Engineering Geology 204 (2016) 23–32

Contents lists available at ScienceDirect

Engineering Geology

journal homepage: www.elsevier.com/locate/enggeo

Laboratory investigation of liquefaction mitigation in silty sand using nanoparticles

Yu Huang [a,b,*], Lin Wang [a]

[a] Department of Geotechnical Engineering, College of Civil Engineering, Tongji University, Shanghai 200092, China
[b] Key Laboratory of Geotechnical and Underground Engineering, Ministry of Education, Tongji University, Shanghai 200092, China

ARTICLE INFO

Article history:
Received 13 June 2015
Received in revised form 19 January 2016
Accepted 22 January 2016
Available online 25 January 2016

Keywords:
Liquefaction mitigation
Nanoparticle
Laponite
Silty sand
Dynamic triaxial tests

ABSTRACT

Nanomaterials are presented in this paper as a novel method of liquefaction mitigation that overcomes the limitations of traditional mitigation methods. The proposed method is different from traditional densification and chemical grouting methods: no ground disturbance occurs and an entire site can be treated. In this study, laponite, synthetic silicate nanoparticles that are nontoxic, pure, highly plastic, and smaller in size than natural clay particles, has been selected as a representative nanomaterial that can be used in conjunction with liquefiable silty sand. Little research has been undertaken on the mixing of such materials. The cyclic behavior and liquefaction resistance of mixtures of laponite and silty sand have been studied by means of dynamic triaxial tests. The pore pressure accumulation process and deformation properties are compared between pure silty sand and laponite–silty sand samples to verify the effect of laponite on the liquefaction mitigation of the silty sand. Additionally, the viscosity of laponite suspensions is measured to determine the appropriate gel time for curing the laponite–silty sand samples. Microstructural imaging with a scanning electron microscope is analyzed in conjunction with liquefaction mitigation mechanisms. Then the effects of laponite concentration and curing time on the liquefaction resistance of the treated samples are discussed. This work provides experimental data to support the beneficial effects of laponite mixing on the reduction of liquefaction susceptibility in saturated silty sand. It also assesses the mechanisms and effects of nanoparticles on liquefaction potential.

© 2016 Elsevier B.V. All rights reserved.

1. Introduction

In recent years, large destructive earthquakes, such as the 2008 Wenchuan earthquake in China, the 2010 Chile earthquake, and the 2011 Great East Japan Earthquake, have resulted in multiple geo-engineering problems, of which liquefaction is particularly prominent (Juang and Li, 2007; Huang and Yu, 2013). Liquefaction is a phenomenon marked by a rapid and dramatic loss of soil strength; it occurs in loose, saturated soil deposits subjected to earthquake motion. The onset of liquefaction is usually sudden. The liquefiable soil's shear strength and shear modulus decrease significantly, resulting in the loss of soil bearing capacity, significant deformation, and soil settlement. This in turn leads to instability and destruction of structures such as building foundations, roads, bridges, and ports, sometimes causing serious losses of life and property (Huang and Jiang, 2010; Verdugo, 2012; Yasuda et al., 2012). Bird and Bommer (2004) examined fifty destructive earthquakes worldwide and found that liquefaction occurred in 62% of those earthquakes, causing 15%–30% of the earthquake damage. Therefore, research on liquefaction mitigation and control is of great importance.

Ground improvement techniques are commonly used to increase the liquefaction resistance of soils and control potential deformation. Traditional in situ liquefaction mitigation methods can be classed in two main categories: in situ densification and grouting. In situ densification methods include deep mixing (Porbaha et al., 1999), dynamic compaction (Shenthan et al., 2004; Yasrobi and Biglari, 2007), and granular piles (Krishna, 2011); these methods can effectively raise the bearing capacity and liquefaction resistance of the soil. However, they have limited applications because they can cause considerable disturbance to ecological and residential environments. Hence, in situ densification is more suitable for open undeveloped sites than for developed sites. Grouting can be used in constrained sites; traditional grouting materials include cement slurry, sodium silicate ($Na_2O \cdot nSiO_2$), and chemical grouts (such as acrylate and epoxy). Cement slurry has a high initial viscosity; therefore, cement grouts are usually injected under high pressure and often are used to form grout columns rather than to permeate the entire area beneath the structure. Chemical grouts present a high risk of damage to adjacent buildings and pollution of waterways if handled improperly (Vik et al., 2000). Therefore, with increased industrialization and urbanization and the progress of creative science

---

* Corresponding author at: Department of Geotechnical Engineering, College of Civil Engineering, Tongji University, Shanghai 200092, China.
E-mail address: yhuang@tongji.edu.cn (Y. Huang).

http://dx.doi.org/10.1016/j.enggeo.2016.01.015
0013-7952/© 2016 Elsevier B.V. All rights reserved.

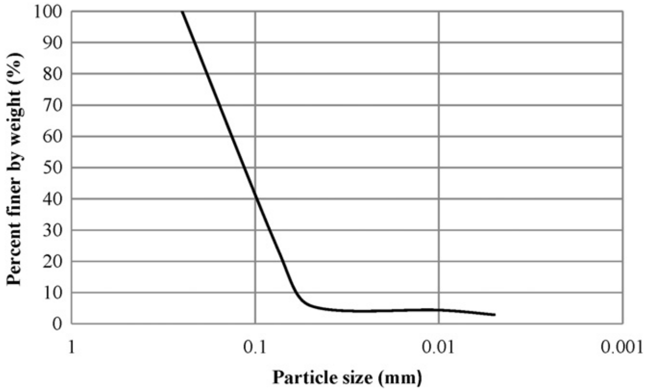

Fig. 1. Grain size distribution of silty sand.

and technology, alternative methods and materials for mitigating liquefaction risks should be explored (Huang and Wen, 2015).

Previous research on liquefaction mitigation has shown that fine plastic materials, such as clay-sized particles (<0.002 mm), can effectively enhance the liquefaction resistance of cohesionless soil (Dimitrova and Yanful, 2012; Ku and Juang, 2012; Kumar et al., 2013). Studies have found a threshold value for the content of clay particles. Below this value, the liquefaction resistance decreases with increasing clay particle content, but above this value, the rule is opposite (Gratchev et al., 2006, 2007; Abedi and Yasrobi, 2010). A chemically modified bentonite suspension has been proved to form a thixotropic gel and improve the liquefaction resistance by modifying the pore fluid between sand grains (El Mohtar et al., 2008). To lower the initial yield stress and viscosity of bentonite suspensions, and therefore help to improve the likelihood of grouting permeation, 0.5–2% sodium pyrophosphate can be added to the soil (Rugg et al., 2011; El Mohtar et al., 2013). Moreover, Witthoeft et al. (2012) proved the effectiveness of bentonite suspension in liquefaction mitigation at field scales using the finite difference method FLAC and thereby verified the scope of the soil reinforcement.

The U.S. National Research Council (2006) gives credit for the first steps in nanotechnology research to soil scientists and engineers whose studies focused on clay-sized particles. Colloidal silica (CS), an aqueous dispersion of silica nanoparticles sized 7–22 nm (Chang and Liu, 1994), was introduced into soil for site remediation (Persoff et al., 1994, 1999). In a recent liquefaction mitigation approach, the diluted CS was slowly injected from the edge of the injection site and transported through natural or artificial groundwater flow into the target position where it subsequently gelled and stabilized the liquefiable site (Gallagher, 2000; Gallagher and Mitchell, 2002). The feasibility and efficacy of CS grouting for the mitigation of liquefaction risk were then verified using centrifugal model tests (Gallagher et al., 2007a) and full-scale field tests (Gallagher et al., 2007b). Similar research findings on the liquefaction mitigation effects using CS have been presented by other researchers (Kodaka et al., 2005; Díaz-Rodríguez et al., 2008; Mollamahmutoglu and Yilmaz, 2010).

Recent studies indicate that synthetic nanoparticles of laponite show promise for use in sand liquefaction mitigation (El Mohtar, 2008). Laponite particles are smaller than clay particles and almost a tenth the size of bentonite particles; therefore, theoretically laponite has advantages for penetrating into finer soils. As laponite has good rheological properties and forms a transparent suspension once dispersed in water, it is usually chosen as a representative material in colloidal science (Levitz et al., 2000; Tanaka et al., 2004; Paula et al., 2009). Preliminary research on the use of laponite for mitigating liquefaction potential has focused on the microstructural characteristics of laponite particles and the rheological properties of laponite suspensions. The results show that laponite has better material properties and conductivity than bentonite (Howayek, 2011; Howayek et al., 2014). So far, however, no experimental data have been published on the cyclic characteristics and liquefaction resistance of liquefiable soil treated with laponite. Moreover, the liquefiable sands used in previous tests were usually pure sands, even though liquefaction of silty sand is not uncommon in seismic events. For example, extensive liquefaction phenomena of silty sands were observed in the Emilia-Romagna region after the 2012 Northern Italy earthquake sequence (Lombardi and Bhattacharya, 2014) and in Southern Taiwan after the 2010 Jiasian earthquake (Chang et al., 2011).

This paper presents the results of a laboratory investigation into liquefaction mitigation of silty sand mixed with laponite in a series of dynamic triaxial tests. The liquefaction resistance and cyclic behavior of laponite–silty sand samples were evaluated, providing experimental data to support the efficacy of laponite for liquefaction mitigation in

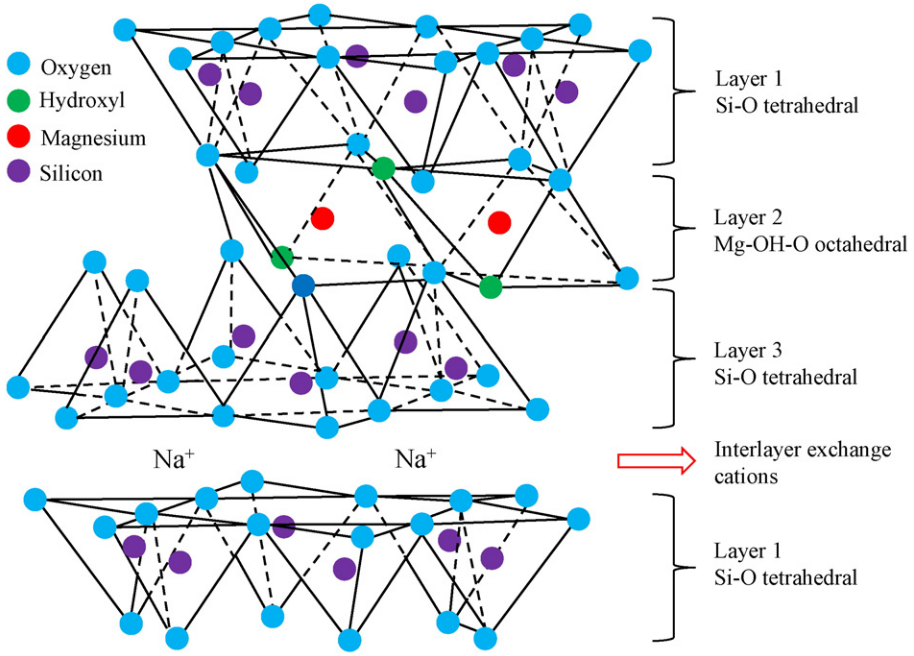

Fig. 2. Idealized structural formula of laponite (based on Rockwood Additives Ltd., 2011).

Download English Version:

https://daneshyari.com/en/article/4743329

Download Persian Version:

https://daneshyari.com/article/4743329

Daneshyari.com