Soils and Foundations 2015;55(3):485–492

HOSTED BY

The Japanese Geotechnical Society

Soils and Foundations

www.sciencedirect.com
journal homepage: www.elsevier.com/locate/sandf

Analysis of stress and deformation of a positive buried pipe using the improved Spangler model

Yong Tian, Hao Liu*, Xue Jiang, Rangang Yu

College of Pipeline and Civil Engineering, China University of Petroleum (East China), Qingdao 266580, China

Received 13 November 2013; received in revised form 27 October 2014; accepted 28 November 2014
Available online 5 May 2015

Abstract

In the Spangler model, the vertical earth pressure is assumed to be uniformly distributed, but it is not. The aim of this study is to improve the accuracy of the stress and deformation calculation for a positive buried pipe by using the new formulae derived from an improved Spangler model. Based on the Spangler model, this study derives the general calculation formulae for the section moment of a buried pipe when the vertical earth pressure is arbitrarily distributed. Furthermore, this study proposes a new model by improving the Spangler model, in which the vertical earth pressure is assumed to be parabolically distributed. Then, the new deformation formulae are derived. At the end of this article, the results of the new formulae are validated through a comparison with the simulated results obtained by FLAC3D software. It is concluded that the new model can simulate the behavior of buried pipes better than the Spangler model.

Keywords: Buried pipe; Spangler model; Stress; Deformation; Formulae; FLAC3D

1. Introduction

Buried pipes are widely used for oil and gas transportation and for city pipe networks. Generally, in many countries of the world, the structural design of buried pipes is based on national standards. Those standards differ from one country to another, but most of them are based on the Marston−Spangler theory (Tian, 1989).

Many closed-form solutions for rigid pipes and culverts are subjected to earth load. Marston and Anderson (1913) first proposed a theory, and developed formulae that are widely used in practice, to estimate the vertical earth load on positive buried rigid pipes and culverts. The Marston model is shown in Fig. 1. Based on Marston‘s work, later researchers (Das and Seeley, 1975; Ladanyi and Hoyaux, 1969; Meyerhof and Adams, 1968; Matyas and Davis, 1983a; Vesic, 1971) made continuous improvements and developed formulae for the vertical earth load on rigid pipes and culverts. Among those formulae, the values for the soil lateral pressure coefficient (k) are different. The influence of soil cohesion and the plane of equal settlement are taken into consideration in some of the above theories, but not in others, as demonstrated (Tian, 1989). Furthermore, the shear plane is assumed to be the circular surface in Vesic‘s theory (Vesic, 1971) relative to the vertical shear plane in other theories. The above differences lead to different values for C_c in those theories.

Spangler (1941) conducted extensive research on flexible pipes. Analysis methods for stress and deformation were proposed and calculation formulae were developed. It is assumed that the vertical earth pressure and subgrade reaction are uniformly distributed on

*Corresponding author. Tel.: +86 150 6682 8856.
E-mail address: 821261214@qq.com (H. Liu).
Peer review under responsibility of The Japanese Geotechnical Society.

http://dx.doi.org/10.1016/j.sandf.2015.04.001
0038-0806/

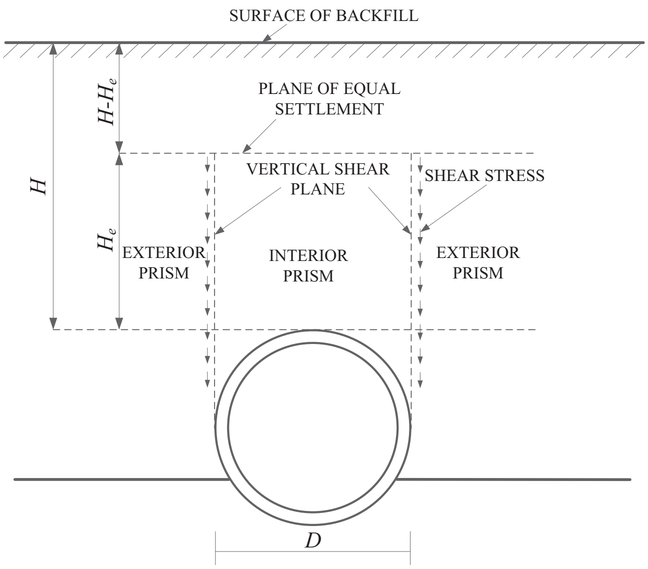

Fig. 1. Marston model.

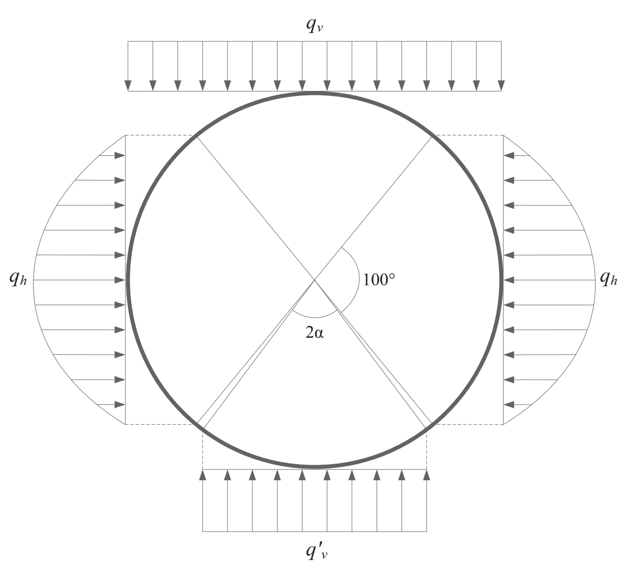

Fig. 2. Spangler model.

the pipe along its diameter. The lateral bearing resistance of soil was assumed to be parabolically distributed over a range of 100°. The Spangler model is shown in Fig. 2.

In the Marston – Spangler theory, the vertical earth pressure is assumed to be uniformly distributed. Actually, some experiments (Li, 2009; Shmulevich et al., 1986) indicate that the vertical earth pressure is not constant at different points on the pipe. Based on the Spangler theory, the aim of this study is to derive general calculation formulae for the section moment of a buried pipe when the vertical earth pressure ($q(x)$) is arbitrarily distributed. Then, the study assumes that the vertical earth pressure is parabolically distributed and derives the moment and deformation formulae for the purpose of obtaining higher calculation accuracy than with the Spangler formulae (Deng and Li, 1998; Spangler, 1941) through a comparison with the numerical values obtained by FLAC3D.

2. Vertical earth load

In Fig. 1, two imaginary vertical planes, known as shear planes Marston and Anderson (1913), are drawn tangent to the two sides of the pipe to define interior and exterior prisms. The plane of equal settlement is a special plane where the relative movement of the prisms is zero. H_e is the height of the plane. Since the deformation of the rigid pipe is nearly zero, the exterior prism moves downward, with respect to the interior prism, and the relative movement induces shear stresses on the shear planes. As a result, the earth load on the pipe is greater than the weight of the interior prism. According to the Marston theory Marston and Anderson (1913), the vertical earth load on rigid pipes can be determined from

$$W_e = C_c \gamma D^2 \tag{1}$$

where W_e is the vertical earth load per unit length of pipe, kN; γ is the unit weight of the backfill, kN/m^3; D is the outside diameter of the pipe, m; C_c is the load factor.

Marston and other researchers have given different solutions to C_c in their theories (Matyas and Davis, 1983b). Based on those theories, however, some simplified formulae are used in many design standards for buried pipes. For instance, Eq. (2) is adopted in "GB50332-2002, Structural design code for pipelines of water supply and waste water engineering" in China (Liu and Yang, 2001) and Eq. (3) is adopted in "USAS A21.1, USA Standard for Thickness Design of Cast Iron Pipe, Thickness Determination for Pipe on Piers or Piling Above Ground or Underground" (Matyas and Davis, 1983b).

$$C_c = 1.4 \frac{H}{D} \tag{2}$$

$$C_c = 1.961 \frac{H}{D} - 0.934 \tag{3}$$

Eq. (1) is suitable for rigid pipes and culverts, and the pipe – soil stiffness ratio should be taken into consideration when calculating the vertical earth load of flexible pipes (Tian, 1994). The formula can be given as

$$W = \xi W_e = \xi C_c \gamma D^2 \tag{4}$$

where ξ denotes the relative stiffness coefficient of the pipe, and the soil is expressed as follows:

$$\xi = \frac{E}{E_d} \left(\frac{\delta}{r} \right)^3 \tag{5}$$

where E is the elastic modulus of the pipe, MPa; E_d is the deformation modulus of backfill, MPa; δ is the thickness of pipe wall, m; r is the radius of the pipe, m.

3. General calculation formulae for section moment and stress

In this section, if the inner pipe wall is subjected to tension, the section moment is designated positive; if the outer pipe wall is subjected to tension, the section moment is designated negative.