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Technical Note

Densification of desert sands by high energy dynamic compaction

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ABSTRACT

The dynamic compaction (DC) method is an effective ground treatment technique widely used in a great variety of soil types and conditions, particularly sandy materials and granular fills. However, the application of DC on very fine desert sandy ground is rare. In this study, dynamic compaction with a high energy level of 8000 kN·m was applied to a desert sand site in Inner Mongolia, China. During DC construction, field tests were conducted to determine the optimum DC operation parameters. This field study included deformation tests, dynamic penetration tests and plate-load tests. Deformation tests included the crater depth per drop and the whole test zone elevations before and after DC. Dynamic penetration tests and plate-load tests were performed to evaluate the final effect of DC. It was found that the allowable ground-bearing capacity and the depth of improvement at the site achieved no less than 450 kPa and 12 m, respectively, as a result of high energy dynamic compaction.

1. Introduction

Desert sands are usually fine-grained and poorly graded materials with small amounts of silt (Al-Aghbari et al., 2009). They easily cause some problems for the construction of infrastructure because they are loose and vulnerable to collapse upon wetting. Therefore, desert sands are not ideal to directly support structures or roads. In recent years, various improvement methods have been used to enhance the performance of poor soils, most of which involve the traditional chemical stabilization and fiber reinforcement.

Depending on different engineering requirements, desert sands can be stabilized by the addition of different additives. Aiban (1994) used cement and calcium carbonate to improve the shear strength of desert sands. Baghdadi and Rahman (1990) added cement kiln dust to desert sands for possible use in highway construction. Al-Aghbari et al. (2009) improved the engineering properties of desert sands by using cement and cement bypass dust. Besides cement, other additives such as bentonite, asphalt and fly ash have been gradually used to stabilize desert sands. Additionally, the addition of fibers can increase the shear strength and reduce the deformation of desert sands. Combinations of stabilizers and fiber reinforcement were also used to improve the properties of desert sands (Al-Aghbari et al., 2009).

Although the stabilization and fiber reinforcement methods can enhance the performance of desert sands, they are usually inadequate for large areas of construction due to economic and environmental concerns. Compared to the above two methods, dynamic compaction is a suitable improvement method for large area ground improvement due to its cost-effectiveness, simplicity and the considerable depth it affects. The method involves repeated impact applications on the soil surface using steel or concrete tampers weighing 100–400 kN (10–40 tons), dropped from heights of 10–40 m. The method is applicable to a wide variety of soil types and conditions, particularly sandy materials and granular fills (Mayne et al., 1984), although prudence is required if it is used with saturated clay and fine-grained soils (Lukas, 1980). There are a number of influencing factors in DC design, which can be sorted into two aspects, namely, the ground property aspect and the DC technique aspect. The former one includes the soil type, the groundwater table and the underlain compressible layer. The latter one includes the weight and shape of tamper, the drop height, the grid pattern, the number of impacts, the termination criterion at each impact point and the time delay between passes (Feng et al., 2010).

The highly complicated ground response to DC is still not properly understood. Until recently, a few analytical and numerical models have been developed to account for the complicated soil behavior during DC. Chow et al. (1992a, 1992b) proposed a simplified model based on the one-dimensional wave equation for predicting the crater depth associated with the weight dropped, which also allows the depth and level of soil improvement beneath the impact zone to be determined. Moreover, Chow et al. (1994) presented the characteristic design curves for selecting the optimum grid spacing in dynamic compaction projects. Pan and Selby (2002) simulated the dynamic compaction of loose soils using finite element method. Lee and Gu (2004) estimated the degree and depth of improvement

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resulting from dynamic compaction on sand based on extensive two-dimensional finite element analyses. Nashed et al. (2009) presented an energy-based method for numerical analysis for the determination of post-improvement soil densities and penetration resistances in sands and silty sands. Unfortunately, due to the DC process which is very complicated, current practice for design, suitability assessment, and determination of optimum field operation parameters still rely on field pilot tests and past experience. Thus, a pilot test is often carried out at the site to ascertain the operational parameters, such as pounder weight, drop height, number of drops per pass, print spacing, and number of passes, so as to minimize the operational costs.

This paper describes a field study for evaluating the effectiveness of DC on desert sands at the eastern site of Inner Mongolia in China. This field study included deformation tests, dynamic penetration tests and plate-load tests. Deformation tests included the crater depth per drop and the whole test zone elevations before and after DC. The number of blows was discussed on the basis of the dynamic penetration tests at the site, and the improvement depth of DC was investigated by taking into account the variation in number of blows against the depth. Additionally, the allowable bearing capacity of DC densified desert sand ground was determined based on the results of plate-load tests.

2. Site description and subsoil conditions

The project under study involves a coal gas plant planned in the desert sand area, more specifically, at Haolaihure Town, Keshiketenqi, Inner Mongolia, China. The site is underlain by wind-accumulated silty fine sands and alluvial fine sands, as shown in Fig. 1. The granular size of the lower layer sands increases gradually from north to south, east to west. Based on the grain size analysis results in Fig. 2, the grain sizes range from 0.08 mm to 0.9 mm, and the site mainly consists of fine to coarse sands, with traces of gravels and silts.

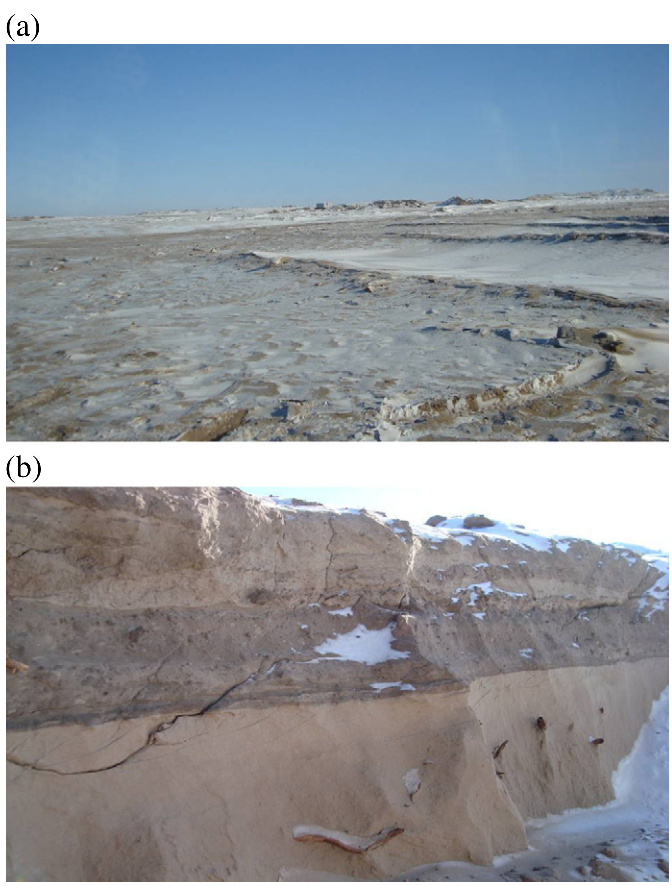

Fig. 1. Site soils under dynamic compaction: (a) site terrain; (b) site soil profile.

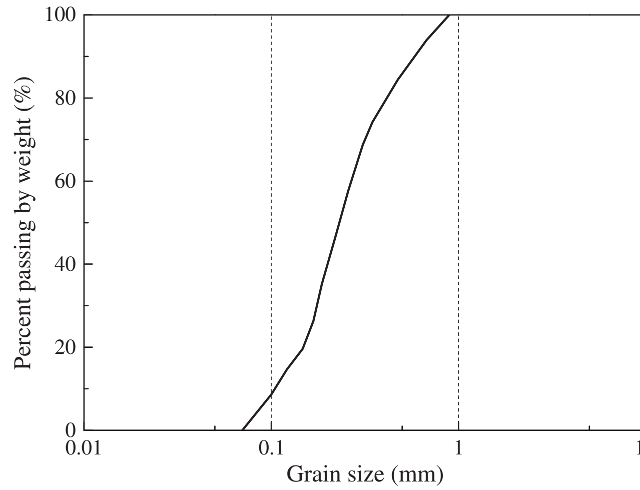

Fig. 2. Typical grain size distribution.

Prior to DC, the preliminary geological investigation was conducted by drilling boreholes. The typical soil profile consisted of four distinct layers. The uppermost soil layer, which varies between 0.2 and 2.5 m thick, was composed of wind-accumulated silty fine sands. The second to third layers, with a thickness of 3.4–6.8 m and 3.2–6.2 m respectively, were both composed of alluvial fine sands but with poor gradation. The fourth layer was also composed of alluvial fine sands with poor gradation, the boring didn't penetrate this layer within the drilling depth. The major properties of soil layers at the site are listed in Table 1. In addition, no groundwater was found at the site within the drilling depth. The soil at the site was generally sands with relatively low water content (2%–5%).

Considering the large area of the site to be treated, traditional methods such as chemical stabilization and fiber reinforcement fell short due to economical concerns. Dynamic compaction was finally chosen to improve the ground. However, a pilot test will be conducted before the official DC execution to determine these key design parameters. The design criteria for allowable ground bearing capacity and improvement depth after DC treatment were no less than 350 kPa and 10.5 m, respectively.

3. Dynamic compaction process on desert sands

The DC execution is a process of densification; the energy produced by DC destroys the original soil structure and expels air and water out from voids, forcing soil particles into a denser state through consolidation. DC design can be influenced by many factors, including the mass of the tamper, the fall height, the number of passes, the sequence of drop point, the grid spacing, the time delay between passes, the termination criterion for each drop point etc. However, due to the complexity of site-dependent conditions, the task is much more difficult. The above-mentioned design parameters are not always

Table 1
Average physical and mechanical properties of the subsoil.

Soil layer	Soil name	Thickness	Natural water content (%)	SPT blow count
1	Fine silty sand (Q_4^{eol})	0.2–2.5 m	4.4	9.6
2	Fine sand (Q_4^{al+pl})	3.4–6.8 m	3.7	16.6
3	Fine sand (Q_4^{al+pl})	3.2–6.2 m	2.8	23.2
4	Fine sand (Q_4^{al+pl})	Not penetrated	2.8	30.1