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The Effects of Fines on Post Liquefaction Strength and Deformation Characteristics of Sand

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Abstract. This study has been carried out to determine how the fines content affects the post liquefaction strength and deformation characteristics of sand. With the GDS dynamic triaxial system, a series of monotonic undrained compression tests of the sand after liquefaction with variation in fines content from 0 to 40% were conducted, and effects of fines content on the post liquefaction strength and deformation characteristics of sand were analyzed. Results show that with the addition of fines up to a fines content of 30%, the stress-strain curve moves downward and axial strain at low intensive stage is increased, beyond this critical value of fines content the trend is reversed. However, shear strength of post-liquefied sand first decreases with increasing fines content, and beyond the critical value of fines content it increases with increasing fines content at the strength recovery stage when are subjected to monotonic loading. At the same time, the strength recovery rate decreases firstly and then increases with the increasing fines content.

Introduction

Liquefaction is the primary reason for ground damage caused by earthquake. Almost all major earthquakes, such as Niigata earthquake and Great Alaskan Earthquake of 1964, Tangshan earthquake of 1976, Osaka-Kobe earthquake of 1995, Wenchuan Earthquake of 2008 and Yushu Earthquake of 2010 in china, provide evidence of the foundation failure and structural damage caused by soil liquefaction. With the development of earthquake investigation and study method, the massive precious macro earthquake disaster materials are accumulated. A new type of ground failure induced by liquefaction which is called liquefaction-induced permanent lateral ground deformation has been widely realized. And it is a potential source of major damage to structures and lifelines during earthquakes. Attempts to predict liquefaction-induced permanent lateral ground deformation require knowledge of the post liquefaction strength and deformation characteristics of sand. In the last score years, researches related to the post liquefaction response of sand have accelerated markedly and several constitutive models of post liquefaction sand have been put forward simultaneously [1~6]. However, most of the studied have been concentrated on clean sands or sands with relatively small amounts of fines such as Canadian Ottawa sand, Japanese Toyoura sand and Chinese Fujian standard sand with the assumption that the behavior of silty sands is similar to that of clean sands. In fact, the pure sand is not generally existed and what widely distributed in the natural world is the mixture of sand and fines such as the sandy soils containing a significant amount of fines and the sandy silt. These soils do liquefy and cause lateral spreads. It can be inferred that simply expand the experience of pure sand to the engineering design inevitably lead to the strength over or inadequately estimated, which can make the design emerging questions such as risk or conservation. Therefore, the research on influence of fines on the engineering behavior of sandy soils has theoretical significance and practical value.

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The effects of fines on the cyclic liquefaction behavior of sands have been studied extensively in the past 30 years. However, numerous laboratory studies have been performed and what have produced appears to be conflicting results. Several studies have reported that liquefaction resistance increases with the increasing fines content [7], or decreases with the increasing fines content [8~10]. Other studies have reported that liquefaction resistance of sand first decrease with increasing fines content, and beyond the critical value of fines content the trend is reversed and the liquefaction resistance increases with increasing fines content[11~13]. The fines may also affect the post liquefaction strength and deformation characteristics of sand.

Based on the above research observations, little systematic experimental research has been carried out on the effects of fines content on post liquefaction strength and deformation properties of sands. So specimens of different fines content sand are prepared using dry density as the controlling parameter. By use of GDS dynamic triaxial system, the laboratory tests on the saturated sand of different fines content after liquefaction are performed to study the effects of fines content （FC） on the post liquefaction properties of sands in this paper.

Test Materials and Test Procedure

The original soil is taken from the site of Yangtze bridge of China. It is gray, loose and silty sand, and the main mineral composition is quartz, feldspar. All of the specimens are mixed and air dried, and then sifted out before the preparation. The grains diameter within the scope of 0.075~0.25mm are selected as skeleton sand, and the grains diameter smaller than 0.075mm are fine grains. The fine grained sand is almost composed of non-plastic silt grains. The sand-silt mixtures are made from sand and non-plastic fines by mass percentage from 0 to 40% respectively. Specimens are prepared with a constant dry unit weight of 1.40g/cm^3. The physical properties for the testes materials are shown in Table 1.

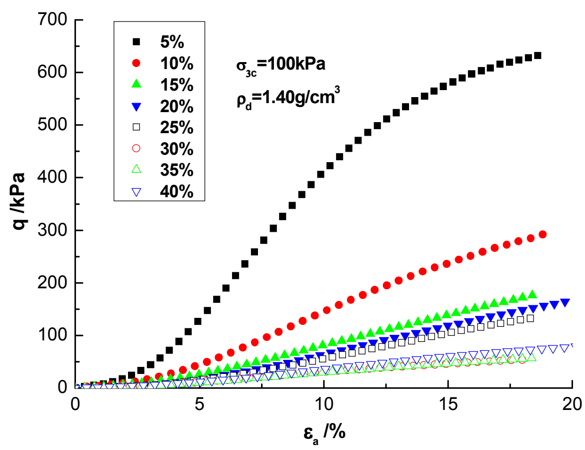
Table 1. Basic parameters for sand samples with different FC

FC[%]	G_S	D_{50} [mm]	C_u	ρ_d [g/cm^3]		D_r
				$\rho_{d\max}$	$\rho_{d\min}$	
5	2.681	0.165	2.145	1.481	1.232	0.714
10	2.683	0.160	2.358	1.602	1.261	0.466
15	2.690	0.148	4.683	1.644	1.260	0.428
20	2.693	0.142	6.058	1.723	1.282	0.329
25	2.695	0.138	7.272	1.742	1.282	0.319
30	2.697	0.130	7.516	1.781	1.284	0.294
35	2.701	0.123	7.755	1.770	1.280	0.309
40	2.703	0.112	7.860	1.781	1.251	0.358

The specimens are 39.1 mm in diameter and 80 mm in height. The remolded samples are prepared by using multi-level wet pounding method, and the samples are composed of five layers. According to dry density and the design of each layer of soil moisture content of the soil samples, the weight of each layer is determined and the soil of each layer is compacted to corresponding height. The interface between the two layers is scarified to ensure the upper and lower layers are in good contacts. After the specimens have been formed, test specimens are saturated and then consolidated isotropically at an initial confining pressure of 100kPa. Undrained dynamic loading at a frequency of 1Hz are conducted on isotropically consolidated sand samples with 5, 10, 15, 20, 25, 30, 35 and 40% non–plastic fines until the initial liquefaction is occurred, and then monotonic undrained compression tests are carried out on the sand after liquefaction. This test equipment is GDS dynamic triaxial system, which can easily convert from one control mode to another control mode during the tests. So it is appropriate for post liquefaction test.

Results and Discussion

The stress-strain curves and pore pressure curve of sand with different fines content after liquefaction are shown in Fig.1 and Fig.2 respectively. As can be seen from Fig.1 and Fig.2, the law of post liquefaction stress-strain curves and pore pressure curves are almost the same with different fines content in the case of the same other run conditions. Post liquefaction stress-strain curves are characterized into three distinct stages shown in Fig 3. At the first stage, the effective shear stress is almost zero and the strain increases greatly. At the second stage, the shear modulus increases with the increasing strain, and in the last stage, the shear modulus decreases with the increasing strain. Likewise, post-liquefaction strain is composed of three stages such as low intensive stage, superlinear strength recovery stage and sublinear strength recovery stage if the sand is extensional at the end of cyclic loading. What is different is that the development situation in three stages of the sand with different fines content, which illustrate the fines content affects the stress-strain curve and pore pressure curve greatly. As shown in Fig.1, the stress-strain curves first slows down, then move up gradually with increasing fines content. The stress-strain curves of fines content 5% is at the top, and the stress-strain curves of fines content 30% almost overlaps the stress-strain curves of fines content 35%, but still can be seen at the bottom is the stress-strain curves of fines content 30%.



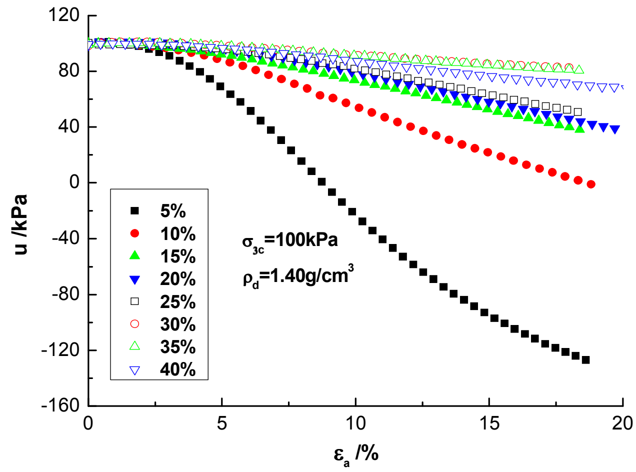


Fig.1. Post liquefaction stress-strain curve   Fig.2. Post liquefaction pore pressure curve

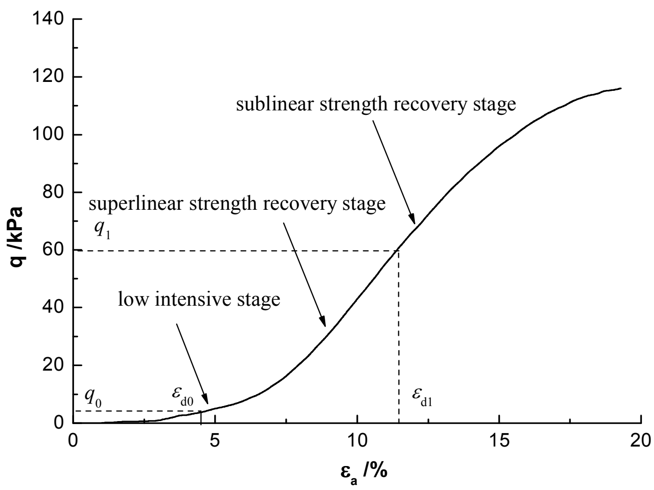


Fig.3. Three different stages of the post liquefaction stress stress-strain curve

Intersection point coordinates of the low intensive stage and superlinear strength recovery stage is (ε_{d0}, q_0), and that of superlinear strength recovery stage and sublinear strength recovery stage is (ε_{d1}, q_1), Characteristics physical quantity of the post liquefaction stress-strain curve of sand with different fines content are shown in table 2. As shown in table 2, axial strain at low intensive stage ε_0 increases with the addition of fines up to a fines content of 35%, corresponding axial strain at superlinear strength recovery stage and sublinear strength recovery stage increase in range, the corresponding strain for pore pressure drop stability also increases accordingly, axial strain at low intensive stage ε_0 reached the minimum value when fines content was 35%. Beyond this value of fines content the trend is reversed and it increases with increasing fines content. The critical content for axial strain at low intensive stage ε_0 is 35% but not 30%, which may be caused by experimental error.

Results show that shearing deformation resistance ability of post-liquefied silty sand first decreases with increasing fines content, and beyond the critical value of fines content the trend is reversed and it increases with increasing fines content at the strength recovery stage when are subjected to monotonic loading. At the same time, the strength recovery rate decreases firstly and then increases with increasing fines content. The change of pore pressure is corresponding to that of stress. From the analysis above, the strength and pore pressure whether at low intensive stage or at strength recovery stage do not monotonously change with increasing fines content, there is a critical content, which makes the change trend opposite before and after it. The critical content is about 30% for sand in this paper.

Table 2 Characteristics physical quantity of the post liquefaction stress-strain curve of sand with different FC

FC/%	ε_0/%	q_0/kPa	ε_{d1}/%	q_1/kPa
5	0.804	5	8.3585	325.7705
10	1.2814	5	9.3224	130.4015
15	1.7993	5	10.8968	91.4596
20	3.1192	5	10.9495	74.593
25	2.9639	5	10.618	61.0655
30	3.32	5	8.5529	25.1377
35	3.5276	5	8.5054	23.4645
40	2.755	5	10.3719	38.0357

To investigating the cause of this behavior, microstructure characteristics of coarse grains and fine grains should be analyzed. Evaluation of microstructure characteristics on silty sand is a complex problem due to the mixture of two different sizes of soil particles. In other words, there is a question that what could be a suitable index of active contacts for a silty sand soil? This problem could be significantly simplified by considering the silty sand as a matrix consisting of two submatrices; the coarser-grain matrix (intergranular void ratio) and finer grain matrix (interfine void ratio), and analyzing how they co-exist with the frame-work of contact force chains. When he finer grain content (FC) is less than a certain threshold value of 30%, The mechanical behavior is affected primarily by the coarser grain contacts, and the intergranular void ratio increases with increasing fines content the contact force and friction force of grains decrease with it, which cause the shearing deformation resistance ability of post-liquefied silty sand decrease. When the value of fines content exceeds the threshold value of 30%, and the finer grains begin to play a rather important role, while the role of coarser grains begins to diminish. The mechanical behavior is affected primarily by the finer grain contacts, and the interfine void ratio decreases with increasing fines content, the contact force and friction force of grains increase with it, which cause the shearing deformation resistance ability of post-liquefied silty sand increase with it.

Conclusions

Results indicate that fines content affect the post liquefaction strength and deformation characteristics of sand greatly, with the addition of fines up to a fines content of 30% stress-strain curve moves downward and axial strain at low intensive stage is increased, beyond this critical value of fines content the trend is reversed. However, Shear strength of post-liquefied sand first decreases with increasing fines content, and beyond the critical value of fines content it increases with increasing fines content at the strength recovery stage when are subjected to monotonic loading. At the same time, the strength recovery rate decreases firstly and then increases with increasing fines content.

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