Geotextiles and Geomembranes 44 (2016) 28–38

Contents lists available at ScienceDirect

Geotextiles and Geomembranes

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

Road surface permanent deformations with a shallowly buried steel-reinforced high-density polyethylene pipe under cyclic loading

Zhigang Cao [a, 1], Jie Han [b, 2], Changjie Xu [a, c, *], Deep K. Khatri [b, 3], Ryan Corey [b, 4], Yuanqiang Cai [a, 5]

[a] Department of Civil Engineering and Architecture, Zhejiang University, Hangzhou, 310058, PR China
[b] Civil, Environmental, and Architectural Engineering Department, the University of Kansas, 1530 W 15th Street, Lawrence, KS 66045-7609, USA
[c] School of Civil Engineering and Architecture, East China Jiaotong University, Nanchang, Jiangxi 330013, PR China

ARTICLE INFO

Article history:
Received 28 March 2014
Received in revised form
27 June 2015
Accepted 28 June 2015
Available online 17 July 2015

Keywords:
Geosythetics
Steel-reinforced HDPE pipe
Unpaved road
Cyclic loading
Permanent deformation
Mechanistic-empirical method

ABSTRACT

Steel-reinforced high-density polyethylene (SRHDPE) pipe is a new type of pipe used in roadways for drainage due to its obvious advantages, such as good corrosion resistance and light weight. In some projects, they are shallowly buried. To investigate the effects of the shallowly-buried pipe on the permanent deformation of road surface under cyclic traffic loading, two laboratory tests of an unpaved road with a buried SRHDPE pipe under cyclic loading were conducted. A 610 mm diameter SRHDPE pipe was buried in a compacted sand trench covered by aggregate or sand base courses in Tests 1 and 2, respectively. A Mechanistic-Empirical (M-E) model was calibrated with the laboratory test data and then adopted to conduct a parametric study on the road surface rutting. It was found that the SRHDPE pipe has very small deflection under the cyclic traffic loadings. The M-E model could predict the permanent road surface deformations well under cyclic loading before the road failed. Parametric studies showed that the road surface permanent deformation was intensified as the stiffness of buried pipe increased. The road surface deformation decreased as the pipe embedment depth increased and an optimum pipe buried depth existed to get the same road surface deformation between the road sections with and without a drainage pipe.

1. Introduction

According to the survey by the US Environmental Protection Agency (EPA) in 2002, an estimated 13,200 miles of new water pipes are installed each year in the United States (AWWA, 2002). Although no newly-conducted survey is found, the installation of new water pipes each year is expected to be more. In the past decade, pipes made of polymeric materials have become alternative to steel and concrete pipes due to their advantages, such as good resistance to corrosion and erosion, light weight, flexibility, and ease of joining (Khatri, 2012). Steel-reinforced high-density polyethylene (SRHDPE) pipe is a new kind of polymeric pipe that has high-strength helically-wound steel ribs covered by corrosion-resistant High Density Polyethylene (HDPE) resin inside and outside. The steel reinforcement adds ring stiffness to the pipe to maintain the cross-section shape during the installation and the steel ribs are expected to carry most of the dead weight of the soil and traffic load. As a result, steel-reinforced HDPE pipes have been increasingly used or considered for use in roads for drainage. In pipe design, pipes are generally divided into two categories, rigid and flexible. Rigid pipes are stiffer than the surrounding soil and mainly rely on their inherent strength to resist the applied loads. Flexible pipes allow for at least 2% deflection to pipe diameter without any structural distress. They are dependent on the capacity of the surrounding soil to carry a major portion of the applied load through ring deformation to activate the lateral passive resistance of the soil. Various methods are available for the design of pipes.

---

* Corresponding author. School of Civil Engineering and Architecture, East China Jiaotong University, Nanchang, Jiangxi 330013, PR China. Tel.: +86 13957132363; fax: +86 571 86055801.

E-mail addresses: caozhigang2011@zju.edu.cn (Z. Cao), jiehan@ku.edu (J. Han), xucj@ecjtu.edu.cn (C. Xu), d938k531@ku.edu (D.K. Khatri), rcorey@ku.edu (R. Corey), caiyq@zju.edu.cn (Y. Cai).

[1] Tel.: +86 13989826845.

[2] Tel.: +1 7858643714; fax: +1 7858645631.

[3] Tel.: +1 7858642923.

[4] Tel.: +1 7858642923.

[5] Tel.: +86 13958090128.

http://dx.doi.org/10.1016/j.geotexmem.2015.06.009

The American Water Works Association (AWWA) M11 (2004) and the AASHTO Bridge Design Specifications (2007) have separate design procedures for steel and thermoplastic pipes. Chambers et al. (1980) and Moser (1990, rev. 2008) also provided design procedures for plastic pipes. Wang and Moore (2015) proposed a simplified design model for rigid pipe joints based on the two-pipe approximation; comparisons with experimental measurements showed that the design equations reflected observed changes in joint response as burial depth increased. Some research has been conducted on the behavior of SRHDPE pipes under static or cyclic loading (for example, Moore, 2009; Masajedian, 2011; Folkman, 2011; Hardert, 2011; and Khatri, 2012). Tafreshi and Khalaj O (2008) conducted laboratory tests on small-diameter high-density polyethylene (HDPE) pipes buried in reinforced sand subjected to repeated loads. The results showed that the percent vertical diameter change and settlement of soil surface can be reduced up to 56% and 65%, respectively, by using geogrid reinforcement, but only one type of pipe, one type of geogrid, and one type of sand were used in laboratory tests. Faragher et al. (2000) conducted a full-scale field test to analyze the performance of buried flexible pipes in real installation conditions under cyclic loadings. It was found that the vertical deformation of the pipe increased fast during initial loading cycles but the rate of deformation decreased as further loading cycles were applied, and the total pipe deformation caused by the cyclic loading was limited. McGrath (2005) conducted a field test for the performance of thermoplastic pipe under highway vehicle loading, it was found that the settlement of road surface was attributed to consolidation of the side filling as well as the thermal contraction and expansion of the pipes; main attentions were paid to the pipe deflections due to static load, thermal effects or climate change, but the effects of cyclic traffic loadings on the road rutting was not considered in the test. Ha et al. (2008) conducted two pairs of centrifuge tests designed to investigate the differences in the behavior of buried high-density polyethylene pipelines subjected to normal and strike-slip faulting. Brachman et al. (2008) presented an investigation of the influences of backfill soil and its placement on the pipe deflections, strains and local bending. Lay and Brachman (2014) conducted a full-scale physical testing to study the structure response of concrete pipe buried in a dense, well-graded sand to the surface loading from a static single truck axle load, the cracking and circumferential bending moment of the concrete pipe were measured. Brachman et al. (2010) presented results from a full-scale experiment conducted on a buried, large-span box culvert to investigate the ultimate limit state of the box culvert. Krushelnitzky and Brachman (2013) investigated the effects of elevated temperatures on deeply-buried HDPE pipe deflections with full-scale physical tests. It was found that the short-term vertical deflections were found to increase by a factor of 1.3 when the temperature was increased from 22 to 80 °C, and the long-term HDPE pipe deflections extrapolated to 50 years were about 3.2% of the original mean pipe diameter at 22, 55 and 80 °C. Sargand et al. (2008) presented the updated long-term field performance data from the thermoplastic pipe deeply buried, including the data of pipe deflections and soil pressure measured at the pipe crown. It was shown that the seasonal fluctuations of environmental (air temperature, soil moisture) conditions caused the fluctuations in the peripheral soil pressure. Corey et al. (2014) investigated the effectiveness of geogrids to protect the buried steel-reinforced HDPE pipes from static loading and reduced deflections and strains of the pipe were measured due to the geogrid reinforcement. The above-mentioned work mainly focused on the performance and design of the pipes. However, for a shallowly-buried drainage pipe in a road, the installation of the pipe may change the stress distributions in the road base and subgrade, which will affect road surface rutting under cyclic traffic loading. Few researches have been performed so far on the traffic-induced permanent deformation of road over the drainage pipe.

For permanent deformations of pavements, two basic approaches have been used to evaluate the deformation behavior in pavements (Chen et al., 2004). The first approach is the empirical methods, which statistically relate the pavement permanent deformation to pavement conditions, such as material properties, loading, and environmental conditions, based on experimental data (AI, 1961; Peattie, 1962; Shook and Finn, 1962; and Chai and Miura, 2002). However, these empirical methods are limited to material, loading, and environmental conditions in the original experiments. The second approach is the mechanistic-empirical (M-E) method, which includes mechanistic response models to calculate resilient strains of pavement layers and damage models to empirically correlate the road resilient response with the rutting behavior of each layer under repeated traffic loading. A nationally recognized mechanistic-empirical pavement design guide (MEPDG) was developed through NCHRP Project 1-37a for conventional flexible pavements (NCHRP, 2004). Pavement design in the United States is currently under the transition from the empirical design method to the mechanistic–empirical pavement design method. Some researchers extended the M-E pavement design method by incorporating the effects of geosynthetic reinforcement (Perkins et al., 2009, 2012; and Yang et al., 2013). However, no research has been done to evaluate the permanent deformation of road with shallowly buried drainage pipes. Therefore, there is a need to investigate the effects of the drainage pipe on the road rutting under repeated traffic loading.

In the present paper, full-scale plate load tests were conducted with an SRHDPE pipe buried in unpaved roads. Two test sections, with aggregate and Kansas river sand as base courses, respectively, were constructed and tested by cyclic loading with five load steps each. The M-E model was calibrated with the laboratory test data and adopted to analyze the road surface rutting under traffic loading. Finally, a parametric study was conducted with the M-E model to evaluate the effects of pipe type and pipe embedment depth on the road surface rutting under cyclic loading.

2. Full-scale plate load tests

Full-scale plate load tests were run in a 3 m wide by 2 m long by 2 m deep box at the Department of Civil, Environmental, and Architectural Engineering of the University of Kansas. An unpaved road section was adopted in the tests due to the difficulty to construct paving layer in the soil test box, and the test is designed to investigate the rutting properties of the road base and subgrade layers with a drainage pipe. The experiment results obtained can be representative of the deformation properties of granular materials in many Kansas roads and give some reference to the road construction all over the world. A 610 mm diameter SRHDPE pipe was placed inside the box with the axis perpendicular to, and centered, in the 3 m width of the box. A 1.22 m wide by 1.14 m deep trench was created in a high-plasticity Fat Clay (CH). On the bottom of the trench, a 150 mm thick bedding layer of Kansas River sand and 460 mm thick Fat Clay was placed. The pipe invert elevation was 610 mm above the bottom of the geotechnical box. The pipe was placed on the top of bedding sand, resulting in a pipe crown elevation of 1.22 m, and backfilled with the same Kansas River sand in 150 mm lifts. A 380 mm thick sand layer, in 127 mm lifts, was placed to the top of the trench. Each lift of the sand was compacted to 70% relative density. For Test 1, a 230 mm thick layer of aggregate base course (commonly referred as AB-3 in Kansas) was placed over the entire width of the box and then compacted at the optimum water content to 95% relative compaction in terms of the maximum