

A Pipeliner's Perspective on Longwall Mining

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Introduction

- There are over 300,000 miles of gas transmission and 175,000 miles of liquid transmission pipelines in the United States
 - Historically, many of these pipelines run from the Gulf Coast to the Northeast
 - A significant number of these pipelines run through the eastern coalfields with their associated longwall mining
 - Interstate pipelines are regulated by the DOT



What Could Possibly Happen?



Overview

- KAI approach for mitigating the effects of longwall mining on high-pressure pipelines:
 - Perform an integrity analysis of pipeline
 - Perform a longitudinal stress analysis to determine the existing stress on pipeline
 - Estimate stress from subsidence
 - Develop a formal mitigation plan



Integrity Analysis

- This is the Single Most Important Step
- A Pipeline is Not Just A Pipeline
 - They vary in age:
 - Nearly 15,000 miles were built before 1940
 - 185,000 miles were built between 1940 and 1970
 - Pipe fabrication and construction practices have seen considerable change over this period



Something You Don't See Anymore-Wrinkle Bends



Integrity Analysis-Why do It?

- Subsidence increases the longitudinal stress on the pipeline
 - This stress increase can result in the failure of defects that would not be of concern under normal operating conditions
 - Examples
 - Circumferential corrosion and stress corrosion cracking (SCC)
 - Pre API 1104 girth welds
 - Coating can be damaged



Integrity Analysis Process

- Includes
 - A review of the history of the pipeline,
 - Review of in-line inspection reports (if available), and
 - Review of girth weld inspection reports (if available)
 - A girth weld is the weld used to join individual lengths (aka joints) of pipe.



Existing Stress

- Hoop stress due to pressure

$$\sigma_{H_pressure} = \frac{P \cdot D}{2t}$$

- Longitudinal stress due to pressure

$$\sigma_{L_pressure} = v \cdot \sigma_{H_pressure}$$

- Longitudinal stress due to temperature

$$\sigma_{L_thermal} = E \cdot \alpha \cdot (T_{installed} - T_{operating})$$

Additional Existing Stress

- There can be other sources of existing stress but they can be very difficult to determine
 - For example bending stresses from construction
 - Usually increase estimate to account for these stresses

Subsidence Stress

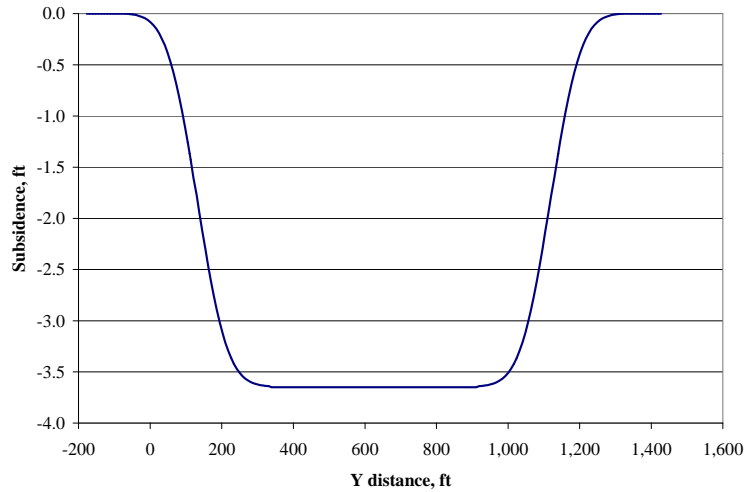
- Steps:
 - Estimate subsidence
 - Depending on analysis also need curvature and horizontal displacement of the soil and soil strains
 - Use subsidence estimate to determine stress
 - Simple hand calculations
 - Soil-pipe interaction finite element analysis

Calculate Subsidence

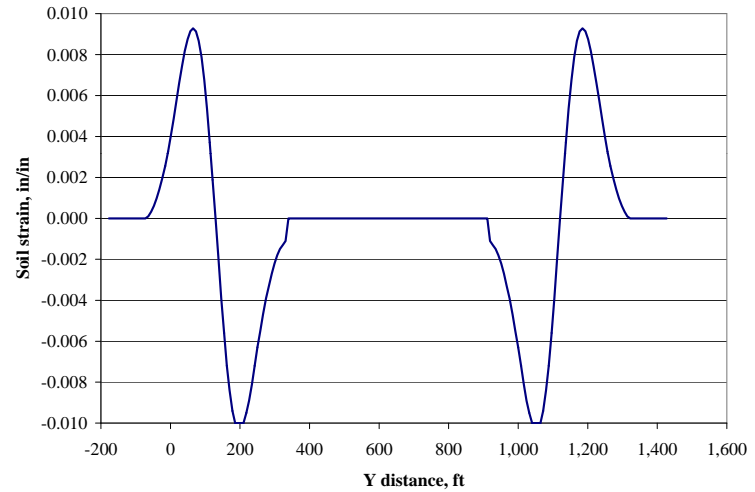
- Use standard estimation programs such as Comprehensive and Integrated Subsidence Prediction (CISPM) and Surface Deformation Prediction System (SDPS)
 - Depending on the analysis need to know subsidence, horizontal soil displacement, soil strain and curvature



Subsidence Calculation Example



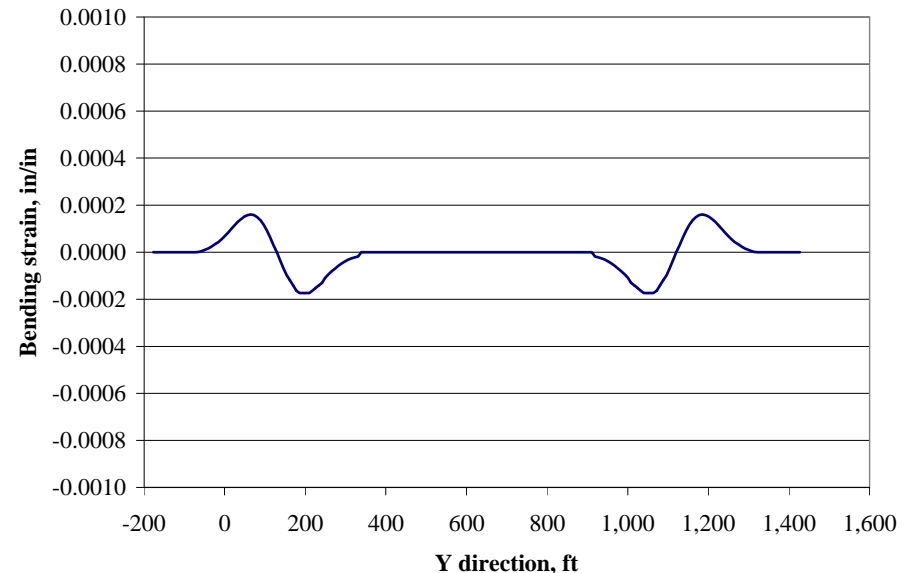
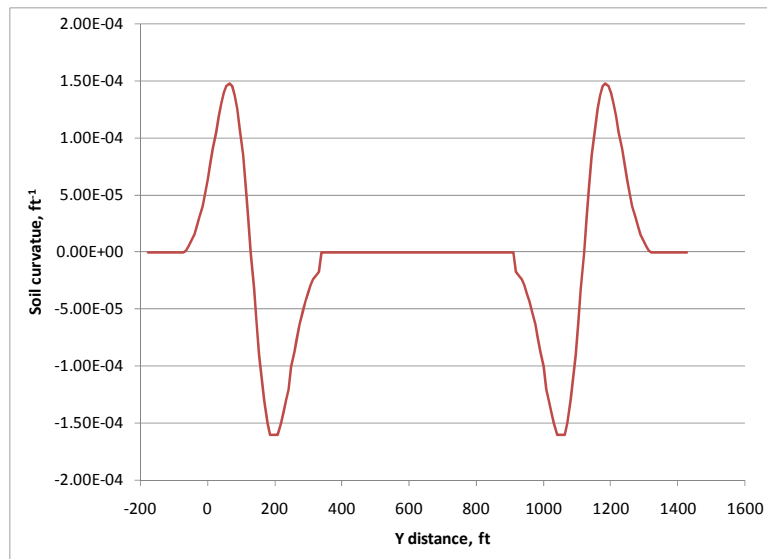
Subsidence



Soil strain

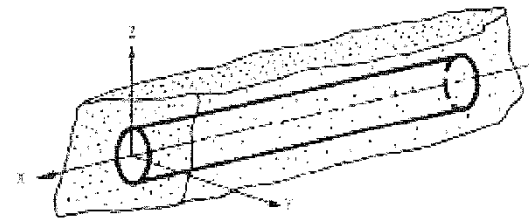
Subsidence Stress

- An initial estimation of the bending strain can be obtained from the curvature
 - Works for buried or exposed pipe but doesn't account for terrain

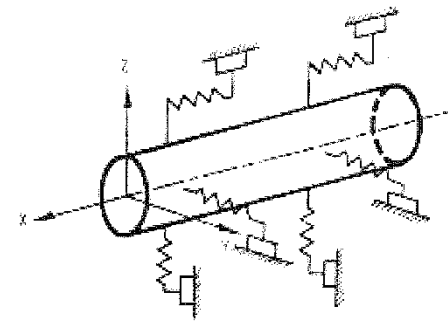


Finite Element Modeling

- A better estimate of stress can be obtained using finite element modeling
 - The pipe soil interaction is modeled as nonlinear springs
 - Exposed pipe is modeled using contact elements for the ground contact



a) Actual Three-dimensional Soil Restraint on Pipeline

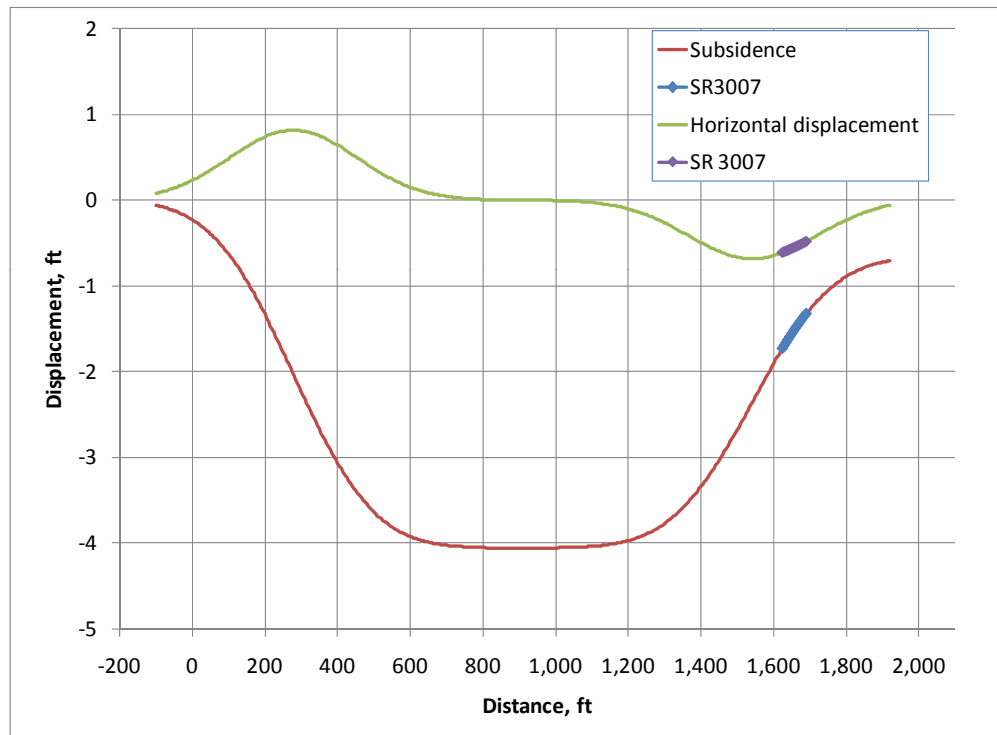


b) Idealized Representation of Soil with Discrete Springs

A Case Study-The Problem



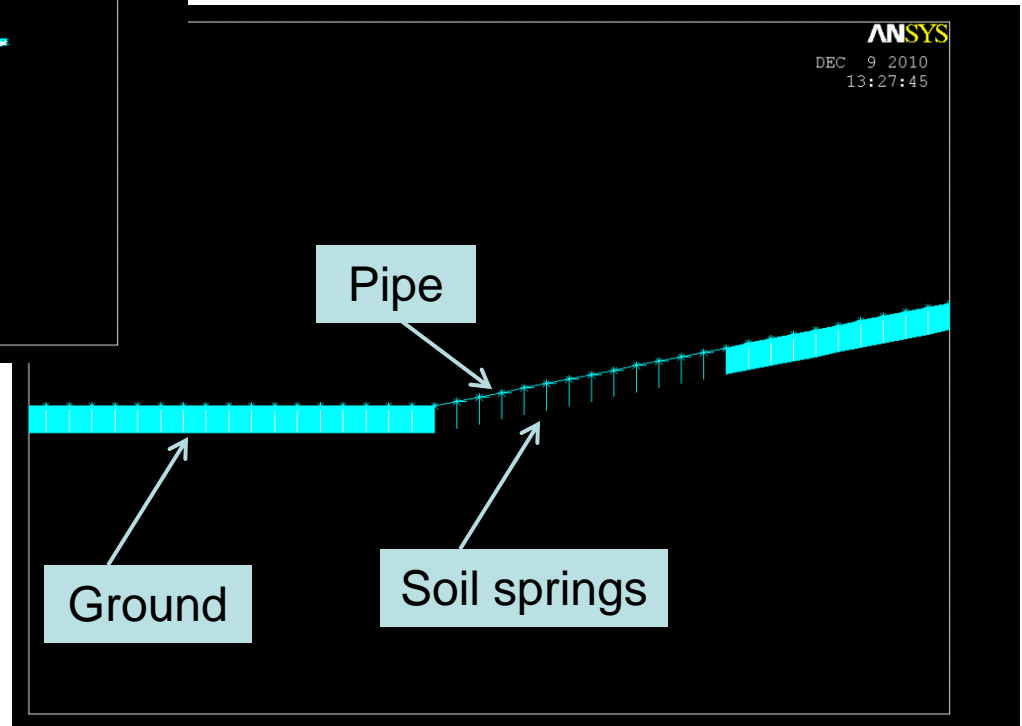
A Case Study-Subsidence



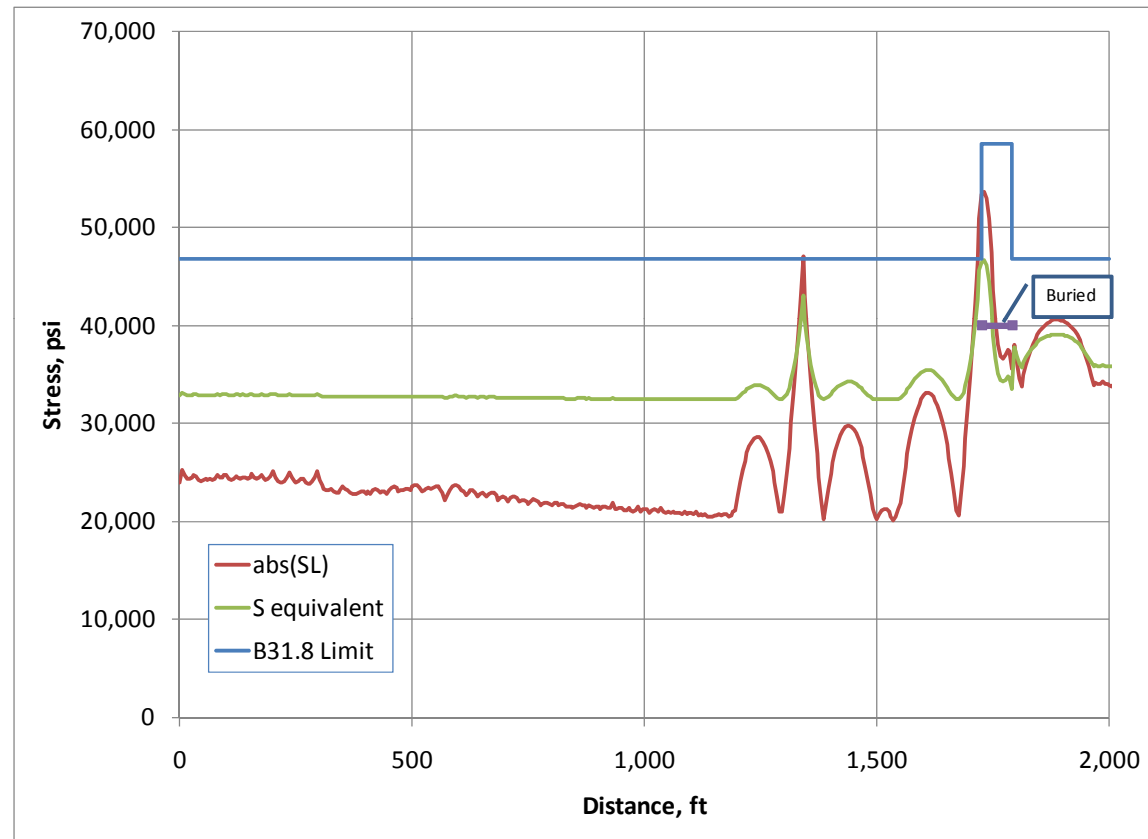
Subsidence and Horizontal
Displacement with Buried Segment



A Case Study-FEA Model



A Case Study-Results



Longitudinal and equivalent stress compared with code limits



Determining Allowable Stress

- In most cases the allowable stress can be determined from design codes
 - ASME B31.4 for hazardous liquids
 - ASME B31.8 for gas
- In some cases additional analysis of pre-existing defects is required to set allowable stress levels



Mitigation Plan

- The recommended steps to take prior to the subsidence
- A multi-level monitoring criterion with appropriate responses for each level
- Inspection procedure required for the monitoring criterion
- Recommendations for post-subsidence mitigation if required

Design for Subsidence

- The Pipeline Research Council International (PRCI) report entitled “Guidelines for Constructing Natural Gas and Liquid Hydrocarbon Pipelines through Areas Prone to Landslide and Subsidence Hazards” gives a summary of state-of-the-art subsidence design



Some Design Strategies

- Increase the pipeline capacity to resist ground movement
- Reduce the soil loads on the pipe
- Modifying the pipe alignment

Bad



Good

