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Physical modeling of lateral spreading induced by inclined sandy foundation in the state of zero effective stress

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ABSTRACT

The state of zero effective stress is a situation at which the effective stress of saturated sand decreases to zero in the process of liquefaction. In the state of zero effective stress, sand particles suspend in water and the foundation is vulnerable to much large lateral deformation. The state of zero effective stress can be achieved through dynamic loading tests, but the obtained state is difficult to sustain a steady situation. To simulate the suspended sand in water under fully liquefied condition, plastic sand, characterized by small specific gravity, is used instead of quartz sand to build an inclined foundation. Salt water with similar density is used to pass in slowly near bottom of the foundation. As observed in tests, the plastic sand is able to suspend in sodium chloride solution (salt water) of a specific density and thus this model can be used to simulate the lateral spreading of a foundation under zero effective stress state. Lateral deformation occurs within a certain depth beneath the ground and the magnitude increases from the bottom up, showing nonlinear behaviors. This paper presents a physical modeling approach for achieving the state of zero effective stress under static laboratory condition.

1. Introduction

During severe earthquakes, liquefaction of sand is one of the major causes of damage to geotechnical structures [1–3]. Effective stress of sand will drop to zero for liquefied sand [4–7]. At the state of zero effective stress, the shear strength of sand will loss, resulting in large flow deformation [8]. However, it is difficult to achieve a steady state of zero effective stress using model tests in a dynamic condition [9–12]. For example, in a triaxial dynamic test of saturated sand, the stiffness of the sand will dramatically decrease when initial liquefaction occurs [13]. The sand sample cannot sustain the applied loading in the zero effective stress state. In contrast, in a shaking table test, the pore pressure in the sand layer will increases to a peak value in a short period of time. The state of zero effective stress disappears instantly once the pore pressure dissipates due to the drainages inside the shaking box [14].

However, according to Terzaghi's theory of effective stress [15], the state of zero effective stress can be reasonably achieved under a static condition while the total stress of soil is equal to pore water pressure. There are two different approaches to achieve the state of zero effective stress in a static condition: (a) pore water in soil is replaced by a fluid with similar density to soil particles; (b) soil particles are replaced by an artificial sand with similar density to pore water. Fluid with similar density to soil particles is generally poisonous organic solvent which is not suitable for a laboratory test, however, an artificial soil with similar density to water is easily found and more suitable in a laboratory. For example, plastic sand made from polycaprolactam [16] has a slightly higher density than water (Fig. 1). The particles of the plastic sand can suspend in a salt water with same density as polycaprolactam. In this paper, the plastic sand was adopted to achieve the state of zero effective stress in the laboratory. Physical model tests of flow deformation induced by the plastic sand with zero effective stress are performed.

2. Test materials

2.1. Physical properties of plastic sand

The physical properties of the particles of the plastic sand and quartz sand are presented in Table 1. The particles of plastic sand

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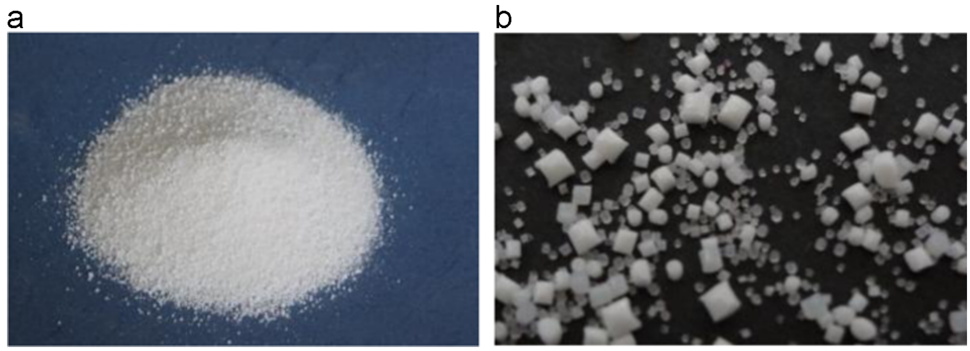

Fig. 1. Plastic sand and particles. (a) Plastic sand, and (b) Particles.

Table 1
Physical properties of particle of plastic sand.

Property	Unit	Plastic sand	Fujian standard sand
Mohs hardness	–	4.5	7.5
Specific Gravity	–	1.14	2.66
Tensile strength	MPa	73.6	10.5
Bending strength	MPa	98.1	–
Water absorption rate in 23 °C	%	1.8	1.01–2.55
Molding shrinkage	%	1.2	–
Melting point	°C	220	1480
Electrical surface resistivity	Ω	< 109	10^2–10^3
Maximum void ratio	–	0.69	0.855
Minimum void ratio	–	0.44	0.554

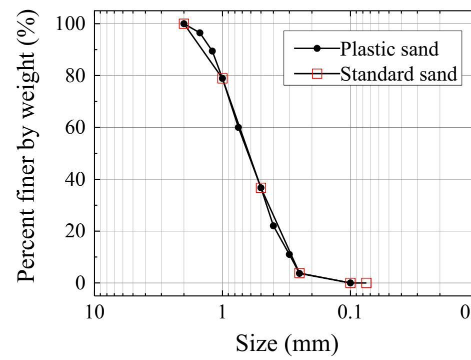

Fig. 2. Comparisons of grading cures between standard sand and plastic sand used in the test.

are made into cylinder shape of various sizes. The particles of plastic sand have similar properties as that of quartz sand, such as insolubility in water, stable chemical durability, high compression strength and high rigidity. The physical properties of particles of plastic sand and quartz sand are presented in Table 1. In this study, the plastic sand is prepared according to a designed mixture as the Fujian standard sand so that they have the same particle size distribution curve as shown in Fig. 2. Fujian standard sand is widely used in laboratory tests of sand liquefaction. Its properties have been investigated by Law et al. [17].

2.2. Mechanical characteristics of plastic sand

Consolidation undrained triaxial tests were performed on cylindrical sample of 39.1 mm diameter and 80 mm height to study the strength of the plastic sand and the Fujian standard sand. The confining stress applied during the consolidation process was 50 kPa, 100 kPa, 200 kPa and 400 kPa, respectively. The axial load was applied on the top of the sand sample until failure strain of 15% occurred. Fig. 3 shows the Mohr circles of the plastic sand and the Fujian standard sand with 30% relative density. The internal friction angles was determined as 35 degree for both plastic sand and Fujian standard sand.

One-dimensional compression tests with cylinder sample of 61.8 mm diameter and 20 mm height were carried out to investigate the compressibility of the plastic sand and the Fujian standard sand. The two *e*–*p* curves obtained from the tests are essentially coincident with each other (Fig. 4). The compression index of the plastic sand and the Fujian standard sand are 0.0532 kPa^{-1} and 0.0486 kPa^{-1}, respectively. According to the triaxial undrained tests and compression tests results, it can be conducted that the plastic sand and the Fujian standard sand have similar mechanical properties. Therefore, the plastic sand can be used to replace quartz sand in the model tests.

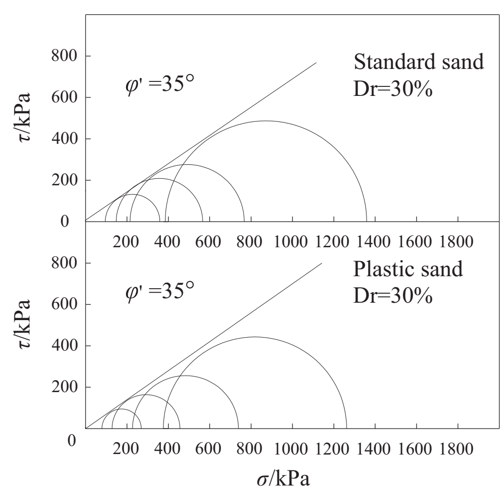

Fig. 3. Comparisons of Mohr circles of plastic sand with standard sand.

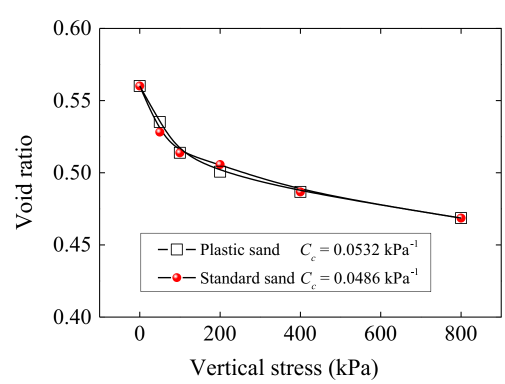

Fig. 4. *e*–*p* curves of plastic sand and standard sand.