Setting records in Singapore

Dr Andrew Ngiam and Ng Eng Bin, Kvaerner, describe the Shell Eastern Petroleum pipeline bundle that links Shell's Bukom refinery with Jurong Island, and which has set a new record as one of the largest 'bottom pull' installations completed to date.

The stringing operation underway at Pulau Ular, which required 85 days to complete.

The waters of Singapore harbour are among the world's busiest, and beneath the surface is an extensive network of submarine pipelines and cables that carry oil, gas, water, fibre optics and other utilities to and from the many hydrocarbon production and processing facilities in the area. Last year, some of these pipelines, designed and installed for Shell Eastern Petroleum Ltd, set a new record as one of the largest 'bottom pull' installations completed to date.

The 4.5 km pipeline bundle, which lies in water up to 28 m in depth, is part of Shell Eastern's US$ 100 million oil refinery complex expansion programme. Comprising eight pipelines in two rows of four and two fibre optic cables, the bundle carries naphtha and other products from Shell's condensate splitter unit on Bukom Island to downstream users such as Petrochemical Corp., Singapore, on Jurong Island. The total combined pipeline length of the eight lines and two cables is 36 km, more than double the previous largest project in Singapore at 16.5 km, which comprised 15 lines and three cables. The Shell pipeline bundle was assembled on the shore of Singapore's Pulau Ular and pulled across the Sinki Fairway seabed to the opposite shore at Seraya on Jurong Island.

Pioneering bottom pull

The engineering, procurement and construction of the project were carried out by Kvaerner, which has a 30 year track record in Singapore. During that time, the company has been involved in more than 95% of Singapore's submarine pipeline projects, many of which have been installed using the bottom pull technique. The bottom pull method offers a number of significant benefits. It is particularly suited for exceptionally active marine areas such as Singapore, and does not interfere with surface traffic unlike some other construction methods, such as lay barge and surface tow. In addition, the trench width is only 5 m, whereas conventional pipelay methods would require a much wider trench, particularly for a large bundle like the Shell pipeline.

One of the first challenges involved selecting the pipeline route in this already congested area. A key constraint was the Singapore Marine Port Authority minimum draft requirement of 18.5 m at low water from the highest point of the armour rock layer that provides protection to the bundle from dragged anchors or other dropped objects. Environmental impact and risk assessment studies were performed to ensure minimum disturbance to

The end of the pipeline comes into view between the sheet piles at the shore approach.

Space limitation required a riser to be installed at each end of the pipeline to bring the tie-in points as close as possible to the shore line.

Ensuring protection

A key element of the project was the design and installation of the filter layer rock and protective rock armour layer to cover the pipeline bundle once it was in place. Model anchor drop and drag tests were carried out by a research institute in Australia to evaluate the design basis to ensure that it would perform under a variety of different conditions, including varying water depths, sea states and climatic changes. In addition to providing protection from dropped or dragged objects, the rock had to be prepared to a tolerance that would not cause impact damage to the bundle during the dumping operations.

The seamless linepipe and bends were manufactured by Sumitomo Corp., Japan, to a very high specification and delivered to a coating yard in Batam, Indonesia.

For the bottom row of four pipelines in the bundle, external corrosion protection is provided primarily by an asphalt enamel coating with sacrificial anodes. These anodes are made from an aluminium-zinc alloy that were manufactured in semi circular sections and attached using welded steel lugs and thermo-welded cables for electrical continuity. These four 12 in. pipe sections were then concrete coated for extra protection from abrasion damage during the pull operation. The pipeline field joints were protected against corrosion using polyolefin-adhesive shrink sleeves with concrete infill.

The top row of pipelines is corrosion protected using a combination of sacrificial anodes and polyethylene coating. The coating is sufficiently strong to withstand any impact from the rock filter layer during the dumping operation. All corrosion coating was 100% holiday tested in the coating yard and the coated pipe was then transported to Pulau Ular, Singapore, via barge.

the marine environment and minimum risk to surrounding facilities and shipping lanes, both during construction and throughout the life of the bundle.

Design life for the bundle and cables is 50 years and a number of key criteria formed the basis of the design, including:

- Internal pressure load.
- External pressure collapse.
- Buckle propagation.
- Pipeline bending radii.
- Thermal load.
- Pipeline spans.
- Externally applied load.
- Stability and abrasion resistance requirements of the bundle during installation.
- Corrosion resistance and allowance during operating life.

Dredging criteria

A 5 m channel had to be dredged along the entire length of the pipeline route. The environmental impact assessment study had highlighted the need to protect a reef and its marine life that was lying adjacent to the pipeline route. This therefore required the use of dredging equipment that would minimise the generation of large quantities of silt and sand. In addition, the high level of traffic in the fairway required selection of equipment with the minimum footprint and not involving large anchor spreads. A further stipulation was the ability to remove hard seabed material that was present as identified in the route assessment survey.

The vessel selected was the *Ave Caesar*, a Dutch backhoe dredger mounted on a flat bottomed barge that could be mobilised using spuds or legs. The dredging and subsequent dumping operations were led by Kvaerner's main subcontractor Van Oord ACZ of The Netherlands. Three different dredging arm configurations were utilised for the various water depths encountered. The longest dredging arm enabled the *Ave Caesar* to dredge in depths of 28 m and was specially designed and fabricated in France for this project.

A total length of 624 m along the bundle trench centre line was too hard to be dredged. Two separate drilling and blasting spreads (one from Belgium and one from the UK) were mobilised to drill and blast these areas, which were then excavated using the *Ave Caesar*. Divers also carried out underwater inspection of blasted areas to verify that the seabed condition was free of obstacles and suitable for the bundle pull.

The pipeline shore approach at Pulau Ular, where the bundle can be seen on the launchway rollers inside the cofferdam.

624 linear m of trench required blasting, which was performed by two separate spreads and then excavated by the *Ave Caesar*.

Preparing for the launch

The launch site was prepared at Pulau Ular where the pipes were welded into strings and laid out on two storage beds prior to bundling during the pull. Fabrication operations were led by McDonnell Dowell, Australia, Van Oord's subcontractor. Each pipeline comprised 19 strings, each approximately 235 m, and one string of 96 m. The stringing operation required 85 days. Welding and NDT operations were based on modified API 1104 and were subject to continuous inspection by Kvaerner site personnel, with all welds and repairs 100% inspected by radiography.

Preparation of the launch site included construction of a launchway with rollers, a sheet-piled cofferdam, and temporary jetty for equipment access to the cofferdam. Setting up the pull winch site at Seraya included construction of a sheet-pile cofferdam, hold-back wall and concrete slab base for the pull winch.

The historic pull

Following completion of the dredging operation, the dynamically positioned Dutch vessel *Jan Steen* laid the 90 mm diameter pull wire in the centre of the trench. The first section of the bundle was launched into the sea by landbased equipment and the sheave block was installed on the pull head by a crane barge. A French manufactured KTC 350 Kley linear pull winch with a safe pulling capacity of 350 t was mobilised from The Netherlands for the pull. The maximum linear velocity during the pull was approximately 4 m/min, depending on local conditions.

Two double armoured fibre optic cables were strapped to the bundle before each pull and as the bundle section was pulled into the sea, the cables were slowly released from their holding drums. These cables, manufactured in Germany, had been selected for their superior protection properties. Once the stern end of one bundle reached the landfall point, the next bundle section was assembled behind it. Temporary transfer beams were used to roll over the strings from the storage yard beds to the launchway for joining to the previous bundle.

In order to increase buoyancy, and thereby minimise the pull force required, a total of 350 buoyancy tanks were used. Specially designed in America and manufactured in Singapore for the pull, each tank had a net buoyancy of 1.2 t. Before selecting the type of buoyancy tank to be used, tanks of different models and densities were tested by immersion in the sea for 30 days to ensure their complete reliability during the pull operations. In the air, the total weight of the pipeline cable bundle was 4077 t, but under water with buoyancy tanks this weight was reduced to only 493 t.

The pull operation required just 19 days to pull 19 of the 20 strings from Ular to Seraya.

Space limitations on the shore ends of the pipeline required a riser to be installed at each end to bring the tie-in points for the eight lines as close as possible to the

Key statistics

- Dredging of 165 000 m^3 of seabed materials.
- Installation of 10 km of fibre optic cables.
- Installation of pipelines and coatings weighing 4000 t.
- Installation of 53 t of sacrificial anodes.
- 120 000 t of gravel placed over the bundle.
- 160 000 t of armour rock placed over the bundle.
- 624 linear m of trench underwater drilling and controlled blasting of very hard rock, with no damage to the adjacent coral reef.

shoreline. At Ular, the lower bends and risers were welded to the cut-off ends of the bundle while it was still supported on the cofferdam rollers. After the rollers were removed, the risers were lowered to the seabed by crane slings and chain blocks and the riser upper bends installed. At Seraya, crane slings and chain blocks also controlled pipe sagbend stresses as the pullhead and bundle were lifted out of the water and the pullhead was cut off. Riser lower bends were welded to the bundle, which was then lowered to the seabed. This was followed by partial backfill of the cofferdam and welding of the riser upper bends.

Once the pull was complete, hydrostatic tests of the pipelines and continuity tests of the fibre optic cables were carried out.

Installing protective rock armour

After successful completion of these tests, the side dumping 2000 t capacity *Jan Steen* commenced backfilling operations. The backfill materials had been specially pre-graded at the Karimun Quarry in Indonesia and shipped by six tugs and barge spreads to a holding barge, *Jamuna II*, anchored in Singapore. Two backhoes onboard the *Jamuna II* filled the *Jan Steen*'s four bays with the backfill material.

The use of *Jamuna II* significantly reduced the round trip time required for the *Jan Steen* to travel to the target area along the bundle route to deposit materials, minimising the total time required for completion of the backfill operations. Dumping of the armour rock commenced once the level of protective filter material deposited over the bundle was sufficient to prevent impact damage during the dumping operations. The *Jan Steen* made a total of 150 trips to deposit 280 000 t of backfill over the bundle.

Final testing and handover

Final anode potential measurements, OTDR tests on the fibre optic cables, further hydrostatic tests, gauging pig runs and one caliper pig run, were then carried out prior to handover of the completed pipelines to Shell.

The project was successfully completed within a fast-track 15 month schedule and within budget. The pipelines are now fully operational and represent the largest bottom pull operation undertaken to date.