Buried pipeline with soil-pipeline interface modelled in 2D and 3D

Keywords

Mohr-Coulomb Friction interface

Problem Description

This example calculates the frictional and normal stresses along the boundary of a pipe buried in soil [1]. The pipe of radius 0.84m and thickness 1cm sits in a square block of soil of dimension 8x8m as shown in figure 1. The soil is subject to an overburden of 1kPa. Gravity is not considered.

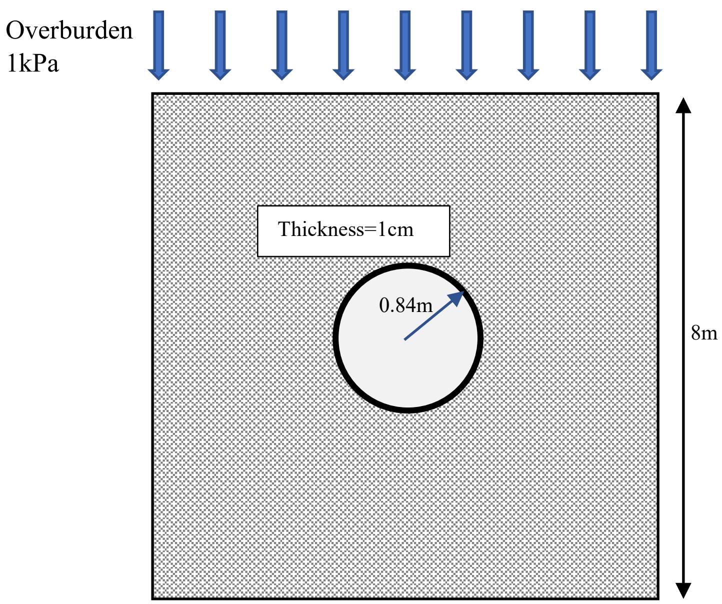


Figure 1: Problem geometry

The interface between the pipe and soil is modelled using the Mohr-Coulomb friction interface elements. Three cases are considered.

(i) frictionless slip ($\tan\phi = 0$),
(ii) stick ($\tan\phi = 2$),
(iii) frictional slip ($\tan\phi = 0.25$).

Discretisation

Utilising symmetry about the centre plane, only one half of the problem is modelled (figure 1). For 2D, the soil is meshed using quadratic plane strain elements, QPN8, the pipeline with BMI3N plane strain beam elements and the interface by IPN6 elements. Whilst for 3D, HX20 solid elements model the soil, QTS8 thick shell elements the pipeline and IS16 the interface. The edges are restrained in the horizontal and vertical directions and rotational restraint is applied to the ends of the beams and shells.

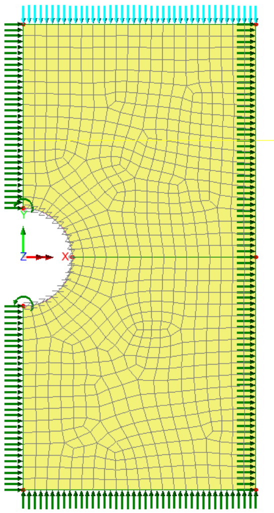


Figure 2: Finite element mesh showing supports and load

Material Properties

The soil and pipeline are modelled by linear elastic materials, the interface between them by Coulomb friction. Table 1 gives the material properties for the test.

Table 1: Material properties

Linear elastic properties

Material	Young's modulus, E	Poisson's ratio, ν
Soil	18400 kPa	0.33
Pipeline	207E6 kPa	0.3

Interface

Material	Normal stiffness, k_n	Shear stiffness, k_s	Angle of friction, ϕ	Angle of dilatancy, ψ	Cohesion, c
Full friction	1E6 kPa/m	1E6 kPa/m	65º	0º	0 kPa
Partial friction	1E6 kPa/m	1E6 kPa/m	14º	0º	0 kPa
No friction	1E6 kPa/m	1E6 kPa/m	0º	0º	0 kPa

Loading Conditions

An overburden pressure of 1kPa is applied to top of the soil as seen in figure 1.

Theory

The interaction between the soil and pipe is governed by Coulomb friction such that the bond between the pipe and soil is maintained by a frictional force but once this is overcome debonding and slip will occur. The maximum shear stress is given by

$$\tau_{max} = c + \sigma_N \tan\phi \tag{1}$$

where τ_{max} maximum shear stress
σ_N normal stress
c cohesion
ϕ friction angle

Comparison

Burns [2] derived an analytical solution for the two extreme cases of full friction and no friction, whilst Katona's FE solution [1] used constraints to model contact as opposed to the penalty approach adopted by LUSAS.

Figure 4 shows the normal and shear stress distribution normalised by the overburden pressure around one quarter of the pipe's circumference. The angle is measured from the crown to the springline. The three cases of full friction, partial friction and no friction are plotted together. Results are plotted for the 2D analysis.

The lower plots show that the shear force for the full friction case reaches a maximum at an angle of 45º tailing off to zero at the crown and springline. In the case of partial friction, the shear force is too much and there is slip with a near constant shear along this portion. LUSAS' results agree well with Katona's for this case. For the case of no friction, no shear forces are developed.

The variation of the normal stress around the pipe periphery shows the greatest variation for the case of full friction and much less variation when no friction is present with the case of partial friction lying in between.

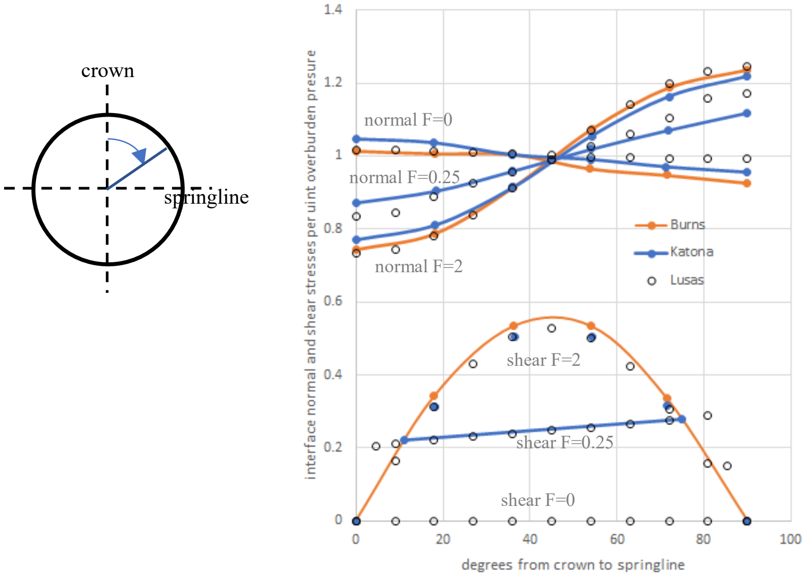


Figure 4: Variation of normal and shear stresses around pipe periphery

Figures 5 and 6 show the shear and normal stresses plotted around the pipe periphery.

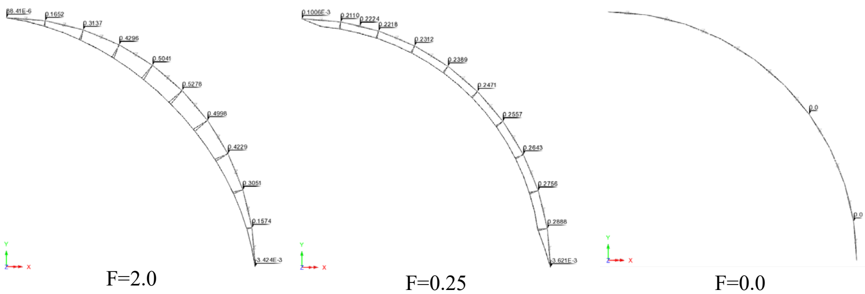


Figure 5: Distribution of shear stress

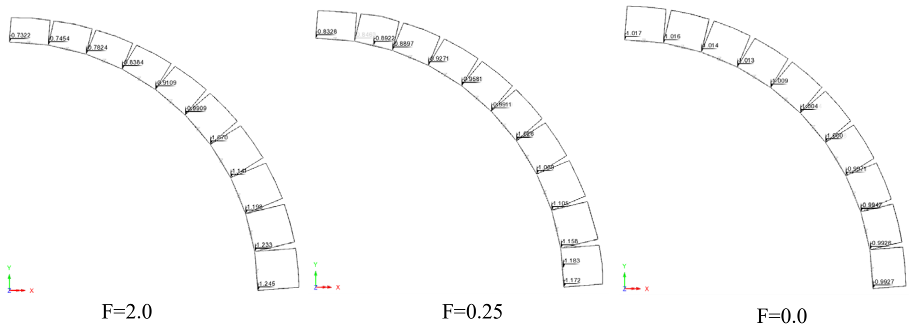


Figure 6: Distribution of normal stress

Figure 7 shows the contours of the vertical stress for the 3D model with full friction at the interface and also the shear and normal stresses distribution on the pipe/soil interface. Shear stress contours on the 3D interface are shown in figure 8.

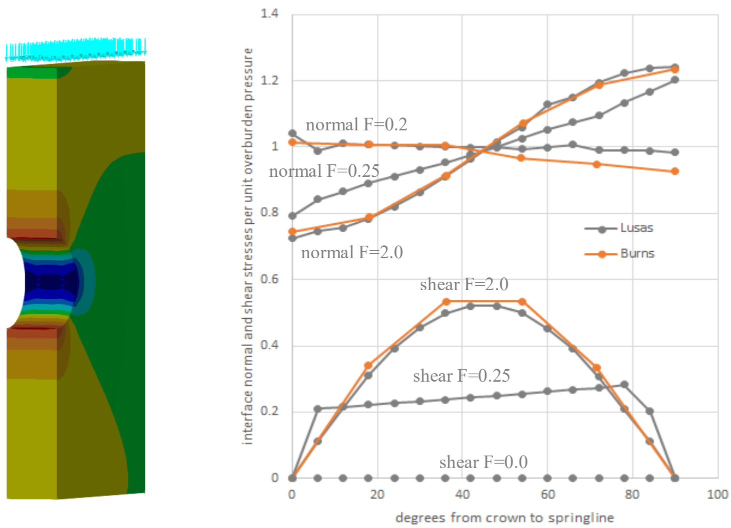
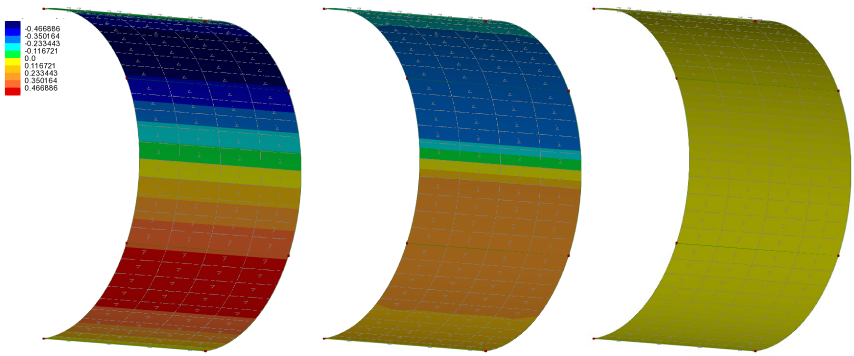


Figure 7: Results for 3D analysis



F=2.0 F=0.25 F=0.0

Figure 8: Contours of shear stress on interface of 3D model

References

1. Katona M.G., A simple contact-friction interface element with applications to buried culverts, Int.J.Num.Anal.Meth in Geomechanics, 7, 371-384, 1983.

2. Burns J.W., An analysis of cylindrical shells buried in elastic media, Ph.D. thesis, Univ.Arizona, Tuscan, Arizona, 1965.

Input Data

buried_pipeline_2D.lvb

buried_pipeline_3D.lvb