Soil Dynamics and Earthquake Engineering 93 (2017) 1–6

Contents lists available at ScienceDirect

Soil Dynamics and Earthquake Engineering

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

Experimental study on effect of fly ash on liquefaction resistance of sand

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ARTICLE INFO

Keywords:
Liquefaction resistance
Fly ash
Sand
Confining pressure
Relative density

ABSTRACT

A series of cyclic triaxial tests were performed to determine the liquefaction resistance of sand stabilised with fly ash (FA). In order to understand the cyclic behaviour of the FA stabilised sand, the effect of relative density (D_r), FA content, confining pressure (CP) and curing time liquefaction resistance were considered. In the first stage of the laboratory tests, specimens of sand mixed with 2% FA under 50 kPa CP and 0.2 CSR with relative density of 20%, 40%, 60%, and 80%, were tested and compared with untreated soil. The results indicated that mixtures of sand-FA in all relative densities have more resistance to liquefaction failure in comparison with untreated soil, and mixture of sand-FA for relative density of 80% has the greatest resistance value. In the second stage, two types of sand-FA mixture (i.e., 4% and 6% FA) with a relative density of 20% under three ranges of confining pressure, namely 50, 70 and 90 kPa, were tested. The results in this stage suggested that the addition of 6% FA to the sand led to an increase in the cyclic response of the soil to the liquefaction in comparison with the specimens of sand mixed with 4% FA in all tested confining pressures. In the last part of the study, variation of the CSR with the number of cycles to liquefaction for a mixture of sand and 2% FA with 20% relative density under 50, 70 and 90 kPa confining pressure were presented and results indicated that the specimens under greater CP liquefied at earlier cycle numbers and vice versa. In continuing to investigate the effect of curing time, the specimens containing 2% FA were cured for 14 and 28 days and tested under 50 kPa CP and 20% relative density. The result showed that an increase in curing time led to an increase in the liquefaction strength of the sand containing FA.

1. Introduction

Studying the behaviour of soil under cyclic loading and seismic waves is a complicated matter in geotechnical earthquake engineering. This issue is even more complicated when these seismic waves happen in saturated soils. This phenomenon has been known as liquefaction in geotechnical engineering. Liquefaction is a natural disaster that happens due to loss of strength and stiffness during seismic events and usually occurs in sandy soils.

Many studies have been conducted to improve sandy soil performances in liquefaction events. For instance, Porcino et al. [1] investigated the effect of cement treated sand on liquefaction resistance and reported that liquefaction strength increased. Ye et al. [2] figured out the pre-shearing effect on liquefaction strength of a sandy soil. They observed that medium to large pre-shearing loadings led to a decrease in the resistance of the liquefaction. Noorzad and Fardad Amini [3] tried to increase the liquefaction resistance of sand using fibre. They reported that increasing fibre length and number led to an increase in liquefaction strength of the sand. In a similar study on the effect of fibre reinforced sand [4], increasing inconsistency in shear strength has been reported by increasing the fibre content of the specimens.

In another study, Karim and Alam [5] studied the effect of non-plastic silt on liquefaction resistance of the sand-silt specimens for a constant relative density. They observed a primary increase in excess pore water pressure by the addition of silt content until a limiting amount was attained. This trend reversed when the silt content passed the limit. An adverse behaviour for cyclic strength has also been reported [5].

The effect of colloidal silica grout on the liquefaction strength of sand was investigated by Gallagher and Michell [6]. They found that the addition of colloidal silica as an agent led to an increase in the deformation strength of the sand. The liquefaction resistance of three types of sand were compared in another study [7]. In this study, dry and saturated samples of clean and silty sand were subjected to a drained constant volume cyclic shear test and it was reported that the liquefaction possibility of the saturated samples could also be estimated by dry specimens. It was also reported that the results of the cyclic behaviour of the saturated and dry sand is different for clayey sand and this soil type needs to be saturated in order to assess its liquefaction strength characteristics.

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http://dx.doi.org/10.1016/j.soildyn.2016.11.012
Received 7 November 2015; Received in revised form 6 September 2016; Accepted 27 November 2016
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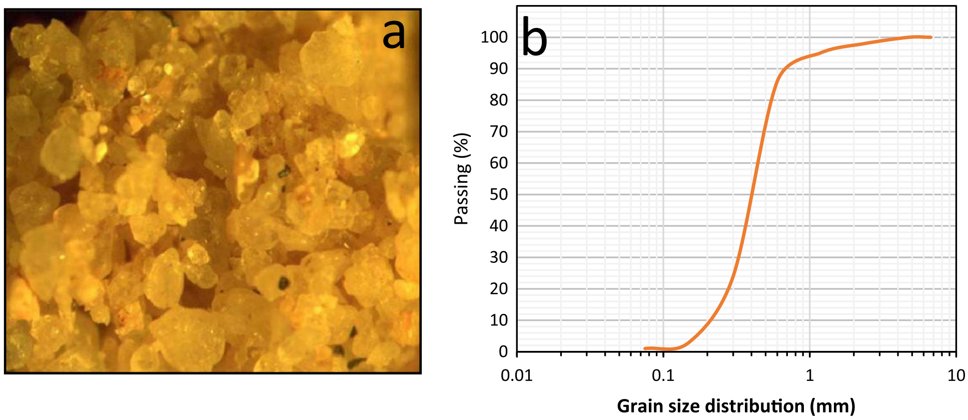

Fig. 1. (a) Scanning electron microscopy (SEM) of the used sand in this study [17]. (b) Particle size distribution (PSD) of the employed Baldivis yellow sand [17].

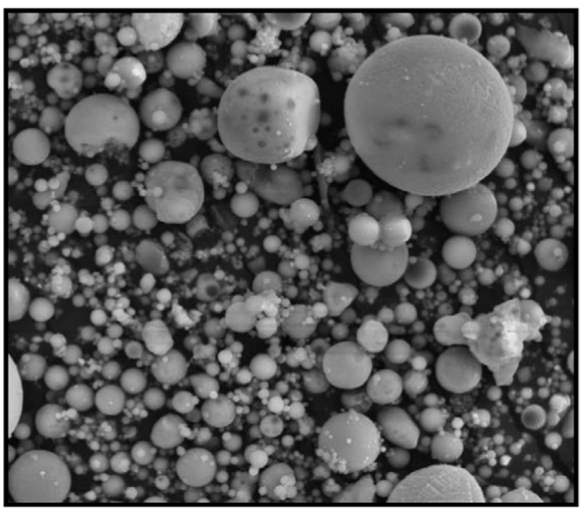

Fig. 2. Scanning electron microscopic (SEM) image of the employed FA [17].

Table 1
Chemical compositions of the employed Collie fly ash [18].

No.	Element	Formula	Percentage
1	Silicon dioxide	SiO_2	51.80%
2	Aluminium oxide	Al_2O_3	26.40%
3	Ferric oxide	Fe_2O_3	13.20%
4	Calcium oxide	CaO	1.61%
5	Titanium dioxide	TiO_2	1.44%
6	Phosphorus pentoxide	P_2O_5	1.39%
7	Magnesium oxide	MgO	1.17%
8	Potassium oxide	K_2O	0.68%
9	Sodium oxide	Na_2O	0.31%
10	Manganese oxide	MnO	0.10%

Application of a chemical agent is one of the main techniques in the soil stabilisation area to improve soil strength [8]. Flyash is one of the chemical additives that recently has drawn attention of scholars [9–12]. The studies that have been performed on effect of fly ash or other additives as an agent, have focused on investigating the mechanical properties of the soil from the static viewpoint of geotechnical engineering [13–16]. However, there are some studies on the cyclic behaviour of the impounded or reinforced FA [13–16].

Investigation of the behaviour of the FA stabilised sand under cyclic loading is a novel issue and a gap in the literature. Similarly, the effect of curing time is a less considered issue in the investigation of cyclic behaviour of soils mixed with additives. Therefore, this study aims to determine the cyclic behaviour of the sand mixed with FA by considering effective parameters such as FA content, curing time, CP and D_r.

Table 2
Experimental program designed to investigate effect of the relative density (D_r), FA content, confining pressure (CP) and curing time (CT) on cyclic behaviour of the fly ash (FA) treated soil.

No.	Test ID	CP (σ)	Relative density, D_r (%)	CSR	Flyash, FA (%)	Curing time (day)
Relative density						
1	$20D_r$-S	50	20	0.2	–	–
2	$40D_r$-S	50	40	0.2	–	–
3	$60D_r$-S	50	60	0.2	–	–
4	$80D_r$-S	50	80	0.2	–	–
5	$20D_r$-2FA	50	20	0.2	2	–
6	$40D_r$-2FA	50	40	0.2	2	–
7	$60D_r$-2FA	50	60	0.2	2	–
8	$80D_r$-2FA	50	80	0.2	2	–
FA content						
9	50CP-4FA	50	20	0.2	4	–
10	70CP-4FA	70	20	0.2	4	–
11	90CP-4FA	90	20	0.2	4	–
12	50CP-6FA	50	20	0.2	6	–
13	70CP-6FA	70	20	0.2	6	–
14	70CP-6FA	90	20	0.2	6	–
Confining pressure and curing time						
15	50CP-2FA	50	20	0.2, 0.35, 0.5	2	–
16	70CP-2FA	70	20	0.2, 0.35, 0.5	2	–
17	90CP-2FA	90	20	0.2, 0.35, 0.5	2	–
18	2FA	50	20	0.2, 0.35, 0.5	2	0
19	14CT-2FA	50	20	0.2, 0.35, 0.5	2	14
20	28CT-2FA	50	20	0.2, 0.35, 0.5	2	28

2. Testing materials

2.1. Sand

The selected sand for this study was obtained from the Baldivis area located 50 km south of Perth in Western Australia. This sand is known