LOUISIANA TRANSPORTATION RESEARCH CENTER
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Performance of Buried Pipe Installation

INTRODUCTION

Existing codes and recommendations often require standard/minimum values for the bedding, backfill, and fill cover geometric and mechanical properties in the installation of buried pipes under transportation facilities. These recommended values are often obtained by considering the worst-case scenario for each component and account only in an approximate way for the soil-structure interaction (SSI) between bedding, backfill, fill cover, and pipes of different materials and mechanical properties. Performance in terms of reliability and cost-effectiveness of the design is not fully addressed by current specifications. The need arises for revising the current specifications to obtain a more efficient design of the installation of buried pipes.

Current design methodologies for buried pipes are still based on the Marston theory for estimating vertical loads. This design method is based on the assumption of an elastic, isotropic soil above and around the pipe. Such an approach has been deemed as over-conservative, given the simplifications associated with these inherent assumptions. In addition, the method does not consider the effects of different bedding materials and thicknesses, nor does it consider the effects of a very soft natural soil, which is commonly encountered in Southern Louisiana.

The buried pipe installation considered in this project is a trench type with vertical walls, shallow cover, and a single pipe. The live loads due to the vehicular traffic produce significant stresses on the pipe and the soil in the trench, with a stress distribution strongly dependent on the specific geometric and mechanical properties of the entire soil-pipe system.

OBJECTIVE

The goal of this research project was to determine the effects of geometric and mechanical parameters characterizing the soil-structure interaction developed in a buried pipe installation. Parameters such as pipe ring stiffness, bedding thickness, trench width, and fill cover height were considered.

The specific objectives of this study were: (a) to provide a rigorous sensitivity analysis to various geometric and mechanical parameters of the performance of buried pipe installations in terms of deformation and stresses in the pipe and deformation (dip depth) at the surface of transportation facility pavement and (b) to provide guidelines for developing a set of recommendations for minimum/optimal requirements on cover height, bedding thickness, and trench width that ensure similar performance for pipes of different materials, i.e., concrete, steel, polyvinyl chloride (PVC), and high density polyethylene (HDPE) pipes.

SCOPE

The scope of this research included the study of the behavior of culvert and pipes buried in trenches excavated below roads with different levels of transit. The local soil conditions in which the pipes were installed were representative of typical locations in Southern Louisiana, i.e., with soft clay. Only single pipe installations are considered. The pipe dimensions studied cover the range between 18 in. and 60 in. of pipe internal diameters. Different materials are considered for the pipes, i.e., reinforced concrete (RC), steel, PVC, and HDPE. This research focuses on culvert pipes buried in shallow cover situations where traffic creates a high live load influence on the pipe. The geometrical properties (circular shape, thickness, and diameter ranges) considered in this investigation are representative of typical drainage pipes and culverts constructed on Louisiana Department of Transportation and Development (LADOTD) projects and do not include box culvert or three-sided structures. The soil-structure interaction behavior between the pipe, the backfill material, and the natural soil surrounding the trench was explicitly modeled and included in the study. Only short-term loading effects were considered. Effects of repeated loading cycles (i.e., fatigue) were not analyzed in this research.

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METHODOLOGY

A study of the SSI between pipes, trench backfill, and natural soil based on the finite element (FE) method was completed during this research. The FE method allows for an accurate analysis of the complex interaction between the pipe, the trench backfill material, and the surrounding natural soil under different conditions, characterized by a wide range of geometric and mechanical parameters.

Appropriate FE models of pipes buried in shallow trenches and positioned below roadways were built using different commercial FE codes to study the sensitivity of the mechanical behavior of the soil-pipe system for a wide range of conditions typically encountered in highway projects in Southern Louisiana. A simplified linear elastic FE analysis was employed to perform an extensive parametric study and sensitivity analysis of soil-pipe installation systems. An advanced nonlinear hysteretic FE analysis was used (a) to validate the linear elastic FE analysis results under the specific conditions representing a proposed modification to current LADOTD requirements for LADOTD highway projects, (b) to accurately evaluate the sensitivity of buried pipe system performance to modeling parameters and SSI effects, and (c) to investigate in detail the combinations of parameter values for which the performance of the soil-pipe installation system may be unsatisfactory.

CONCLUSIONS

The results of the sensitivity study, based on simplified linear elastic FE analysis, suggested that:

- An excavation width, W, equal to two times the internal pipe diameter, D, is usually sufficient for flexible pipes in soft soils.
- The performance of the soil-pipe system can significantly improve for increasing values of cover height, H_c. For each pipe material and diameter, it is possible to find an optimal cover height, H_c, beyond which the performance improvement of the soil-pipe system is negligible.
- The use of stiff bedding material can cause a significant stress concentration at the bottom of the pipe. The bedding thickness and bedding material stiffness should be determined in order to ensure that the bedding of the pipe is stable.
- The natural soil stiffness significantly influences the performance of soil-pipe systems.
- The performance of soil-pipe systems depends crucially on the type of road surface. A stiffer road pavement distributes the stresses produced by the live loads more uniformly over a much larger area of soil and considerably improves the performance of the soil-pipe system.
- The conditions most likely to produce unsatisfactory performance of the soil-pipe system coincide with the installation of large pipes (D > 42 in.) in yielding soils under flexible road pavements (e.g., asphalt).

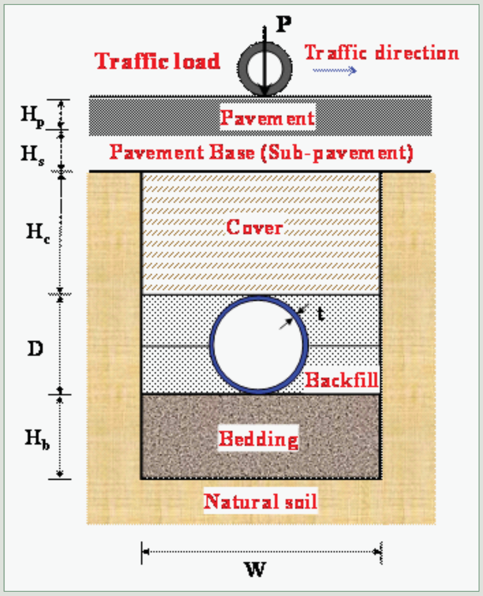
The results of the nonlinear hysteretic FE analysis provide the optimal cover height for pipes with internal diameter D = 42 in. and 60 in., made with different materials, i.e., RC, steel, PVC, and HDPE. It was also found that the value of the minimum recommended cover height should be expressed as a function of the pipe diameter in order to ensure a homogeneous level of performance.

RECOMMENDATIONS

The research results confirm that the performance of the soil-structure interaction system constituted by the pipe, the trench backfill, and the natural soil surrounding the trench significantly depends not only on the pipe material and stiffness, but also on geometric parameters defining the trench in which the pipe is installed. Minimum requirements for these geometric parameters can be established to obtain equivalent performance of different pipe systems under similar design conditions.

Other aspects not considered in this research but worthy of further study include: (a) the effects of the removal of the trench installation wall; (b) the response of soil-pipe systems to loads acting for prolonged period of time (i.e., long-term behavior); (c) dynamic effects and fatigue; and (d) the effects of fluctuation of the water level in the soil near buried pipes. Experimental studies are also needed to accurately calibrate the parameters used to build the nonlinear FE models of buried pipe systems and to validate the results obtained from numerical modeling. Finally, the development of appropriate modeling and analysis techniques is of paramount importance in order to properly account for the uncertainty that affects geometric and material parameters of the pipes, trench, filling material, natural soil, and loading conditions.

This research focuses on soil conditions typical of Southern Louisiana. The results of this research, when integrated with appropriate experimental data and field experience, can be used as guidance in establishing guidelines for the alternate selection and application of typical highway drainage products, such as pipes and culverts.



Buried pipe installation: transversal view (cross-section)

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