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Performance of laterally loaded piles in improved coal ash deposit

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Abstract

A series of pile load tests was conducted at a fossil fuel power plant in Taiwan to evaluate the performance of piles in a coal ash deposit that were improved using gravel compaction. The data from lateral load tests on two large-sized reinforced concrete piles were analyzed in this study. The original penetration resistance of the coal ash layer was low, but it increased after the ground improvement. Based on the load-defection curves of the test piles, the complete relationships of equivalent subgrade reaction coefficient k_h with lateral displacement were derived and compared with those suggested by the Architectural Institute of Japan (AIJ) and the Japan Road Association (JRA). A composite SPT-N value was adopted to include the contribution of the gravel piles. It was found that the JRA equation using the composite SPT-N value fitted well with the relationships. Moreover, the experimental pile response and *p-y* curves were deduced using the inclinometer slope data. The relationships of the secant k_h of the *p-y* curves vs. the normalized lateral displacement were further compiled and compared with those predicted by the JRA method. It was shown that the predicted curves using the composite SPT-N values also agreed well with the experimental relationships. Through a comparison of the profiles of the soil reaction with some existing lateral limiting soil pressure formulas, it was found that Prasad and Chari's method was able to yield predictions close to the ultimate soil reaction.

Keywords: Coal ash; Ground improvement; Piles; Lateral loads; Field tests

1. Introduction

Fossil fuel is a major source of power in Taiwan. A great deal of coal ash is generated during the combustion of coal; and therefore, the treatment of coal ash is an important issue for fossil fuel power plants. In Taiwan, coal ash is often added to Portland concrete to improve its engineering properties. It is also hydraulically filled into ponds near power plants to create land for constructing generator factories or coal storage warehouses.

A hydraulically filled coal ash deposit is normally loose; and therefore, it has to be improved in order to increase its strength before any construction is done on it. The sand/-gravel compaction pile method is commonly used for ground improvement. It installs piles made of compacted sands or gravels into the soft ground. The method can increase the liquefaction resistance and the bearing capacity of loose sandy soils (Okamura et al., 2003; Hatanaka et al., 2008) or accelerate the consolidation of soft clayey soils and the drainage of sandy soils (Rao et al., 1997; Yi et al., 2013). Sand/gravel compaction piling has also been introduced in Taiwan and is becoming increasingly popular for improving coal ash deposits (Hwang and Tu, 2002; Lin et al. 2009). The sand compaction pile method was shown to be effective for hydraulically filled coal ash ponds to increase SPT-N and CPT-q_c values. In addition, another method, the heavy compaction method, was recently applied to a coal ash ground and found to be effective for improving the ground (Kokusho et al., 2012).

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Piles are often used as foundations of coal storage warehouses in power plants to support the vertical structure loads. In addition to vertical loading, the piles may also be subjected to lateral loading, such as wind and earthquake loads on the structures. In engineering design practice, the *p-y* method is commonly used to analyze the nonlinear behavior of laterally loaded piles; it employs sets of nonlinear relationships between the soil reaction (p) and the pile displacement (y) to define the subgrade horizontal stiffness for different depths of soil along the piles. Using the data from pile load tests, a number of *p-y* models for sands (Reese et al., 1974; O'Neill and Murchinson, 1983) and clays (Matlock, 1970; Reese and Welch, 1975) have been proposed. However, few studies have been done on the lateral behavior of pile foundations in improved coal ash deposits; and therefore, more research is needed on the rational design of lateral piles in this type of ground.

In 2013, the construction of ten coal storage silos was planned in an area filled with coal ash near a fossil fuel power plant in Linko, Taiwan. The area was to be improved by gravel compaction piles. Each silo was designed to have an inner diameter of 46 m and a height of 77.3 m, with the capacity to store about 7000 MN of coal. Piles were adopted to be the foundations of the silo structures. The piles were reinforced concrete piles with a diameter of 2 m and a length of 26.5 m. In order to understand the actual performance of the piles in a coal ash area improved by gravel compaction piles, a series of pile loading tests, including a compression test, a tension test, and two lateral tests, were conducted before the above construction.

For a better understanding of the lateral behavior of piles in an improved ash ground, this study analyzed the data from the lateral load tests and retrieved the experimental load-transfer curves (i.e., *p-y* curves). From the results, the characteristics of subgrade reaction coefficient k_h and the *p-y* curves of the test piles, along with the applicability of general k_h formulas in the design codes to improved coal ash grounds, were investigated.

2. Site conditions

The soils at the coal silo construction site are composed of coal ash fill from EL. 9.0 m to EL. −9.0 m, and weathered sandstone below EL. −9.0 m. On the west side of the construction site, a region of 32 m × 22 m in plan, which had been improved by gravel compaction piles, was chosen for performing the pile load tests, as shown in Fig. 1. The ground level at and around this region was lowered to EL. 4.5 m and the gravel piles were installed from this elevation. The water level was located at about EL. 1.0–1.4 m. As shown in Fig. 1, 16 boreholes (eight outside and eight inside the improved area) were adopted for the SPT and CPT subsoil investigation. Boreholes T5-T8 were located outside of the improved area; the soil properties in this region without the ground improvement are shown in Table 1. The penetration resistance of the coal ash fill was quite low; the average SPT-N value was 5 and the CPT-q_c values were about 2500–3500 kN/m^2. The gravel piles had a diameter of 1.0 m, a length of 11.3 m (the upmost 1.3 m was null), and a spacing of 3 m (three times the pile diameter). The backfill material for the piles was

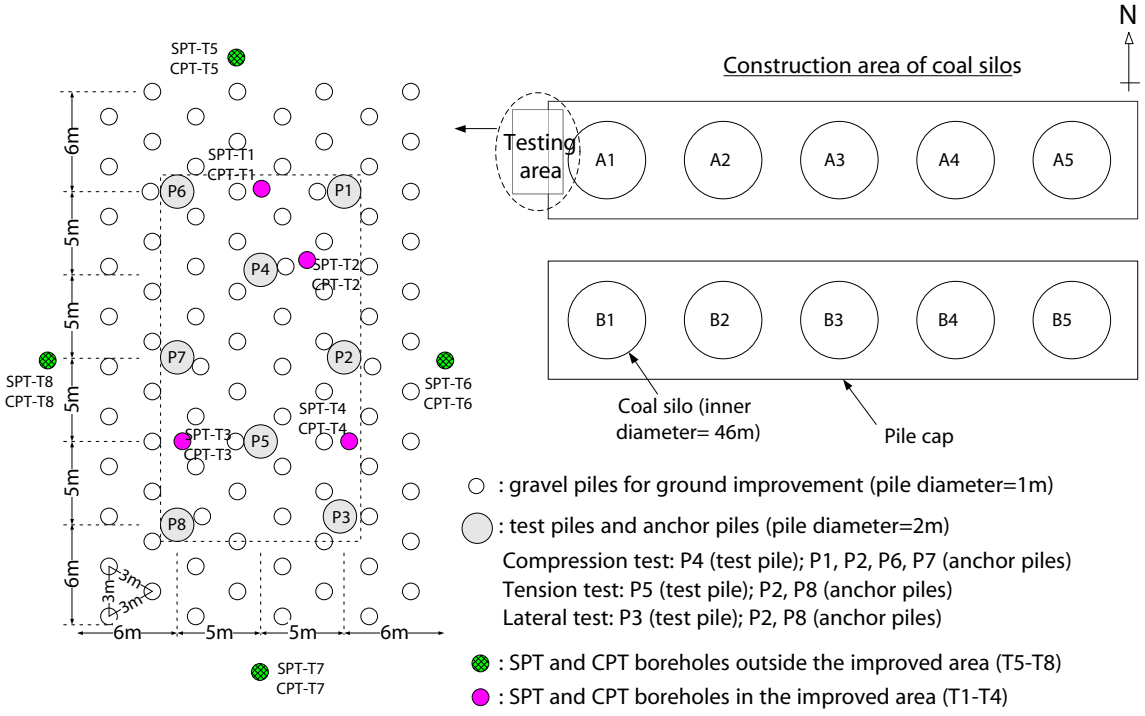

Fig. 1. Construction site of coal silos and test site of pile loading tests.

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