

ANALYSIS OF THEORETICAL VERSUS ACTUAL HDD PULLING LOADS

Jeffrey S. Puckett, P.E.¹

ABSTRACT

In 1995, the Pipeline Research Committee at the American Gas Association published a manual titled *Installation of Pipelines by Horizontal Directional Drilling, an Engineering Design Guide*. This manual included a method to estimate loads and stresses imposed on pipelines during installation by horizontal directional drilling (HDD). Since the initial development of the calculation method, theoretical pulling loads determined by this method have been compared against actual pulling loads recorded during HDD installations. This paper presents an analysis of theoretical and actual pulling loads to determine if modifications to the calculation method are warranted based on documentation from completed HDD projects. The specific documentation utilized in this analysis consists of joint-by-joint carriage force gauge readings recorded during actual HDD installations.

INTRODUCTION

Load and stress analysis for an HDD pipeline installation is different from similar analyses of conventionally buried pipelines because of the relatively high tension loads, bending, and external fluid pressures acting on the pipeline during the installation process. In some cases these loads may be higher than the design service loads (J. D. Hair & Associates, et al. 1995). Considering the magnitude of HDD installation loads, analysis of the stresses that they impose is critical in order to insure that acceptable limits are not exceeded. A detailed procedure for analyzing HDD installation loads is described in *Installation of Pipelines by Horizontal Directional Drilling, an Engineering Design Guide*. For convenience, this procedure will be referred to as “the AGA method” from this point forward.

During HDD installation, a pipeline segment is subjected to tension, bending, and external pressure as it is pulled through a prereamed hole. Tension results from frictional drag between the pipe and the wall of the hole, fluidic drag as the pipe is pulled through viscous drilling fluid, and the effective (submerged) weight of the pipe as it is pulled through elevation changes within the hole. Bending stress is induced as the rigid pipe is forced to negotiate the curvature of the hole. External pressure from the drilling fluid surrounding the pipe induces an external hoop stress assuming the pipe is not filled with a fluid of equal or greater density. The stresses and failure potential of the pipe are a result of the interaction of these loads. The AGA method provides a reasonably simple means to estimate HDD installation loads, calculate the resulting stresses, and determine if a given pipe specification is adequate (J. D. Hair & Associates, et al. 1995).

¹ Project Manager, J. D. Hair & Associates, Inc., 2121 S. Columbia Ave., Suite 101, Tulsa, Oklahoma 74114-3502; phone 918-747-9945; jpuckett@jdhair.com

DESCRIPTION OF CALCULATION METHOD

The AGA method is ultimately concerned with pipe stress as opposed to the total force exerted by the horizontal drilling rig. Pulling loads calculated by this method represent only the tensile force transmitted to the pull section as a result of conditions in the hole. Loads resulting from the drill string, the reaming assembly, and the above-ground portion of the pull section (typically supported on rollers) are not included in the calculation. Drill string and reaming assembly loads are omitted because they don't act on the pull section and therefore have no impact on pipe stresses. Although loads resulting from the above-ground portion of the pull section do have an impact on pipe stresses, these loads are omitted from the AGA method for two primary reasons. First, loads from above-ground pipe are seldom critical to the success of an installation due to the fact that they approach zero as the drag forces within the hole approach their maximum. Second, if these loads should become critical, the use of pipe side assistance techniques can essentially counteract their impact. If a direct correlation with the overall rig force is desired, loads resulting from the drill string, reaming assembly, and above-ground pipe must be estimated and added to the calculated tensile load obtained by the AGA method.

In order to calculate a pulling load using the AGA method, the drilled path is first modeled as a series of straight and curved segments as necessary to define its shape. The forces acting on each segment are then resolved sequentially from pipe side to rig side to determine the resultant tensile load at the end of each segment. Neglecting drag forces from the above-ground portion of the pull section, the initial tension on the first segment is zero. The initial tension for each subsequent segment is equal to the tension at the end of the previous segment. The total tensile load at the end of the pullback process is determined by summing the individual forces required to pull the pipe through each of the straight and curved segments defined in the drilled path model.

It is important to note that the AGA method employs several assumptions. It is assumed that the pipe is being installed in an open hole which has been prereamed to a diameter approximately 12 inches (30 cm) greater than that of the pull section. As a result, loads calculated for an installation through a collapsed hole or an inadequately prereamed hole are not expected to be reliable. It is also assumed that the hole is filled with drilling fluid of a known (or assumable) density. Finally, coefficients used in the calculation of frictional and fluidic drag must be assumed. When the AGA method was first developed, values for these coefficients were recommended based on available data from similar applications. These coefficients were intentionally incorporated as variables allowing them to be modified as better information becomes available.

RECENT ANALYSIS

Since the development of the AGA method, calculated pulling loads have been compared against actual pulling loads on numerous HDD installations. In general, tensile loads calculated by this method have compared favorably with recorded rig

loads. However, it was observed that the loads predicted by the AGA method commonly exceeded rig loads as pullback neared completion. This was not unusually surprising considering that assumed input parameters used in the AGA method are generally conservative. However, in March of 2000 while evaluating a proposed crossing which was borderline from the standpoint of installation loads, it became necessary to refine the input parameters used in the calculation method to more closely match actual loads. In order to accomplish this, an analysis was undertaken using documentation from completed HDD installations. This analysis focused on more accurately defining the fluid drag coefficient, being the input parameter with the greatest uncertainty.

Upon reviewing information from completed projects, it was determined that the Colville River crossings on the North Slope of Alaska provided excellent documentation of the actual loads required for a complete analysis. Two of these installations were selected as being most applicable, specifically installations of an 18-inch (457.2 mm) seawater injection pipeline and a 20-inch (508 mm) crude oil pipeline. Both of these crossings had drilled lengths in excess of 4,300 feet (1,311 m) and were installed in March of 1999 by Horizontal Drilling International (HDI) of Houston, Texas. The specific documentation utilized from these installations consisted of joint-by-joint carriage force gauge readings for the swab pass and pullback operations. Using these gauge readings in conjunction with conversion tables provided by HDI, the actual pulling force exerted by the rig for each joint of these operations was entered into a spreadsheet for analysis. This information is presented graphically in Figures 1 and 2 for the seawater injection and crude oil pipeline installations, respectively.

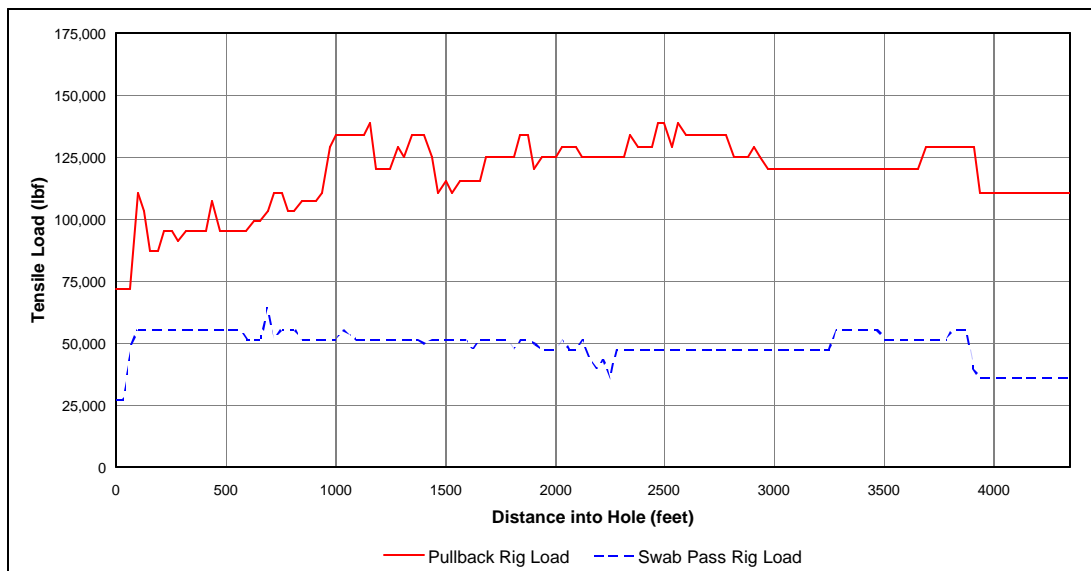


Figure 1. Recorded rig loads vs. distance into hole
Colville River crossing - 18-inch (457.2 mm) seawater injection pipeline

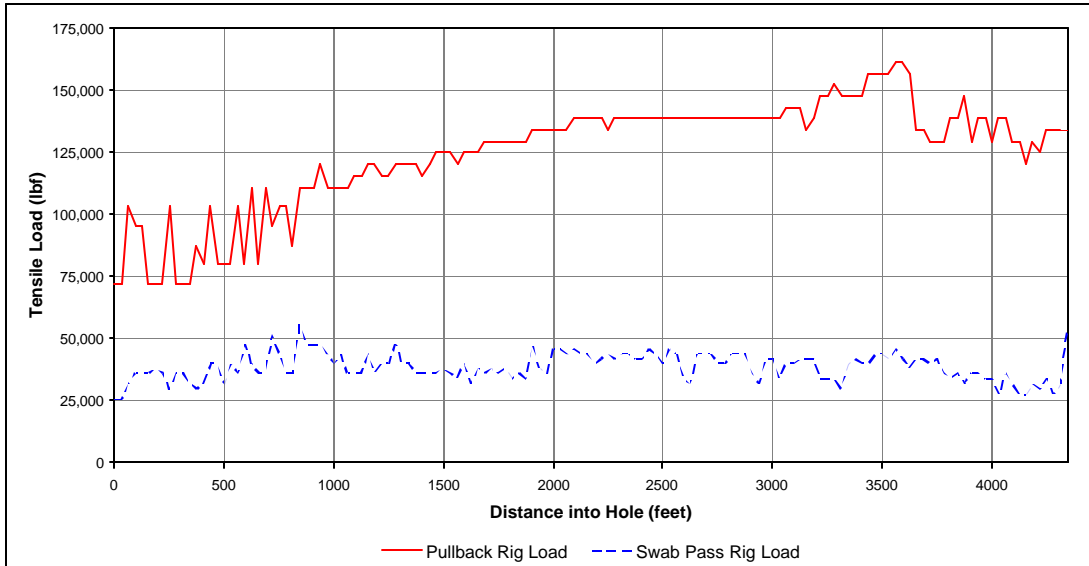


Figure 2. Recorded rig loads vs. distance into hole
Colville River crossing - 20-inch (508 mm) crude oil pipeline

As previously noted, the AGA method is intended to estimate the tensile force transmitted to the pull section as opposed to the total force exerted by the horizontal drilling rig. Therefore, in order to compare calculated tensile loads with recorded pulling loads, the forces resulting from the drill string, the reaming assembly, and the above-ground portion of the pull section were estimated and subtracted from the recorded rig loads. This yielded a resultant tensile load on the pull section which could be compared against calculated loads. The methods used to estimate these forces are described in the following paragraphs.

DRILL STRING LOAD

The tensile load resulting from drill pipe in the hole is greatest at the beginning of pullback when the drill string extends the entire length of the crossing. This load decreases as pullback progresses, reaching zero at the completion of pullback when no drill pipe remains in the hole. Data from the Colville River crossings was analyzed in order to estimate the maximum drill string load corresponding to the start of pullback. On both Colville crossings, rig loads during the swab pass and pullback increased noticeably on either the second or third joint of the operation, possibly because the reaming assembly was still in the mud pit for at least one joint length. For the sake of analysis, the reaming assembly load was assumed to be zero on the first joint of both the swab pass and pullback. Taking this into account, the rig load on the first joint of the swab pass resulted only from the drill string in the hole and a relatively short section (approximately 300 feet or 90 meters) of tail string on the surface. Neglecting the impact of the tail string, the rig load on the first joint of the swab pass is equal to the maximum drill string load. This load was assumed to decrease linearly to zero at the completion of pullback.

ABOVE-GROUND PIPE LOAD

As with the drill string, the tensile load resulting from the above-ground portion of the pull section is greatest at the beginning of pullback when the entire pull section is supported on rollers. This load also decreases to zero as the tail end of the pull section is pulled off the rollers and into the hole. On the first joint of pullback, again assuming zero load due to the reaming assembly, the rig load is comprised of the maximum drill string load, the maximum above-ground pipe load, and a minimal load resulting from the length of the pull section in the hole. With only around 30 feet (9 meters) of pipe in the hole, the load resulting from the pull section was neglected. Therefore, the maximum load resulting from above-ground pipe essentially becomes the difference between the rig load on the first joint of pullback and the maximum drill string load determined previously. Again it was assumed that this load decreases linearly to zero at the completion of pullback.

REAMING ASSEMBLY LOAD

Assuming that pullback proceeds through an open hole prereamed to a diameter 12 inches (30 cm) greater than that of the pull section, it is reasonable to assume that the load applied to the reaming assembly will remain fairly constant over the length of the crossing. However, variations in the rig load during the swab pass indicate that the reaming assembly load does deviate somewhat at certain locations in the hole. In order to incorporate these deviations, the rig loads from the swab pass were utilized to estimate reaming assembly loads during pullback on a joint-by-joint basis.

Considering that the swab pass and pullback were performed with the same reaming assembly and proceeded in the same direction, it was assumed that the load resulting from the reaming assembly was approximately the same during both operations. Since the drill string extends from entry to exit during the entire swab pass, the reaming assembly loads were estimated by subtracting the maximum drill string load (determined previously) from the recorded rig loads for each joint of the swab pass.

RESULTANT TENSILE LOAD

The resultant tensile loads on the pull section for each joint of the pullback operation were estimated by subtracting the loads resulting from the drill string, above-ground pipe, and reaming assembly from the recorded pullback rig loads. This resultant tensile load was then plotted against the distance into the hole. Tensile loads calculated by the AGA method at specific locations along the drilled path were then plotted for comparison to the resultant tensile load. These calculated loads were based on simplified models of the as-built pilot hole survey data from the Colville River crossings. A comparison of the resultant tensile loads and the calculated loads revealed that the calculated loads, using a fluid drag coefficient of 0.05 psi (345 Pa), were substantially greater than the actual loads as pullback neared completion. After running several pulling load calculations using different fluid drag coefficients, it was determined that a coefficient of 0.025 psi (172 Pa) most closely matched the data from the Colville installations. This can be seen in Figures 3 and 4 which show

calculated data points based on fluid drag coefficients of 0.025 psi (172 Pa) and 0.050 psi (345 Pa) along with the resultant tensile loads estimated from recorded rig loads.

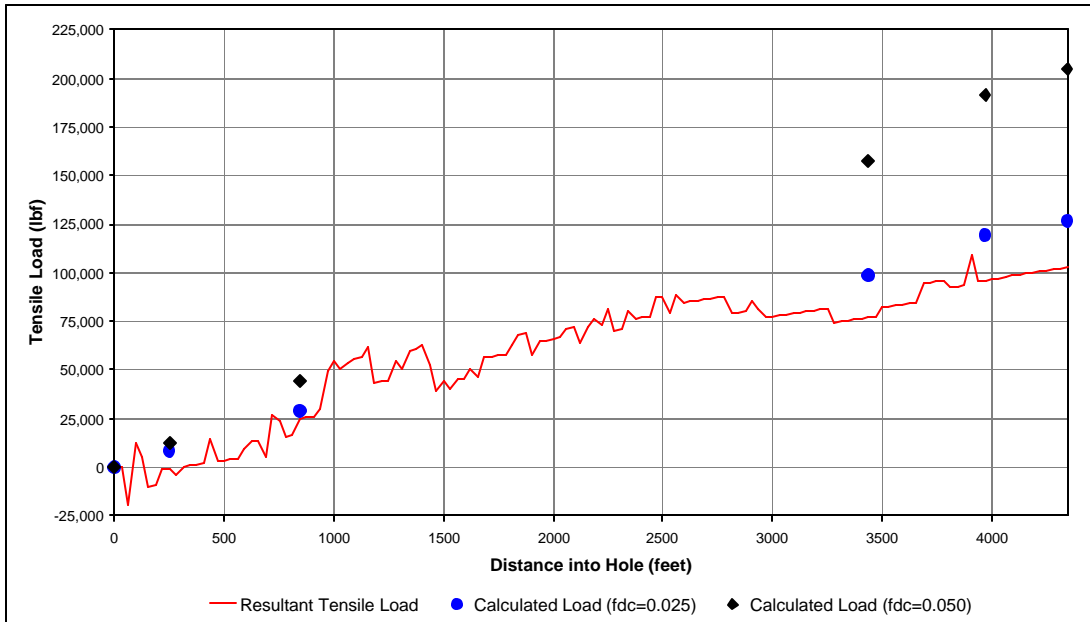


Figure 3. Tensile loads vs. distance into hole
Colville River crossing - 18-inch (457.2 mm) seawater injection pipeline

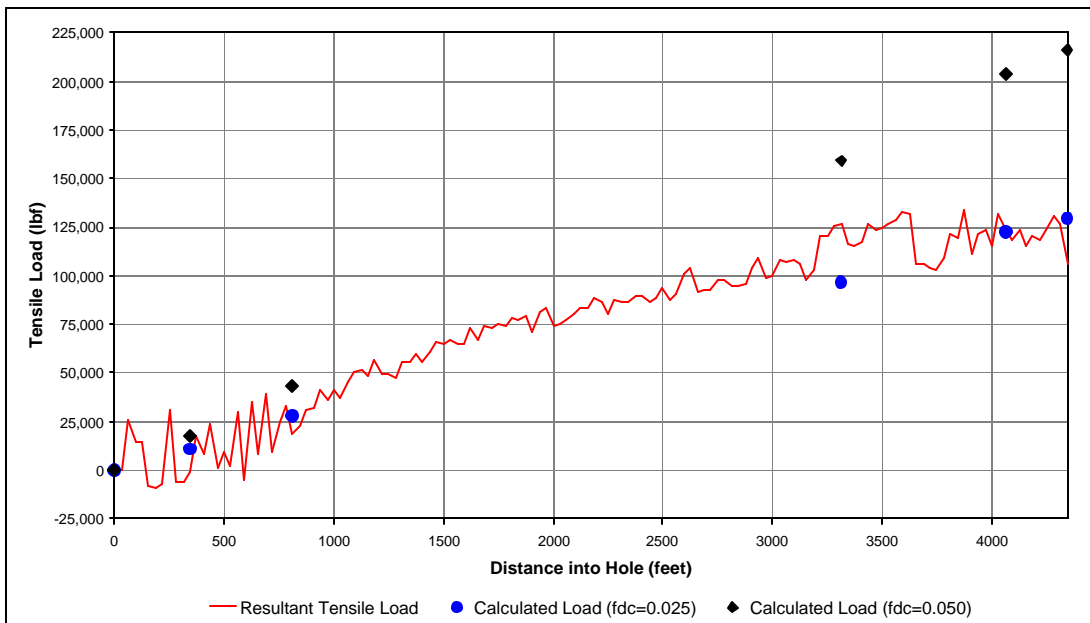


Figure 4. Tensile loads vs. distance into hole
Colville River crossing - 20-inch (508 mm) crude oil pipeline

CONCLUSIONS

Based on this analysis, a fluid drag coefficient of 0.025 psi (172 Pa) is believed to result in more accurate pulling load calculations than the previously recommended value of 0.05 psi (345 Pa). Furthermore, the results of this analysis, coupled with observations on numerous HDD installations, suggest that the technical basis for the AGA calculation method is sound, and that the method can be used to predict HDD installation loads reliably under most conditions. However, continued analysis is necessary to verify that the results of this analysis continue to hold true for a wide variety of HDD installation scenarios. Development of methods which allow for direct measurement of loads acting on the pull section during the HDD installation process has obvious merit. Implementation of such methods on a widespread basis will provide valuable feedback which can be utilized to further refine the AGA calculation method.

HDD pulling loads are affected by numerous variables, many of which are dependent upon site-specific conditions and individual contractor practices. These include prereaming diameter, hole stability, removal of cuttings, soil and rock properties, drilling fluid properties, and the effectiveness of buoyancy control measures. Such variables cannot easily be accounted for in a theoretical calculation method designed for use on an extensive basis. For this reason, theoretical calculations are of little benefit without a certain level of knowledge and experience in HDD construction.

REFERENCES

J. D. Hair & Associates, Louis J. Capozzoli & Associates, and Stress Engineering Services (1995). "Installation of Pipelines by Horizontal Directional Drilling, An Engineering Design Guide", prepared for the Offshore and Onshore Design Applications Supervisory Committee of the Pipeline Research Committee at the American Gas Association.