Horizontal Directional Drilling Guide

TECHNICAL PAPER: Design Considerations for Intersect Method of HDD

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Unidirectional HDD has been the conventional method of practice for many decades. However, ever increasing project challenges demand innovative methods of pipe installation using HDD. One such method is the intersect method where a single alignment is achieved by drilling from both ends so as to connect the drills underground.

This method has been used for many reasons in recent times. The decision on whether a HDD project is conventional or intersect can be based on many factors such as drill fluid properties, geometry of drill, local topography, geology along the alignment, entry and exit elevations, total length of HDD, depth of installation, availability of equipment, length of the conductor sleeves and the capacity of overburden to restrain the drill fluid pressures.

It is important to note that HDD designs are iterative processes and all the design considerations are interdependent. It is necessary to examine them as a whole instead of examining individual factors affecting the design. A graphical HDD pressure analysis provides us with a better understanding of the intersect method, in particular, the effect of drill fluid pressures in an HDD intersect. The graphical HDD pressure analysis is also intended to assist in the overall design and decision-making process by conducting parametric analysis of various alignments based on anticipated drill fluid pressures and geology.

DESIGN CONSIDERATIONS

Alignment Control

Alignment control is a combination of accurate interpretation of the geological conditions, contractor’s experience and use of appropriate tools to successfully drill through the given soil conditions. Although conventional drills can be accomplished for lengths greater than 8,000 ft (Bennett, 2008); alignment control can be a major challenge beyond 4,000 ft in adverse soil conditions. In such cases, it may be necessary to use the intersect method.

Equipment and Logistics

Based on the equipment available to the contractor at the time of the project, intersect method facilitates the use of combinations of small and large rigs to execute the drill successfully. Unidirectional drill on the other hand may need large rigs and sequential drills to do the same.

Geology along the Alignment and Installation Depth

The local geology is often the most important design consideration for any HDD project. The design begins with the geotechnical boring program to assess the subsurface conditions. The boring locations are planned depending on the length of drill and expected variations in the subsurface conditions. In order to come up with a sound design for any HDD project, it is necessary to assume some of the design parameters based on the design model used. In the case of the cavity expansion model, it is important to obtain critical soil characteristics such as density, friction angle and soil cohesion, which are not normally available from geotechnical boring logs alone. There have been many publications in the past emphasizing the importance of conducting appropriate tests to obtain project specific data.

Unfortunately, not all projects can accommodate an exhaustive test program that may be required to collect all the soil parameters. This makes it important to have reality checks since the available test data may only be indicative of the general site conditions and are usually conducted on a small percentage of area compared to the total area of the site. An experienced HDD engineer should therefore analyze and apply the data to reflect realistic conditions for the design. In other words, a Geotechnical Baseline Report that provides a reasonable interpretation of the geotechnical conditions is crucial for any complex HDD project. In the absence of such reports, the graphical HDD pressure analysis described below can be used as supplemental software. This method of analysis would benefit design consultants and contractors alike in helping to improve their overall understanding of the intersect design process and its advantages.

In-situ Conditions

Waterways: Long distance drilling in waterways presents its set of unique challenges such as length of drills, protected marine habitats, etc. In such cases, using the intersect method versus sequential drills will reduce the numbers of drills, disturbance to the natural topography, permitting requirements and associated costs.

Urbanized areas: Highly urbanized areas have their share of challenges such as congested streets, space constraints to set up equipment, topography, high traffic density, pedestrian traffic, and presence of emergency services. Associated challenges include high social costs, opposition from the public, permit challenges, time constraints. In such cases, intersect method can help reduce the social impact to the public and in turn, the economic impact to the businesses in the vicinity of the project by reducing the equipment setup areas and increasing the length of HDD. This is substantiated by the graphical HDD pressure analyzer used for a HDD project in a highly urbanized area in a city in the southeast as described below.

HDD alignment design and drill pressure analysis

Figure 1. HDD alignment and surface profile indicating the difference in elevation

The change in elevation between the entry and exit locations and the type of geology dictate the alignment design. Figure 1 shows the vertical HDD align-
ment for the project with the difference in elevations of approximately 70 ft. The alignment has three vertical curves. The top of rock runs parallel to the surface at a depth of approximately 50 ft. However, rock is much closer to the surface for the last third of the alignment on the uphill side necessitating introduction of a vertical curve in the middle of the alignment to avoid the rock.

Figure 2 indicates the anticipated maximum allowable pressure for this alignment. The variation in the maximum allowable pressure is based on the soil conditions and the overall depth of the alignment. Further, changes can be made to the geometry of the alignment and the soil properties at the design stage in order to understand the influence of each soil parameter (in this case friction angle, cohesion and shear modulus since cavity expansion theory is used to model the pressures). Upon completion of this process, the values of the anticipated maximum allowable pressures remain unchanged throughout the design.

The next step of the design involves calculation of the anticipated minimum drill fluid pressures (Pmin) required to successfully execute the drill. One of the unique aspects of the design of Pmin is that some of the drill fluid parameters can only be known during the actual drilling since they are adjusted in the field based on the drill pressures experienced for the given soil condition. The calculation of Pmin is in essence only an approximation of what the actual drill pressures would be based on the engineer’s experience.

The anticipated minimum drill fluid pressures decrease when drilling from a point of lower elevation to a point of higher elevation. This occurs when the drill mud is assisted by gravity during its return to the entry pit. In Figure 3, Pmin increases gradually to a value of approximately 45 psi. However, it then drops due to a combination of ascending alignment geometry, decreased overburden and the head on the higher side of the alignment, which aids in the return of the drill mud. This could result in

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**Figure 2.** Graphical representation of the anticipated maximum allowable pressure for the HDD alignment

**Figure 3.** The anticipated minimum drill fluid pressure drilling from lower side to the higher side as shown in blue

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inadvertent returns of drill fluids as indicated in Figure 3 by the blue line when it crosses the red line. This occurs prior to the final vertical curve and therefore cannot be contained by a conductor sleeve.

It is suggested that the engineer calculate P_{min} when drilled from both directions in order assess the most conservative design. Drilling from a point of higher elevation to a point of lower elevation results in an increase in P_{min}. This occurs due to the increased pressure required for the returning drill mud to overcome the head on its way toward the entry location which often leads to frac-out as shown in Figure 4. Drilling from higher side to the lower side, the value of P_{min} increases to a value of approximately 110 psi before it reduces gradually as the alignment flattens toward the lower side. As shown in Figures 3 and 4, frac-out occurs on the exit side of each drill. Again, this occurs prior to the vertical curve. Although conductor sleeves (casing pipes) are used to mitigate the risk of frac-outs, it may not be possible to employ conduct sleeves on the exit side as easily as on the entry side in the case of conventional HDD.

In such cases, both the values of P_{min} are overlapped on each other in order to obtain an optimum point of intersection for a given set of drill fluid parameters. The location of the intersecting point should be along straight segments in order to reduce the chances of misalignment. Graphical representation of the point of intersection enables a better understanding of the appropriate location of intersection and various factors affecting the design.

Another unique aspect of HDD design is that certain drill fluid properties are assumed as a part of the design process to predict the drill fluid pressures. In reality, these drill pressures depend on the type of drill mud used by the contractor and their in-situ properties. Since these properties cannot be accurately known ahead of time, the engineer must assume certain drill fluid properties during the
Horizontal Directional Drilling Guide

Figure 6. Location of intersection can be optimized based on the availability of equipment, geometry of drill and the drill fluid parameters

Technology has come a long way in recent years to make the underground intersect a reality. However, despite having all the technologies that assist in execution of HDD by the intersect method, the aim of this paper is to emphasize the importance of having a thorough understanding of down hole mud pressures which is crucial for the intersect design of HDD. The proposed graphical HDD pressure analyzer provides a visual platform which helps to produce technically sound designs and thus mitigate risks involved in this method of HDD.

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design stage. The graphical HDD pressure analyzer assists the engineer to make changes to the drill fluid properties such as yield point, density and plastic viscosity in order to track the change in the point of intersection and thus obtain a general idea of a safe point of intersection. Figure 5 indicates the point of intersection to be at approximate STA 15+30. Figure 5 and 6 indicate the change in the location of intersection due to the change in the assumed mud density from 10 to 11 ppg, yield point from 20 to 35 lb/ft2 and plastic viscosity from 30 to 24 cp.

Upon setting the baseline design parameters, the software can be used in the field to monitor drill mud operations. In situ samples of drill fluids can be used to conduct sensitivity analysis to understand the effect each parameter has on the overall design and customize a combination that would make the HDD successful. A combination of changes in drill rate, pump rate and real-time analysis of drill fluid parameters can assist an experienced HDD or drill fluid engineer to effectively extrapolate the drill pressures based on the samples examined and thus mitigate the risk of hydrofracture to the extent possible.

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