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A Cone Penetration Test-Based Improvement Factor for Sand Above Sabkha After Wet Vibro-Replacement

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ABSTRACT: *The Wet Vibro-replacement technology has been utilized on various construction projects to improve weak soil layers by inserting stiff stones and* increasing the density of*the surrounding soils. A better understanding of stone columns' efficiency can be achieved by comparing the soil parameters around them before and after they are installed.Therefore, a method to determine the expected degreeof improvement would provide requiredinformation for reasonable and cost-effective design of stone columns. The purpose of this paper was to understand better the attitude of sand and Sabkha soils improvement through Wet Vibro-replacement, as well as how the changes in ground conditions affect the interpretation of the cone penetration test used to measure the effectiveness. Research is based on published and field data collected from projects in eastern Saudi Arabia. Based on the results of the Cone Penetration Test (CPT), the Improvement Factor is established which quantifies the degree of improvement in sandy soils due to the construction of stone columns. The results presented show that the* improvement*factor is sensitive to* predicting*the value of post-CPT.*

KEYWORDS: *Wet Vibro-replacement; Sabkha soil; Stone columns; Cone Penetration Test.*

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I. INTRODUCTION

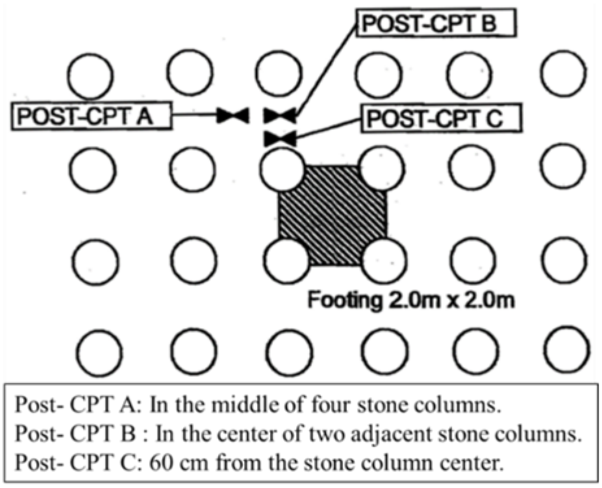
The word Sabkha is originally an Arabic name meaning salt flat, which has been used to describe salty flats underlain by sand, silt, or clay, and often inlaid with salt[1]. Excessive settlements and cracking are common problems in the foundations and structures built on Sabkha soils [1]. Sabkha soils are widely distributed throughout Saudi Arabia, obviously along with the eastern and western coastal areas. Improvement using Wet Vibro-replacement has been used on numerous infrastructure projects in Saudi Arabia to strengthen and densify Sabkha soil[2]–[4].

Ground development using Wet Vibro-replacement leads to the complexity of site characterization as it affects the conditions of surrounding soils and therefore changes the properties of such soils[2]. The overall ground improvement is achieved by a combination of reinforcement by stiffer stone, densification of soils due to vibration accompanying wet vibro-replacement, and probably an enhanced drainage condition[2]. The response to variations in soil parameters surrounding the stone columns before and after installation will provide a stronger understanding of the effectiveness of the stone columns. CPT is often used for quality control (QC) because this test provides a fast and cost-effective, continuous profile against the depth of the stone column [5]. The efficiency of the reinforced ground stone column is evaluated by changes in the values of readings before and after the installation of stone columns [6]–[8].

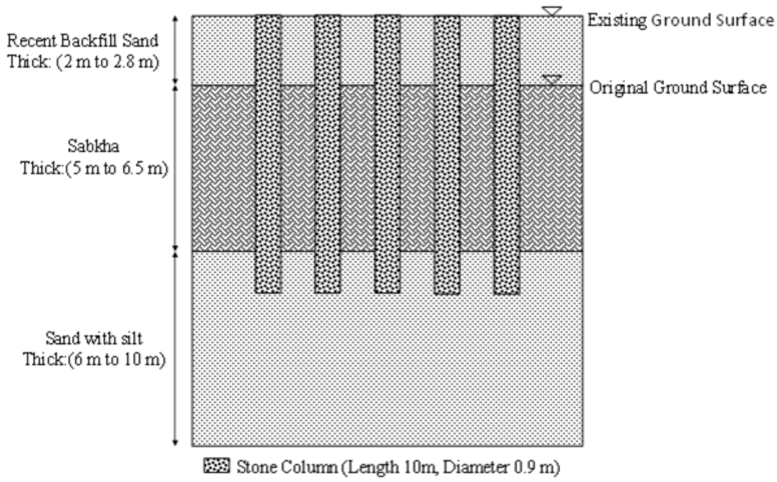
The purpose of this paper is to develop a new improvement factor to predict post-CPT of sandy soils that are affected by wet vibro-replacement as these are essential for stone column modelling and design in this type of soil. The research is based on documented and field data collected from projects in eastern Saudi Arabia.

II. FIELD DATA

The research data were taken from geotechnical reports and construction documents of the project located in Eastern Saudi Arabia. Thesabkha formation is accessible in all areas of the project up to 6.50 m thick. The ground improvement process begins with the construction of sand layers 2 to 3 meters above weak Sabkha soils, followed by the installation of stone columns using Wet Vibro-replacement. The main purpose of the sand layer is to provide a stable bed for the structure's foundation, accelerate Sabkha consolidation, and raise the level of the structures. The stone columns were installed up to 10 m below the working level and have a diameter of approximately 0.9 m, with square grids of 2 m×2 m. The soil conditions for the project are shown in Fig. 1 (a). To ensure that the required bearing capacity for the improved soil is achieved, four full - scale field plate load tests were carried out on the working stone column area. Footing load tests were conducted near boreholes and CPT to identify the soil profile. A total of twelve post-CPTs were carried out around the footing load test to assess soil conditions after the installation of stone columns. The distances between the Pre-CPT and Post-CPT holes were approximately a few meters to a maximum of 8 meters. All tests were carried out on the configuration of the stone columns and the CPT positions as shown in Fig. 1(b).



(a)



(b)

Fig.1. (a) Typical Existing Soil Profile within Projects Site.(b) Layout for full - Scale Field footing Load Tests and Post-CPT's.

III. EVALUATION OF SOIL LAYERS UPON WET VIBRO-REPLACEMENT

Pre-CPT and Post-CPT around footing load tests before and after Wet Vibro-Replacement are shown in Fig. 2. Clear improvement was observed in the sandy layer above Sabkha. The Wet Vibro-replacement may increase the density and horizontal stress of the surrounding sandy soil. The combined effect of these changes on CPT response is usually an increase in the cone tip resistance.Due to the disturbance of cemented soil bounding during the Wet Vibro-replacement activity and lack of surface confinement, there are a few pointswhere the Pre-CPT value is higher than the Post-CPT. Conversely, Post-CPT testing shows an improvement of around 1 m of above layer in the upper part of sabkha and no significant change in the remaining layer to a depth of 6 to 7.5 m below the ground surface. Dry Sieve data show that Sabkha is below 4 meters (70 percent < 0,075 mm) and contains very fine materials. The filed result demonstrated that the techniques of Wet Vibro-replacement are usually ineffective if the percentage weight of fines reaches 20 percent [9]Also, Hussin and Mackiewicz stated that no substantial improvement was achieved with the Wet Vibro-Replacement method when the fines materials exceeded 12 percent and the degree of improvement was more relevant to the quantity of the clay content than to the silt[10][11]. The soil under the Sabkha was classified as sand with a high pre-CPT value (> 20 MN/m^2) this value increases with depth and refusal at a depth of not more than 7.9 m. The decrease in the depth of the refuse point of Post-CPT indicates that this layer was slightly improved due to the installation of the stone columns.

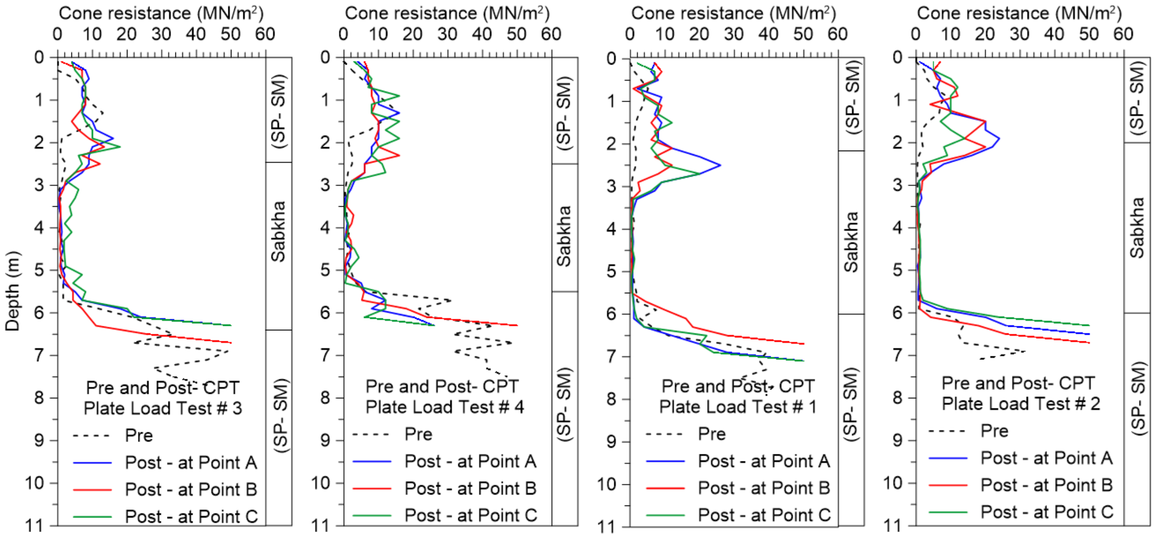


Fig. 2. ***Pre- CPT, Post- CPT around footing load tests.***

IV. IMPROVEMENT FACTOR OF SAND ABOVE SABKHA

Based on the interpretation of findings of field data, an improvement factor for the sand layer above sabkha soil was proposed, as shown in Figure 3. The improvement factor can be used to evaluate the enhancement in sand soils due to the installation of stone columns using a wet vibro replacement process. Significant improvement is expected to occur in very loose and lose sand (Pre-CPT<4MN/m^2) due to the installation effect of Wet Vibro- replacement and the relative density change to medium (Post-CPT between 4 and 12 MN/m^2). Light improvement is expected to occur in the medium relative density sand (Pre-CPT between 4 and 12 MN/m2), as shown in Fig. 3.

The value of Post-CPT can be predicted as:

$$\text{Average Post\_CPT} = \text{Improvement factor} \times \text{Average Pre\_CPT} \quad (1)$$

This consideration is restricted only to the sand layer above the Sabkha soil and can be used as a tool for optimizing the design of the stone columns.

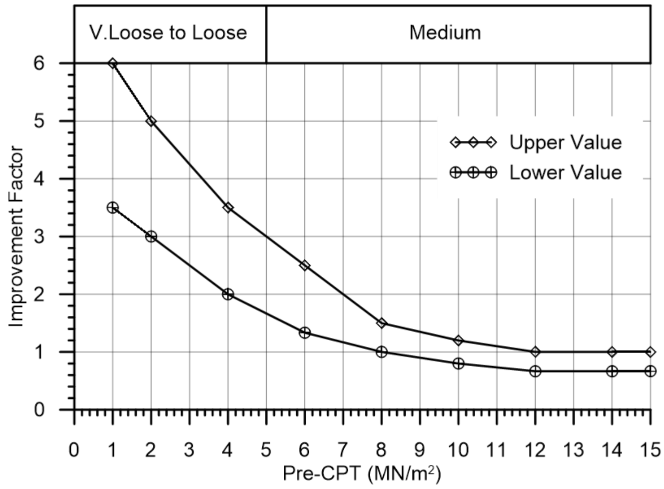


Fig. 3.Upper layer Improvement Factor.

V. CONCLUSIONS

An improvement factor for the sand layer above sabkha soil to estimate the enhancement due to Wet Vibro- replacement was developed in this study.The improvement factor can be used to predict the Post-CPT, and therefore the properties of sand treatment can be interpreted from the Pre- CPT. This consideration is restricted only to the sand layer above the sabkha soil and can be used as a tool for optimizing the design of the stone columns. Slight improvement occurred in the Sabkha layer, especially at the top 1 to 1.2m. The value of CPT tip resistance in the sand layer below Sabkha (to a depth of 15 m) is approximately the same in Pre and Post Wet Vibro- replacement, because this layer's strength is high before stone columns are inserted. Therefore, the vibration accompanying the Wet Vibro- replacement may not result in a significant change in this layer. The results of the case studies indicate the densification achieved from Vibro replacement is a function of the initial density and fine content of the material.

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