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ScienceDirect
Engineering Structures 30 (2008) 588–594
ENGINEERING STRUCTURES
www.elsevier.com/locate/engstruct

Soil–structure interaction for deeply buried corrugated steel pipes Part II: Imperfect trench installation

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Received 14 November 2006; received in revised form 22 February 2007; accepted 11 April 2007
Available online 21 May 2007

Abstract

The potential benefits of the imperfect trench installation method were studied for corrugated steel pipes. The imperfect trench installation method has mostly been used to reduce earth pressure on buried rigid pipes by inducing reverse soil arching over the pipe. Because corrugated steel pipes are relatively flexible, they induce a small amount of reverse soil arching. Therefore, there has been limited research regarding the effects of imperfect trench installation on flexible pipes such as those fabricated with corrugated steel. The objective of this study was to demonstrate the efficiency of the imperfect trench method for buried corrugated steel pipes. An optimum soft zone geometry for imperfect trench installation is proposed to maximize the reduction of the earth pressure on buried corrugated steel pipes. Predictor equations for arching factors, maximum stresses, and deflections of corrugated steel pipes were formulated that incorporate the proposed optimum soft material zone geometry. Parametric studies revealed that the proposed imperfect trench installation can reduce the maximum wall stress by as much as 69%.
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Keywords: Backfill; Corrugated steel pipe; Embankment installation; Finite element method; Imperfect trench installation; Poisson's ratio; Soil–structure interaction

1. Introduction

The earth pressure on the deeply buried pipe is affected by relative settlements between soil prisms directly above and adjacent to the pipe [1]. These relative settlements generate shearing stresses that are added to or subtracted from the dead weight of the central prism and affecting the resultant load on the pipe. When the relative settlement of the soil prism directly above the structure is less than that of the adjacent soil prisms, as usually found in embankment installations, the earth load on the pipe is increased by the amount of the downward shearing forces exerted on the central soil prism (negative soil arching). Likewise, when the relative settlement of the soil prism directly above the structure is greater than that of the adjacent soil prisms, as depicted in trench installations, the layers of soil in the central prism are subjected to a reverse arch shape deformation and consequently the earth load on the pipe is reduced by the upward shearing forces exerted on the central soil prism (positive soil arching).

It is known that earth pressure on buried pipes can be significantly reduced by placing compressible lightweight material such as baled straw, leaves, compressive soil, or expanded polystyrene above a pipe [2]. These lightweight materials reduce earth pressure on buried pipes by inducing reverse soil arching over the pipe. Fig. 1 illustrates a typical installation which is called imperfect trench installation or induced trench installation (referred to ITI hereinafter). The ITI has mostly been used to reduce vertical earth pressure on rigid pipes. Depending upon the geometry of the soft material zone, the horizontal earth pressure can be significantly increased at the expense of the reduced vertical earth pressure. McAffee and Valsangkar [3] reported a case study of ITI of rigid pipes in New Brunswick, Canada. They measured earth pressure on a recently constructed pipe and confirmed higher-than-expected lateral earth pressure, almost as high as vertical earth pressure. They concluded that these higher lateral pressures need to be considered in the design of pipes with ITI.

Because corrugated steel pipes are relatively flexible, they induce a small amount of reverse soil arching. Therefore, there has been limited research regarding the effects of imperfect trench installations on flexible pipes such as

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0141-0296/$ - see front matter Published by Elsevier Ltd
doi:10.1016/j.engstruct.2007.04.006

Notation

The following symbols are used in this paper

B_s thickness of soft material below invert;
D pipe diameter;
E_s modulus of elasticity of lightweight material;
F_v generated friction force or shear stress;
H backfill height;
H' distance from the crown to the bottom of soft zone;
H_s height of soft zone;
HAF horizontal arching factor in embankment installation;
R_d reduction rate of deflection;
R_h reduction rate of horizontal arching factor;
R_{ms} reduction rate of maximum wall stress;
R_r reduction rate;
R_v reduction rate of vertical arching factor;
r radius of gyration;
VAF vertical arching factor in embankment installation;
W width of soft zone;
W_e total vertical earth load;
X maximum values computed in the embankment installation;
Y values expected in the imperfect trench installation;
ν Poisson's ratio;
σ_{ms} maximum wall stress;
$\beta 1, \beta 2$ nondimensional parameters.

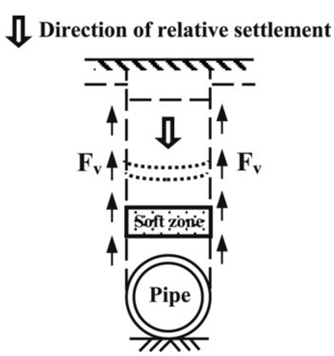

Fig. 1. Mechanism of imperfect trench installation (F_v = generated friction forces or shear stresses).

those fabricated with corrugated steel. The objective of this study is to investigate the efficiency of ITI for corrugated steel pipes (referred to CSP hereinafter) and to present an effective measure to overcome higher-than-expected lateral earth pressures in conventional ITI. After synthesizing and quantifying analytical data collected from some 1200 hypothetical models, an optimum geometry for the soft zone in ITI is proposed. Predictor equations for the reduction rates of arching factors, deflections, and maximum wall stresses are proposed as a function of the modulus of elasticity of the lightweight material and the pipe slenderness ratio (ratio of the pipe diameter to thickness). The reduction rate, in this study, was defined as follows:

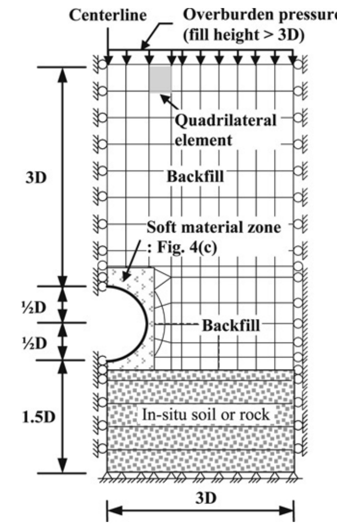

Fig. 2. Schematic finite element models for imperfect trench installation (D = pipe diameter).

$$R_r(\%) = 100\left(\frac{X-Y}{X}\right) \tag{1}$$

where R_r = reduction rate; X = maximum values (arching factors, deflections, wall stresses) computed for embankment installations (presented in the companion paper, Kang et al. [4]); and Y = values expected with ITI.

2. Background

Spangler [5] applied the approach that he developed for negative projecting conduits to an installation type developed earlier by Marston and Anderson [1] to reduce earth loads on the structure in embankment installations. In traditional imperfect trench installations, backfill is placed and thoroughly compacted on both sides of the conduit and for some distance above the conduit. Then a trench is dug in this compacted fill by removing a prism of soil having the same width as the conduit and refilling with very loose lightweight materials as shown in Fig. 1. The imperfect trench installation is a special case that is somewhat similar to the negative projecting conduit, but is even more favorable from the standpoint of reducing the earth load on the structure [6].

The imperfect trench installation method in Fig. 1 is designed to gain the benefits of a trench installation in an embankment condition. The word "trench" in ITI is in fact a misnomer as there is no trench in the in situ soil. It is a remnant of a terminology used by Marston [2].

Imperfect trench installation procedures for buried pipes have not been improved since the work of Marston [1,2] and Spangler [5,7]. There has been limited research regarding the quantitative aspect of earth load reduction in imperfect trench installations. Vaslestad [8] proposed equations for determining earth loads in imperfect trench installations. Vaslestad et al. [9] reported that the Vaslestad equations showed good agreement between earth pressures measured on a full scale imperfect