FINITE ELEMENT CALCULATIONS OF HYDRAULIC FRACTURING DURING HORIZONTAL DIRECTIONAL DRILLING

by

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ABSTRACT

Horizontal Directional Drilling has become commonplace for the trenchless installation of utility conduits and other buried pipe infrastructure. Developed to reduce surface disturbance and minimize construction time, the technology can be a cost-effective replacement for traditional open-cut installations. However, one of the problems associated with Horizontal Directional Drilling that is still inadequately understood is hydraulic fracturing. During insertion of utility conduits and other buried pipe infrastructure, drilling slurry is used to stabilize the soil around the excavation zone prior to pulling the new pipeline into place. Hydraulic fracturing occurs when the drilling slurry flows through tensile fractures in the soil surrounding the excavated zone caused by the pressures of the slurry itself. Fracture creation depends on the drilling slurry pressure inside the newly created conduit as well as the properties and stress state of the surrounding soil.

While varying the soil parameters from those of soft clay to those of very stiff clay, the elastic and elasto-plastic response of purely cohesive soil to the Horizontal Directional Drilling process is examined using finite element analyses. When there was an elastic response of the host soil, elasticity theory predicted the annular tangential stress in the host soil and could be used to predict the maximum allowable drilling slurry pressure to prevent tensile fracturing. In cases where shear failure of the soil occurred, plasticity theory predicted the annular tangential stress in the yielded areas. Following shear failure, the annular tangential stress increased with an increase in slurry pressure, and tensile fracturing was therefore no longer a threat. By combining the elasticity and plasticity theories, the minimum annular tangential stress could be predicted for a given set of drilling conditions. If this value was greater than the tensile strength of the soil, tensile fracture was not a threat. However, if this value was less than the tensile strength of the soil, tensile fracture *was* a threat, and the maximum allowable drilling slurry pressure was calculated using elasticity theory. Design formulae that reflect soil parameters, slurry parameters, and the tensile strength of the soil are presented and compared to another published design equation that quantifies the development of unconfined plastic flow. While that other design equations is commonly used to predict the maximum allowable drilling slurry pressure, the comparison revealed that in some conditions, the existing design equation may significantly overestimate the hydraulic fracturing pressures.

Finite element analyses are also used to study the elasto-plastic response of purely frictional soil that included the annulus of cohesive filtercake that forms where the drilling slurry penetrates out into the surrounding soil. When there was shear failure of the filtercake layer, plasticity theory predicted the annular tangential stress in the yielded areas. However, when it remained elastic the elasticity theory did not adequately predict annular tangential stresses. Both filtercake thickness and drilling slurry pressure were found to control the magnitude of the critical annular tangential stress. In addition, the complex plasticity distribution observed in the surrounding frictional soil was found to have a substantial effect on the annular tangential stresses.