Construction and Building Materials 29 (2012) 201–205

Contents lists available at SciVerse ScienceDirect

Construction and Building Materials

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

Use of steel and polypropylene fibers to improve flexural performance of deep soil–cement column

Piti Sukontasukkul *, Pitthaya Jamsawang

Department of Civil Engineering, King Mongkut's University of Technology-North Bangkok, 1518 Pibulsongkarm Road, Bangsue, Bangkok 10800, Thailand

ARTICLE INFO

Article history:
Received 29 April 2011
Received in revised form 13 September 2011
Accepted 2 October 2011
Available online 24 November 2011

Keywords:
Flexural performance
Fiber reinforced soil cement
Deep cement mixing
Polypropylene
Steel fibers

ABSTRACT

In this study, steel and polypropylene fibers are used to improve flexural performance of soil–cement pile. Deep cement mixing (DCM) technique has been used for decades in Thailand to improve the strength of soft clay in Bangkok and vicinity. However, since it is made of about 10–20% of cement, it also shares similar properties as the harden cement such as good compressive strength, low permeability, and poor tensile and flexural strengths (brittle). In several occasions when subjected to bending moment caused by horizontal loadings (induced by large embankment), the poor flexural strength can lead to a failure of the soil–cement column. In order to improve its flexural strength and brittleness, a technique of mixing short fibers (similar to that used in conventional concrete) is introduced to the soil cement mixture. Two types of fiber are used to produce the fiber reinforced soil cement (FRSC): polypropylene and steel fibers at three different volume fractions of 0.5%, 0.75% and 1.0%. Flexural performance of the FRSC is carried out according to ASTM C1609. Results show improvements in the flexural performance as seen by the increase in the equivalent flexural strength ratio and the residual strength when the fibers are incorporated into the mix. The polypropylene fiber is found to perform better than the steel fibers. With the increasing volume fraction, the toughness is also increase.

1. Introduction

The properties of Bangkok soft clay are low strength, high compressibility and low permeability. Several techniques have been adopted to improve the properties of soft clay for example, in situ earth reinforcement and piles of various materials, partial or complete ground replacement, geotextiles, preloading, grouting, deep mixing pile or sand pile; timber or concrete piles: micro piles, cast-in situ piles. These techniques have their own advantages and disadvantages [1].

Deep mixing (DM) techniques, developed during 1960s, were first reported in the literature in the early 1970s. The deep mixing stabilizing process typically takes place by mechanical dry mixing, wet mixing or, grouting [2,3].

The deep cement mixing (DCM) was introduced in 1999 [2]. In this technique, the cement powder is added into the soil during the mixing process. The properties of DCM are somewhat superior to the DM in both of strength and permeability. The DCM pile becomes widely used to improve the engineering properties of thick deposits of soft ground and effectively reduce settlements of full-scale embankments [4,5]. However, similar to the conventional concrete, the properties of the DCM is also affected by the properties of cement in terms of brittleness and poor flexural (or tensile) strengths [6]. When subjected to vertical and horizontal loads induced by embankment, large settlements may occur due to horizontal movements [7]. In addition, horizontal loads can also cause the bending moment in DCM pile and cause the pile to fail in tension (due to its brittleness).

Although the DCM technique is effective in improving the compressive strength of the DM column, the improvement on the brittleness is still needed. This study is aimed primarily to improve that property and increase its toughness by mean of adding short fibers into the DCM mixture.

Short fibers have been used for centuries to reinforce brittle materials like cement or masonry bricks. There are many fibre types available nowadays for commercial use such as steel, glass, synthetic materials (polypropylene, carbon, nylon, etc.) and some natural fibers. For convention fiber reinforced concrete (FRC), the typical fibers volume fraction is in the range of 0.5–1.0%. At the practical volume fraction used in SFRC (<1%), the increase in compressive, tensile, or flexural strength is small because the matrix cracks essentially at the same stress and strain as in plain concrete. The real advantage of adding fibers is that, after matrix cracking, fibers bridge these cracks and restrain them. In order to further deflect the beam, additional forces and energies are required to pull out or fracture the fibers. This process, apart from preserving the integrity of concrete, improves the load-carrying capacity beyond cracking [8–17].

* Corresponding author. Tel.: +66 2 913 2500x8621 25; fax: +66 2 587 4337.
E-mail addresses: piti@kmutnb.ac.th, piti_sk@hotmail.com (P. Sukontasukkul).

0950-0618/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.conbuildmat.2011.10.040

Fig. 1. Specimens wrapped in plastic sheet.

Table 1
Properties of Bangkok soft-clay.

Property	Value
Specific gravity	2.68
Liquid limit	95%
Plastic limit	42%
Saturated unit weight	15.6 kN/m^3
Natural water content	74%
Undrained shear strength	15.6 kPa

In this study, the fiber reinforced soil cement (FRSC) is prepared using 2 different types of fibers (steel and polypropylene) at three different volume fractions: 0.5%, 0.75% and 1.0%. The experiment begins with determining the optimum moisture and cement contents to meet the unconfined compressive strength requirement. After that the specimens are cast in form of beams to test under third point loading condition. Results in terms of peak strength, residual strength and area under load–deflection curve are evaluated and discussed.

2. Experimental procedure

2.1. Materials

Soil: Bangkok soft clay extracted from the depth between 5 and 8 m (Fig. 1, Table 1).

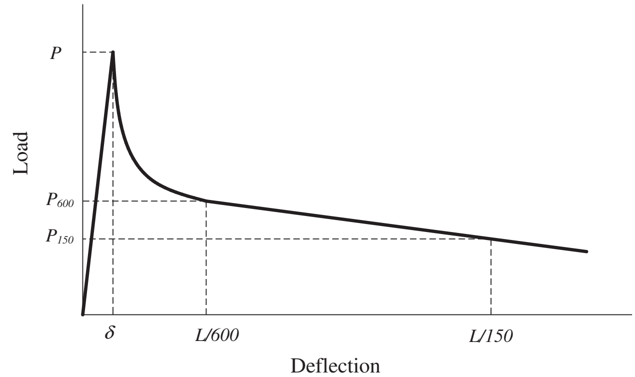

Fig. 2. Schematic illustration of load–deflection curve for calculating first-peak strength (f) and residual strengths (ASTM C1609).

Cement: Portland type I
Fibers: Steel and polypropylene fibers with properties as shown in Table 2

2.2. Determining optimum mix proportion

According the requirement of the Highway Department of Thailand (HDT), the minimum unconfined compressive strength of soil–cement should be at least 6 ksc (~0.6 MPa). The process of determining optimum mix proportion consists of (1) determining the moisture content of the soft clay, (2) remixing the soft clay with water to obtain the total moisture contents of 70%, 100%, 130% and 160%, (3) mixing cement into the remixed-clay at 10%, 15% and 20% by weight of dried clay, (4) casting the soil cement into cylindrical shaped specimens, and (4) testing the specimens at the age of 28 days under unconfined compression condition (Fig. 1). The mix with lowest cement and water content that pass minimum requirement of 0.6 MPa is selected as the optimum mix proportion (according to the test results, the optimum moisture and cement content for the controlled mix that pass the requirement is found at 100% and 20%, respectively, see Section 3.1).

2.3. Specimen preparation for flexural performance test

After the optimum mix proportion is determined, the specimens are then prepared in form of cylinder with dia.-50 × 100 mm and beam with 100 × 100 × 350 mm. For plain soil–cement, all ingredients (cement, clay and water) are mixed in a mixer for 5 min and cast. For fiber reinforced soil cement, fibers are added into the fresh soil–cement and mixing is continued for another 5 min until the fibers are distributed thoroughly. The specimens are demolded after 24 h and wrapped with plastic sheet for 28 days prior the test date (Fig. 1). Details on mix proportion and number of specimen are given in Table 3.

Table 2
Properties of Fiber.

Materials	Specific gravity	Shape	Length (mm)	Section (mm)	Aspect ratio (l/d)	Tensile strength (N/mm^2)
PP	0.91	Fully crimped	58	Rect. 1.0 × 0.5	52	450
Steel-s	7.8	Hooked end	35	Circle dia. –0.55	64	1100
Steel-l	7.8	Hooked end	60	Circle dia. 0.90	67	1100

Table 3
Specimen designation and detail.

Designation	Moisture content (%)	Cement content (%)	Fiber			No. of specimen
			Mat.	Length (mm)	Vol. frac. (%)	
P-SC	100	20				5
SFSC-L0.5	100	20	Steel	60	0.5	5
SFSC-L0.75	100	20	Steel	60	0.75	5
SFSC-L1.0	100	20	Steel	60	1	5
SFSC-S0.5	100	20	Steel	35	0.5	5
SFSC-S0.75	100	20	Steel	35	0.75	5
SFSC-S1.0	100	20	Steel	35	1	5
PFSC-L0.5	100	20	PP	58	0.5	5
PFSC-L0.75	100	20	PP	58	0.75	5
PFSC-L1.0	100	20	PP	58	1	5
Total number of specimens						50