ARTICLE IN PRESS

Available online at www.sciencedirect.com

ScienceDirect

Soils and Foundations xxx (2018) xxx–xxx

www.elsevier.com/locate/sandf

Development of a new loading test apparatus for microfocus X-ray CT and its application to the investigation of soil behavior surrounding driven open-section piles

Takahiro Sato [a,*], Kunihiko Onda [b], Jun Otani [a]

[a] X-earth Center, Kumamoto University, 2-39-1, Kurokami, Chuo-ku, Kumamoto 860-8555, Japan
[b] JFE Steel Corporation, 1-1, Minamiwatarida-cho, Kawasaki-ku, Kawasaki 210-0855, Japan

Received 9 September 2016; received in revised form 16 February 2018; accepted 8 March 2018

Abstract

In recent years, X-ray CT scanners with task-specific modifications, such as microfocus and/or a synchrotron, have been widely implemented in a variety of fields, including medical and industrial fields. Since microfocus X-ray CT systems enable the visualization of whole samples, and also yield a relatively high resolution of the region of interest in the sample, they are commonly utilized in the fields of soil mechanics and geotechnical engineering. This paper describes a novel loading test apparatus that is specifically designed for microfocus X-ray CT systems capable of performing loading tests to investigate soil behavior during the installation of driven open-section piles. The loading tests were designed to take the micro-level spatial resolution of microfocus X-ray CT systems into account. Digital image correlation (DIC) is subsequently implemented to analyze the obtained CT images, making it possible for measurements to be taken of the displacement fields in the ground following installation of the model pile. Finally, the versatility of this novel test apparatus is proof of its high potential for application in different types of loading tests.

Keywords: X-ray CT; Loading apparatus; Pile foundation; Sand; Visualization; Image analysis (**IGC:** E04/E14)

1. Introduction

An X-ray CT scanner was originally developed as a medical diagnostic tool for the human body. The system enabled visualization of the structures and organs in the human body by exploiting the differences in density throughout these structures and organs. Since its development, the X-ray CT system has been widely applied in the field of geomaterials and geotechnical engineering. Desrues et al. (1996) presented the first report demonstrating the use of the medical X-ray CT system to the imaging of soil materials, and discussed the strain localization of geomaterials. Otani et al. (2000) later used images of the same soil materials using an industrial X-ray CT system with a higher resolution than its medical counterpart. Regarding geotechnical testing, in 2002, Otani et al. (2002) proposed the first laboratory-use triaxial compression testing system with in-situ X-ray scanning. In their study, triaxial compression testing was conducted together with X-ray CT scanning. Since then, many researchers have begun employing the same type of compression testing apparatus (Hall et al., 2010a; Andò et al., 2013; Higo et al., 2013). The microfocus X-ray CT system is one of several types of X-ray CT systems. Its popularity can be attributed to its relatively high spatial resolution and to its flexibility, which allows the user to focus on particular regions of interest within the materials (Kikuchi et al., 2011; Andò et al.,

Peer review under responsibility of The Japanese Geotechnical Society.

* Corresponding author.
E-mail addresses: sato@tech.eng.kumamoto-u.ac.jp (T. Sato), ku-onda@jfe-steel.co.jp (K. Onda), junotani@kumamoto-u.ac.jp (J. Otani).

https://doi.org/10.1016/j.sandf.2018.03.004
0038-0806/

Please cite this article in press as: Sato, T. et al., Development of a new loading test apparatus for microfocus X-ray CT and its application to the investigation of soil behavior surrounding driven open-section piles, Soils Found. (2018), https://doi.org/10.1016/j.sandf.2018.03.004

2013; Higo et al., 2013). It should be noted, however, that this higher spatial resolution typically comes at the cost of a limit on the specimen size: this varies depending on the CT system. Despite this limitation, X-ray CT scanners are being implemented in pile loading tests (Otani et al., 2006; Taenaka et al., 2007; Kikuchi et al., 2008).

In this study, a new loading apparatus is specially designed for implementation in microfocus X-ray CT scanners. The specifications of the microfocus X-ray CT scanner located at Kumamoto University are briefly introduced; additionally, a few of the system constraints necessary for installation of the loading apparatus are highlighted. Subsequently, the features of the proposed loading machine are introduced, and the conditions under which the test apparatus is installed in this system are discussed.

To evaluate the performance of the proposed test apparatus, the driven open-section piles, including a sheet pile, are selected, and the behavior of the soil surrounding the pile shaft during its installation in the model ground is investigated. Fig. 1 shows the conventional cross-sectional shapes of several pile foundations divided into two categories: closed-section and open-section. The schematics of basic sheet pile and pipe pile are illustrated in Fig. 1(c) and (a), respectively, providing examples of open-section and closed-section pile types. While both open-section piles and sheet piles are asymmetrical, H-shaped steel piles are symmetrical (Fig. 1(b)). It seems that the axial asymmetric shape of sheet piles may engender a stress imbalance in the ground during vertical loading; moreover, it can be assumed that this stress imbalance induces the incline that forms during sheet-pile installation. In order to further investigate this phenomenon, the testing apparatus described herein was developed and implemented.

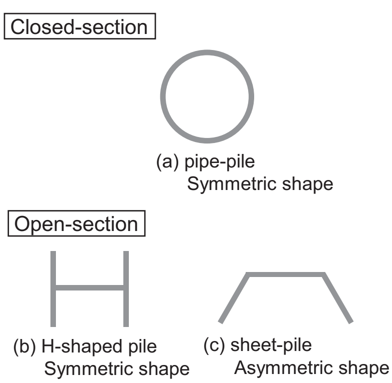

Fig. 1. Different types of pile shape.

Recently, imaging resolution and quantitative evaluation of soil displacement and strain have been improved for X-ray CT applications. Hall (2006) developed a basic analysis program implementing digital image correlation (DIC) to measure the displacement and strain field in soil. This method has been used by many researchers (Andò et al., 2013; Higo et al., 2013; Takano et al., 2015), and was used in this study.

2. Test apparatus

Fig. 2 shows the microfocus X-ray CT ((a)–(c)) and industrial X-ray CT ((d)–(f)) setups at Kumamoto University; (a) and (d) show an overview of each CT apparatus, whereas (b) and (e) provide interior views of the respective rooms in which each CT scanner is located. The most fundamental components of the CT scanner setup are the

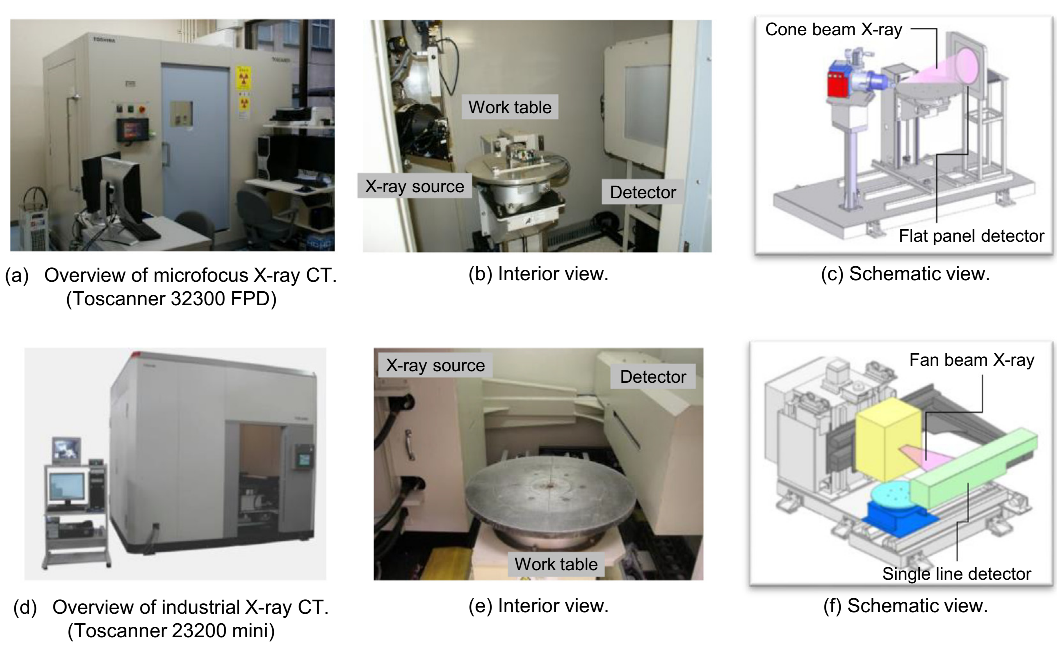

Fig. 2. X-ray CT scanner in Kumamoto University.

Please cite this article in press as: Sato, T. et al., Development of a new loading test apparatus for microfocus X-ray CT and its application to the investigation of soil behavior surrounding driven open-section piles, Soils Found. (2018), https://doi.org/10.1016/j.sandf.2018.03.004