LIMIT STATES OF PROFILED THERMOPLASTIC PIPES UNDER DEEP BURIAL

By

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ABSTRACT

The limit states of thermoplastic pipes with different wall profiles are investigated to develop a Load and Resistance Factor design method for the profiled pipe. The study uses simplified design equations and the finite element method together with laboratory measurements to examine various potential limit states. This study is part of a research project sponsored by the National Cooperative Highway Research Program to develop new AASHTO limit states design procedures for thermoplastic pipes.

Full-scale buried pipe tests are conducted in the "biaxial cell" and the "hoop cell" at the University of Western Ontario, with commonly used profiled high-density polyethylene and polyvinyl chloride pipes. Test instrumentation includes measurement of soil stresses and deformations, pipe deflections, and wall strains on the profiles. Arrangements are made to monitor continuously the development of liner and corrugation buckling during the tests.

Measurement of local wall strain demonstrates local bending on the profile walls under earth loads. The mechanisms of local bending are different at the springline and the crown and invert of the pipes. The circumferential strain on a profile element stabilizes when local buckling fully develops in that element and further load is carried by the other elements in the profile. Stabilized strain values are therefore utilized as experimental measurements of critical buckling strain for comparison with calculations of critical strain based on the plate-buckling model of Bryan. Bryan's model with edge support coefficient of 4 provides a reasonable lower bound estimate of the critical buckling strains.

The power law model of Janbu together with Mohr-Coulomb plasticity is used to capture the non-linear behavior of the soil measured in the test cell. Two-dimensional finite element calculations based on those soil models are close to measured values of pipe deflections and circumferential strains on the profile elements not undergoing local buckling or local bending. Analysis using an equivalent linear elastic model averaged up to any particular stress level can also be used to capture the accumulated effects of soil non-linearity up to that stress level. Simplified design equations with the average soil modulus provide deflection estimates within 15% of the measured values. Simplified equations for the vertical arching factor are also shown to be effective, successfully predicting measured hoop strains. The simplified design equation for bending strain provides more conservative upper bound values.

Axisymmetric finite element analysis with explicit modeling of the profile is used to investigate local bending within the profiled pipe under the axisymmetric loading conditions imposed in the hoop test cell. For simplicity, two helically wound profiles (one tubular and one box shaped) are idealized as having axisymmetric geometry. The idealization works well for the tubular profiled pipe; however, the axisymmetric assumption for the boxed profile provides excessive values of hoop strain but unconservative estimates of axial strain. The axisymmetric idealization may not be suitable for helical profiles with thick lateral elements, like the boxed profile.

Local bending under biaxial loading is simulated successfully using the three-dimensional semi-analytical finite element analyses. However, the semi-analytical analysis is based on linear soil-pipe interaction. When backfill soils are well graded and dense, they show almost linear stress-strain relations, so the semi-analytical finite element method can provide useful estimates of local bending stress and strain for buried profiled pipe. While loose granular backfill exhibits a nonlinear stress-strain response, a secant or average modulus can be used in the local bending calculations.

A study of pipes with the soft soil support under the haunches reveals that a concentration of strain develops at the middle of the haunch on the pipe inner wall, and adjacent to the boundary of the weak zone on the profile crest. An approximate method based on a thrust reduction factor and a higher strain factor is proposed to consider these strain concentrations in design calculations for profiled pipes.

KEYWORDS: Thermoplastic pipe, profiled pipe, buried pipe, pipe testing, local bending, local buckling, simplified design equation, soft haunch, vertical arching factor, strain factor, thrust reduction factor, soil-pipe interaction, finite element analysis, limit state design.