Success for HDD intersects in Saudi Arabia

In January 2008, two parallel HDD intersect crossings were started from Berri Causeway under the bay to Abu Ali Island at Al-Jubail on the Arabian Gulf Coast of the Kingdom of Saudi Arabia. These two parallel HDD crossings were novel because of their extreme lengths, both 3,050 metres from entry to exit.

THE PROJECT, FINISHED in January 2009, consisted of the installation of a 24 inch steel oil trunk line from Berri Oil Field and a 30 inch steel water injection line for secondary recovery operations in Berri Oil Field. The two lines were parallel with approximate separation of 18 metres at the center of the crossing. The hole size of the 24 inch crude oil trunkline was 32 inch and the hole size of the water injection line was 42 inch. The weight of the 24 inch pipe was about 900 metric tonnes and the weight of the 30 inch pipe about 1,525 metric tonnes.

The project was carried out in five phases:

- ***Phase 1:*** Site installation operations
- ***Phase 2:*** Pilot hole drilling / intersect operations
- ***Phase 3:*** Reaming / hole opening operations
- ***Phase 4:*** Pipe pulling operations
- ***Phase 5:*** Site de-installation operations

The solution to a problem with removing a 42 inch hole opener for the 30 inch water line has been previously reported in this magazine, *Undersea rescue in Saudi Arabia*, April 2009, Issue 3.

This article will focus on the technical importance to the horizontal directional drrilling (HDD) industry of the intersect method, in particular phase 2; the drilling of the two pilot holes and their successful completion with the HDD intersect method. This project was a milestone in the use of HDD intersect technology, being the two longest underground intersects completed to date.

Each pilot hole was completed by drilling from both sides simultaneously and guiding the merger of the two holes underground to a point about 1,000 m from the Abu Ali side exit point.

Saudi Aramco, the project owner, contracted the pipeline construction job to AL Robaya Est, who subcontracted the underwater HDD drilling to a joint venture between Digital Connection Co. Ltd. (DCL), a Saudi Arabia company, and Tatco Boring, an Abu Dhabi company.

Planning

A dredging solution was ruled out due to environmental concerns about harm to valuable marine life, high currents in the bay and possible interruptions to shipping.

A conventional HDD crossing, drilling from an entrance point to an exit point, was proposed but eventually ruled out for several reasons. The crossings were so long that a substantial risk existed for twisting off the drill pipe or for becoming stuck while trying to complete a 3,000 metre crossing due to the risk of differential forces on the drill pipe downhole. The entrance angles on the Abu Ali side and the exit angles on the Berri Causeway side were both fairly steep, which would cause increased push and pull forces on the drilling as well as on the reaming and casing operations following pilot hole completions. The product pipes were large and heavy, one 24 inch line, weighing about 900 metric tonnes, and one 30 inch line, weighing about 1,525 metric tonnes. These weights could create frictional forces that could potentially cause the drill pipe or the hole openers to become stuck or lost down hole.

Because of these anticipated forces on the drill string while drilling, a conventional, HDD crossing was ruled out in favor of the least risky method, the underground intersection of two independent boreholes drilled from each side of the bay between Berri Causeway and Abu Ali Island, the horizontal intersect.

Drilling a HDD intersect requires specialised technology in the vicinity of the actual intersection of the two bores. DCL-Tatco subcontracted the guidance of the pilot hole drilling to Prime Horizontal Ltd, the pioneer of intersect drilling. Prime Horizontal has already successfully completed more than 25 such intersect projects. The company used the ParaTrack-II system equipped with an axial magnet sub located in the target borehole as the magnetic source for navigation of the actual intersections.

Soil sample borehole data provided by Saudi Aramco was made at intervals over the length of the crossing's bore paths. The deepest point reached was 37 metres below the sea bottom. The soil ranged from medium hard, light grey, sandy silt, dense gravels and layers of hard brown clays from the Abu Ali entry side to calcarenite (calcareous sandstone) and hard grey silt on the Berri exit side.

Maximum forces which could be applied to the drill string were computed to avoid buckling or breaking drill pipe downhole. A profile of the expected mud pressures

Herrenknecht HK 150T drilling rig at Berri Causeway site.

Herrenknecht HK 250T drilling rig at Abu Ali site.

down hole due to depth and annulus size was developed, giving expected and maximum allowable pressures along the bore path. If these maximum pressures were exceeded there would be a risk of drilling fluids escaping from the pilot hole, an event to be avoided.

Pressure while drilling

Downhole pressure was monitored with the ParaTrack Pressure While Drilling (PWD) module attached to the ParaTrack-II steering tool. This module has pressure sensors both inside and outside the drill string so it is easy to work out if an increased pressure in the annulus is due to an increased mud pressure in the drill string or from a blockage in the annulus somewhere further up the drill string. The PWD module therefore enables a quick reaction to such blockages and greatly reduces the chance of a loss of returns while drilling, a potentially serious problem both on long and environmentally sensitive jobs.

Drilling Equipment

On the Abu Ali side a Herrenknecht HK 250 T HDD drilling rig was used for pilot hole drilling and reaming. Thereafter it was replaced by a Herrenknecht HK 400 M HDD drilling rig for pipe pulling operations. On the Berri Causeway side a Herrenknecht HK150 T HDD drilling rig was used for pilot hole drilling and was eventually replaced by the HK250 T HDD drilling rig for forward reaming and pipe pulling operations assist.

Because of the medium-to-hard formations expected and the size of the product pipes, 6 5/8 inch mud motors with 1.5 degree and 2.0 degree bent subs were used together with 12 1/4 inch TCI (Tungsten Carbide Insert) tri-cone drill bits.

To accommodate the 12 1/4 inch drill bits and to control entry angle at eight degrees and build to the zero degree desired angle for transit of the bay, a 16 inch guiding casing of approximately 200 m length was used on both side entry points. Once the pilot holes reached their target inclinations of zero degrees from the horizontal, the remainders of the crossings were horizontal at zero degrees and at a depth of about 30 metres beneath the sea bottom.

Magnetic guidance

The basis of magnetic guidance of HDD drilling operations is the creation of a magnetic field of a simple geometry in the vicinity of the drill bits. The strength of this magnetic field should be greater than the Earth's magnetic field and should be greater than any time dependent magnetic fields produced by nearby earth structures or metal infrastructure. The ParaTrack steering tool mounted behind

Timing of Berri Causeway Project

The table below shows the completion dates of the key activities on this project. Each intersection was completed in two months; a very satisfactory accomplishment for underground intersects of more than 3,000 meters.

Abu Ali Site installation was completed on 7 November 2007.

Berri Causeway site installation was completed on 11 November 2007.

Drilling from Abu Ali for the 24 inch pilot hole started on 8 November 2007, and was completed on 9 December 2007. Drilling from Berri Causeway for the 24 inch pilot hole started on 8 November 2007, and was completed on 29 December 2007.

Drilling from Abu Ali for the 32 inch pilot hole started on 25 January 2008, and was completed on 23 February 2008. Drilling from Berri Causeway for the 32 inch pilot hole started on 28 December 2007, and was completed on 14 January 2008.

Thereafter, reaming and hole opening operations were started.

Item	Description	Date	
		Start	Completed
	24 inch Oil Trunk Line		
1	Pilot Hole Drilling 24 inch 150 Ton Rig at Berri	11-Jan-08	21-Mar-08
2	Pilot Hole Drilling 24 inch 250 Ton Rig at Abu Ali	21-Jan-08	21-Mar-08
3	Mobilization 400 Ton for 24 inch (To replace 150 Ton Rig)		15-Feb-08
4	Intersect		16-Mar-08
5	Pipe Pulling 24 inch (Total 18 hours)	16-Jun-08	17-Jun-08
	30 inch Water Injection Line		
1	Mobilization 400 Ton for 30 inch		19-Jun-08
2	Pilot Hole Drilling 30 inch400 Ton Rig at Abu Ali	21-Jun-08	05-Aug-08
3	Pilot Hole Drilling 30 inch 250 Ton Rig at Berri	12-Jul-08	05-Aug-08
4	Intersect		01-Aug-08
5	Pipe Pulling 30 inch (Total 38 hours)	12-Jan-09	14-Jan-09

the drill bit, consisting of three magnetometers and multiple accelerometers, measures the magnetic field to produce the azimuthal direction of the borehole. The accelerometers produce the inclination of the borehole. Combined with the length of pipe downhole, the azimuth and inclination of the borehole give the operator a position of the drill bit, thereby creating positive steerability to keep the drill bit on the pre-project planned track.

While there are many magnetic sources that can be used with ParaTrack, the simplest magnetic field geometry is produced by a closed loop wire loop through which electric current is passed. In the case of this geometry, the magnetic field lines are straight lines parallel to the long axis of the closed wire loop, particularly easy to use for navigation.

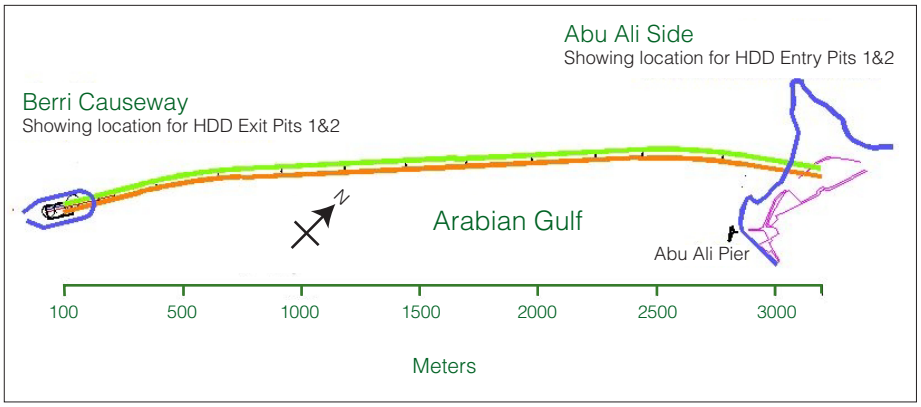
For the extremely high resolution required to complete an intersect underground, a separate Axial Magnet sub located in the target borehole is used to perform the last few metres of the underground intersect instead of the closed wire loop.

Pilot hole drilling

For both pilot holes, the pilot hole for the 24 inch oil pipeline and the pilot hole for the 30 inch water line, a closed loop guidewire was placed on the sea bottom from Abu Ali to Berri Causeway. Divers were used together with surface small boats to place heavy weights (anchors) on the sea bottom at approximately 10 m intervals along the surface track of the underground bores. Their locations were surveyed with GPS. Once all the anchors were in place, the double guidewire was attached to each weight, leaving a minor bit of slack in the line wire to account for movements caused by sea currents.

The pilot hole for the 24 inch product pipe was completed first, followed by the pilot hole for the 30 inch product pipe. For each pilot hole, drilling operations beneath the guidewire on the sea bottom commenced simultaneously from Berri Causeway and from Abu Ali. The guidance of the drilling was performed with the ParaTrack-II steering tool mounted behind the drill bit of each pilot hole sensing the magnetic field established by the double guidewire on the sea bottom.

The bottom hole assembly for both boreholes consisted of the drill bit, the mud motor, the bent sub and the ParaTrack-II steering tool installed between two 9 m lengths of non-magnetic drill pipe. Two ParaTrack-II systems were required for the project since drilling from Abu Ali and Berri Causeway occurred at the same time.



CAD Drawing showing plan and profile view of the Berri Causeway bore paths.

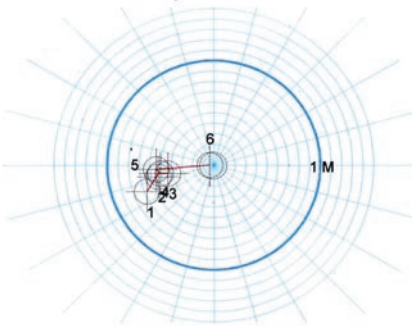
When the two bores approached in close proximity to each other, the Berri Causeway bottom hole assembly was changed to contain the ParaTrack-II steering tool and the Axial Magnet sub. The Axial Magnet sub contains a collection of bar magnets giving centimetre accuracy in the position of the ParaTrack-II Steering tool behind the bit of the Abu Ali bore relative to the position of the Axial Magnet sub behind the Berri Causeway drill bit. The final few metres of navigation to the intersection point which was located approximately 1,000 metres from the Abu Ali Exit point was performed with the Axial Magnet source rather than with the guidewire source.

During the final approach to the intersection, the operator used one of the displays in RivCross, the ParaTrack software, to visualise and measure the approach vectors to the target as shown right. The six smaller circles inside the 1 m circle represent the final six positions of the drill bit as it approached the target bore.

Once intersection was reached, the Abu Ali pilot hole string was pulled from the hole immediately followed by pushing the Berri Causeway pilot hole string through the already drilled hole to the exit point at Abu Ali. This completed the first pilot hole for the 24 inch line. Immediately thereafter, the pilot hole was started for the 30 inch line.

No undue problems were encountered during the drilling of either pilot hole with the exception of several occurrences of the guidewire on the sea bottom being cut by shipping operations in the Arabian Gulf.

After completion of the pilot holes, reaming and hole opening operations followed. At this stage, the role of Prime Horizontal was finished.



Intercept Vector Plot.

This project gives testament to the arrival of HDD intersect drilling as a proven technology, no longer in the experimental stage. From the point of view of the magnetic guidance of HDD projects, the Berri Causeway project was a great success, due in large measure to the excellent pre-project planning by all parties involved in the project.

Chairman of DCL Abdullah Natheer said "The Project was very challenging. It was the first in many ways, the length, the diameter of the product pipe, the diameter of the bore hole, the weight of the pipe, the environment.

"Even though these were record breaking crossings, and the challenges were great, the co-operation of everyone involved, including a sizable number of overseas participants, contributed positively to make it possible."

Mr Natheer would also like to thank Mr Saleh Al-Robaya, Managing Director of Al-Robaya Est, who demonstrated excellent support and understanding of the execution of all project phases, and his project partner, Mr Saeed Khoury, Managing Director of TATCO, Abu Dhabi.

For more information contact:

Prime Horizontal www.primehorizontal.com

Digital Connections Co. Ltd., www.dc-sa.com/Services.htm