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World Record 56" Direct Pipe Landfall® Installation

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1.0 ABSTRACT

TC Energy partnered under a strategic alliance with Mexico's Federal Electricity Commission proposed to design and construct the Southeast Gateway Project which consists of approximately 720 kilometers of 36" marine and onshore pipeline which will transport natural gas, connecting the supply from Tuxpan, Veracruz, to delivery points in Veracruz and Tabasco. Within the project, the pipeline made landfall to connect with onshore piping and compressor stations at three locations. These landfalls were installed below the shoreline connecting onshore and offshore pipe utilizing trenchless construction methods. The landfalls consisted of a world-record 1,370-meter 56" Direct Pipe® (DPI), a 1,700-meter 118" microtunnel, and a 1,047-meter 56" DPI that the 36" gas pipelines were installed within.

This paper will discuss the world-record 56" DPI landfall. This is the first DPI of this size to ever be installed and was a milestone for trenchless construction industry. The complexity of this project required extensive front-end engineering and design to evaluate the feasibility of construction to overcome the site-specific constraints of the crossing. Many challenges were overcome during design and construction such as subsurface challenges resulting in the MTBM becoming stuck for 1 month, use of 2 thruster units, design of product pipe configuration to allow insertion through the casing without damaging cathodic protection system while allowing grouting of the casing-pipe annulus, marine support, and safe removal of the MTBM.

The Client, Engineering Team, and Contractor worked closely together through the design and construction phases to successfully complete the landfall and product pipe installation.

2.0 OVERVIEW

2.1 SGP PROJECT

The Southeast Gateway Project (SGP) consists of 720 kilometers of new 36-inch diameter high-pressure natural gas pipeline along the east coastline of Mexico, with the majority of the pipeline being installed offshore within the Gulf of Mexico. The SGP pipeline originated near Tuxpan, Veracruz and terminated near Paraiso, Tabasco and made landfall at three (3) locations at Tuxpan, Veracruz, Coatzacoalcos, Veracruz, and at Dos Bocas, Tabasco. The purpose of the pipeline is be to transport natural gas at a capacity of 1.3 billion cubic feet per day where it will supply other critical projects and provide a secure supply of natural gas to the Yucatan Peninsula for power generation.

At the landfalls, the 36-inch offshore pipeline will tie into onshore piping to supply gas to onshore facilities. Due to critical and protected wildlife habitat, environmental sensitivity, and complexities associated with the surf zone near the coastline, these pipeline landfalls must be constructed utilizing trenchless construction methodologies. TC Energy, with support from multiple engineering and construction specialists, determined that Direct Pipe® and microtunnel were the most feasible trenchless methods of construction for the installations. These landfalls are summarized below:

Table 1. Summary of SGP Landfalls

Landfall	Construction Methodology	Casing Pipe	Length	Product Pipe(s)
Veracruz Norte (Tuxpan)	Direct Pipe®	56-inch Steel Pipe	4,500 ft (1,370 m)	36-inch Steel Gas Pipeline
Coatzacoalcos	Microtunnel	118-inch Concrete Pipe	5,580 ft (1,700 m)	2x36-inch Steel Gas Pipeline, 1x24-inch Steel Water Supply line
Dos Bocas	Direct Pipe®	56-inch Steel Pipe	3,440 ft) (1,047 m)	36-inch Steel Gas Pipeline

The overall SGP project offshore pipeline route and landfall locations are shown below:

Figure 1. SGP Project Route & Landfalls Location

2.2 VERACRUZ NORTE LANDFALL DIRECT PIPE

The Veracruz Norte segment of the SGP Pipeline is the northernmost segment and consists of approximately 21 kilometers of NPS 36 gas pipeline which starts from the point of reception (POR) with the interconnect to the Tuxpan-Tula System at Montegrande Measurement Station continuing to the end of the segment at the landfall site after being compressed at the Veracruz Norte Compressor Station. The Veracruz Norte Landfall site is located approximately 10 miles (16 km) north of Tuxpan, Veracruz, Mexico. After the landfall, the pipeline continues offshore where it makes landfall again to be compressed in Coatzacoalcos and then continues back offshore where it terminates at the Point of Delivery (POD) within Dos Bocas.

Various trenchless construction methods were evaluated for the construction of the landfall including Horizontal Directional Drill (HDD) and Microtunnel. Upon completion of multiple detailed feasibility studies, DPI was ultimately selected as the most cost-effective means of installing the pipeline below the Gulf of Mexico while minimizing the environmental impact due to construction footprint and risk of hydraulic fracture. The Veracruz Norte DPI was successfully completed on March 26, 2024 and at the time of this publication, is considered the longest 56” (AVN1200) DPI in the world.

The Veracruz Norte Landfall installation consisted of a 56-inch diameter steel casing DPI measuring approximately 4,500 ft (1,370 m) in length which housed the 36-inch gas pipeline that was pulled through the casing and grouted in place. The DPI installation was launched from land roughly 1,825 ft (556 m) inland and crossed beneath the Oro Verde River, protected mangroves, a private beach, and exited within a dredged pit in the Gulf of Mexico roughly 2,675 ft (815 m) offshore. The location of the Veracruz Norte DPI alignment is shown below.

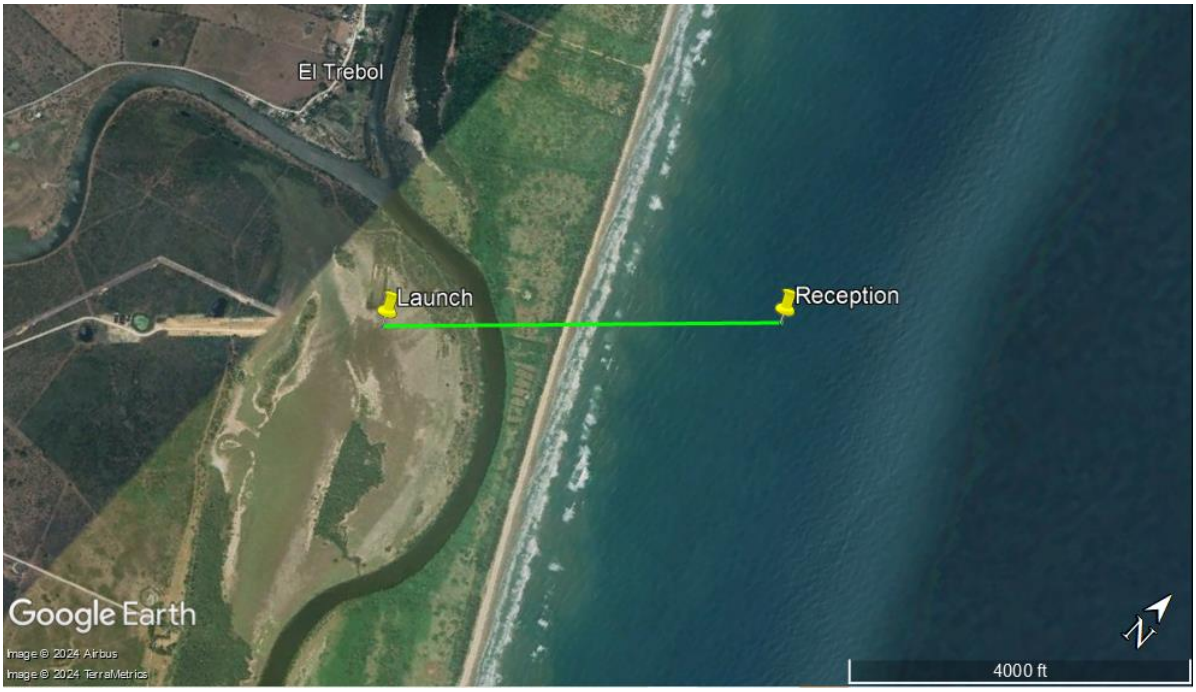


Figure 2. Veracruz Norte DPI Landfall Location

Details of the Veracruz Norte DPI installation are summarized within Table 2, below.

Table 2. Veracruz Norte DPI Design Parameters

Parameter	Casing Pipe	Product Pipe
Pipe Size	56.00" (1422mm)	36.00" (914.4 mm)
Material Specifications	API 5L X70 PSL2	API 5L X65 PSL2
Coating	Uncoated	3LPP
Wall Thickness (of landfall section)	0.75" (19.05 mm)	1.25" – 1.5" (31.75 mm - 38.1 mm)
Maximum Allowable Operating Pressure	14.7 psi (14.7 psi) (atmospheric pressure)	2,250 psi (15,514 kPa)
Max/Min Design Temperature	73°F (22.8° C) (temperature of seawater)	122° F (50° C) / -14° F (10° C)
Assumed Installation Temperature	73°F (22.8° C) (temperature of seawater)	55° F (12.8° C) (ground temperature)
Direct Pipe Length:	4,500 ft (1,370 m)	
DPI Entry Angle	5°	
DPI Exit Angle	2°	
Design Radius	9,843 ft (3,000 m)	
Launch Depth (top of pipe)	14.7 ft (4.5 m) below grade	
Exit Depth (top of pipe)	9.8 ft (3.0 m) below seafloor / 37.5 ft (11.4 m) below sea level	
Maximum Depth below Launch	46.3 ft (14.1 m)	
Maximum Depth below Exit	11.8 ft (3.6 m)	

Multiple companies and specialists from around the world coordinated and worked together in order to ensure a safe and successful installation of the landfall. Table 3 outlines the key parties involved with the design and construction of the Veracruz Norte DPI.

Table 3. Key Contributors and Roles

Role	Company	Office Location
Owner	TC Energy / TGNH	Canada / USA / Mexico
Mainline Design Engineer	Techint	Argentina / Mexico
Onshore Mainline Contractor	Techint	
Tunneling Contractor / Tunneling Engineer	GDI	Italy / Mexico
Offshore Engineering Contractor / Marine Support	Worley (formerly IntecSea)	USA
Owner Engineer Support	CCI & Associates, Inc	Canada / USA
DPI Equipment Manufacturer	Herrenknecht	Germany

3.0 DESIGN CHALLENGES

3.1 GEOTECHNICAL CONDITIONS

A combination of geotechnical and geophysical studies was carried out in order to determine the subsurface conditions and geotechnical feasibility of the DPI at the landfall site. The geotechnical study included seven (7) vertical bores drilled along the tunnel alignment and the geophysical investigation consisted of SRT, ERT, as well as downhole seismic studies completed along the alignment and transverse to the alignment. The site investigation revealed that the DPI would encounter three (3) predominant soil units along the tunnel length. Table 4 outlines the three soil layers as well as associated risks that they pose to tunneling operations.

Table 4. Geotechnical Conditions

Soil Unit	Depth	Description	Primary Concerns
1	From 0 to 15' – 25' (From 0 to 4.5 – 7.5 m)	Compact Poorly Graded Sand with Silt	Poorly graded sand is prone to borehole collapse and silt may be sensitive to

		(SP-SM)	moisture, posing a risk of over-excavation, heave, settlement, or formation of sinkholes. Contractor should practice care while tunneling to steadily advance through materials and not over-excavate or pump too much slurry.
2	From 15' – 25' to 46' (From 4.5 – 7.5m to 14m)	Stiff-to-V. Stiff Low-to-High Plastic Clay with Sand (CL-CH)	Clay may have a tendency to swell around or stick to the pipe or equipment as well as clog the cutter face and annulus. Rate of penetration and thrust force should be closely monitored during tunneling to prevent over-penetration and potential deformation of the in-situ soils.
3	From 46' (14m) to below the tunnel profile depth	V. Dense Silty Sand with Sandstone Inclusions (SM)	Sandstone fragments may potentially cause wear to cutter face or damage other components of MTBM

Groundwater was measured during geotechnical drilling and standpipes were also installed near the launch point where groundwater could be continually monitored throughout preparation for and execution of the tunnel. Groundwater was encountered at an average depth of approximately 3.3 ft below ground surface, however, this would be expected to rise during storm events. The entire tunnel length would be expected to be below the water table, and the launch pit elevation would be dug below groundwater level, requiring dewatering to allow for tunneling activities to take place.

3.2 CASING SIZE SELECTION

Due to the required length of the DPI landfall, installing the 36" product pipe directly would not be feasible, as the maximum recommended length for a 36" DPI would be roughly 2,620 ft (800m). In order to install the DPI along the 4,500 ft (1,370 m) length, either a 48" or 56" OD casing was required to be installed which housed the product pipe. The product pipe was supported on spacers within the casing and the annulus was grouted to fill the void and mitigate corrosion issues between the steel casing and steel product pipe. The casing was also be required to provide sufficient strength and stiffness to withstand the loads and stresses during installation, therefore, required a high grade and wall thickness.

Both 48-inch and 56-inch casings were evaluated for use in the DPI installation through a thorough assessment of cost and risk analysis. The casing size selection was dependent on several factors, including: the availability of a microtunnel boring machine (MTBM) of the required size that is capable of the installation, achievable drive lengths of the tunnel, grouting operational requirements, cathodic protection measures, and annular space requirements for the product pipe and pipe jewelry assembly. Additionally, the casing was be required to allow manned access into the tunnel and into the MTBM in order to allow for maintenance and replacement of parts which is especially important for an installation of such great length, which either size would provide. In total, the casing was required to house the following:

- 36" Carrier Pipe
- 5.2" Anode Link
- 6 x 3.5" HDPE Grout Pipes

A 48-inch and 56-inch casing and carrier pipe assembly option were proposed for the project which are illustrated in Figure 3:

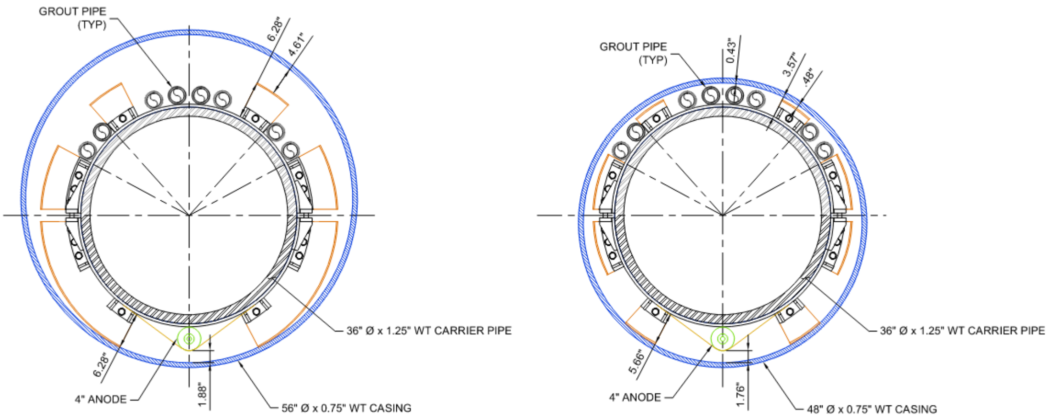


Figure 3. 48" and 56" Casing and Carrier Pipe Assembly Options

Ultimately, the 56-inch casing was selected over the 48-inch casing due to added flexibility provided by the lager casing during the installation of the product pipe assembly. The 56-inch casing pipe provided more clearance from the carrier pipe assembly which increased the likelihood of successful installation into the casing while being pushed from land. Additionally, the 56" casing allowed for adaptation of the grouting and cathodic protection plans by providing more annular space to add or modify the grout lines and anodes, as required. Although the material costs for the larger casing size were higher, the added flexibility and redundancy provided by the larger casing was considered to be more heavily weighted. The final 56" casing and spacer design is illustrated within Figure 4, below.

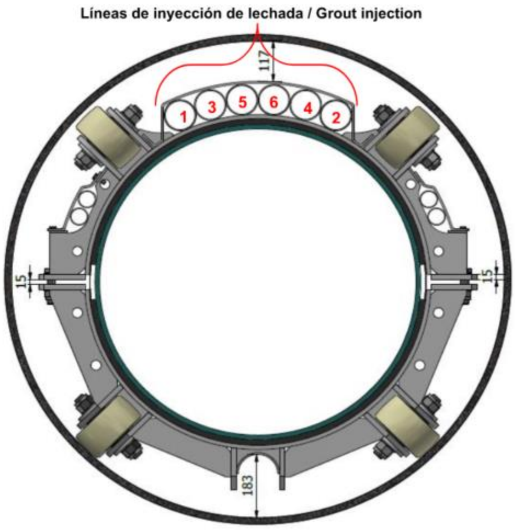


Figure 4. Final 56" Casing and Carrier Pipe Assembly

The casing and spacer setup installation during construction can be seen in Figure 5.

Figure 5. 56" Casing and Carrier Pipe Assembly During Construction

3.3 INSTALLATION FORCES

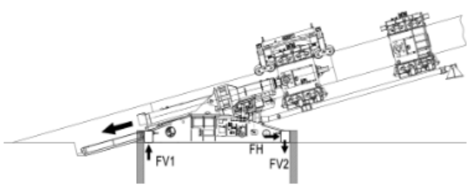
As the world-record length 56" DPI installation, the thrust force analysis and casing stress analysis were among the most important engineering responsibilities completed. Due to the required length and size of the installation, there were three (3) major concerns that were required to be overcome to successfully install the casing:

1. providing sufficient thrust capacity for successful completion,
2. ensuring a stable and secure launch pit and thruster foundation to prevent excessive movement during tunneling operations, and
3. ensuring that the casing pipe would not fail due to excessive thrust forces during installation.

Ensuring these conditions could be met was one of the most critical and complicated engineering tasks on the project.

3.3.1 Thrust Force & Anchoring Calculations

The thrust force calculations and casing pipe stress analysis for the DPI design geometry were completed by GDI and reviewed by CCI on behalf of TC Energy. The thrust force calculations completed by GDI yielded a maximum estimated static thrust force of roughly 2-million pounds (force). In order to supply sufficient thrust force for the installation, Techint proposed utilizing two (2) HK 750 PT Pipe thruster units installed in-line within the launch pit, each with an available thrust capacity of 1,686 kips (7,500 kN), providing a total thrust capacity of 3,372 kips (15,000 kN).



Launch angle	HK 750 PT		
	FV1	FV2	FH
0°	2998	2298	7500
1°	2366	2235	7499
5°	2627	1973	7471
7°	2753	1839	7444
10°	2935	1633	7386
12°	3053	1493	7336
15°	3222	1280	7244

Figure 6. Reaction Forces (in kN) of HK750 Thruster Unit

The launch shaft that housed the two thruster units needed to be designed to withstand the maximum expected thrust force with an added factor of safety. The launch shaft was constructed utilizing a combination of sheet piling, rigid reinforced concrete base slab, and pipe piling which were tied together and secured to the thruster frames. The launch pit was designed to withstand a maximum service load greater than the calculated maximum thrust force for the installation, and a maximum design load of the dual thruster capacity limits. Details of the launch shaft and thruster layout are shown below for reference.

Figure 7. Dual Thruster Launch Shaft Setup

3.3.2 Casing Pipe Stress Analysis

A stress analysis was required to be completed for the casing pipe to verify that the proposed material specifications would be sufficient to ensure that the pipe could withstand the expected installation forces. Techint completed a stress analysis for the casing pipe during installation which were reviewed by CCI on behalf of TC Energy. Two maximum loading conditions needed to be met by the casing pipe in order to exceed the minimum project requirements:

(1) Maximum Estimated Thrust Load

(2) Maximum Capacity of 2 thrusters operating at full capacity

The results of the analysis revealed that the casing pipe would theoretically remain within allowable limits based on the design radius of 9,843 ft, (3,000 m). Steering tolerances were needed to be developed for the tunnel to be able to correct or adjust the tunnel path while still ensuring the casing would remain within allowable stress limitations and preventing excessive thrust loading. Any reduction in bending radius of the tunnel would increase the stresses experienced by the casing while simultaneously increasing the thrust demand of the DPI. The bending radius that would produce nearly 100% of maximum allowable stress on the casing pipe, or ultimate radius, was calculated to be 6,200 ft (1,890 m), therefore the minimum allowable 1-joint radius for the pipe was selected to be 6,560 ft (2,000 m) to provide some additional buffer from the ultimate radius.

GDI calculated the ultimate allowable thrust load for the NPS 56, X70, 0.75” WT casing pipe based on the minimum allowable 1-joint radius which exceeded the maximum expected static thrust force. This ultimate allowable thrust load also exceeded the maximum capacity of both thrusters acting at full power.

3.4 Depth of Cover

The landfall alignment crossed beneath sensitive environmental features, including a river, protected mangroves, the beach, and the Gulf of Mexico which required careful planning and coordination to limit potential environmental impacts during construction. The key component to limiting potential impact to these features was ensuring sufficient depth of cover could be maintained beneath them to minimize risk of disturbances such as settlement or heave, sinkholes, and inadvertent surface release of slurry during installation. Multiple installation methods were evaluated, including trenching, HDD, and DPI, and it was determined that DPI would provide the highest assurance of environmental protection to the surrounding area. In general, DPI can be installed at much lesser depths of cover than HDD due to the lower slurry pressures during tunneling (as compared to HDD fluid pressures during pilot hole installation) and because the borehole is supported by the casing pipe during advancement, preventing borehole collapse and creating subsidence or sinkholes at surface behind the MTBM.

A DPI depth of cover must be chosen that provides sufficient overburden confining pressure to prevent fluid migrating to surface during execution. The risk of hydraulic fracture to surface is typically greatest near the launch pit where the MTBM enters undisturbed ground due to low depth of cover. For this crossing the contractor targeted a minimum depth of cover of 3 x MTBM outer diameter which is the general industry rule of thumb. To achieve this a berm was placed ahead of the launch point to provide this minimum depth requirement. In order to provide additional contingency against hydraulic fracture beneath the newly placed and compacted berm, a geotextile membrane was placed at the interface between native ground and compacted fill and the berm was lined with sheet piles along the edges to provide additional strength to the soil matrix above the launch. Overall, the risk of hydraulic fracture was determined to be low.

The launch pit was excavated below the groundwater table, therefore, a well point system was utilized to dewater the area to prevent ingress or flooding during construction. This was further aided by the implementation of a concrete base slab. Groundwater monitoring was conducted using piezometers installed near the launch site which determined the amount of water needed to be drawn from the well. A seal was installed at the launch to prevent backflow of groundwater or slurry into the shaft from the tunnel annulus.

Figure 8 – Top view of the seal within the launch shaft.

3.5 WORKSPACE

Workspace was required to be built up to 5 ft (1.5 m) above sea level on a massive platform, in length above which provided 2 ft (0.6 m) of clearance above the 500-year storm flood elevation to mitigate the possibility of the site flooding during large weather events which are common during the wet season at the project location. The platform area measured approximately 2,950 ft (900 m) x 213 ft (65 m) which was sized to accommodate the DPI installation and the subsequent carrier pipe installation within the casing, therefore was roughly double the spread of a conventional DPI installation. The launch shaft and dual thruster installation, casing and carrier pipe stringing, welding, coating, testing, and installation as well as supporting equipment, and facilities for personnel all required careful coordination and sequencing on location to ensure that sufficient room would be available within the platform.

4.0 CONSTRUCTION EXECUTION & CHALLENGES

Based on project requirements and site conditions, the team determined casing specifications and equipment needs, which included two 750-ton thrusters and an AVN1200 MTBM equipped with a mixed ground cutterhead and rippers. However, record-breaking installations rarely go without a hitch.

Halfway through the tunnel path, the team encountered a significant challenge: the MTBM and casing stopped moving, and the thrust forces began to increase significantly. The presence of very high plastic clay, along with other unplanned stoppages, dramatically increased friction on the casing wall, pushing the limits of the two thrusters. With the casing pipe sitting for over a month allowed the in-situ soils to collapse back into the overcut, thus causing the casing to become stuck in multiple places along the string

Through collaboration and planning, utilizing the decades of combined experience within the team, coupled with pressing schedule constraints, multiple iterations of contingency planning transformed a conventional DPI installation into a hybrid approach which utilized concepts of a microtunnel into the DPI execution.

For more than a month, the MTBM and casing were stuck over 10 meters below the seabed on the offshore side. It was only through persistent contingency planning and innovative thinking that the casing finally began to move again, ultimately completing the installation with only one thruster and a lubrication system along the casing.

4.1 STUCK PIPE

4.1.1 Challenge: High Friction on The Casing Pipe

As the MTBM progressed along the alignment a zone of highly reactive clay slowed progress and swelled around the machine causing a rapid increase in friction between the formation and the casing.

While efforts were being made to get the casing moving again, enough downtime had passed allowing other sections of the overcut to collapse onto the casing which increased the overall friction on the installed casing pipe under the ground.

4.1.2 Solution: High Friction on The Casing Pipe

Ultimately, to reduce the friction issue and continue advancing the tunnel, the team installed additional lubrication points directly into the casing behind the MTBM and revised the engineered drilling fluid plan. The contingency measure utilized over 120 additional lubrication ports strategically located along the casing and an engineered drilling fluid plan that aimed to combat the very sticky clay while ensuring the required conditions for other soil formations. Lubrication slurry was pump through these ports which agitated the blocked overcut and free up the casing from the soil that was locking it in place.

While conventional DPI involves lubrication in the overcut through ports installed in the MTBM only, this project required a different approach. The new lubrication ports, supplemented with additional pumps and hoses, created an automatic lubrication system for the entire casing length, significantly reducing friction during thrusting activities. This is more commonly encountered within microtunnel installations where specialized engineered jacking pipes would incorporate lubrication ports every few joints of pipe through the tunnel length. This transformation required fast reactions from all involved teams, from shipping equipment from overseas to refining the tunneling slurry recipe and creating confined space entry procedures to ensure the safety of personnel entering the tunnel to perform the modifications to the casing and slurry lines.

Figure 9 – Bentonite injection boxes, typically utilized with microtunnel installations, were installed at strategic locations inside the DPI casing

4.1.3 Challenge: Slipping Clamp Inserts

During attempts to get the tunnel moving again the thruster clamp inserts began to slip along the casing pipe. In warmer conditions and after prolonged use, when the thruster clamp grips the casing pipe the rubber inserts at the contact point can slip gradually over the pipe when larger thrust forces were applied. As a result, when the pipe was stuck, and full force was applied to extract the pipe the inserts would slowly slip which prevented the full thrust force being exerted.

4.1.4 Solution: Slipping Clamp Inserts

To mitigate the slippage of the clamp inserts the contractor welded "stoppers" onto the casing pipe at regular intervals to eliminate the flex and slip from the clamp inserts. The larger wedge-shaped steel pieces were welded to the casing pipe to allow for the clamp to exert the force directly to the casing pipe with a steel-on-steel contact patch to the clamp itself eliminating the need for the clamp inserts.

Figure 10 – Additional supports welded to casing pipe to improve thrust force application

4.1.5 Challenge: Worn Tunnelling Components

Due to increased overall circulation time within the closed loop system and abrasive nature of the predominantly sandy formation, components within and on the cutterhead of the MTBM were showing signs of excessive wear which were monitored based on the tunnelling performance and slurry pressures. For an installation of such length, some wear was expected, however, the rate of wear that was experienced was faster than anticipated. The wear to the tunneling components included:

- Overcut and cutterhead tooling wear
- Nozzle wear
- Valve wear
- Pumps and Seals
- Thruster and Hydraulic Power Pack

4.1.6 Solution: Worn MTBM components

Some passages for slurry and hydraulic fluid were closed within the MTBM to increase pressure behind the nozzles to the tunnel face in order to increase effectiveness. Additional spare parts were also delivered to site if components failed and needed to be substituted. Along with the confined space safety measures, a plan was developed to allow expedient repair and replacement of the worn parts. The 56" tunnel allowed for the MTBM to be hermetically sealed from groundwater or seawater, subsequently allowing for safe access into the casing and MTBM. Ease and logistics of manned access was one of the major considerations when determining the ultimate size of the casing.

4.1.7 Challenge: Separation Plant Stoppages & Electrical Troubleshooting

Electrical issues were encountered during construction which caused temporary stoppages resulting in troubleshooting and downtime, further increasing the risk of overcut collapse and increased friction.

4.1.8 Solution: Separation Plant Stoppages & Electrical Troubleshooting

Additional generator sets were delivered to site to provide redundant power supply. Also, contingency planning for vital equipment operation and maintenance were developed to prevent additional lengthy downtime.

4.1.9 Challenge: Separation Plant & Fluid Performance

Slurry properties, particularly viscosity, were being modified at an increased rate when advancing through saline or brackish water-bearing formations, when compared to tunnelling through formations holding clean ground water, due to the salt content in the formation. These formations were to be expected on the coast and under the seabed, depending on their hydraulic conductivities.

The contractor had not originally planned to have a centrifuge installed within their slurry separation and recirculation plant which is used to clean the slurry of fines such as clay which can thicken the slurry and reduce its effectiveness during tunneling. While tunneling through the clay zone, an increase in ultra fines was encountered that were not able to be properly treated and cleaned at the separation plant without a centrifuge, therefore, controlling the slurry fluid weight became challenging. Heavier slurry could result in increased friction on the casing pipe.

4.1.10 Solution: Separation Plant & Fluid Performance

An improved separation process was implemented by the tunneling contractor which included additional separation plant components and a centrifuge with polymer injection.

Figure 11 – Imrpoved separation plant with centrifuge

4.2 TUNNEL ABANDONMENT CONTINGENCY PLANNING

Upon confirming that the technology was reaching its limits and the possibility of the crossing failing, the team quickly evaluated options to abandon the existing tunnel progress and proceed with alternate paths forward to complete the landfall installation. These options included the following:

4.2.1 Abandoning a Large Portion of the Hole

If partial retraction was successful and a reduction in thrust force was achievable, one solution which was evaluated was to retract the tunnel and “kick out” from the current alignment and modify the alignment to avoid the clay zone, steering below and around it into a more favorable formation, and re-entering the previously planned tunnel alignment after the tunnel is past the clay zone. To prevent settlement or disruption to surface from the potential loss of borehole integrity from the unsupported length of tunnel, the existing borehole left behind by the casing and MTBM being retracted would be grouted in place simultaneously with the extraction. The tunnel could then resume and steer under the abandoned portion and ultimately maintain the same reception point.

4.2.2 Redrilling A Parallel Crossing

Another contingency measure that was evaluated was constructing a new tunnel parallel to the abandoned casing in the event that the tunnel was unable to be retracted from below the seafloor, or if, upon extraction, it was deemed infeasible to make another attempt at completing the tunnel along the current alignment. This would allow the parallel installation to take place simultaneously while the initial casing extraction efforts were still under way to limit downtime. The Contractor would be required to mobilize an additional thruster unit to site and install a new launch shaft which would be logistically challenging, however, there would be a possibility to utilize the thruster unit and MTBM that just completed the casing installation at the southernmost landfall in Dos Bocas after some expedited refurbishment.

This method would be very costly, as it would involve the potential abandonment of thousands of feet of 56" casing pipe, and the MTBM assembly, as well as operation of an additional Direct Pipe spread and crew onsite. Using the experience gained from the initial attempt at the casing installation, the Contractor could plan and design a new tunnel alignment and profile to advance through more favorable conditions and implement adjusted construction execution methodologies to account for the potential of sticky clays.

4.2.3 Retract & Refurbish

Another option considered was to retract the casing entirely in order to perform maintenance and refurbishment to the MTBM. This method would assume that the MTBM would be successfully freed, full removal of the casing, and grouting of the borehole. After the MTBM has undergone necessary repairs, the option of redrilling along the same alignment or pursuing an alternative parallel alignment could be pursued.

4.2.4 Recover The MTBM In Place

In the event that the MTBM was unable to be retracted, independent of the selected path forward with another tunnel installation, the project was posed with an expensive issue – the loss of an advanced piece of tunneling equipment, of which only a few exist in the world. To address this issue the project team evaluated the possibility of recovering the MTBM by digging down vertically to retrieve it at a depth of nearly 40 ft (12 m) below the sea floor and 12 ft (3.5m) of water more than 500 ft (150 m) offshore. Such an excavation would require a specially engineered coffer dam and extensive dewatering efforts to complete and would be an expensive and logistically challenging endeavor. Pursuing this option would require an additional environmental impact study and a potential for several months of permitting efforts for approval.

4.3 Resumption Of Tunnelling

Ultimately, the casing pipe and MTBM were able to be dislodged with thrust forces of less than 700 kips utilizing the modified tunnelling procedure described above which allowed the tunnel to advance through the clay zone and eventually transitioned into sand. The tunnel was eventually successfully completed, reaching the planned reception point where the MTBM was later removed and the casing would be prepared to receive the carrier pipe.

4.4 Schedule

Early site preparation works for the Veracruz Norte landfall commenced in June 2023, with sheet pile pit construction completing in December 2023. A summary of key dates for the drilling program is provided in the table below:

Table 5. Project Execution Schedule

Milestone	Date
Site Works and Launch Shaft	June 2023 to December 2023
Start of Tunneling	10-Dec-2023
Mid-Weld Completed (700m)	4-Jan-2024
Tunneling Stoppage	18-Jan-2024
Troubleshooting Period	19-Jan to 3 Mar 2024
Preparations to resume tunneling	4-Mar to 7 Mar 2024
Completion of Tunneling (1370m)	27-Mar-2024

Onshore Product Pipe Insertion	16-Apr to 30-Apr-2024
MTBM Recovered	13-May-2024
Offshore Product Pipe Pull	14-May-2024
Grouting of Pipeline	14-Nov-2024
Pipeline Commissioning	2025

4.5 MTBM RETRIEVAL

The MTBM advanced into a pre-dredged excavation on the sea floor at the reception point of the alignment. The slurry and umbilical lines were separated from the MTBM and the bulkhead door closed before separating the MTBM from the casing pipe using an engineered separation module.

Divers were sent down to the MTBM to verify the separation of the MTBM from the module and then using airbags the MTBM was floated up to surface where a large offshore vessel was waiting to lift the MTBM out of the water.

Figure 12 – Retrieval of the AVN1200 MTBM from the sea floor at the reception point.

4.6 CARRIER PIPE PULL-IN

After completion of the casing installation, the gas pipeline was installed within the casing in two stages. The first stage involved pushing the first approximately 4,430 ft (1,350 m) of carrier pipe into the casing using onshore equipment (Pipelayers or "sidebooms"). Spacers were installed on the product pipe, and a "half-pipe" ramp was constructed to guide the product pipe into the casing, as shown in the figures and pictures below:

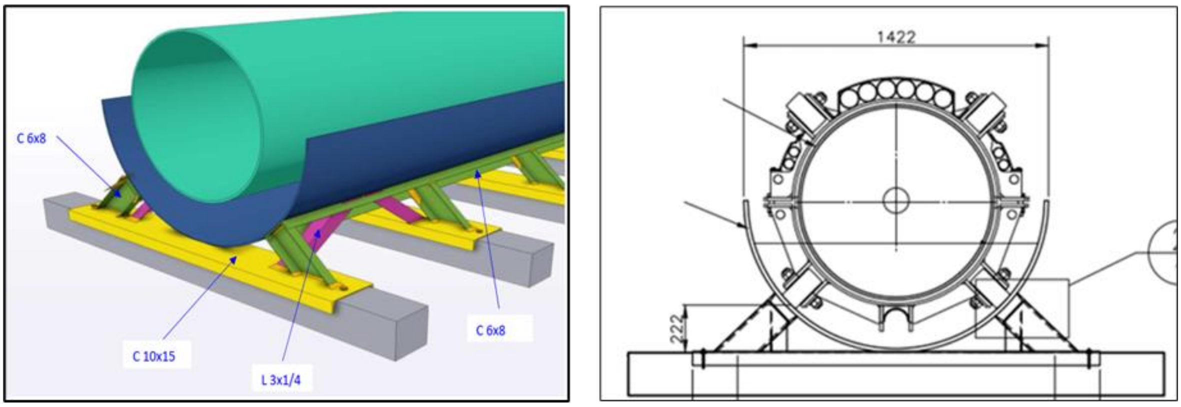


Figure 13 – Onshore "Half-Pipe" and Product Pipe Spacers

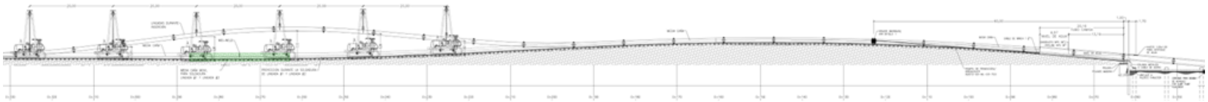


Figure 14 – Onshore Sideboom Layout for Product Pipe Push Installation

In the second stage, the specialized offshore vessel which was used to recover the MTBM from the seabed pulled the product pipe string an additional 1,680 ft (512 m) to the final tie-in point with the offshore pipeline. This two-stage approach helped to minimize the amount of time that the expensive and schedule-critical offshore vessels was required.

Figure 15 – AllSeas Tog Mor, vessel used to pull the Product Pipe string to its final tie-in location. Picture is from the Sur de Texas – Tuxpan Pipeline, Tamiahua Landfall (2017) which was installed in a similar manner

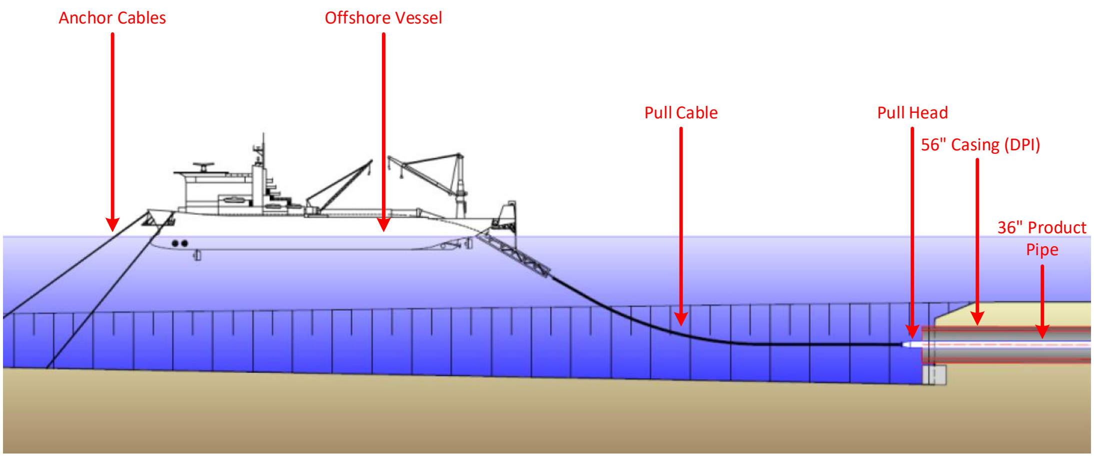


Figure 16 – Pulling Configuration Diagram (Simplified)

Before problems were encountered with this DPI, Veracruz Norte was scheduled to be the first point of arrival of the offshore vessels in March 2024. The plan was for the 5 vessels to complete their scope first in Veracruz Norte, then proceed to complete similar work at the other landfalls in Dos Bocas and Coatzacoalcos in series. To mitigate substantial vessel standby costs, the Project changed the vessel schedule to first Dos Bocas, then Veracruz Norte, and finally Coatzacoalcos. This provided additional time for the team to resolve the issues at the Veracruz Norte Landfall before the rescheduled arrival of the offshore fleet.

4.7 ANNULUS GROUTING

In order to ensure pipeline integrity and minimize potential movement of the carrier pipe within the casing during operation after pipeline commissioning, the annulus between the casing and the carrier pipe was required to be grouted. More than 1,500 cubic yards of cement-bentonite grout was pumped into the annulus utilizing the 6 x HDPE tremie lines attached to the product pipe. A grout mix was designed by GDI to ensure that sufficient working time window would be available for the grout to be pumped through the tremie lines before hardening. The annulus at the offshore end was plugged off to prevent infiltration of seawater and to allow seawater to escape while grouting to prevent formation of voids. Additionally, air bleed lines were installed onto the carrier pipe with the tremie lines to allow air to escape and prevent damage to the casing from suction during grouting. After a week of continuous grouting operations, the annulus was successfully grouted and the carrier pipe landfall section continued preparations for commissioning.

5.0 CLOSING

After several years of front-end engineering and planning, detailed engineering design, and nearly a year of construction, the record-breaking 56" Veracruz Norte DPI Landfall installation was successfully installed. Many obstacles were faced during the design and construction phases which included challenging environmental constraints, equipment and material limitations for a DPI installation of such magnitude, and a month-long stoppage during construction due to stuck casing, however, through careful planning and determination, the project team persevered. The Veracruz Norte Landfall is a vital link for connecting the onshore and offshore piping of the SGP project which is anticipated to be fully commissioned in 2025 and will supply natural gas to the Yucatan Peninsula, benefiting millions of Mexican citizens. Although buried deep below the Gulf of Mexico, the Veracruz Norte Landfall stands as a testament to collaboration between a muti-national team utilizing cutting-edge technology to deliver important Mexican infrastructure.