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Resistance and swelling of Tabriz marl soils stabilised using nano-silica and nano-alumina

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The effects of nano-silica (NS) and nano-alumina (NA) additions on problematic marl soil in Tabriz, Iran were investigated. Marl soils constitute the foundations for most projects in Tabriz. Due to water absorption, these soils are liable to volume change, leading to instability risks in the foundations. Various physical and chemical methods have been employed to stabilise these soils. In the present study, for the first time, reconstructed samples of Tabriz marl were stabilised with various percentages of NS and NA, which have fewer negative environmental effects compared with ordinary additives such as Portland cement or lime. Soil swelling behaviours were evaluated experimentally using tests for Atterberg limits, density, free swelling, swelling pressure, California bearing ratio (CBR) and direct shear. Field emission scanning electron microscopy and X-ray powder diffraction analyses were conducted at curing times of 1, 7 and 28 days. It was found that NA had a greater effect on reducing the swelling of stabilised samples than NS. However, NS had a greater effect on increasing the strength (CBR).

Keywords: environment/geotechnical engineering/site investigation

1. Introduction

Improving the geotechnical properties of soils is one of the major issues in civil engineering. Marl soils are problematic in most cases. These soils are of clay type and consist of 35–65% clay and 35–65% calcium carbonate. The main criteria to be considered when designing structures on marl soils include deformability of the soil and, in some cases, low strength. In terms of strength and other engineering qualities, marl soils do not meet the standards required for various types of activities and several chemical, mechanical and physical methods thus have been developed to improve marls (Bahadori *et al.*, 2020; Poulos, 2018; Simpson and Tatsuoka, 2008; Torabi and Heidari, 2020; Zahedi *et al.*, 2021). For soil improvement, cement, fibre and other additives have been used to enhance the physical and mechanical parameters of clayey soils and chemical soil stabilisation using lime or cement is a proven technique to improve soil performance (Alipour *et al.*, 2017; Chai *et al.*, 2019; Pakbaz and Alipour, 2012; Shrestha *et al.*, 2015; Yamashita *et al.*, 2016). However, the production of ordinary Portland cement requires large amounts of energy and emits a significant amount of pollution (Funk *et al.*, 2019; Kavyateja *et al.*, 2020). Considering the widespread use of coal in the cement industry, the emission of environmentally hazardous gases and the consumption of large amounts of energy, water and aggregate materials, searching for new binders for soil improvement has received much attention (Bhardwaj and Sharma, 2020; Suescum-Morales *et al.*, 2021).

In comparison with traditional cement, nanomaterials such as nano-alumina (NA), carbon nanotubes and colloidal silica (nano-silica (NS)) are generally non-toxic and inert. The addition of nanomaterials as soil strength improvers strength does not involve any pollution or environmental issues (Camani *et al.*, 2020; Del Mar Orta *et al.*, 2020; Latifi *et al.*, 2015; Shafigh *et al.*, 2014). The addition of nanoparticles leads to a reduction in soil swelling indices (Abedi and Yasrobi, 2010; Faisal *et al.*, 2021; Pham and Nguyen, 2014), while the addition of nanoclay to clayey soil considerably increases its liquid limit (LL), plastic limit (PL) and parameters related to shear strength (Mohammadi and Niazian, 2013; Tabarsa *et al.*, 2018).

Taha and Taha (2012) carried out compaction tests on clayey soils treated with NA and the results indicated a decrease in both expansive strain and shrinkage strain. Luo *et al.* (2012) reported that adding NA to soil reduced its maximum dry unit weight, increased the optimum moisture content (OMC) and reduced its plastic index (PI). Ghasabkolaei *et al.* (2016) found that adding 9% Portland cement to the soil dry weight and a small amount of NS (1.5% of the cement content) improved the soil strength by up to 38%. The effects of NS and nanoclay on clean and polluted (with crude oil) CL soil samples were studied by Zomorodian *et al.* (2017). They concluded that the nanoclay had a stronger effect on the strength parameters of the soil and found that the optimum concentrations of