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Lecture

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LONG-EXTENSION SHORE APPROACH – A SUCCESSFUL CASE OF A 3,010.39m HDD FOR LNG PIPELINE INSTALLATION IN SANTOS, BRAZIL

Abstract

In the past two decades, countries have sought to implement actions to promote the use of less polluting fuels, with natural gas playing a significant role in this energy transition. However, although Brazil has considerable natural gas reserves, a significant portion is associated with oil reserves, especially in the pre-salt layer. This association, coupled with growing demand, has driven the expansion of liquefied natural gas (LNG) imports and the proliferation of regasification terminals, such as Floating Storage Regasification Units (FRSU). The location of these terminals is influenced by environmental, operational, safety, and logistical criteria, resulting in their installation at some distance from the coast. This configuration requires the execution of shore approach directional drilling to connect offshore units to coastal infrastructure. This is the case with the Santos LNG pipeline, a crucial part of the Baixada Santista Gas Supply Structural Reinforcement project, a strategic initiative aimed at enabling the flow of gas processed from the offshore terminal to be installed in the Santos Channel to the mainland. The pipeline was designed to transport a maximum capacity of 14 million cubic meters of natural gas per day and has a total length of 8.5 kilometers, including the 3,010.39-meter-long shore approach developed and executed by DrillTec Serviços de Perfuração Ltda. The project was completed on 19/02/2024, with the installation of 313 API 5L X-52 Ø16“ with 0.886“ wall thickness steel conduits in a directional borehole constructed along a trajectory composed of 81.09% rock (approximately 2,441 meters) with initial and final sections in incompetent soil, utilizing interception technique and reamed to a Ø26“ diameter.

Key Words - HDD; Shore Approach; Furo de Interceptação; Transição Energética; GNL; Gás Natural

1. PROJECT DESCRIPTION

The Santos LNG pipeline has a total length of 8.5 km and is an important part of the Baixada Santista Gas Supply Structural Reinforcement project, owned by TRSP/COMGAS, a strategic initiative aimed at facilitating the flow of processed gas from the offshore terminal to be installed in the Santos Channel to the mainland. The pipeline is intended to connect the offshore LNG Terminal, designed to receive, store, and vaporize liquefied natural gas from FRSU (Floating Storage Regasification Unit) ships to the new City Gate located in Cubatão, state of São Paulo, Brazil.
The company selected for the construction of the shore approach for this project was DrillTec Serviços de Perfuração Ltda, a leading South American company in horizontal directional drilling (HDD), both onshore and offshore, and specialized in a wide range of crossings, including pipeline connections for transportation of oil, natural gas, water, effluents, ore, as well as fiber optic installation, among others. The shore approach in question aimed to connect the LNG Terminal to the coast, with a planned extension of approximately 3,000 meters.

1.1. Location

The LNG Terminal, designed to accommodate FRSU-type ships, is located in the navigational channel of the Port of Santos, near the area known as Largo do Canéu, between Bagres Island and the Piaçaguera Channel, approximately 700 meters from the nearest coastline.

The Cubatão City Gate is situated at kilometer 267 of the Cônego Domenico Rangoni Highway (SP 055), in the municipality of Cubatão, in the state of São Paulo, Brazil.

As illustrated in Figure 1, the onshore entry point of this shore approach is located within the area currently occupied by Usiminas company, near the area known as Dique do Furadinho, while its exit point is adjacent to the maritime terminal.

Figure 1: Shore Approach Location

It‘s worth noting that the project is located in a region characterized by the presence of significant remnants of the Atlantic Forest, which is protected by various environmental conservation units. The project‘s surroundings encompass a total of eleven of these units, with four of them within a three-kilometer radius of the maritime terminal.

1.2. Restrictions

Given its magnitude and location, numerous restrictions were imposed by various disciplines for the completion of the project, notably including project technical specifications, local geological conditions, and the environmental vulnerability of the area. The combination of these factors, coupled with the inherent characteristics of HDD methodology, set a high technical and operational threshold for the realization of the directional borehole.

From a technical standpoint, the main requirements for executing this shore approach included a length of approximately 3,000m to be traversed in a single span and a trajectory containing two horizontal curves of approximately 7 degrees to maintain alignment within the right-of-way.

Regarding geological characteristics, the Baixada Santista region presents high complexity, making it difficult to anticipate the geotechnical characteristics of the lithologies present and their stratigraphic position. According to some authors, the area would feature a layer of soft organic clay deposited over a layer of gravel resting on decomposed gneiss bedrock. However, other authors claim that the subsurface consists of layers of sand, occasionally interlayered with very soft to soft clay layers, overlain by layers of clay with medium to stiff consistency.

Using data from the first hypothesis, the project would be constructed in a layer of organic clay, approximately 40 meters thick, with very soft to soft consistency (SPT of 0 to 2), interspersed with sand layers and lenses, deposited over a layer of gravel covering the crystalline basement.

Regarding the environment, it is important to note that the services were carried out within a sensitive and vulnerable ecosystem, conditioned by its own geographic and geological characteristics and subject to high protection and regulation.

As a result, to carry out HDD activities, it was necessary to respect and comply with various environmental restrictions, imposed directly or indirectly, including:

- Dimensions of the area for Rig Side jobsite installation.
- Offshore location of the Pipe Side in estuarine river zones.
- Incompetent geological formation at entry and exit points, extremely vulnerable to frac-out occurrences.
- Impossibility of installing a magnetic field for steering systems.

2. PROJECT DESIGN

For the realization of this project, given the quantity, specificity, and complexity of the factors that could influence the construction process, a preliminary analysis of each element with potential impact on the execution of the shore approach was conducted.

In this case, when associating the inherent characteristics of HDD methodology with the geological conditions and environmental vulnerability of the area, two requirements consistently stood out: the length of the borehole and the location of its exit point, which needed to be overcome for the success of the project.

Within this perspective, as outlined in the following sections, in the development of the executive design and in the construction of the project, DrillTec endeavored to apply the best techniques of planning, logistics, and drilling engineering in accordance with the standards established in applicable international norms for HDD.

2.1. Engineering Solution Considering the Extension

The extension of a directional borehole is limited by technical and operational factors that are interrelated, such as drilling and pumping equipment capacity, hydraulic pressure, drilling fluid volume, available area for jobsites, and pipeline assembly, among others.

For instance, as drilling progresses and the borehole length increases, system pressure losses also rise, demanding higher hydraulic pressure to overcome them. However, even if the pumping equipment can provide the required pressure, it needs to be limited to the formation fracturing pressure, which is typically low due to the relative shallow depth of HDDs.

Therefore, the extension-pressure relationship is a crucial determinant, both for drilling and for the environment, as formation fracturing could compromise the borehole walls, leading to complex operational issues.

To mitigate the inherent risks of large extensions, attempts were made to plan the construction of this directional borehole in two sections, with an intermediate operational jobsite, an alternative discarded due to the contractor‘s requirement to build a single span. Subsequently, a study was conducted to evaluate the possibility of executing a conventional HDD crossing, drilling from an entry point to an exit point, with an approximate length of 3,000 meters. This alternative was also discarded due to several risks.

One of the risks would be the need to impose hydraulic pressure on the bentonite fluid jets to enable drilling and reaming activities to proceed. Additionally, for an extension of 3,000 meters, the force required on the drill bit, exerted through the drill pipes, would pose a substantial risk of pipe torsion or column jamming.

Assessing these and other operational risks, such as buckling and the torque required to meet the planned extension, as well as the difficulty of tool orientation, it was decided to perform the shore approach using the technique known as Well Interception, in which 2 (two) pilot holes are drilled simultaneously, from each end, and guiding the fusion of the two at a predetermined point underground.

The definition of the extension of each pilot hole, establishing the section for interception operations, was based on the operational capacity of the drilling rigs, respecting the requirement that drilling be carried out in straight sections of the borehole, both in plan, azimuth 133.02°, and in profile, inclination of 90°.

In the end, considering factors such as SPT of the layers, minimum cover, hydraulic pressures, it was defined that the interception section, with a length of about 50m, would begin approximately 1,000m from the shore approach exit point. Therefore, with a total projected extension initially of 2,950.96 meters, the pilot holes had the configurations presented in Table 1.

Construction Site	Location	Drilling Rig	Planned Extension (m)
AA1	Offshore	PD 100	1.055,11
AA2	Offshore	HK 300T	1.955,28

2.2. Drilling Rig and Construction Sites

For the application of the pilot hole interception methodology, it is logically necessary to use two drilling rigs, each installed at one end of the directional bore.

The use of this configuration with two pieces of equipment allows for a combination of force and torque between the rigs to enable operations in both directions, minimizing the risk of drill pipe buckling and conducting column maneuvers with greater safety.

Thus, at the onshore jobsite, designated as AA2, located near the Dique de Furadinho, the drilling rig, a Herrenknecht model H275 HK 300T, was installed. It has a Max. Push Force of 1000kN and Max. Pull Force of 3000kN, with a Max. Torque of 120 kN.m. This rig completed the pilot hole over its entire length (about 2,000m) and performed the reaming to the final diameter of 26“ up to approximately 2,500m in length.

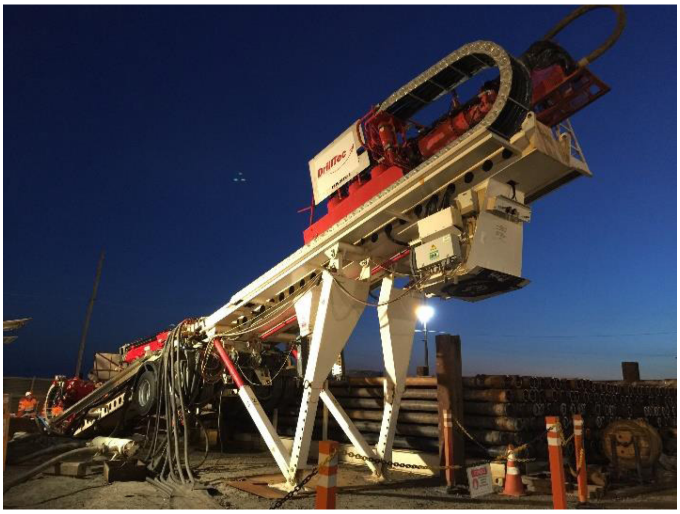


Figure 2: Drilling Rig - Herrenknecht H275 HK 300T

In the final phase of the project, specifically during the last reaming stage, DrillTec acquired the HK500 rig and decided to use it for the assisted start-up of the equipment on this project. Therefore, the HK300 was replaced by the Herrenknecht H200-HK 500T rig, with Max. Push Force: 5000Kn and Max. torque: 140 kN.m, which completed the remaining reaming to a diameter of 26” and pulled the 16” conduit pipe column.

Figure 3: Drilling Rig - Herrenknecht H200-HK 500T

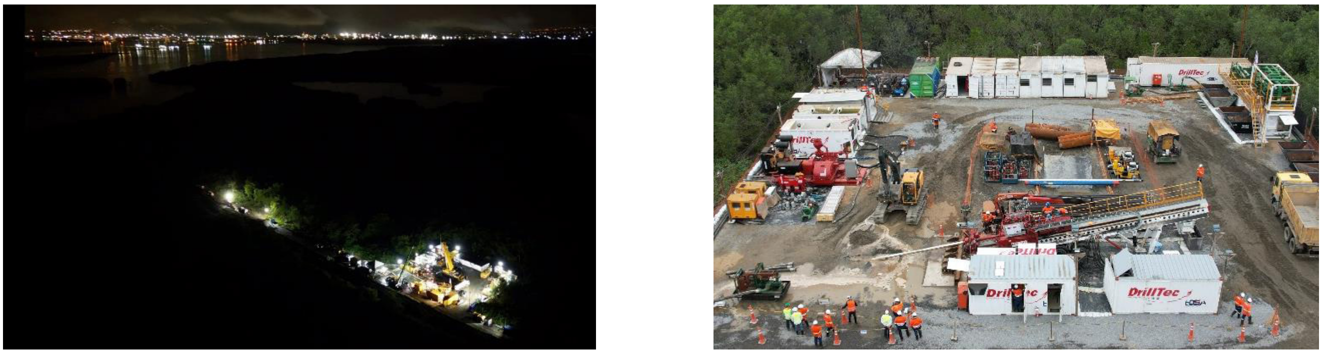


Figure 4: Operations Conducted 24 hours a day.

The second drilling rig, manufactured by Prime Drilling, model PD100-50RP-L, with a Max. Push Force of 1,100kN and Max. Pull Force of 1,100kN, and Max. torque of 50 kN.m, was installed on a barge specially designed to accommodate all HDD equipment and necessary facilities. Positioned near the future maritime terminal, this rig conducted a pilot hole of approximately 1,000m in length and assisted with column torque during the 26“ reaming phase, rotating to the right to reduce torsion on both the drilling column and the Herrenknecht drilling rig.

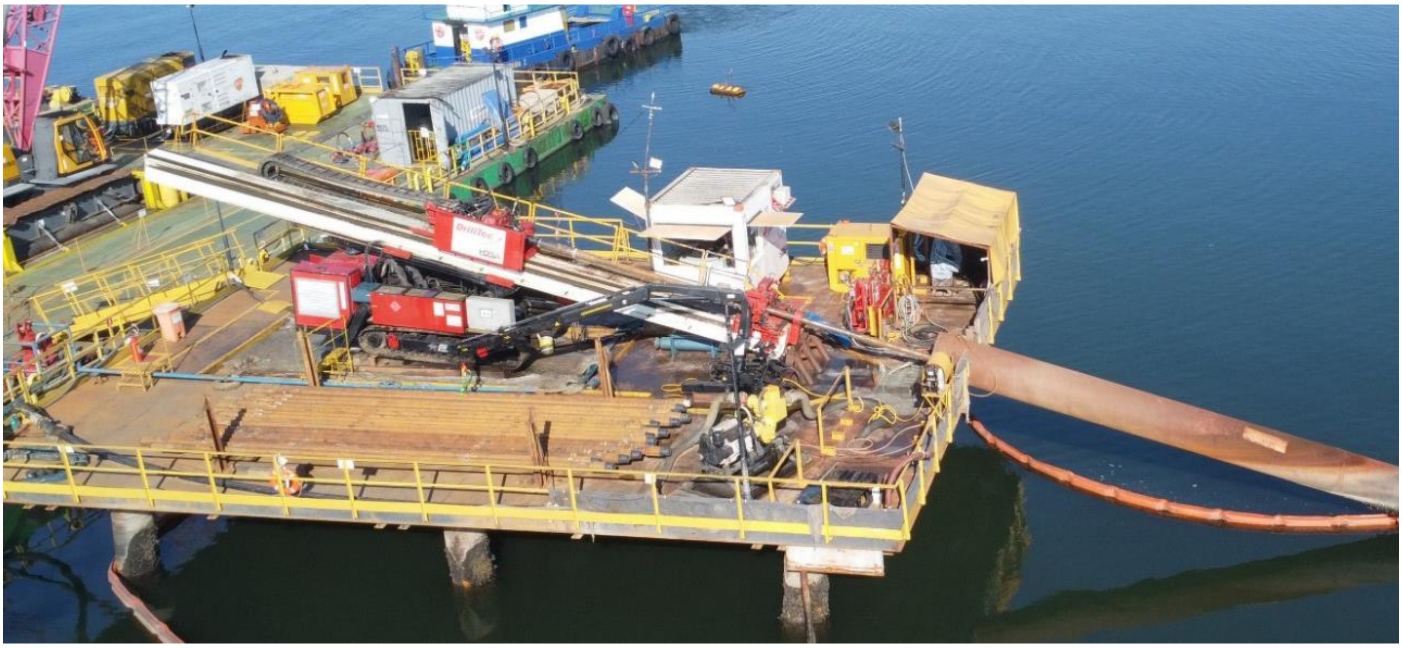
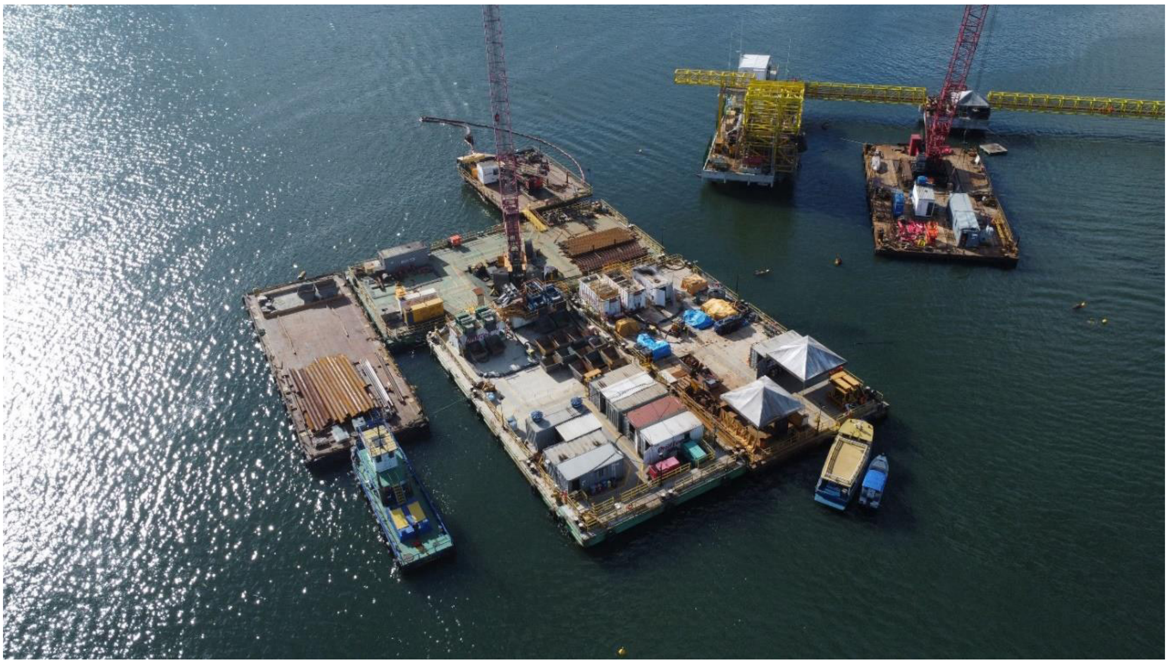


Figure 5: Drilling Rig – Prime Drilling PD100/50RL

In addition to the fully adapted barge, to enable the safe execution of operations and provide adequate space for activities from this jobsite, the project included a second barge equipped with a crane with a lifting capacity of approximately 250 tons, as illustrated in the photographic records presented below.



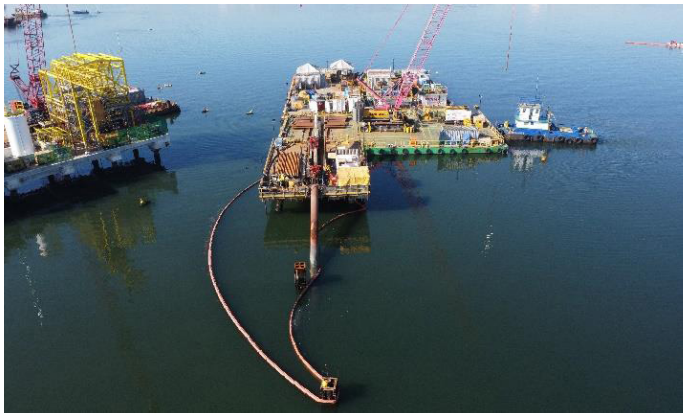


Figure 6: Offshore Infrastructure

It is worth noting that a rigorous overall maintenance plan for machines, equipment, and tools was implemented to ensure the performance of these components and reduce downtime. This plan also included specific procedures for critical equipment, such as drilling rigs, triplex pumps, centrifugal pumps, drainage pumps, mixers, recyclers, storage tanks, breakout units, generators, among others.

2.3. Planning

In this project, as well as in all projects carried out by DrillTec, when developing the executive design, efforts were made to identify all constraints and assess them individually and collectively. This allowed for the construction planning to be carried out, establishing the best methodology for operation execution and preventive and mitigating measures for each of the expected impacts. The main activities carried out in the planning and execution of this project are listed below, along with a summary of each.

- Definition of the Pilot Hole Trajectory

The definition of the directional borehole geometry was based on the results of geotechnical surveys and technical requirements of the project.

Initially, based on the results obtained in the basic project, the trajectory was defined at elevation -40m, as this would be the best geological condition to be traversed, with almost the entire drilling occurring in a layer consisting of fine sand, fine gravel, and organic matter, moderately compact.

However, after conducting additional investigations, with the surveys advancing to a depth of 50m or to the rocky top, the new results indicated that the best technical alternative would be at elevation -80m, as nearly 2,500m would be drilled within a horizon composed of gneissic rock, with a compression strength of approximately 90 MPa.

The decision to drill at a deeper elevation, in a much more consolidated formation, aimed to improve the mechanical conditions of the borehole to prevent collapse, given that it was a directional borehole with over 3000m in length. Nevertheless, the project schedule was drastically impacted due to encountering conditions different from those expected, where rocks with compressive strength of around 250 MPa were found, compared to the initially planned 90 MPa.

Additionally, due to the need to meet the client's requirements, combined horizontal and vertical curves had to be executed on both sides of the drilling, which increased the level of difficulty of the project, mainly due to the complexity of the geological formation encountered during drilling.

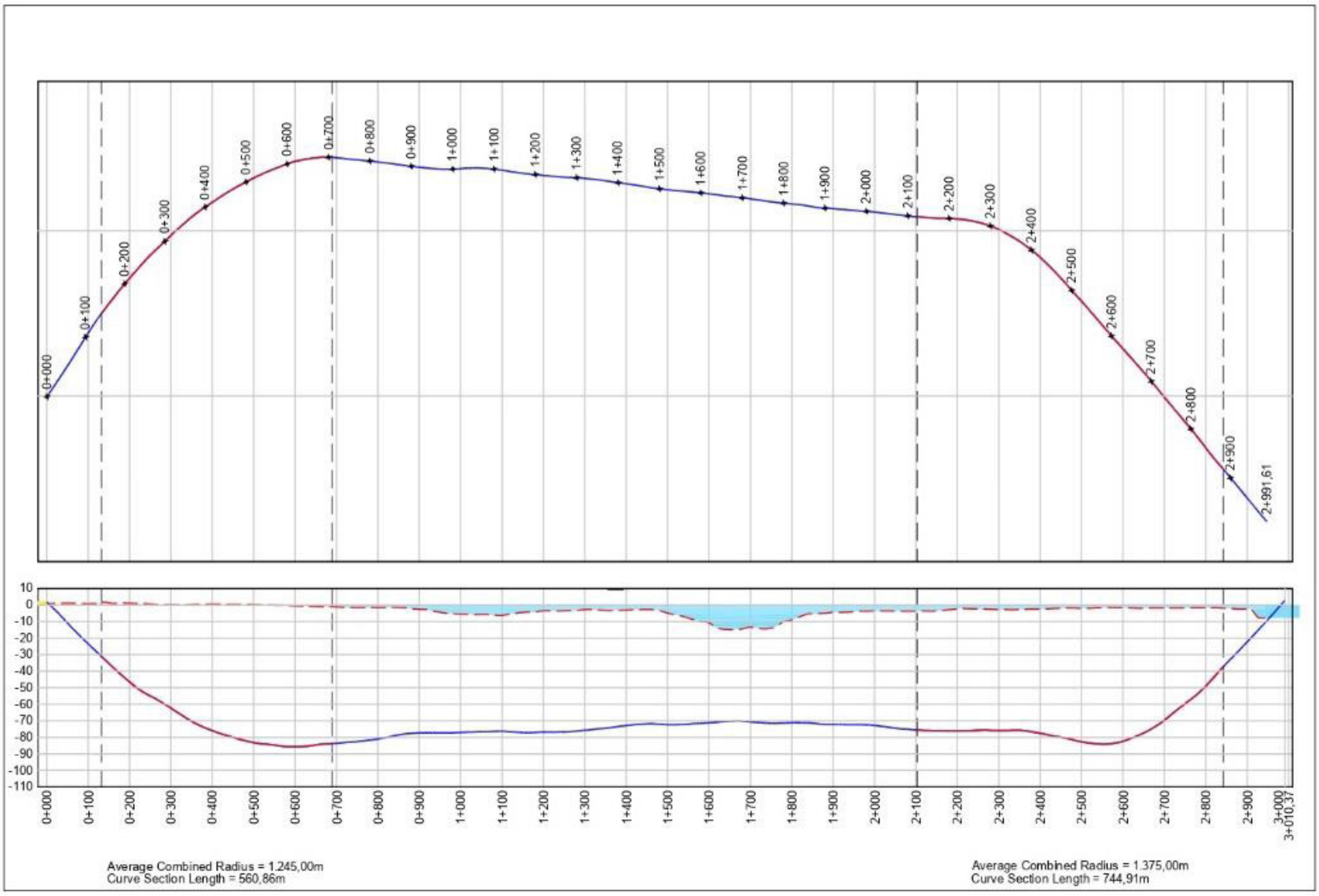


Figure 7: As Drilled in Plan and Profile View

- Definition of the Minimum Radius of Curvature

The definition of the curvature radii was based on the characteristics of the conduit pipe and the drill pipes. Additionally, the trajectory specifications provided by the client were taken into consideration.
Based on the configuration defined in the executive design for its trajectory, the minimum curvature radius of this directional borehole was established at 700m. This was the value sought during its execution.
However, following the calculations of the minimum curvature radius method outlined in API Bulletin D20, it was agreed that radii of 610m, measured in both horizontal and vertical planes, for every segment of 3 (three) joints (30 meters), would be considered acceptable.
On the other hand, to avoid doglegs and tortuosity that could generate more friction, stress, and hydraulic deficiency in the well, it was defined that the curvature radius at the point of interception of the pilot holes should be 5,000m and, at a minimum, 2,000m during the execution phase.

- Selection of Cutting Tools and BHA

The tool specification was developed based on the geological-geotechnical information of the area.

Figure 8: Drill Bit Used for Rock Drilling (TCI, code IADC 627, HDX 40).

The drill bit program was elaborated following the guidelines of the IADC code, with an HDX 12.1/4'' HDS-TCI ULTRA-PREMIUM, IADC 627 (HDX 40) selected for rock drilling and an MT IADC 135 type bit for soil.

The reamer selected for rock sections was an INROCK HDX 37– TCI ROCK REAMER with a 26'' OD, equipped with a Blade Centralizer 12.1/4'' and 5 sealed bearing cutters, while for soil sections, a Fly Cutter and HYBRID reamer were chosen.

Within this activity, other components of the Bottom Hole Assembly (BHA) were also defined, such as drill pipes, a bent sub for soil excavation, a bottom hole motor for rock drilling, non-magnetic drill collars (NMDC), the type of Pressure While Drilling (PWD) system, among others. It's worth mentioning that, to assist in preventing formation damage, BHAs generating low annular pressure were selected.

- Definition of the Drilling Fluid and Hydraulic Program

The fluid and hydraulic program was developed to determine the pumping pressure and flow rate for the combination of jets to drill each section of the borehole or perform specific operations. The pressure and flow rate values used in each construction stage are presented in Table 3.

- Calculation of the Expected Forces, Efforts, and Pressures

The maximum forces that could be applied to the drilling string were calculated to prevent buckling or breakage of the drill pipe at the bottom of the well, also considering the analysis of BHA buckling. To minimize risks, 16" diameter casing pipes were installed at both ends of the pilot hole.
Additionally, the loads and stresses imposed on the drill string during pulling and the force required for its movement and drag were determined, with the results being analyzed against mechanical limits specified in technical standards.
To control and prevent hydraulic fracturing in environmentally sensitive areas, while also avoiding borehole collapse, a profile of estimated mud pressures at the bottom of the well was developed based on depth and annular dimensions.
The set of measures implemented to reduce operational risks enabled the establishment of a range of values for each drilling parameter aimed at preventing occurrences of fractures, collapses, and formation damage during the operations.

- Definition of the Steering System

For guidance, control, and correction of the pilot holes' direction according to the projected trajectory and profile, it was necessary to use a steering system that ensured the highest possible precision for their intersection. There was also a restriction on installing a surface cable grid for generating a magnetic field.
Therefore, considering these constraints, the ParaTrack Gyro Module (PGM) steering system was chosen, a tool that combines the ParaTrack Steering Tool (PST) magnetic system and gyroscope compass technology.
Since the PGM inertial system does not require the generation of an artificial magnetic field, its use would eliminate magnetic disturbance in measurements, allowing for greater precision in the PST system readings and faster drilling progress, as indeed occurred during the execution of the holes.
Additionally, the system could be used to monitor annular fluid pressure during drilling, which also contributed to preventing formation fracturing.

3. PROJECT EXECUTION

The executive process for the construction of the shore approach of the Santos LNG pipeline consisted of five stages, as detailed in Table 2.

Stage	Diameter
Pilot Hole	12 ¼"
Soil Reaming	24"
Rock Reaming	26"
Cleaning	26"
Pull Back	22"

As planned, the construction of the pilots began with the execution of the hole named AA2, from the onshore jobsite, on July 1, 2022, reaching the projected intersection area of the holes on October 17, 2022, after drilling an accumulated extension of 1,925.79m.

The main operational issue in this hole was the change in geological conditions detected from 150m, where an alteration was observed compared to those indicated in the investigative studies, reducing the predicted extension of residual soil, which led to an excavation in rock about 145m greater than that projected in the design.
On the other hand, the pilot hole AA1, starting from the offshore jobsite, began on August 18, 2022, with its interception position reached on February 28, 2023, at extension 1,025.41m.

It is worth noting that, for the execution of the trajectory of this shore approach, with a combined curve in each of the pilot holes, DrillTec maintained strict control of the steering parameters, raising and analyzing the radii of curvature at each segment of 3 joints.

In the end, the smallest radius of curvature measured in the pilot hole was 507m, highlighting that the minimum calculated radius according to the specifications in item 4.1.2 of the 4th Edition of the DCA Technical Guidelines could be 374m, for tubes with a diameter of 16”, as in this case.

With the pilot holes in their respective projected positions, the procedures for interception began, consisting of approaching the drilling columns of each of them within the defined area, with hole AA2 located slightly above hole AA1, so that the latter was inserted underneath the former.

With the help of field measurements of magnetic field by the PMR (Passive Magnetic Ranging) method, the interception of the pilots occurred on April 24, 2023, after hole AA1 advanced to its extension of 1,099.82m, corresponding to an extension of 1,910.57m on the AA2 side, meaning the first one entered about 15m into the second one.

Then, the drilling of hole AA2 continued until its drilling column met the column from hole AA1, which occurred within the predicted intersection zone. With the successful execution of the interception operation, the date of April 24, 2023 is considered as the completion date of the pilot hole construction activities of the T1 section of the pipeline.

Subsequently, only after the completion of all the work of the hole interception operation, on June 2, 2023, the two reaming stages of the pilot hole from 12 ¼” to a diameter of 26” began, which was completed on January 25, 2024.
The main highlight of this phase was the replacement of the main drilling rig by another one with higher operational capacity, with the HK 300T drilling rig being replaced by the HK 500T drilling rig.

During and after the completion of the reaming, the hole underwent cleaning and conditioning processes, aiming to reduce the amount of gravel inside the directional.

This highlight is made because, as a good practice, to constantly improve hole stability and decrease the presence of cut material inside it, DrillTec‘s process is to clean and condition the hole during the reaming execution, at each maneuver for cutting tool replacement.

The hole cleaning and conditioning operations, along with the preparatory activities for the pulling of the conduit column, were carried out between January 26, 2024, and February 15, 2024.

After all preparations, on February 16, 2024, the pulling of the 16” conduit pipe column into the directional hole began, with the pulling being carried out from offshore to onshore, by the HK 500T drilling rig installed at jobsite AA2.

After about 60 uninterrupted hours of operation and without any relevant occurrence registered, the installation of the column composed of 313 (three hundred and thirteen) conduit pipes in this shore approach was completed, with full success, on February 19, 2024.

During the pulling, in accordance with the previously calculated values, the highest torque recorded was 83 kN.m, occurring in the first joint, a value that decreased throughout the operation. On the other hand, the maximum pulling force recorded was 59 tf, with the values mostly varying between 55 tf and 45 tf up to about 700m of column extension and thereafter registering values below 40 tf.

Finally, Table 3 presents a summary of the operational parameters used in each of the stages carried out for the construction of this shore approach, always observing the range of values defined in the design for each of them.

Stage	Operation phase	OD	WOB (tf)	RPM	Torque (kN.m)	Flow rate (GPM)	Pressure (bar)	ROP (m/h)
1ª	Pilot Hole	12 ¼”	10/25	40	40	250/300	25 a 35	14/4
2ª	Soil Reaming	24”	30	35	30	350	30	19
3ª	Rock Reaming	26”	55	25/30	70/80	400/500	40	6
4ª	Cleaning	26”	10	25/35	80	500	20	30
5ª	Pull Back	22”	-	30	70/80	400	20	60

3. CONCLUSION

As with any other construction method, the methodology applied in HDD drilling consists of a set of activities, rules, and procedures that define the process and establish minimum requirements and best practices for its application, outlining its range of application.

In the case of this project, where numerous technical and natural variables were present, it must be concluded that the success achieved is related to a series of factors, ranging from the preliminary and ongoing assessment of conditions and technical options, the planning of the executive project and operations, logistics, personnel, and equipment used, to the adherence to engineering standards and concepts, and above all, engineering solutions developed specifically for this project.

4. ACKNOWLEDGMENTS

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