevent sympathetic detonation. Using of Blast Densification can induce volume changes 2 or 3 times larger than that occur with large earthquake and increase relative Density of loose saturated deposits more than 70%.

2- Methodology

Effective and considerable parameters for design of EC Include: weight of charge in Blast holes, depth of charge and distribution of charges in the layer to be compacted, distance of blast holes, number of Blast phases, sequence of blast holes explosion and charge decks explosion in one hole. Each mentioned parameters are designed considering the final acceptable result, limitation of other parameters and environmental aspects.

One of the aspects that are very important in prediction of blast densification results is energy attenuation in soil mass. After detonation the energy attenuates in the soil mass between the charge and a given soil element. Powder Factor (PF) is a suitable parameter for defining the energy attenuation from the explosive charge and is defined as:

$$PF = \frac{1000W}{V} \quad (1)$$

Where:

PF: Powder Factor, g/m^3

W: Charge weight, kg physical situation of Blasting,

V: Volume of treated soil mass, m

After Blast Densification, Ground surface settles rapidly because soil structure changes to more dense and compact configuration. Surface settlement measuring is a common way for evaluation of EC. Because this measurement is simple and fast. The purpose of this study is suggesting the correlation for predicting of settlement of loose saturated deposits due to Explosive Compaction. For this purpose, 18 different sites from U.S, Canada, France, Poland, Nigeria and etc. have been compiled and studied. Existence of saturated loose sand layers in various depth and liquefaction hazard, make construction in these areas difficult; therefore, EC was used for loose deposits treatment. All sand layers in mentioned areas were quite saturate and has very low relative densities (D_r<40%) Therefore, liquefaction potential in these sites has been probable. Modifying loose sand layers with 5 to 40 meters thickness even located at the depths of 25 meters indicates the ability of blast densification as effective and notable deep soil improvement method.

With Analyzing data on collected sites, below parameters were calculated:

3- The average depth of charges

4- The average used Powder Factor

5- Settlement percentage of treated layer

Base on calculated data and by using nonlinear optimization, existence correlations for predicting of settlement due to blast improvement were optimized and new correlation was suggested.

3- Maine Contributions

A data bank including 18 blast densification projects were presented in this paper with full information about site conditions, Explosive Compaction design parameters and amount of layer settlement after EC.

Available correlations in literature for prediction of settlement after EC were investigated and optimized in this paper. Using nonlinear optimization changed

Coefficient of correlations and made them more accurate. But, According to these relations total used powder factor is just effective parameter in final settlement. While other parameters like depth of charge or number of blast phases can affects final settlement.
In this study, by using calculated data from data bank correlation (2) was suggested for prediction of final settlement after EC. In this relation in addition the Powder Factor the effects of other parameters including average depth of charges and number of phases are considered.

$$\Delta h = \frac{1.0735(\overline{PF}^{0.57})(1.52^{\log(N)}}{D^{0.205}}) \quad (2)$$

Where:
Δh : Settlement percentage of treated layer
$\overline{PF}$: Average Powder Factor
N: Number of EC phases

4- Simulation results

For comparison between existence correlations in literature and optimized shape of them and new suggested relation, two statically parameters (Standard Deviation (SD) and Average Absolute Relative Error (AARE)) were used. The amount of these parameters for mentioned relations presents in table.1. Figure.1 indicates the situation of settlements that were calculated from suggested correlation against real settlement that measured in the field for studied cases.
According to the Table.1 and Figure.1 Suggested correlation has more accurately than others. This indicates in addition of input energy, other parameters such as depth of charge and number of phase impact on final Blast Densification results.
The position of Parameter related to the number of phases (N) in new correlation states that influence of first and second phases are more than third or fourth phases. On the other hand the position of *D* in new correlation states that for good compaction by EC, it is necessary to increase amount of charge with increasing of explosive charge depth.

Table.1: Accuracy of the correlations

correlations	AARE	SD
Narin, van Court, 1997 (logarithmic)	48%	0.53
Narin, van Court, 1997 (Power)	38%	0.44
Optimized logarithmic correlation	32%	0.38
Optimized power correlation	28%	0.27
Suggested correlation	25%	0.24

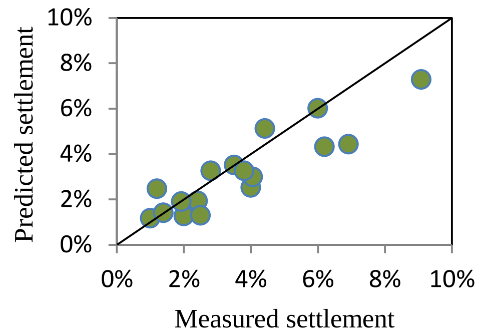

Figure 1: Matching the results of suggested correlation with the results of field measured settlement.

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