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Trenchless Excavations for Underground Pipelines in Difficult Geology

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ABSTRACT: No-Dig constructions in the city might encounter various difficulties. And the difficulties or obstacles, which might cause schedule delays and damage to the pipes. Among the others, the conditions of overcut and stuck could be the most common and critical to a pipejacking project. This study considered various difficult conditions, including different overcut range and sticking position, together with different resistance, jacking force, etc. The ABAQUS finite element software was applied for three-dimensional numerical simulations for pipe-jacking with different difficult situations. The analyses focused on the pipejacking in gravel formations, and the suggestions were concluded based on the results. The results suggest that the location of sticking and its severity (different frictional coefficient was set) affect the stress field in the pipe. And the worst condition, i.e., the totally stuck, the adjacent soil and pipe will experience excessive deformation, which must be avoided. Therefore, lubrication to avoid this extreme scenario is essential in the pipejacking operation. For the case with large diameter, unavoidable overcut and highly variable geology, the above suggestions are more crucial.

KEYWORDS: Pipejacking, No-Dig, Difficult geology, Numerical analysis, Soil-pipe interaction

1. INTRODUCTION

Due to the rapid urban development, which makes the space of construction more and more limited, trenchless technologies including shield excavation and pipejacking are more and more popular for the installation of utility pipelines in Taiwan area. In the operation of pipejacking, the copy cutters are commonly applied to make the gap between the shield machine and the soil mass, i.e., the overcut, such that the resistance of friction can be properly reduced. However, if the overcut was improper due to the variation of soil or other factors, the overcut could collapse and cause high resistance or the condition of sticking to the extreme. In the conditions of high resistance or sticking, the operation could be hindered by the shortage of jacking force, and the pipes could be over-stressed or damaged.

For the analysis of soil-pipe interaction during a pipejacking, there are three majors approaches, i.e., analytical method, physical modeling, and numerical modeling. However, to have an analysis more close to the reality, the numerical modeling is more feasible. For the numerical modeling of pipejacking, the soil mass is commonly considered as an elastoplastic material. The shield machine and the pipes are considered as more rigid elastic bodies. Nevertheless, the study on the effect of overcut and sticking is scarce. In this study, numerical method was applied to analyse the impact of overcutting and sticking on the soil-pipe interaction, with different overcutting and stuck considerations in a pipejacking. In this study, the pipejacking cases in Taichung area of Taiwan are adopted as examples, and suggestions are given based on the analysis results.

2. METHODOLOGIES

2.1 Meshes and Boundary Conditions

The boundary conditions and element type are considered are as below: (A) the bottom face is confined by hinges and the surrounding vertical faces are framed by rollers, (B) three-dimensional solid elements (C3D8I) are used to simulate the soil and the pipe, and (C) interface elements are applied to simulate the soil-pipe frictional behavior. Numerically, we simulate the pipejacking process by repeating three numerical steps: remove the soil element in the pipe and at the pipe location, equilibrate the domain to obtain and accumulate the influences, and drive the pipe elements forward. The three-dimensional functions of the finite element software ABAQUS (Abaqus, Inc.,2005) were applied in this study.

To simulate the pipejacking cases, the pipe is assumed 10m below surface, and the 40m * 40m * 25m block of soil was considered. The jacking pipes are 2.5m long, 2m in diameter and 0.2m in thickness. The pipejacking machine is also considered as 2.5m long and 2m in diameter. The overburden is set to be 11.5m below surface. However, for the case of the curved pipejacking, 20 m in the radius of curvature was considered. The special jacking pipes are 0.8m long, 2m in diameter and 0.2m in thickness (Liu, 2010). After all, 17800 elements were used for the straight line pipejacking case (see Figure 1) and 27432 elements were used for the curved pipejacking case (see Figure 2).

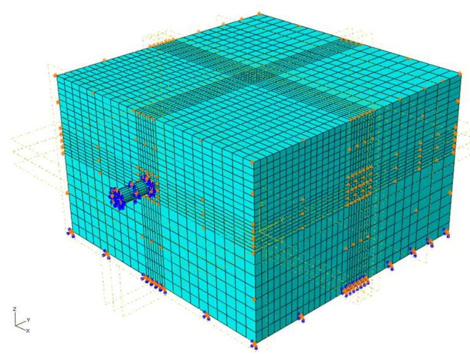


Figure 1 The Mesh for Straight Line Pipejacking

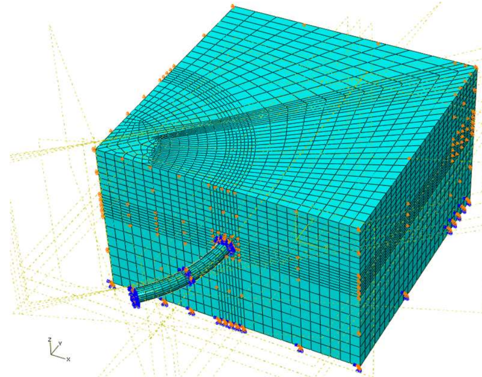


Figure 2 The Mesh for the Curved Pipejacking

2.2 Material Properties

Based on the experiment results to the geomaterials in Taichung area, the extended Drucker-Prager model is adopted as the constitutive law. The failure criterion is deduced by in situ tri-axial testing results, the Young's modulus is considered increasing with depth. The required parameters for the Drucker-Prager model were obtained by the least square fitting of the triaxial test results. However, for simplicity, the material peoperties of the pipes and shield machine were considered as linear elastic.

According to the related references (SINOTECH, 1993; CECI, 1994; Chen et al, 1995; Wu et al, 1995; Ren et al, 1998), mechanical properties were adopted for the analyses as shown in Table 1. In addition, we consider the Young's modulus as 30GPa, the Poison's ratio as 0.3, the density as 2400 kg/m^3 for the pipes, and the Young's modulus as 200GPa, the Poison's ratio as 0.3, the density as 7850 kg/m^3 for the pipejacking machine.

Table 1 Mechanical properties of the gravelly soil

C(kPa)	**ψ(°)**	**E(MPa)**	**ν**	**a**	**b**	**β(°)**	**γ(kN/m^3)**
15	37	300	0.3	0.69309	1.0004	46.18	21

2.3 Consideration of Overcutting and Sticking

Overcutting is a common phenomenon in pipejacking as the size of the cutter head is generally designed larger than the size of the shield and the pipes behind it. It is helpful for the advancing, only if the amount of overcutting is reasonable. Otherwise, negative effect will be encountered which might cause the stoppage of advancing or the subsidence on the surface. To numerically analyze the effect of overcutting, we must consider remove one more layer of soil outside of the shield machine. However, due to the gravity, the removal of an extra layer of soil should be restricted at the upper half of the periphery. In this study, the overcutting was considered by removing a layer of soil at the upper half of the periphery for the straight line pipejacking. However, due to the asymmetrical deformation in the inner side and outer side, two different overcutting conditions, i.e., 135 degree case and 180 degree case (Milligan and Norris, 1996), were considered for the curved pipejacking, as shown in Figure 3. In addition, different locations of sticking (the elements in red) were considered for comparisons.

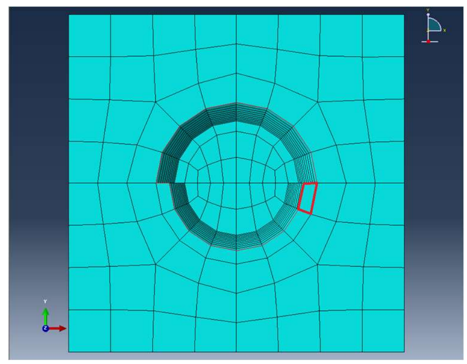
3. RESULTS AND DISCUSSIONS

3.1 Straight Line Pipejacking

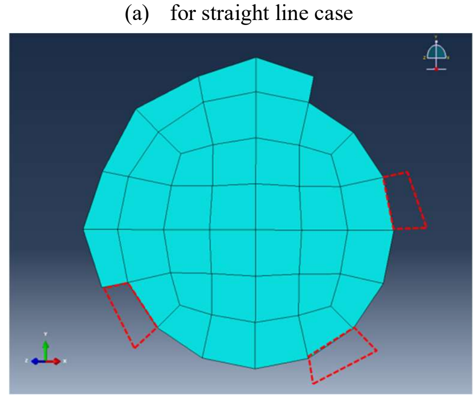
In this study, the condition of sticking is limited in a size of one element (0.5m*0.5m), at different locations as shown in Figure 3 (a). In order to study the behaviour of the concrete pipes, the front, the middle, and the tail of the second pipe were considered as the locations of sticking. For the overcut, it is considered from the cutter head to the meshes ahead of the stuck element. The soil mass the concrete pipes are considered as elastoplastic with different parameters. The results of a series of analyses suggest:

Figure 3 Details of the steel reinforcement

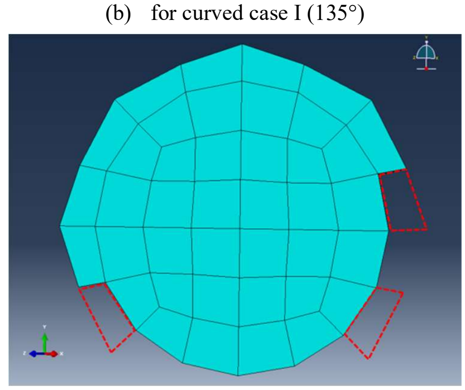
1. There are two type of sticking, i.e., the sticking with high resistance (μ=0.523) and totally stuck ($\mu=\infty$). The results reveal that the stress states are quite different at the inner side and outer side of the pipes. For the case of sticking with high resistance (μ=0.523), the stresses at the inner side are larger than those at the outer side. However, contrarily, the stresses at the inner side are smaller than those at the outer side for the case of totally stuck. (see Figure 4)
2. For the case of sticking with high resistance (μ=0.523), with the jacking force suggested by empirical formula, the pipe string can be jacked to the proposed location. The pipes can be jacked properly if the jacking force is larger than the suggested one. However, the difference between the stresses at the inner side and the outer side increases if the location of sticking is closer to the launch shaft, as shown in Figures 5~6.
3. The results suggest that the stresses increase about 5~25 times and the displacements increases about 27~70 times for the frictions coefficient increase from 0.523 (sticking with high resistance) to ∞ (totally stuck).
4. For the case of stuck with overcut, the impact of stuck is more serious than the case without overcut. The stresses increase about 5~25 times and the displacements increases about 65~200 times for the frictions coefficient increase from 0.523 (sticking with high resistance) to ∞ (totally stuck).



(a) for straight line case

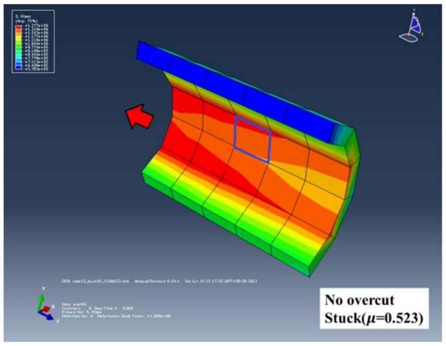


(b) for curved case I (135°)

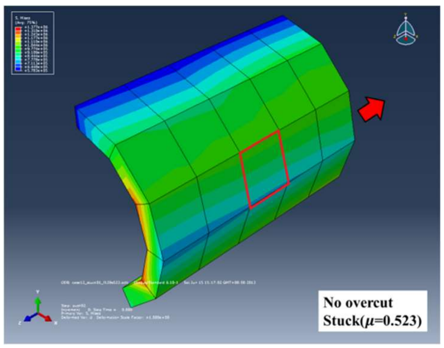


(c) for curved case II (180°)

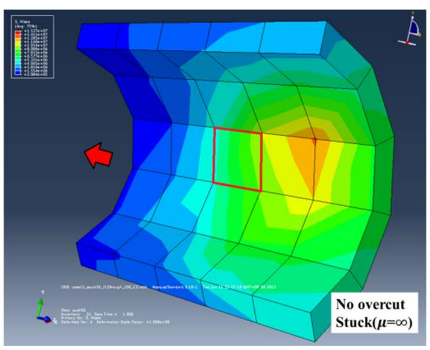
Figure 3 The Meshes for the Simulations of Overcut



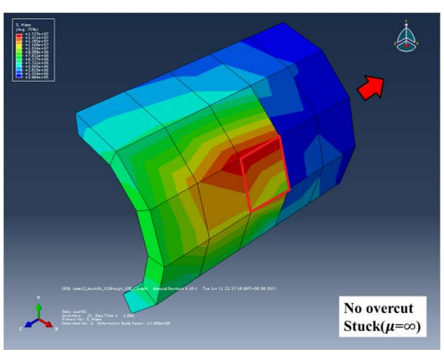
(a) inner side with μ=0.523



(b) outer side with μ=0.523



(c) inner side with $\mu=\infty$



(d) outer side with $\mu=\infty$

Figure 4 The Stress Fields for the Straight Line Case of Overcut with Sticking

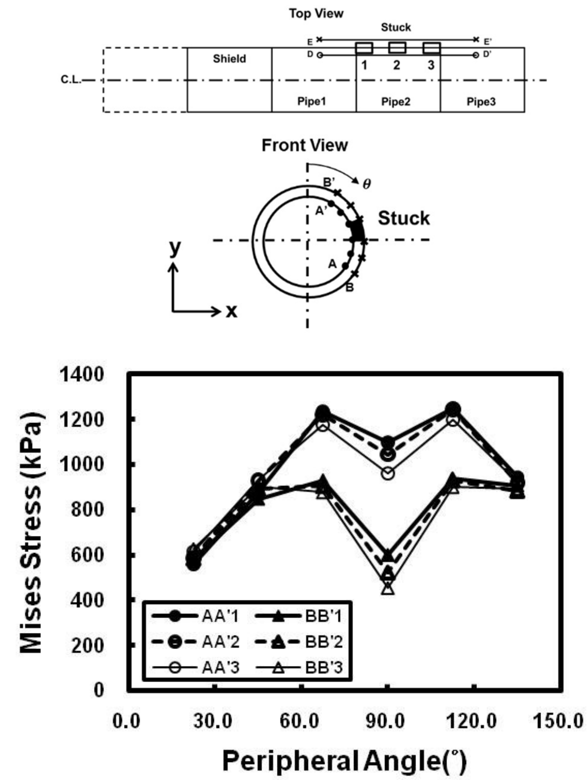


Figure 5 The Stress Distribution for the Straight Line Case of Overcut with Sticking at Different Locations above the String Line

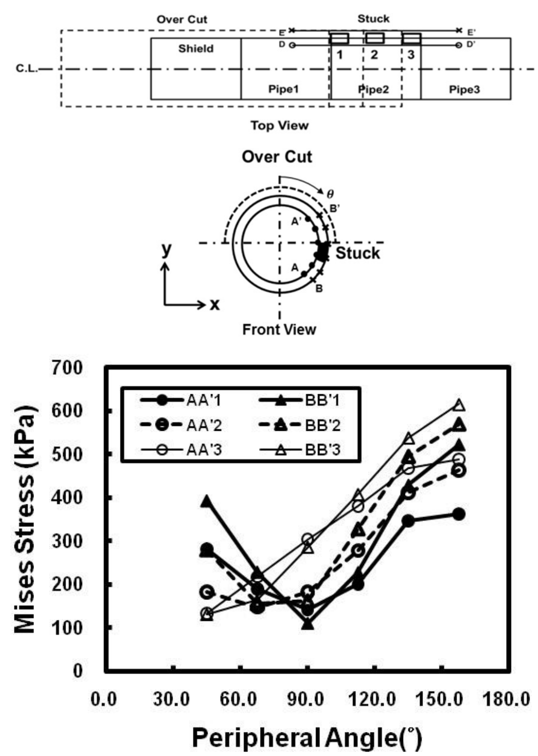
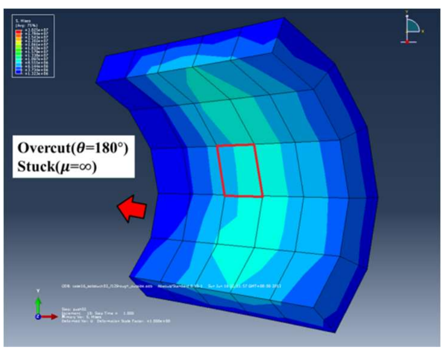


Figure 6 The Stress Distribution for the Straight Line Case of Overcut with Sticking at Different Locations below the String Line

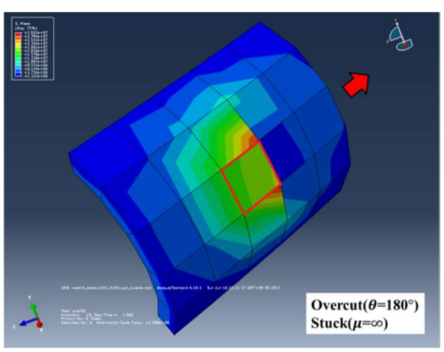
3.2 Curved Pipejacking

Similarly, the condition of sticking for the case of curved pipejacking is limited in a size of one element (0.5m*0.5m), at different locations as shown in Figure 3 (b)~(c). In order to study the behaviour of the concrete pipes, the front, the middle, and the tail of the second pipe were considered as the locations of sticking. However, for the overcut, two different types of overcut are considered from the cutter head to the meshes ahead of the stuck element. The soil mass the concrete pipes are considered as elastoplastic with different parameters. The results of a series of analyses suggest:

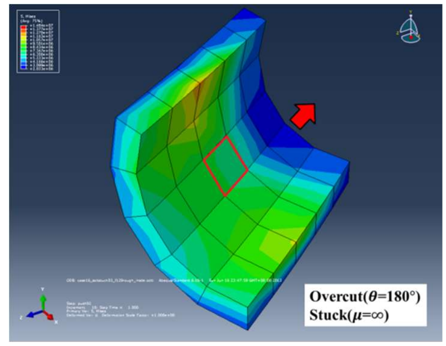
1. For the curved pipejacking with a condition of sticking, three locations of sticking were considered in the analyses. The results suggest that the impact of stuck at the inner side of the curve is less severe than that of the case at the outer side of the curve. (see Figure 7).
2. For the case with a totally sticking ($\mu=\infty$), the impact will be constrained (the stress concentration area will be reduced) when the location of sticking is close to the overcut. For the case of sticking at the inner side of a curve, the influence of the sticking limits to a 30° range. On the contrary, for the case of sticking at the outer side of a curve, the influence of the sticking increases to a 90° range (see Figure 7).
3. The stresses at the outer side of the pipe is generally larger than those at the inner side of the pipes, especially at the section with a stuck. The overcut will alleviate the stress difference (see Figures 8~9). For the case of stuck at the inner side of the curve, the results suggest a high stress concentration as well (see Figure 10).



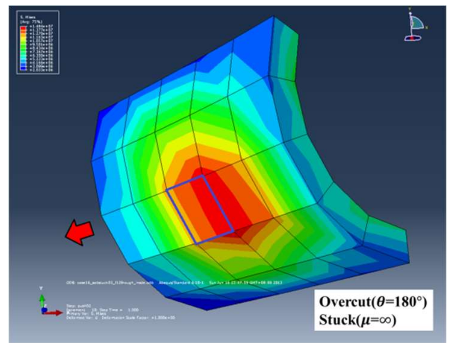
(a) inner side with a stuck at outer side



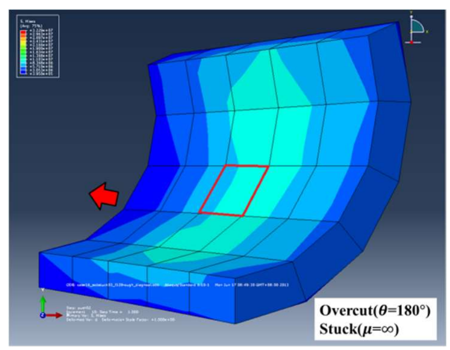
(b) outer side with a stuck at outer side



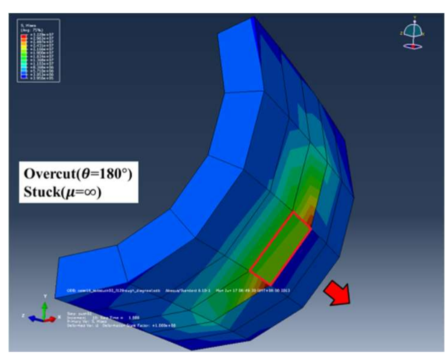
(c) inner side with a stuck at inner side



(d) outer side with a stuck at inner side



(e) inner side with a stuck at lower outer side



(f) outer side with a stuck at lower outer side

Figure 7 The Stress Fields for the Curved Line Case of Overcut with Sticking

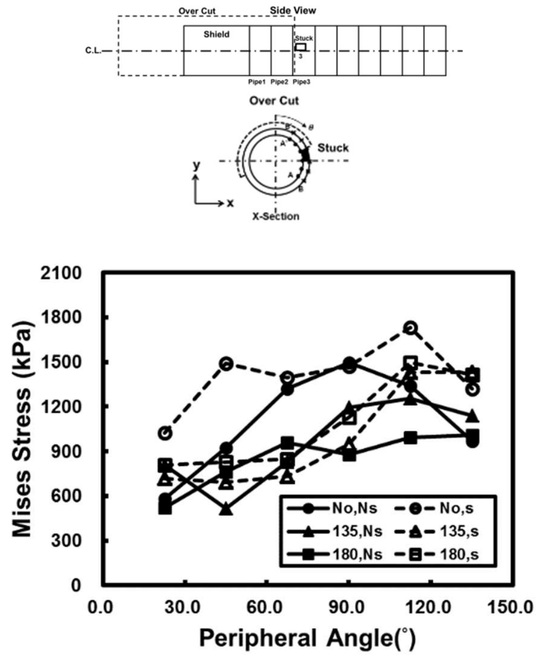


Figure 8 Stress Distribution along A-A' for the Curved Line Case of Overcut with Sticking at the Outer Side above the String Line

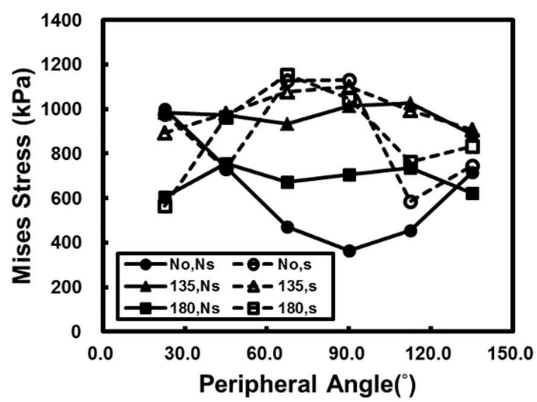


Figure 9 Stress Distribution along B-B' for the Curved Line Case of Overcut with Sticking at the Outer Side of the Curve above the String Line

4. CONCLUSIONS AND SUGGESTIONS

A proper overcut can help to reduce the resistance during pipejacking. It can not only reduce the difference between the stresses at the inner side and the outer side of the pipes, but also help to avoid the potential damages to the pipes during jacking process. For the section of overcut, the stress can be reduced by about 50~65% for the straight line case, and by about 15~35% for the curved line case

For the case of stuck, the stresses at the section of overcut are much higher than those at the section without overcut. In other words, the impact of the stuck above the string line is more serious. The stress can increase about 2~4 times for the straight line case, and about 1.1~1.3 times for the curved line case

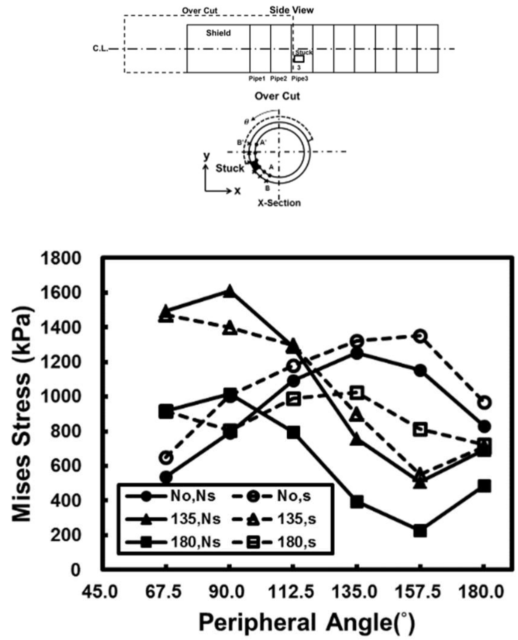


Figure 10 Stress Distribution along A-A' for the Curved Line Case of Overcut with Sticking at the Inner Side of the Curve below the String Line

The results suggest the backfill to the overcut could help to reduce the stress difference, avoid the collapse of the overcut, and help to avoid the damage to the pipes. The condition of sticking with high resistance is better than the condition of totally sticking, which also suggests the lubrication is essential to avoid the stoppage of pipejacking.

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