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Experimental Investigation of Fluidic Drag on PVC Pipes

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1. ABSTRACT

In HDD operation significant friction forces develop between the borehole and the drill string, reamer and product pipe. The paper presents the results of an experimental and numerical simulation study based on a small scale test setup which focused on investigation of friction coefficients between PVC pipe and different drilling fluid compositions. This part of the study consists of direct measurement of the dynamic friction drag (μ_b) between the slurry in the simulated borehole and the surface of the PVC pipe. This phase includes two slurry densities (8.3 and 9.80 ppg) mixed with two different soil types representing different levels of construction efforts (i.e., quality of cleaning the borehole). The effect of gelation was also evaluated by allowing the slurry to set for 2 min, 15 min, 1 hr, 3 hrs, and 24 hrs; simulating planned and unplanned delays (e.g. butt-fusion operation, hydro-lock, drill rig breakdown, and frac-out) in the pullback process. Fluidic drag factor (μ_{mud}) was also calculated which can be used in conjunction with ASTM F-1962 after performing some full scale tests. Evaluation of the forces needed to re-mobilize a pipe following a discontinuity in the pull-back process (i.e., break-out forces) and resulting stresses developed in the pipe product at the vicinity of the pull head were also performed in addition to numerical simulation. The results may be beneficial in optimizing the HDD installation process.

2. OBJECTIVE

Significant friction forces develop between the borehole and the drill string, reamer, and product pipe during HDD construction. The research summarized in this paper is a continuation of Part I of the study which focused on investigation of friction coefficients between fusible PVC™ pipes and different compositions of drilling fluids (Hassan et. al. 2013). This Part of the study consists of direct measurement of the dynamic friction drag (μ_b) between the slurry in the borehole and the surface of the PVC pipe. This phase will include two slurry densities (8.3 and 9.80 ppg) mixed with two different soil types representing different levels of construction efforts (i.e., quality of cleaning the borehole). The effect of gelation will also be evaluated allowing the slurry to set for 2 min, 15 min, 1 hr, 3 hrs, and 24 hrs, simulating planned and unplanned delays in the pullback process (e.g. butt-fusion operation, hydro-lock, drill rig breakdown, frac-out).

This work may provide approximate quantitative values for:

a. Fluid drag factor (μ_{mud}) that can be used in conjunction with ASTM F-1962 and the PRCI model for Fusible PVC™ pipes.
b. Evaluation of forces needed to re-mobilize a pipe following a discontinuity in the pull-back process (i.e., break-out forces) and resulting stresses developed in the pipe product in the vicinity of the pull head.

3. TECHNICAL CONSIDERATIONS

The pullback operation is a function of interaction between the soil, drilling fluid, and the surface of the pipe. An accurate pulling load prediction is important in HDD operations because an under capacity drill rig can lead to a pipe getting stuck in the borehole, while applying too large of a pull force can overstress the pipe material leading to damage and premature failure of the pipe. Forces acting on the pipe during the pull-back operation are shown in Figure 1.

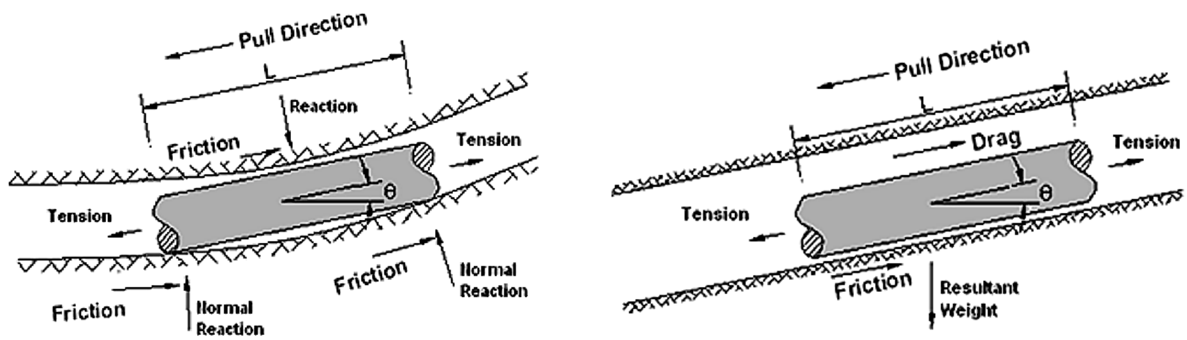

Figure 1: Pipe-Borehole Interaction during Pull Back in HDD Installation (after Huey et al., 1996) – Curved Section (Left) and Straight Section (Right).

4. PROTOTYPE DEVELOPMENT

4.1. PREPARATION OF SETUP

A prototype of the proposed test setup was developed first. One 4" diameter 4'-9" long clear plastic tube identified as Pipe-A and one 9'-0" long 2" diameter PVC pipe identified as Pipe-B was taken. It was planned to pull the Pipe-B through drilling fluid contained inside the Pipe-A (see Figure 2).

Figure 2: Schematic View of the Proposed Setup

Two 4" to 2" F-F PVC adapter was taken and the inner ring was machined off in a lathe. Next, a 2" diameter 8 " long piece of a pipe was pushed through the adapter and the 4" portion of the adapter was filled with expandable foam, so the foam cannot set inside the 2" portion of the adapter. Later, the foam was trimmed about an inch from the outer edge (see Figure 3) of the adapter. Deployment of foam in such a manner was expected to form a seal out of drilling fluid around the outer surface of the Pipe-B.

Figure 3: Removal of Inner Ring in a Lathe (left) and Trimmed Foam Layer inside the Adapter (right)

Next, 4 holes were drilled approximately at 90 degrees on the adapters and on the clear pipe. The adapters were attached on both ends of the clear pipe (see Figure 4) using screws.

Figure 4: Drilling Holes on the Adapter and Pipe-A (left) and Adapter Attached to the Pipe-A (right)

Circular marks were drawn on the Pipe-B at 6" apart indicating 7 (seven) equal segments and was slipped inside the Pipe-A through the modified adapters and the setup was levelled on a stand. One end of Pipe-B was attached to a winch cable via the 25 lb capacity load cell. Recording accuracy of the load cell was up to 4 decimal places (see Figure 5).

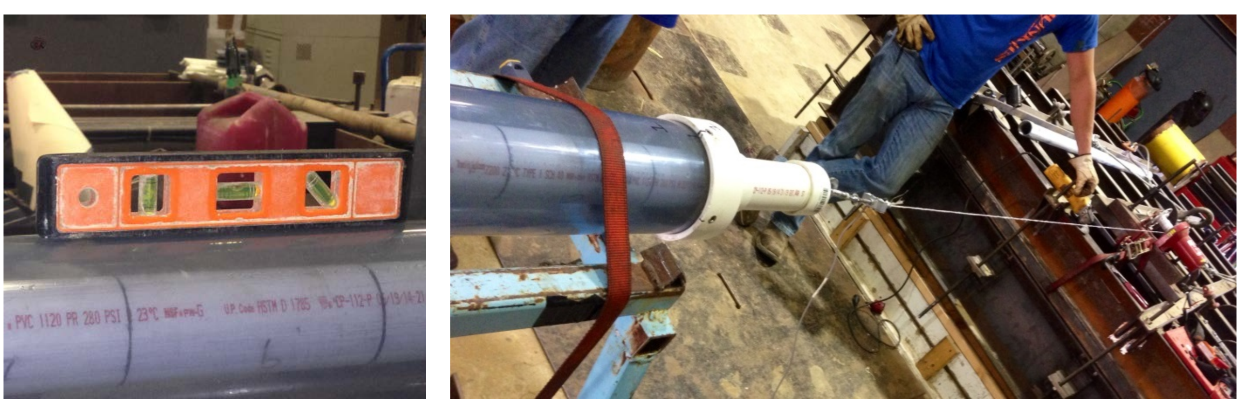

Figure 5: Setup Levelled (left) and Pipe-B Attached to a Winch Cable via the Load Cell (right)

4.2. PREPARATION OF DRILLING FLUID

The required volume of drilling fluid was prepared based on the calculated annular space between the Pipe-A and Pipe-B. The additives required for drilling fluids were mixed with water in a 5-gallon bucket using a paint stirrer. Prior to adding any additives, the pH of the fresh water was measured using pH strips and found to be between 6.50 and 7.50. Soda ash was added to fresh water to increase the pH value to between 9 and 10. The hardness was measured using hardness measuring strip and average hardness was found to be around 60, which fell into the acceptable range of 50 to 120.

Next, BORE-GEL® was added slowly while the fluid was stirred at constant rate to ensure uniform blend with water without formation of clumps. Later, liquid EZ-MUD® was added directly to the bucket at a rate of one quart every 4 to 5 minutes. The process continued by adding additives (NO-SAG® and Penetrol®) until the desired viscosity was attained. The viscosity of the drilling fluid was kept low (funnel viscosity 41 seconds) and high (too thick to measure) to compare the difference in surface drag force between the Pipe-B and the drilling fluid. The preparation of the drilling fluid and the prepared drilling fluid is shown in Figure 6. The ingredients used for preparing the drilling fluids and properties of the two prepared drilling fluids are given in Table 1.

Figure 6: Preparation of Drilling Fluid (left) and Prepared Drilling Fluid (right)

Table 1: Ingredients and Properties of Drilling Fluid

Ingredients and Properties	Low Viscous	High Viscous
Soda Ash, quarts	0.01	0.01
BORE-GEL®, lb	1.50	0.40
EZ-MUD®, quarts	0.01	0.01
NO-SAG®, lb	0.01	0.01
Penetrol®, quarts	0.15	0.01
pH	10	10
Total Hardness, TH	60	70
Funnel Viscosity, sec	41	N/A*
API – Filtrate Volume, ml @ 7.50 min	13	4
Rheology Test @ 300 rpm	22	N/A*
Rheology Test @ 600 rpm	34	N/A*
Plastic Viscosity (PV)	12	N/A*
Yield Point (YP)	10	N/A*
Density (ppg)	8.30	9.80

** Too thick to test*

4.3. TESTING AND RESULTS

The prepared drilling fluid was poured into the annular space between the Pipe-A and Pipe-B by lifting up one side of the setup and slid the Pipe-B inside (see Figure 7). Later the setup was levelled again and the Pipe-B was repositioned before it was pulled 3'-0" by rolling in the cable connected to the winch shaft.

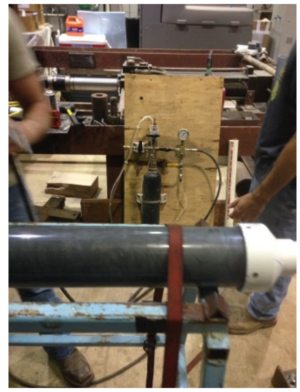

Figure 7: Lifting of the Setup Prior to Pouring of Drilling Fluid (left) and Set up with Drilling Fluid (right)

Three scenarios were considered while Pipe-B was pulled – no drilling fluid (Scenario-1-NDF), low viscosity drilling fluid (Scenario-2-LV – 8.3 ppg), and high viscosity drilling fluid (Scenario-3-HV – 9.80 ppg). Pulling forces were recorded for all cases and are presented in the results section. After the pipe was pulled, the seals were checked for pressure application by connecting a garden hose to the setup. No pressure was developed during the Scenario-1-NDF and Scenario-2-LV, but for Scenario-3-HV, a pressure of 14 psi was observed (see Figure 8).

Figure 8: Pulling the Pipe-B (left) and Pipe-B pulled with applied of pressure (right)

Each time Pipe-B was pulled, the pull forces were recorded every second. The plots are shown in Figure 9. The initial drag force required to break the adhesion for high viscous drilling fluid (Scenario-3-HV) was found above 25 lbf which reached the capacity of the load cell attached. Same force for Scenario-2-LV and Scenario-1-NDF was found around 3 lbf and 2.61 lbf respectively. Pulling force for Scenario-3-HV was found to be between 8 and 9 times higher when compared to the other scenarios, indicating fluidic drag force has significant impact during HDD installation. An increment in the pulling force for Scenario-3-HV was found at the end of the test which might be due to the accumulation of drilling fluid at the end where the Pipe-B was pulled out of the Pipe-A. Similar phenomenon was not observed for Scenario-2-LV as the fluid viscosity was low. Higher force recorded for Scenario-2-LV when compared to Scenario-1-NDF indicates drilling fluid has some drag force on the pipe. Effect of different soil types and gelation was not observed for this small scale experimental setup and therefore was not included in the paper.

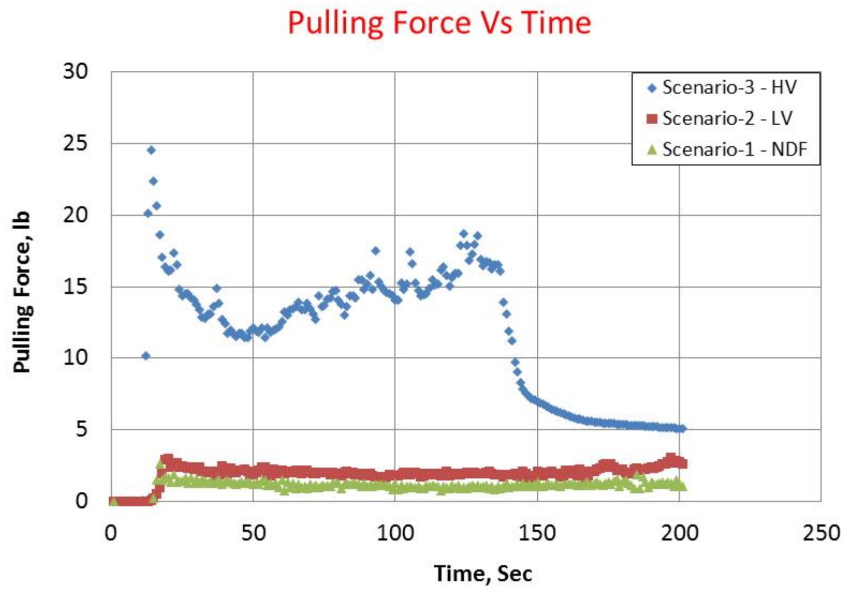

Figure 9: Pulling Force Vs Time for All Scenarios

5. NUMERICAL SIMULATION AND RESULTS

Numerical simulation of the bore-hole inside was developed by the computational fluid dynamics (CFD) software named COMSOL. The model was first developed to mimic the actual test condition – pulling of the inner pipe through the low and high viscosity fluid with no turbulence and the plot is shown in Figure 10. For the low viscosity fluid the pulling load was found to follow the trend of the experimental results up to around 190 seconds. However, for the high viscous fluid the same load was found to follow the similar pattern up to around 130 seconds indicating accumulation of load data in the simulation software and did not reflect the actual field condition where the fluid lock broke suddenly.

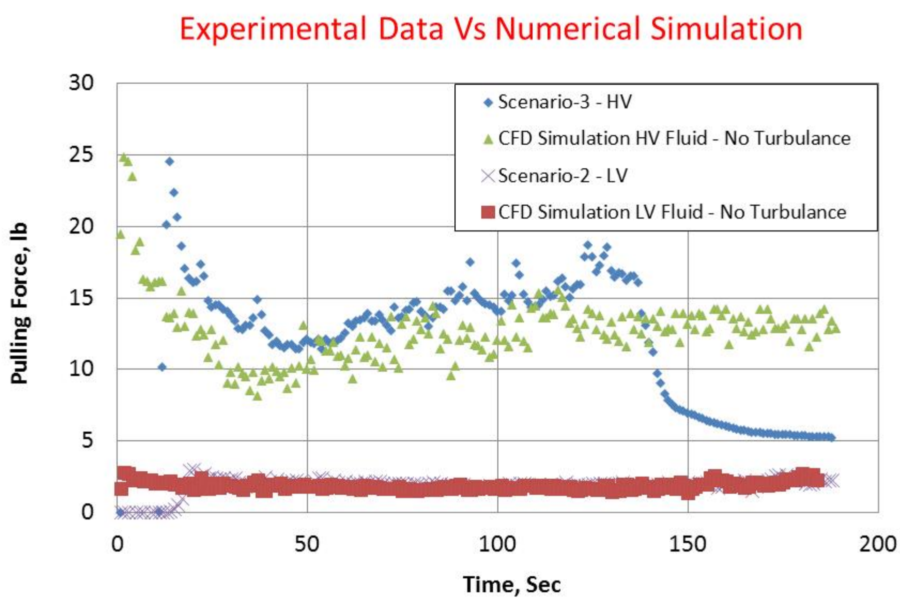

Figure 10: Comparison of Experimental Data and Numerical Simulation

Building on this model, next minor turbulence was introduced at the front of the pulling head. Turbulence was created in two different directions - on the circumferential plane (CP) and the longitudinal plane (LP) (see Figure 11) and the numerical model was created to mimic the experimental setup.

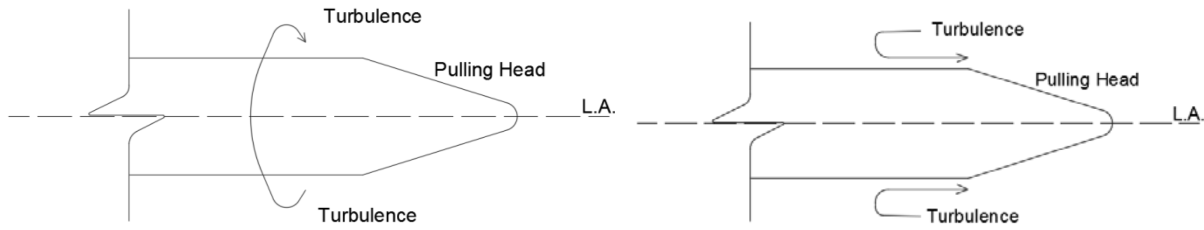

Figure 11: Turbulence on circumferential plane (left) and longitudinal plane (right)

Pulling force for low viscous fluid did not show significant change and therefore is not presented here. However, substantial change for the pulling force related to high viscous fluid was observed and presented in Figure 12. Contribution of turbulence generated along the circumferential axis was found somewhat less in comparison to the turbulence produced along the longitudinal direction where around at some point maximum 20% reduction in overall pulling force was observed.

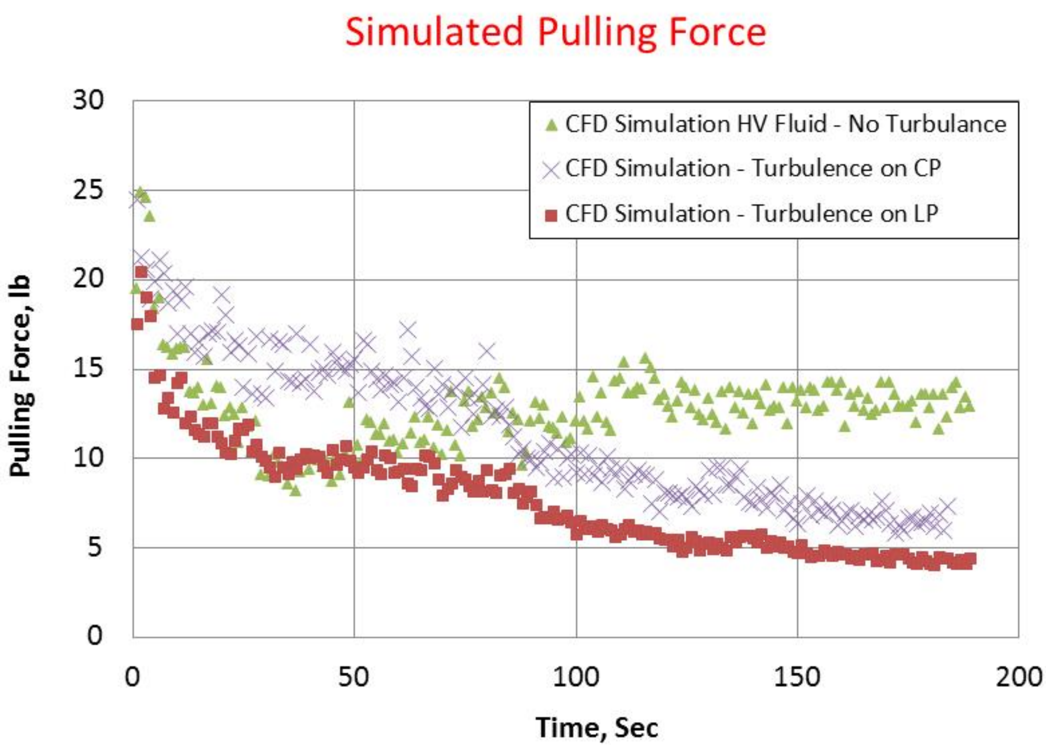

Figure 12: Reduction in pulling force due to turbulence

6. CONCLUSION AND FUTURE WORK

Significant friction forces develop between the borehole and the drill string, reamer and product pipe during HDD operation. The paper presents the results of a study based on a small scale experimental setup and numerical simulation that focused on investigation of friction coefficients between PVC pipe and different drilling fluid compositions. In the experimental setup, required pulling force for high viscous drilling fluid was found to be more than expected. The numerical simulation showed the creation of turbulence along the appropriate direction helped reduce the pulling force by around 20 percent; this could turn out to be significant during onsite application by reducing the total energy consumption, helping with pumping of drilling fluid and cooling of drilling equipment. Future study may include further experimental work for development of a pulling head prototype in-built with turbulence creator at the front for different soil-drilling fluid combinations.

7. ACKNOWLEDGEMENT

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