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On the Role of Geogrid Reinforcement in Reducing Earth Pressure on Buried Pipes: Experimental and Numerical Investigations

M.R. Ahmed, V.D.H. Tran, M.A. Meguid*

Civil Engineering and Applied Mechanics, McGill University, Montreal, Canada

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Abstract

Understanding the distribution of earth pressure on buried structures is essential for the analysis and design of pipes, tunnels and vertical shafts. This paper presents the results of an experimental investigation that has been conducted to measure the distribution of contact pressure on rigid pipes using tactile sensing technology. The method allows for a continuous pressure profile to be measured around the pipes using flexible sheets that can follow the cylindrical shape of the pipes. The physical model involves a buried pipe installed in granular material subjected to strip surface loading. The effect of introducing a geogrid reinforcement layer above the pipe on the distribution of contact pressure is also examined. To further study the distribution of pressure on the buried structure and the soil-geogrid interaction, numerical analyses are performed using a multi-scale finite-discrete element framework that allows for both the explicit modeling of soil particles using discrete elements and the modeling of the embedded structure using finite elements. The numerical framework is first validated using the experimental results and then used to investigate the detailed behavior of the soil-pipe system.

Keywords: Contact pressure measurement; Buried pipes; Multi-scale modeling; Finite-discrete element

1. Introduction

Measuring the earth pressure acting on buried structures has been used in practice to monitor the performance of subsurface structures including foundations, culverts, buried pipes, retaining walls and tunnel linings. Pneumatic, hydraulic, vibrating wire and strain-gauge based devices are among the commonly used techniques for earth pressure measurement, particularly for large-scale projects where stiff load cells are installed at selected locations against the walls of the structure. The performance of different contact pressure measurement cells in geotechnical engineering applications has been reported by several researchers, including Carlson (1939), Peattie and Sparrow (1954), Selig (1964), Hanna (1985), Dunnicliff and Green (1988), Lazebnik and Tsinker (1997), Talesnick (2005), Ahmed and Meguid (2009) and Corey et al. (2014). It has been concluded that rigid cells typically read stress levels that are either low or high relative to the actual soil stress depending on the cell stiffness, size, aspect ratio and placement procedures (Selig, 1964; Kohl et al., 1989; Talesnick et al., 2011).

Tactile pressure sensors, adapted from the robotics industry, have been successfully used in geotechnical engineering applications to measure the distribution of normal stress in granular soils (Paikowsky and Hajduk, 1997; Paikowsky et al., 2000, 2002, 2006; Springman et al., 2002). A standard tactile

*Correspondence to: Civil Engineering and Applied Mechanics, McGill University, 817 Sherbrooke St. W. Montreal, Quebec, Canada H3A 0C3. Tel.: +(514) 398 1537; fax: +(514) 398 7361.

E-mail addresses: mahmoud.ahmed@mail.mcgill.ca (M.R. Ahmed), viet.tran@mail.mcgill.ca (V.D.H. Tran), mohamed.meguid@mcgill.ca (M.A. Meguid).

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sensor typically consists of an array of force-sensitive cells embedded between two flexible polymeric sheets to measure the normal pressure distribution. Due to their limited thickness (usually less than 1 mm), tactile sensors possess favourable characteristics with respect to the aspect ratio and the stiffness over conventional load cells. In addition, being flexible enables the shaping of the sensing pads to cover curved surfaces. Hence, they are suitable for cylindrically shaped structures (e.g., pipes, shafts or tunnels). Palmer et al. (2009) used tactile sensing technology to measure the contact pressure on a buried pipe subject to lateral loading, considering the time-dependent characteristics of the polymeric sheet containing the sensing units. Tessari et al. (2010) reported that tactile pressure sensors can be used in geotechnical centrifuge to measure at-rest, active and passive lateral earth pressure values on retaining structures. Olson et al. (2011) used tactile sensors to record the seismic earth pressure acting on model foundations in a series of centrifuge tests. Gillis (2013) developed a calibration method for tactile pressure sensors to be used in geotechnical centrifuge. Ahmed et al. (2013) used tactile (TactArray) sensors to measure the distribution of contact pressure on a buried structure subjected to repeated loading. The sensors consist of two specially designed pads containing two sets of orthogonal electrodes (plates) separated by a flexible insulator that acts as a spring allowing for conformable and stretchable pad designs. The tactile pads have proven to provide high sensitivity and repeatability of the measured pressure. Enhancing the bearing capacity of shallow foundations using geogrid reinforcement has recently been investigated by several researchers (e.g., Abu-Farsakh et al., 2013; Chakraborty and Kumar, 2014). Corey et al. (2014) presented the laboratory results of a high-density polyethylene pipe buried at a shallow depth and subjected to static loads with or without geogrid. The contact pressure and the deflection of the flexible pipe were recorded as the results of the geogrid reinforcement.

In this study, an investigation into the distribution of contact pressure on buried pipes is conducted using both experimental and numerical methods. The experimental work involves a thick-walled PVC pipe that is instrumented with tactile sensors and buried in granular material, while a vertical strip load is applied at the surface above the centreline of the pipe. The effect of placing a geogrid reinforcement layer on the distribution of radial earth pressure is examined. Validated by the experimental results, a multi-scale numerical model is then developed and used to investigate the earth pressure on the pipe over a range of applied loading. In this technique, the three-dimensional geometries of the geogrid and the pipe are properly modeled using finite elements (FE), while the soil particles are modeled using discrete elements (DE). The coupling of the finite and discrete element methods allows for the modeling of the interaction between the pipe and the soil and provides a closer look into the three-dimensional response of the geogrid material.

The experimental setup and test procedure are first presented followed by a brief description of the numerical framework used to carry out the analysis. The results of both the physical and numerical models are then grouped and compared to allow for the validation of the developed model. The responses of both the pipe and the geogrid layer are investigated under increasing surface loading up to soil failure.

2. Experimental Study

The experimental setup consists of a thick-walled pipe embedded in granular backfill material contained in a strong box. The pipe is instrumented using tactile sensing pads wrapped around its outer perimeter covering the area near the middle third of the pipe length. A universal MTS testing machine with a capacity of 2650 kN is used to apply the strip loading (see Fig. 1). A detailed description of the experimental setup components is given below.

2.1. Strong box

The strong box used in the experiments is shown schematically in Fig. 1a. The box dimensions (1.4 m × 1.0 m × 0.45 m) are selected such that they represent a two-dimensional loading condition. The rigid walls are placed far from the pipe to minimize the boundary effects. The distance from the outer

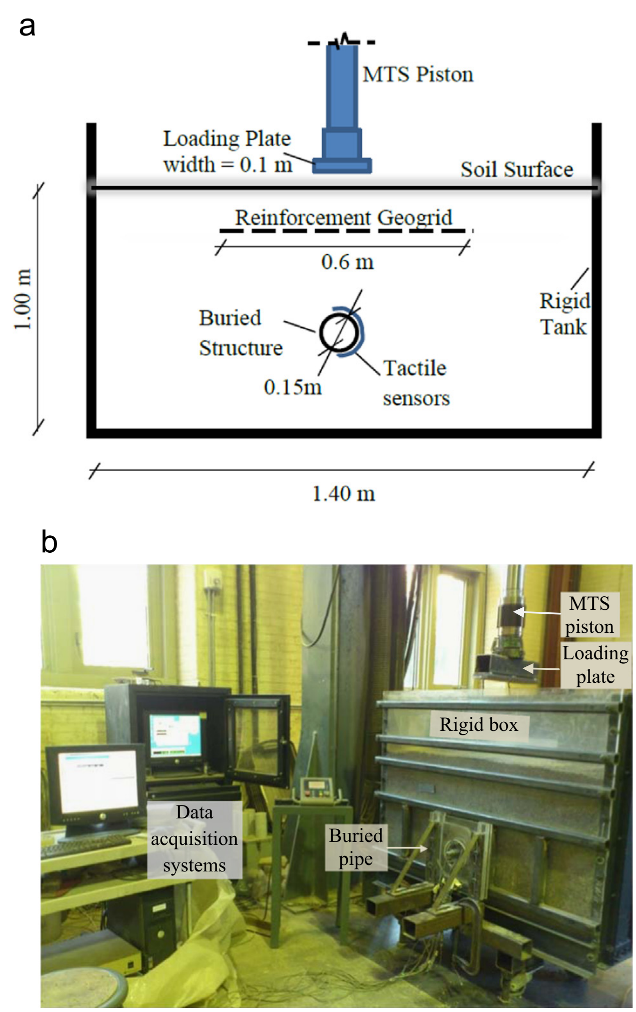

Fig. 1. Testing facility used in experimental work: a) Schematic of rigid tank and buried pipe and b) Photograph showing details of experimental setup.