Performance Evaluation
of Buried Pipe Installation

Preliminary Results

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2009 Louisiana Transportation Conference
Baton Rouge, February 10, 2009
Outline

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**Problem Statement**

**Motivations:**
- Buried pipe performance and reliability is not fully addressed by current specifications
- New competing materials (PVC, HDP)

**Objectives:**
Determine effects of geometric and mechanical parameters on soil-structure interaction developed in buried pipe installation

**Scope:**
Rational basis for revision of current provisions on buried pipe installation in Louisiana and USA.
Methodology

• The soil-structure interaction between pipe and soil is studied using the **finite element method**.

• **Performance measures** are defined from finite element response quantities.

• **Parametric studies** are performed on different geometries, materials, configurations, natural soil situations.

• Analysis is focused on **performance sensitivity to design variables**.
Parameters considered in this study:

- Pipe material and geometry
- Bedding properties
- Fill properties and compaction
- Surrounding soil properties
- Importance of facility

The load P is obtained from AASHTO design load, considering an impact factor c = 1.5

Other data are obtained from AASHTO material properties for pipe design and are provided by LTRC in order to represent typical soil conditions for Louisiana.
Cross-Section Properties of Pipes

Critical approximations:
- Linear elastic materials
- Linear geometry
- Simplified boundary conditions

Cross-section properties considered in this study:

- **Pipe material:**
  - Concrete: $E = 2,900$ ksi
  - Steel: $E = 29,000$ ksi
  - PVC: $E = 400$ ksi
  - HDP: $E = 140$ ksi

- **Pipe diameter:** $D = 18”$, 36”, 42”, 48”, 60”

- **Pipe diameter/thickness ratio, $D/t$:**
  - Concrete: $D/t = 10, 20, 30$ (referred to as RC10, RC20, RC30)
  - Steel: $D/t = 50, 100, 200$ (referred to as S50, S100, S200)
  - PVC: $D/t = 10, 20$ (referred to as PVC10, PVC20)
  - HDP: $D/t = 10, 20$ (referred to as HDP10, HDP20)
Design Parameters for Sensitivity Study

The design parameters considered are:

1. Dip depth at the surface, $\delta$, with design limit $\delta_{\text{lim}} = 0.1\text{in}$
2. Maximum stress at the pipe ring, $\sigma_{\text{max}}$

A third design parameter (ring deflection) is not considered herein, since it imposes constraints which are automatically satisfied when the requirements on $\delta$ are satisfied.

Two different safety coefficients are introduced and used to evaluate design conditions:

1. $SC_\delta = \delta_{\text{lim}}/\delta$
2. $SC_\sigma = \sigma_{\text{lim}}/\sigma_{\text{max}}$

It is found that $SC_\delta$ is usually smaller than $SC_\sigma$.

Deformations control the pipe design and installation.
The natural soil stiffness is crucial.

Different minimum requirements are needed between stiff and yielding soil.

Stiff and yielding soils can be specified in terms of initial stiffness, choosing a value in the interval 5-10 ksi.

Calibration of this value requires more advanced nonlinear FE analysis studies, which will allow also to study the effects of soil strength.
Sensitivity Study (2)

Trench width (W)

Model properties: D = 60”; H = 12”; B = 6”
\[ E_{\text{fill}} = 30 \text{ ksi}; \quad E_{b, \text{pave}} = 45 \text{ ksi}; \quad E_{\text{soil}} = 5 \text{ ksi} \]
Pavement type: Asphalt, \( h = 4" \), \( h_{\text{base}} = 10" \)
Sensitivity variable: trench width \( W = 18-30-60 \) in

\[ \frac{E_{\text{fill}}}{E_{\text{soil}}} = 6 \]
**Sensitivity Study (3)**

The trench width has a moderate effect on the displacement safety coefficient $SC_\delta$.

The effect depends on the ratio $E_{fill}/E_{soil}$ and becomes significant for $E_{fill}/E_{soil} \geq 10$.

For $W > D/2$ (i.e., total width of the trench > 2D), this effect is always very small.
The cover height (for $H \leq D$) has a significant positive effect on the displacement safety coefficient $SC_\delta$

This effect increases for increasing flexibility of the pipe

Further study is required to evaluate the cover height effects for $H \geq D$

Nonlinear FE analysis is required to model soil arch effects
Sensitivity Study (5)

Bedding thickness (B)

$\frac{E_{\text{bedding}}}{E_{\text{soil}}} = 1$: uniform material

Model properties: $D = 60''$; $H = 12''$; $W = 18''$;
$E_{\text{fill}} = 30$ ksi; $E_{b_{\text{pave}}} = 45$ ksi;
$E_{\text{soil}} = 5$ ksi; $E_{\text{bedding}} = 5$ ksi

Pavement type: Asphalt, $h = 4''$, $h_{\text{base}} = 10''$

Sensitivity variable: Bedding depth $B = 6$-12-24 in
For uniform distribution of stresses, a layer of 6” of loose bedding material is required (and sufficient) immediately below the pipe.

In presence of yielding soil, the bedding thickness can be increased and the additional material (at depth larger than 6” below the pipe) should be compacted at the same level of the backfill material.
The stiffness of the backfill material is very important.

Adequate compaction and material quality must be ensured everywhere and required in the specifications.
The road pavement type is a crucial factor in the performance of buried pipes.

In presence of rigid pavement (concrete), any pipe configuration performs satisfactorily if the pavement is not damaged.
The displacement at the road surface increases almost linearly for increasing pipe diameters.

Minimum requirements for satisfactory performance of buried pipes need to be functions of the pipe diameter.
Validation of Installation Requirements

The installation requirements are verified for all combinations of the following conditions:

- **Road pavement type:**
  - Asphalt pavement with $h = 4\text{in}$;
  - Asphalt pavement with $h = 10\text{in}$;
  - Concrete pavement with $h = 8\text{in}$.

- **Surrounding soil properties:**
  - Moderately stiff soil ($E = 5\text{ksi}$);
  - Yielding soil ($E = 1\text{ksi}$);

- **Pipe diameter:**
  - $D = 18\text{in}$
  - $D = 60\text{in}$

- **Pipe material:** Concrete, Steel, PVC, HDP

- **Importance of facility:** Low ADT, Moderate ADT, High ADT
Results for roads with Low ADT

Asphalt pavement with h = 4in

Performance is not satisfactory!

Moderately stiff soil (MSS):
\[ E_{\text{soil}} = 5 \text{ ksi} \]

Yielding soil (YS):
\[ E_{\text{soil}} = 1 \text{ ksi} \]

Modeling assumptions:
The road pavement type is asphalt with h = 4” and \( h_{\text{base}} = 10” \).
The pavement base material has stiffness \( E_{\text{b, pave}} = 30 \text{ ksi} \).
The backfill material has stiffness \( E_{\text{fill}} = 30 \text{ ksi} \).
The bedding material has stiffness \( E_{\text{bedding}} = 10 \text{ ksi} \).
Results for roads with High ADT

Concrete pavement with $h = 8$in

Very high safety factors!

Modeling assumptions:
The road pavement type is concrete with $h = 8”$ and $h_{\text{base}} = 10”$.
The pavement base material has stiffness $E_{b,\text{pave}} = 45$ ksi.
The backfill material has stiffness $E_{\text{fill}} = 45$ ksi.
The bedding material has stiffness $E_{\text{bedding}} = 10$ ksi.

Moderately stiff soil (MSS): $E_{\text{soil}} = 5$ ksi

Yielding soil (YS): $E_{\text{soil}} = 1$ ksi
Possible Improvements (1)

Modeling assumptions:
The road pavement type is asphalt with \( h = 4\) in and \( h = 10\) in.

Recommendations:

1. Increase minimum cover to
   - Concrete: \( H \geq \max(D/4, 12”)\)
   - Steel and PVC: \( H \geq \max(D/2, 24”)\)
   - HDP: \( H \geq \max(D, 48”)\)

2. Require high quality and high compaction of fill material (\( E_{\text{fill}} = 45\) ksi)
Possible Improvements (2)

Results for roads with Low ADT
Concrete pavement with $h = 8\text{in}$

In presence of rigid road pavement (concrete), the safety coefficient are very high also for the worst case scenario

- The minimum dimensional requirements can be relaxed
- A more accurate study based on nonlinear FE analysis is required to calibrate the relaxed requirements

Based on the current results, it is safe to keep the same requirements used for low ADT also for moderate and high ADT
Main Results

1. **Performance in terms of maximum deflection** (dip depth) at the surface is often the **most demanding requirement** for buried pipe installation.

2. The performance of the soil-structure system is crucially dependent on the **road pavement type**. For rigid pavement (concrete), pipe deformation is generally very small.

3. **Natural soil stiffness, backfill stiffness, cover height** are very important.

4. **Bedding thickness** and **trench width** have smaller effects on deformation. These effects depend on the ratio between the bedding and fill material stiffness and the natural soil stiffness.

5. **Pipe diameter, D, significantly affects surface displacement**. For $D \geq 48$ in and flexible pavement (asphalt), cover height should be function of $D$. 
Preliminary Recommendations

1. For rigid pavement (concrete), minimum requirements can be relaxed. Continuity of the pavement is crucial.

2. For $D \geq 48$in and flexible pavement, the minimum requirement on minimum cover in presence of yielding soil should be function of the pipe diameter, e.g.:
   - Concrete: $H \geq \max(D/4, 12”)$
   - Steel and PVC: $H \geq \max(D/2, 24”)$
   - HDP: $H \geq \max(D, 48”)$

3. For uniform distribution of stresses, a layer of 6” of loose bedding material is required immediately below the pipe. Additional bedding thickness should be compacted as the backfill material.
Ongoing Studies

Different linear and non-linear finite element models and programs are currently being used to study:

1. effects of direct modeling of natural soil surrounding the pipe trench
2. finite element model mesh sensitivity
3. three-dimensional effects
4. effects of different modeling options for the applied loads
Direct Modeling of Natural Soil

Mesh Expansion for D = 18" (HDP)
Three-Dimensional Effects

Stress in D18 RC Pipe for Varying Model Thickness

- 0 Vertical 0 Horizontal
- 0 Vertical 11.25 Horizontal
- 8 Vertical 0 Horizontal
- 8 Vertical 11.25 Horizontal

Mesh Thickness (ft) vs. Moment (k-in)
Suggested Model for Nonlinear Finite Element Analysis
Nonlinear staged Finite Element analysis will be used for:

1. Calibration of the soil stiffness value to distinguish between stiff and yielding soil
2. Study of effects of soil strength
3. Study of effects of material (cracking, fracture, plasticization) and geometric (buckling) nonlinearities
4. Study of effects of installation procedures
5. Calibration of other important parameters for cases in which the performance estimated from linear analysis is not satisfactory
Acknowledgements

• LA Department of Transportation and Development

• Louisiana Transportation Research Center (project 08-6GT)

• LA DOTD PIPE Committee

• Dr. Zhongjie “Doc” Zhang, Pavement and Geotech Research Administrator

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect those of the sponsors.

Thank you!

Questions?