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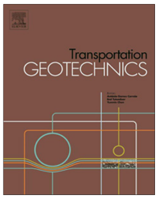

Experimental investigation of the earth pressure distribution on buried pipes backfilled with tire-derived aggregate

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ABSTRACT

This paper presents the results of an experimental investigation that has been conducted to measure the earth pressure distribution on a rigid pipe buried in granular material and backfilled with tire-derived aggregate (TDA). An experimental setup has been designed and built to allow for the installation of an instrumented pipe in granular material and measuring the contact pressure acting on the pipe wall. Tactile sensing technology is used in this study to measure the soil pressure acting on the pipe. This method allows for a continuous pressure profile to be recorded using flexible sheets that follow the cylindrical shape of the pipe. Two sets of experiments are performed in this study-one set with only granular backfill material (benchmark tests) and the second involved the introduction of a soft zone of tire-derived aggregate above the pipe. Results show that the induced trench installation, described in this study, was successful in reducing the vertical loads on the buried pipe. The average measured earth pressure above the crown of the pipe was found to be as low as 30% of the overburden pressure for installations with granular backfill material. Significant reduction in radial pressure was also recorded at the invert with pressure reduction of about 77% with the introduction of the soft TDA zone.

Introduction

The rapid growth of the transportation industry around the world has resulted in an enormous amount of waste tires generated yearly, making safe disposal of this waste material a dire necessity and extreme challenge. Tire-derived aggregate (TDA) is an engineered product made by cutting waste tires into 25–305 mm pieces that can be used to replace natural aggregates in civil engineering applications [7]. Extensive research has been done over the past two decades (e.g. [3,5,29,26,20]) to examine the performance of TDA under different loading conditions. These studies demonstrated that TDA is a suitable fill material with engineering properties that are comparable to conventional aggregates. Applications include the construction of large embankments, bridge abutment backfill, retaining walls and pavement subgrade.

TDA is generally classified, based on size and gradation, into two types: Type-A, with a maximum particle size of 75 mm, and Type-B with a maximum particle size of 305 mm [2]. Direct shear tests performed on Type-A TDA samples [8,31], suggested that the shear resistance of the material increased with the increase in normal load with no apparent peak value. The measured friction angle was found to be about 36°, which increased to about 39° for TDA-sand interface. Compression tests were also performed on different TDA materials [19,32], and the results indicated that the material compressibility is highly dependent on the initial unit weight and the applied stress level.

Another TDA application in civil engineering that utilizes the compressibility and lightweight characteristics of the material is in buried structures. It is known that the magnitude and distribution of earth pressures on buried pipes and culverts are highly dependent on the relative stiffness of the structure and the backfill material. To reduce earth loads on these rigid structures, the induced trench installation method has been proposed (e.g. [13,4]). In this method, the loads are redistributed around the structure by introducing a compressible material above the upper wall to promote positive arching. Expanded polystyrene (EPS) which has low stiffness and exhibits a desirable elastic-plastic behavior has been successfully used in these applications [30,14,15,18,16,17]. When an embankment is constructed over a buried conduit with compressible inclusion (see Fig. 1), the soft zone compresses more than its surrounding fill, and thus positive arching is induced above the conduit.

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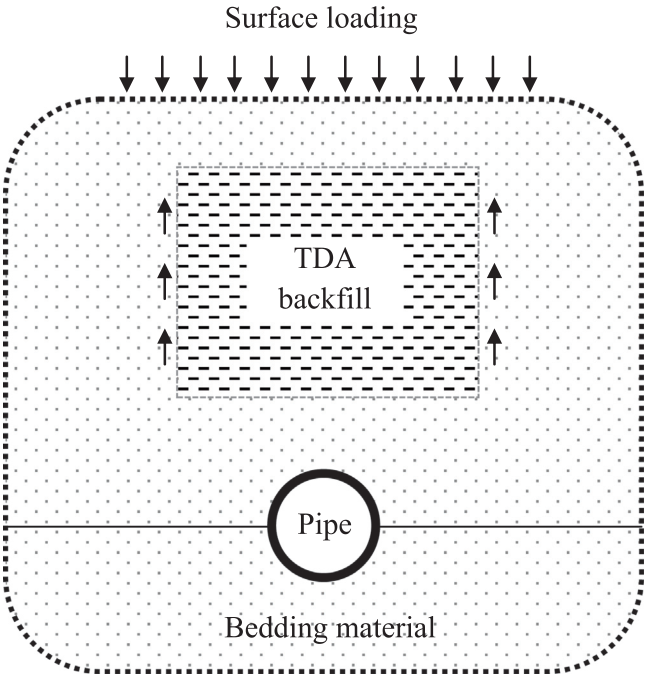

Fig. 1. Schematic of a buried pipe overlain by a layer of TDA backfill.

This method of installation dates back to the early 1900s. Researchers studied the relevant soil-structure interaction using experimental testing and field instrumentation (e.g. [24,12,28,21]), as well as numerical modelling [10,9,27], to help understand the method and to address uncertainties with this design approach.

In this study, an investigation into the contact pressure distribution on buried pipes is conducted using laboratory experiments. The experimental work involves a thick-walled PVC pipe that is instrumented with tactile pressure sensors and buried in granular material while a distributed load is applied at the surface. The tactile sensors used in this study are adapted from the robotics industry and have been successfully used in geotechnical engineering applications to measure the distribution of normal stresses in granular soils (e.g. [22,25,1]). A standard tactile 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, tactile sensors possess favourable characteristics with respect to aspect ratio and stiffness over the conventional load cells. In addition, being flexible enables shaping the sensing pads to cover curved surfaces, hence suitable for cylindrical shape structures. Meguid et al. [16,17] used tactile (TactArray) sensors to measure contact pressure distributions on both circular as well as square shaped structures.

The measured pressures are initially presented for a benchmark condition where only granular backfill material is used and the results are compared with Hoeg's analytical solutions [6]. A series of experiments are then performed by incrementally increasing the surface pressure for two backfill conditions: (1) the pipe is backfilled with only granular material; and (2) a layer of TDA is introduced above the pipe. The experimental setup and test procedure are presented in the next section, followed by the pressure results of the two-backfill conditions. The results of each are compared at different locations on the circumference of the pipe.

Experimental setup

The experimental setup consists of a thick-walled pipe embedded in granular backfill material contained in a test chamber. 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 distributed load, utilizing a rigid steel platform. A detailed description of the experimental setup is given below.

Test chamber

The test chamber used in the experiments is shown schematically in Fig. 2. The dimensions (1.4 m × 1.0 m × 0.45 m) are selected in order to represent a two-dimensional loading condition. The rigid walls are placed far from the pipe to minimize boundary effects; wherein the distance from the outer perimeter of the pipe to the sidewalls of the tank is more than 4 times the pipe diameter [11]. All steel wall surfaces are previously epoxy coated and covered with two plastic sheets. The first sheet is adhered directly to the walls of the box whereas the second is loosely placed in a manner that the two sheets are separated using a thin layer of grease. This layer aims to minimize friction between the backfill material and the rigid walls during soil placement and surface loading.

Instrumented pipe

The pipe used for this study (15 cm in outer diameter and 1 cm in wall thickness) is instrumented using two custom-made sensing pads installed directly on the pipe wall. TactArray distributed pressure measurement system [23] (Pressure Profile Systems, Los Angeles, CA, USA) – used in this study – consists of two sets of orthogonal electrodes separated using a flexible insulator that acts as a spring allowing for flexible pad designs. On applying normal load to the sensors, the distance between the electrodes changes, resulting in a change in capacitance; whereas, applying a tangential force changes the effective area between the electrodes. The capacitive sensors are thus capable of detecting pressures by sensing the applied forces. Each sensing pad contains 255 square-shaped sensors with pressure ranging from 0 to 140 kPa. The sensors are protected from backfill abrasion by covering the instrumented pipe with a thin layer of stiff rubber sheet as shown in Fig. 3a. Shim stocks made from the same pipe material are used to provide a similar contact surface condition onto the original pipe as well as to absorb the shear stresses developing at the soil-pipe interface.

It should be noted that, although the pipe has been chosen to perform such that no significant deformation develops during loading, two LVDTs are installed orthogonally inside the pipe to ensure the validity of this assumption. The maximum diameter change, at surface pressure of 100 kPa, was found to be less than 0.04 mm, which is considered insignificant.

Sensor calibration

In addition to the manufacturer calibration, a series of experiments has been conducted to study the effect of the protective layers on the measured pressure. A pneumatic system was used to apply vertical pressure directly over the sensing pad. The pressure was gradually increased up to a value comparable to that expected in the experiment. The response was compared before and after the addition of the protective layers (Fig. 3b). The data recorded by the sensing pad demonstrates scattered pressure readings,