Microscopic characteristics of nanoparticles for seismic liquefaction mitigation

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ABSTRACT

Seismic liquefaction mitigation based on nanomaterial is a new method different from traditional chemical grouting, and its basic concept is that nanoparticles suspensions are slowly injected from the edge of the liquevable site and transported through the groundwater flow into target position to improve the liquefaction resistance of liquefiable sand. The properties of the nanoparticles have important connections with the effects and mechanism of nanoparticles for liquefaction mitigation. Different from primary research on macroscopic geotechnical properties, this paper focuses on the microscopic characteristics of nanoparticles. The microscopic test, Transmission Electron Microscopy (TEM), was conducted to build up the microstructural characterization description of the nanoparticles for treating liquefiable soils, using laponite as representative nanoparticle. The morphology, size and internal microstructure of laponite particle in dry state were obtained by TEM test. Then the relationship between microscopic characteristics and seismic liquefaction mitigation are discussed. The specific objectives of the work are including providing the direct micrograph for the size and microstructure characteristics of laponite and analyzing the microscopic characteristics of nanoparticles related with liquefaction mitigation. This work can help establish structure characterization description of laponite applied to liquefaction mitigation and explore the microscopic nature of nanoparticles liquefaction resistance characteristics.

Keywords: liquefaction mitigation, nanoparticles, laponite, microscopic characteristics, TEM

1 INTRODUCTION

Liquefaction is a phenomenon marked by a rapid and dramatic loss of soil strength, which can occur in loose, saturated soil deposits subjected to earthquake motions. Certain types of soil deposits, such as sand deposits, hydraulic fills, and mine tailings dams are particularly susceptible to liquefaction. The onset of liquefaction is usually sudden and dramatic and can result in large deformations and settlements, floating of buried structures, or loss of foundation support. Lateral spreading is a related phenomenon characterized by lateral movement of intact soil blocks over shallow liquefied deposits. Displacements caused by lateral spreading can range from minor to quite large. Gently sloping areas along waterfronts are most susceptible to lateral spreading. As a consequence, bridges and other waterfront infrastructure can be damaged significantly due to lateral spreading.

As the liquefaction can cause caused grave losses of life and property, research on the liquefaction mitigation and control should be particularly important and paid more attention. Traditional liquefaction mitigation methods are mainly can be classified into four kinds: densification, replacement, drainage and grouting, mainly including: soil replacement, vibration compaction, dynamic compaction, blast compaction, cement grouting, lowering of ground water table and so on. However, these traditional methods have limitation of full-field treatment and cause intensive disturbance to the residential environment.

A novel seismic liquefaction mitigation based on nanomaterial is proposed by Gallagher (2000). Its basic concept is that nanoparticle suspensions are slowly injected from the edge of the injection site and transported through the groundwater flow into target position. Then the nanoparticle suspensions can transform from liquid phase to gel phase to cement individual soil grains and reduce hydraulic conductivity of formation. Some preliminary explorations of liquefaction mitigation based on nanomaterials have been conducted and proved to improve liquefaction resistance effectively (Kodaka et al. 2005; Díaz-Rodríguez et al. 2008; Mollamahmutoglu and Yilmaz 2010; Mohtar et al. 2013).

For particulate suspensions injected into the liquefiable site, the particle size is the controlling factor determining the penetrability. The smaller the size is, the easier to penetrate. The traditional grouting material like Ordinary Portland cement has an average particle size of about 20 microns so the cement slurry can only...
be inserted into soil pores that are three to five times larger than its own particle size; therefore it is difficult to use the slurry in fine soils. Compared with traditional stabilizers, it is generally accepted that nanomaterials have particles of nano-scale size to penetrate finer soils. However, the direct microscopic observations on nanoparticles have been rare and most preliminary explorations on this method are mainly about macroscopic geotechnical properties and the liquefaction mitigation effects by laboratory dynamic tests, model tests, and full-scale field tests. So in this paper transmission electron microscopy analysis on nanoparticle was conducted to build up the microstructural characterization description of the nanoparticles for treating liquefiable soils. These microscopic properties of the nanoparticles have important connections with the effects and mechanism of liquefaction mitigation.

2 NANOPARTICLES FOR SEISMIC LIQUEFACTION MITIGATION

According to the primary research, three main typical nanoparticles including colloidal silica, nano bentonite and laponite have been used to improve liquefaction resistance and proved effectively. The nanoparticles for seismic liquefaction mitigation all belongs to layered silicate nanoparticle that has some similarities with the natural clay particle.

In this study, laponite RD (herein referred to as laponite) was the representative nanoparticle; a synthetic hectorite produced by Southern Clay Products, Inc., Gonzales, Texas. Laponite is a synthetic layered silicate nanoparticle with a thickness of 1 nm and a diameter of 25 nm, almost 10 times smaller than bentonite. Laponite has layered structures of two tetrahedral and one octahedral layers, similar to a natural montmorillonite structure (Fig.1) with the following chemical composition (%): SiO: 65.82, MgO 30.15, Na2O 3.20, Li2O 0.83, and corresponds to the general formula: [Na0.7]0.7[Mg5.5Li0.3O20(OH)4]0.7- (Howayek et al. 2014).

Fig. 1. Idealized structural formula of laponite (based on Rockwood 2011)

Because some of the bivalent magnesium ions are replaced on the particle surface by a lithium ion valence, its surface emits a large number of negative charges. Hydroxides on the edge such as Mg-OH and S-OH take a small amount of positive charge for protonation. This leads to extra negative charge in each layer, so appropriate amount of sodium ions fill between interlayers. Laponite can quickly disperse in water into disc sheet-shape grain structures, forming a colourless transparent suspension. After a period, some of the suspended material settles losing liquidity (Levitz et al. 2000).

3 TEM OF LAPONITE PARTICLES

This paper presents the experimental results of the microscopic characterization study conducted on laponite in its dry form using transmission electron microscopy (TEM) technique. This test provided information on the shape, size and microstructure of laponite particles. TEM is a microscopy technique in which a beam of electrons is transmitted through an ultra-thin specimen and an image is formed from this interaction. TEM is capable of imaging at a significantly higher resolution than light microscopes so that it is suitable to observe the microscopic images of nanoparticles.

To get the clear images, specimen should be ultra-thin. Specimens for observation in the transmission electron microscope were prepared by dispersing the laponite powder in the volatile solvent like ethyl alcohol, then placing 1 or 2 drops of laponite suspension onto “holey” carbon films supported on copper grids. These specimens were allowed to air dry followed by a vacuum oven heating to 60 °C for 2h. Images of very dilute laponite suspensions were obtained by using JEM-2100 high-resolution transmission electron microscopy.

Fig.2. Transmission electron micrograph for laponite

From the TEM image shown in Fig. 2, the micro image of laponite particle agglomerates is presented. The size is around 100 nm, and surface morphology is flocculation shape. But the individual laponite particles by TEM are difficult to observe. So in the TEM image, the size is much more than individual nanoparticle with diameter of 25 nm. This is because during the manufacturing laponite suspension process particles agglomeration of laponite powder will occur.

For comparison, the TEM micrograph of natural clay particle, kaolinite is shown in Fig. 3 (Howayek
As it is known, the size of natural clay particles is commonly at the micro level. It’s clear to see from the micrograph that kaolinite particle diameter of 1 μm and surface morphology is regular and flat. So according to the comparison between the TEM micrographs of laponite and kaolinite, we can see the nanoparticles are much smaller in size and the particle surfaces were definitely different. So the nanoparticle suspension can easily penetrate finer soils.

Fig. 3. Transmission electron micrograph for kaolinite (Howayek 2011)

Fig. 2 shows the size and morphology of laponite particle agglomerates in low magnification. The microstructure of laponite can be observed by increasing magnification factor as shown in Fig. 4. From the micrograph, layered internal structure of laponite particle agglomerates can be seen and most of the layered structures present directional alignment. This layered structure can help nanoparticle strip rapidly in water and transform into flake particle to form aqueous dispersion.

Fig. 4. Transmission electron micrograph for laponite at high magnification

4 MICROSCOPIC CHARACTERISTICS OF NANOPARTICLES

The experimental results by TEM have been presented then the relationship between microscopic characteristics and liquefaction mitigation will be discussed as follow.

4.1 Micronization of particle size

Comparing the grain size of natural rock and soil mass with that of nanoparticles, the micronization process evolves as the grain size decreases from gravel to sand, fine particle and finally, nanoparticle. Nanoparticles have the dominant advantages in size compare with the traditional bulk materials. They can easily dispense in the pore space between the soil grains, especially in fine soil like silt which has liquefaction susceptibility under low pressure.

4.2 Surface effect

As its particle size decreases, a nanoparticle’s specific surface area increases. This means the surface of the atom increases, leading to larger ion exchange capacity and increased interaction with other particles. Soil particles with a larger specific surface area will be surrounded by more water molecules. The existence of nanoparticles leads to water accumulation; thus, soil that contains nanoparticles usually has higher liquid. And the higher plasticity property improves the liquefaction resistance of liqueable non-plastic or low plasticity fines.

4.3 Microstructure of nanoparticles

The microstructure of nanoparticles presents layered structure with directional alignment. This special microstructure of nanomaterials will affect the interaction with water when nanoparticles are added to water. The interlayer cations can dissolve and layered structure of laponite particles can transform rapidly into flake particles and dispersed in water phase. This aqueous suspension which has good rheological properties will help improve the sand liquefaction resistance.

5 CONCLUSION

According to transmission electron microscopy tests and analyses, the microscopic characteristics such as morphology, size, and microstructure of laponite particles in dry state were obtained. Then, the relationship between microscopic characteristics and liquefaction mitigation are discussed. The microscopic characteristics of nanoparticles can show the feasibility and effectiveness of this liquefaction mitigation method because of the small scale and special microstructure. So nanoparticle is a promising material to apply in the seismic liquefaction mitigation. And compared with traditional chemical grouting method for liquefaction mitigation, this new method can greatly reduce the disturbance effect on the surrounding environment, so it is suitable for both virgin site and developed site with structures.

ACKNOWLEDGEMENTS

This work was supported by the National Natural
Science Foundation of China (Grant Nos. 41372355 and 41511130069).

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