Available online at www.sciencedirect.com
ScienceDirect
Tunnelling and Underground Space Technology 22 (2007) 644–654
Tunnelling and Underground Space Technology incorporating Trenchless Technology Research
www.elsevier.com/locate/tust

# Simplified model for numerical calculation of pull forces in static pipe-bursting operations

Samuel T. Ariaratnam [a,*], Ulf-Hilmar Hahn [b,1]

[a] Ira A. Fulton School of Engineering, P.O. Box 870204, Arizona State University, Tempe, AZ 85287-0204, United States
[b] Stuart Olson Construction, 12836-146 Street, Edmonton, Alberta, Canada T5L 2H7

Available online 3 July 2007

**Abstract**

Trenchless pipe replacement, or pipe bursting, is defined as the replacement of an original pipe by fragmenting the existing conduit and simultaneously installing product pipe in its place. In the static method of pipe replacement, the original pipe fails in tension by radial forces developed from the cone-shaped bursting head geometry that are applied to the pipe wall from within the pipe, as it is pulled or pushed through the existing pipe. The fragmented pieces are pressed into the surrounding soil as it is being displaced, thus creating a cavity for the product pipe. This paper presents a simplified model to calculate the maximum pull force (a function of the friction, bursting, and soil compression shear forces) required to be overcome to complete a static pipe-bursting pull. Based on site-specific information, the model provides an initial avenue for contractors, engineers, and manufacturers in planning successful trenchless pipe replacement projects.


*Keywords:* Pipe bursting; Pull force; Infrastructure; Numerical analysis

## 1. Introduction

In recent years, the demand for trenchless construction, such as pipe replacement, has grown rapidly as these trenchless technologies are recognized as feasible, practical, and cost effective alternatives to existing traditional underground utilities installation methods. The North American Society of Trenchless Technology defines trenchless construction as "a family of methods, materials, and equipment capable of being used for the installation of new or replacement or rehabilitation of existing underground infrastructure with minimal disruption to surface traffic, business, and other activities." This minimal impact on the daily life, traffic, and commerce of the area served by and along the pipeline being replaced or installed is of key significance, especially as the nation's underground utility network is being overhauled and further expanded.

Pipe replacement, also known as pipe bursting, is a trenchless technology that is a cross between new construction and pipe rehabilitation. Pipe bursting is recognized as the only method of trenchless rehabilitation that can replace an existing line with a completely new pipe, providing total pipe replacement (Lueke and Ariaratnam, 2000b). In addition, the replacement pipe can be of equal or larger diameter than the existing pipe, thus maintaining or increasing flow capabilities of the utility line. These are the two distinct capabilities unique to pipe bursting in comparison to other trenchless rehabilitation methods.

For a trenchless pipe replacement project to be successful, there are various factors that must be taken into account. These include the normal logistics of any construction project, such as aspects of economy, schedule, and resources. Additionally, the machinery used to complete the pipe pull for the pipe replacement project must have sufficient capacity to be able to complete the pull (i.e. installation). While machine capacities may be obtained from manufacturer specifications, quantifying the pull load or pipe resistance is often neglected. At present, industry predominantly relies on past experience. This

* Corresponding author. Tel.: +1 480 965 7399; fax: +1 480 965 1769.
*E-mail addresses:* ariaratnam@asu.edu (S.T. Ariaratnam), ulf.hahn@stuartolson.com (U.-H. Hahn).
[1] Tel.: +1 780 452 4260.

0886-7798/$ - see front matter 
doi:10.1016/j.tust.2007.05.006

**Notation**

| | |
|---|---|
| $A_{pr}$ | cross-sectional area of replacement pipe (m$^2$) |
| $A_{sc}$ | area of soil compression (m$^2$) |
| $C_b$ | bursting force correction factor |
| $C_f$ | friction force correction factor |
| $C_{sc}$ | soil compression force correction factor |
| dA | differential pipe cross-sectional area (mm$^2$) |
| $d_{ie}$ | inside diameter of existing pipe (mm) |
| $d_{ir}$ | inside diameter of replacement pipe (mm) |
| $d_{oe}$ | outside diameter of existing pipe (mm) |
| $d_{or}$ | outside diameter of replacement pipe (mm) |
| $D_{GWT}$ | depth to ground water table (m) |
| $D_{pf}$ | depth of pipe at finish of pull section (m) |
| $D_{ps}$ | depth of pipe at start of pull section (m) |
| $D_x$ | horizontal length to peak of triangular soil profile (m) |
| $D_y$ | vertical length to peak of triangular soil profile (m) |
| $f_{bl}$ | breaking length factor |
| $f_{np}$ | number of pieces factor |
| $f_{pa}$ | piece angle factor (°) |
| $f_{scl}$ | soil compression limit factor |
| $F_b$ | bursting force (kN) |
| $F_{bn}$ | normal component of bursting force (kN) |
| $F_{bp}$ | parallel component of bursting force (kN) |
| $F_f$ | friction force (kN) |
| $F_h$ | hoop force (kN) |
| $F_n$ | normal force (kN) |
| $F_p$ | pull force (kN) |
| $F_{pp}$ | internal pipe pressure force (kN) |
| $F_{sc}$ | soil compression force (kN) |
| $F_{scn}$ | normal component of soil compression force (kN) |
| $F_{scp}$ | parallel component of soil compression force (kN) |
| $h_{SLi}$ | height of the *i*th soil layer (m) |
| $i$ | soil layer index |
| $K$ | coefficient of lateral earth pressure |
| $L_{os}$ | oversize of bursting head to outside diameter of replacement pipe (mm) |
| $L_p$ | length of pull (m) |
| $L_{sc}$ | length of soil compression (mm) |
| $p$ | internal pipe pressure (MPa) |
| $P_s$ | soil pressure applied on pipe (kN/m$^2$) |
| $P_{sn}$ | normal component of soil pressure applied on pipe (kN/m$^2$) |
| $P_{sp}$ | parallel component of soil pressure applied on pipe (kN/m$^2$) |
| $S_{pr}$ | outside surface area of replacement pipe (m$^2$) |
| $t_{pe}$ | pipe thickness of existing pipe (mm) |
| $t_{pr}$ | pipe thickness of replacement pipe (mm) |
| $u$ | soil pore water pressure (kN/m$^2$) |
| $W_{pr}$ | weight of replacement pipe (kN) |
| $W_{prn}$ | normal component of weight of replacement pipe (kN) |
| $W_{prp}$ | parallel component of weight of replacement pipe (kN) |
| $W_{prul}$ | weight of replacement pipe per unit length (kg/lm) |
| $\alpha_r$ | load uncertainty factor = 1.1 |
| $\gamma_{di}$ | dry unit weight of soil (kN/m$^3$) in *i*th soil layer |
| $\gamma_{mi}$ | moist unit weight of soil (kN/m$^3$) in *i*th soil layer |
| $\gamma_{wi}$ | wet unit weight of soil (kN/m$^3$) in *i*th soil layer |
| $\gamma_{pr}$ | unit weight of replacement pipe (kN/m$^3$) |
| $\Delta h_e$ | exposed length of busting head (mm) |
| $\Delta x$ | length of failure piece (mm) |
| $\theta_h$ | angle of bursting head (°) |
| $\theta_p$ | existing pipe slope angle (°) |
| $\mu_{sp}$ | friction factor for soil–pipe interface |
| $\pi$ | 3.14 |
| $\sigma_{1e}$ | ultimate failure stress of existing pipe (MPa) |
| $\sigma_h$ | total horizontal soil pressure (kN/m$^2$) |
| $\sigma'_h$ | effective horizontal soil pressure (kN/m$^2$) |
| $\sigma_v$ | total vertical soil pressure (kN/m$^2$) |
| $\sigma'_v$ | effective vertical soil pressure (kN/m$^2$) |
| $\sigma_T$ | total soil pressure (kN/m$^2$) |
| $\sigma_p$ | pull force uncertainty factor = 0.9 |

paper provides a theoretical outline, developed from first principles, incorporating site-specific aspects such as depth of cover, soil conditions, and original pipe material, to calculate and quantify the maximum pull force encountered during a static pipe-bursting pull.

## 2. Overview of pipe bursting

Pipe bursting is an emerging trenchless method of replacing an existing pipe. Pipe bursting was first developed the late 1970s in the United Kingdom by D.J. Ryan and Sons (Howell, 1995). Further developments to the pipe-bursting method were made in Europe during the 1980s. While used extensively in the United Kingdom and Europe, it was not until the early 1990s that pipe bursting was first employed in North America (Lueke and Ariaratnam, 2001).

The pipe-bursting process is defined as the replacement of the host pipe by fragmenting the existing conduit and installing the product pipe in its place (CCET, 1991). Generally, bursting is accomplished by pulling a cone-shaped bursting head through the host or original pipe. The front end of the bursting head is smaller than the inside diameter of the existing host pipe, while the tail end of the head is slightly larger than the outside diameter of the new product pipe. The leading face of the bursting head is tapered to