Abstract
This paper presents the requirements that led to the successful implementation of a subsea hydraulic hammer for installation of conductors offshore Brazil.

The Parque das Conchas development required conductors both for wells and for the two Artificial Lift Manifolds (ALM). For the 36 inch well conductors it was important that the conductors were installed off the rig critical path and for the 48 inch ALM conductors the critical issue was the accuracy of the conductor height for subsequent manifold placement. The solution was to install the respective conductors using a subsea hammer deployed from an Anchor Handling Vessel (AHV).

The ALM templates were transported offshore vertically on the AHV’s A-frame, submerged and rotated to a horizontal position, and deployed to the seafloor. Once the templates were correctly positioned, the well and ALM conductors were transported offshore on a specially outfitted barge. The conductors were launched from the barge while connected by a line to the anchor handler. Then they were lowered and allowed to self-penetrate into the seabed. Once all the conductors were installed, they were hammered to depth using a subsea hydraulic hammer. Both ALM templates were placed accurately in position within 1.5 deg heading and 0.5 m in the horizontal plane and all conductors were successfully installed within verticality and height tolerances.

The campaign included many industry firsts, in water depths ranging between 1650 and 1920m in relatively harsh met-ocean conditions. The industry firsts include:
- Vertical template transportation/insertion through water plane followed by horizontal lowering from AHV
- Deepwater hydraulic hammer spread deployed and operated from AHV
- A new depth record (1920 m water depth) for deepwater hammering.

With the installations in Brazil the operating envelope of deepwater conductor installation with a hydraulic hammer has been significantly increased and provides a viable alternative to conductor installations with a deepwater drilling rig.

Introduction
The BC-10 block, operated by Shell Brasil E&P, is located in the Campos Basin, off the coast of Brazil, approximately 120 km SW of the city of Vitoria in Brazil (Fig. 1.). In late 2007 operations commenced to install the facilities and wells for the Parque das Conchas project; a cluster development of discovered fields known as Ostra, Abalone and Argonauta (Fig. 2.).

The Operator was investigating solutions for the installation of conductors that could receive a mud line Electrical Submersible Pump (ESP) module that provides the artificial lift for the field. The conductor size had to be 60 m long with an inside diameter (ID) of 45 inches. Another complicating factor was that these conductors had to be very accurately installed through the ALM templates with respect to stick-up above mud line (Fig. 3 and 4). It was realized that any opportunity to reduce the use of rig time, both in terms of cost and availability, would add value to the project; the proposed off-line installation of both the ALM and well conductors was seen as an opportunity to do so.

In view of the high global utilization rate of deepwater drilling units, InterMoor was investigating where there could be opportunities to save rig time based on innovative offshore solutions. Performing installation operations from the ‘Back of the Boat’ (the Contractor’s area of expertise) could yield cost effective solutions for reducing rig time utilization for the Operator.

Jointly, the Contractor and Operator developed installation concepts that satisfied both the Parque das Conchas conductor installation requirements and utilized safe offshore deployment procedures.
Installation Concept

Large diameter pipe has been installed with subsea hydraulic hammers for a number of offshore applications. Pile installation performance using a subsea hammer for the foundations of Tension Leg Platforms (TLP) in the Gulf of Mexico has been documented in a previous paper (Doyle, 1999). Suction technology for deepwater installation of piles (Faul, 1998) can be adapted to increase the force available for the pile (or conductor) soil penetration, and deeper penetration enhances the pipe’s freestanding stability prior to docking the subsea hydraulic hammer.

Traditionally these installations have been from large crane barges or construction vessels. Such vessels have the advantage of offering a very stable working platform, but come at high cost and limited availability. The Contractor’s concept was to utilize the Operator’s AHV for both the ALM spacer template and the artificial lift and well conductor installations.

The following objectives were set:

- Develop methodology for safe deployment, lowering and installation of ALM spacer templates from AHV.
- Develop methodology for conductor installation using AHV.
- Install all conductors within 0.5m horizontal and 1° verticality tolerances.
- Install ALM spacer templates within 0.5m horizontal and 1.5° heading tolerances.
- Minimize personnel exposure.

A summary of the installation methods is given below. More details will be given later in this paper:

- Transport and install the ALMs from the AHV.
- Build a dedicated launch barge and transport the welded ALM and well conductors offshore.
- Launch the conductors from the barge and install the conductors with the AHV to the self-penetration depth.
- Hammer the conductors, with the AHV as work platform, to the required depth.

Justifications for adopting the concept were:

- Control of the installation tolerances and installation reliability for the 48” ALM conductors was much better than the alternatives considered. Furthermore the selected concept was technically more mature.
- Installation of the ALM templates and their conductors early in the Parque das Conchas project and prior to the arrival of the MODU would allow for maximum flexibility for scheduling the subsequent construction phases of the ALM by both the construction vessel (main manifold installation) and the MODU (Liner and ESP module installation in the conductor).
- When the project was sanctioned the total conductor installation scope was 33 well conductors. Based on this scope, the economics also showed a modest cost saving for the well conductors compared with a MODU operation.

Conductor installation requirements

In parallel with the concept, installation requirements and tolerances were developed for both the ALM template placement and the conductors.

Requirements:

- Two ALM spacer templates (Fig. 3) to be installed with a total of six slots to laterally control the location of the 48 in. dia. foundation conductors. ALM-1 weighed 55 tons and had four slots; ALM-2 weighed 35 tons and had two slots.
- Six 48 in. dia. x 60 m foundation conductors to be installed through the slots on the ALM spacer templates (Fig. 4). As the name implies, these piles were the foundation supports for the 200 ton manifold and acted as conductors for the electrical submersible pump (ESP) system.
- Eleven 36 in. dia. well conductors to be installed at various locations in the Parque das Conchas Field.

Tolerances:

- ALM spacer templates to be installed within 1.5 m horizontal accuracy, and 1.5° heading accuracy. Failure of delivery within the set tolerances could mean re-working of well trajectories, flow line routes, manifold positions or jumper designs
- The six 48 in. dia. x 60 m conductors had to be installed through the slots in the two ALM spacer templates. The clearance in the slots was ½ in., and after self weight penetration, the conductors were to be driven to a predetermined distance as marked on the pile. Final tolerances were for each conductor’s elevation to be within 2 in. of each other, and within 1° verticality.
- The eleven 36 in. dia. x 50 m conductors were to be installed as freestanding conductors and had installation tolerances of ±0.5 m horizontally, <1° vertically and were required to be driven to a predetermined elevation marked on the conductor. Where the well conductors were located in the same drill center the relative elevation of the conductors was to be provided within 0.3 m of each other to eliminate the need for a change in riser space out for the MODU during batch operations.
Design and Engineering

Conductor Design

Conductor pipe design
Wellhead conductors for deepwater subsea wells are typically installed with the jetting technique. For this project the conductors would be driven to the desired penetration depth with a subsea hydraulic hammer. A jetted conductor is made up in sections with connections on a Mobile Offshore Drilling Unit (MODU). The driven conductor was designed to be welded onshore to the desired length (50 m for the 36 in. diameter wellhead conductors and 60 m for the 48 in. ALM conductors) and subsequently installed in one piece. The design of the conductor pipe, in terms of length, wall thickness and material grade was determined by the load bearing requirement to support the well and the expected bending and fatigue loads, as documented by Bogard and Matlock (1990), API RP-2A (2000).

The top section of the 36 in. wellhead conductor is the low pressure Well Head Housing (WHH) of the selected marine wellhead assembly and is welded onshore to the conductor pipe. Hammering was to be directly on the top of the WHH.

The top of the ALM conductors was fitted with a special housing with design features for hammering, suction head attachment and guide cone attachment. The extra wall thickness of the ALM conductor housing also resisted ovalization of the cross-section; a very important consideration for later manifold installation.

Each ALM conductor was designed to carry a share of the ESP manifold weight plus the weight of one of the ESP modules, which would later be mounted on top of each of the ALM conductors.

Marine wellhead design
In addition to the requirements of serving as the well foundation to receive the high pressure WHH of the Marine Wellhead system, the low pressure WHH was designed for two additional functions:

a) Interface with and transmit energy from the hydraulic subsea hammer.

b) Provide connection interface for the Suction to Stability (STS) head. The STS head allowed suction to be used to increase the penetration of the conductors beyond their self-weight penetration depths.

The WHH vendor was provided with calculated impact stresses expected to occur during the hammer phase. The vendor confirmed that no housing damage would occur at the stress levels provided; therefore hammering directly on the WHH was acceptable.

Conductor driveability analysis
A conductor drivability analysis was performed using a Wave Equation Analysis Program. It was determined that the Menck MHU-270T hammer with a driving energy of 270kJ at 1,000 m water depth was sufficient to drive the conductors to grade with the assumption of upper bound soil shear strength and the presence of sand layers. Actual conditions produced relatively light driving; for full conductor penetration the 48 in. conductors required a blow count of approximately 3000, the 36 in. 750 blows.

A check of driving fatigue was performed using conservative driving energy, weldment and stress concentration factor assumptions. No significant fatigue damage was predicted.

Development of installation procedure
Detailed procedures had to be developed for each phase of the project. As the project was unique in many respects, the new tasks were computer simulated to ensure that appropriate safety margins were met.

Lowering analysis – The challenge
When lowering heavy objects on a line from the surface in deep water where excitation from vessel motion is present, there is a danger the system will experience resonance with resultant high vertical displacements and dynamic line loading. A simple single-degree-of-freedom, mass-spring-damper model can illustrate the problem where the mass is the object being lowered, the spring is the lowering line and damping is primarily a result of hydrodynamic drag on the object.

When the object is suspended under the AHV but still close to the water surface, the natural period of the system is short, typically 3 to 4 seconds. As the object is lowered, the stiffness of the spring (i.e. the lowering line) is reduced and the natural period lengthens. Depending on the hydrodynamic mass of the object, the spring stiffness of the lowering line and the available water depth, there is a potential for the natural period of the system to increase until it equals the peak period of the excitation motion. If this happens, resonance occurs and very large amplitude motions of the lowered object can occur, limited only by system damping and the ability of the lowering line to resist the dynamic line tensions.

The Solution
This analysis was executed using a fully 3D non-linear time domain finite element program capable of dealing with the arbitrarily large deflections of flexible elements from their initial configurations.

Passive heave compensators were installed into the system to reduce resonance to a manageable level. The compensators act as soft springs; by connecting them into the lowering line, one can dramatically increase the systems natural period. When
the natural period of the lowering system is shifted sufficiently, spring isolation will occur wherein the vertical amplitude of
the object is now less than the input amplitude at the stern of the AHV.

The computer simulation, as outlined above, is able to model more features than just mass, spring and damping rates in a
single degree of freedom model. For example, the following can be included:

- Hydrodynamic mass of the object
- Translational and rotational drag on the object
- Translational and rotational damping of the object
- Translational and rotational added mass for the object
- Line properties such as axial and flexural stiffness, damping and drag
- Vessel scantlings
- Vessel response properties (i.e. RAO's)
- Regular or random sea states

The most problematic objects to be lowered were identified as the ALM-1 and ALM-2 spacer templates. For example, the
4-slot spacer template ALM-1 is 7.6m x 16.3m in plan but only 2m high. Such a shape will generate very high drag and
added mass related forces when accelerated through the water column. So high, in fact, lowering the templates through the
water surface in a horizontal orientation would have likely damaged the lightly framed spacer templates. This analysis result
led directly to the decision to have the templates enter the water in a vertical orientation to reduce form drag and added mass.
It was confirmed that once the compensators are deployed and operational, the templates could be safely lowered in a
horizontal orientation.

**ALM installation procedures**

The initial plan was that the AHV would carry both ALM spacer templates on the main deck of the vessel, and deploy
them from a horizontal position on deck to a vertical position below the A-frame and from there over-boarded through the
water surface. This plan changed for the following reasons:

- Detailed engineering during procedural development suggested that during the planned upending stage, before the
  ALM spacer template could reach a vertical orientation, the template’s bottom section would enter the water. It was
determined that a combination of drag forces and entrained water could damage the template when the stern of the
AHV heaved upwards in all but calm sea states.
- The upending process offshore required the synchronization of three winches operating simultaneously. This meant
  that, although feasible, the upending process would be a slow and complex operation. The offshore execution team
  was also reporting unusually high southerly swells for the time of year, adding to the risk.
- Upending offshore also meant increased personnel exposure.

As a result, a new transportation position was developed where the ALM templates were supported on the A-frame in a
near vertical position and safely sea fastened for transportation to the field (Fig. 5). This technique was accepted after
presenting engineering analysis to support the concept and gaining Marine Warranty (Noble Denton, 2005) approval. In
addition to concept approval, the Marine Warranty Surveyor also inspected and certified each ALM load out.

The main advantages of this new technique were as follows:

- The template was loaded as originally intended and complied fully with the Contractor’s ALM Load Plan. The
difference now was that the template was upended to the vertical position in port, rather than the open sea, with the
assistance of a quayside crane.
- The template was sea fastened in a manner that not only allowed for the AHV crew to quickly release the load for
  deployment, but also allowed them to continually monitor the tensions of the sea fastenings and make adjustments,
  when required during transport.
- With the template already safely in the vertical position, when the AHV arrived on location the sea fastenings were
  released quickly and the template lowered straight into the water column in the vertical orientation. This meant the
  template deployment operation was reduced to a matter of minutes rather than hours and that the template entered
  the water edge-on in a vertical orientation. This significantly reduced drag added mass and entrained water effects
  such that the template could be deployed without heave compensation.
- Most importantly, there was now no requirement for personnel on deck during the template deployment operation.

**Conductor Launch Analysis**

The 48 in. OD ALM foundation conductors and the 36 in. OD well conductors were transported to site on a modified flat-
top barge (Fig. 6) The conductors were moved one-by-one onto ramps on the starboard side, and rolled off the ramps into the
water. The top of the conductors were attached to a pre-determined length of the AHV's work wire, so once the conductors
were launched from the barge they would swing down underneath the AHV's stern roller in a pendulous manner (Fig. 7 and
8).
This concept eliminates the need for large offshore crane and substitutes a more available and less costly AHV with its winch and stern roller. The engineering models showed that this technique would work as expected with little to no shock loading on the work wire or conductor.

Due to the absence of a suitable crane, a method of moving and launching the foundation and well conductors on the transport barge was needed. A shuttle system was designed that moved transversely across the barge deck on specially design support beams. The shuttles were able to move under the conductors that were supported on three elevated support beams. Once positioned under the conductor to be moved, the shuttle arms could lift the conductor off its supports. The shuttle could then move the conductor (now safely secured to the shuttles) to the launch station. Just before launching, the straps securing the conductor to the shuttles were removed and the shuttles lowered the pile onto two launch ramps. At this point, the conductors rolled off the ramps into the water. The shuttle system was designed to operate in up to a 5 degree list with a period of 10 seconds.

**Hammer Launch**

The hammer used to drive the conductors to grade was an MHU-270T hydraulic hammer outfitted with a subsea girdled power pack. Due to the limited overhead room available underneath the 300 ton capacity A-frame mounted on the stern of the AHV, upending the hammer from its shipping skid to an upright orientation for deployment was not a viable option.

The method chosen has much in common with a technique used to launch suction piles from an AHV; to which, the pile is skidded aft along the work deck until its center of gravity extends past the end of the vessel and the pile starts to tilt over the stern roller. The pile is then slowly tilted on the stern roller until vertical; some rigging is removed and the pile is ready for lowering by the A-frame.

In the case of the hammer, a tilt frame was designed and fabricated. The tilt frame was designed to distribute the loads from the stern roller contact point to hard points on the hammer. With the hammer in the tilt frame, it was possible to skid the hammer aft and tilt it onto the stern roller. When at about 60 deg, the hammer was remotely released from the frame and continued rotating until vertical. At this point, the hammer was lifted off the tilt frame and the frame was recovered onto the work deck. Once the hammer umbilical and anti-twist clump weight were configured, the hammer was ready for deployment.

Analysis of this deployment aid included dynamic load prediction and stepwise static equilibrium calculations of the hammer and frame as it moved over the stern roller so the tilt frame structural design could be performed.

The hammer was lowered on a torque-neutral 3.5” Spectra rope (Fig. 9). This rope, with a rated break strength of 285 tons, was lowering a hammer weighing 58 tons; thus it was very important that the hammer avoided a resonance condition. As a result, the hammer lowering system was also modeled to include the passive heave compensators. This analysis confirmed that the Spectra rope had sufficient capacity for the procedure.

**Vessel requirements**

Requirements for the operation for the AHV were such that they could be provided by most modern day AHVs, and included the following:

- Level 2 dynamic positioning capabilities (DP2).
- 300 ton winch with a capacity for 2000m of 4” dia. rope.
- Secondary winch.
- 150 ton A-frame.
- Deck area with a minimum of 800m²
- Accommodation for 50 persons.
Project Execution

HSE Plan Highlights

Health, Safety and Environmental (HSE) issues had a high profile due to the nature of the project where many operations had not been executed before or were unfamiliar to the crews. Every operation was designed to minimize personnel interface with equipment or to eliminate the requirement to have personnel present in a working area. This is demonstrated by the following:

- Wire rope was replaced by synthetic Spectra rope on the end of the work wire. This was designed for easy handling on the barge, eliminating the need to bring onboard and manually handle large diameter wire rope in a limited work space while connecting to the STS head.
- Wire stopper on the barge was designed to be released by a small winch and crane combination. This was designed to remove any personnel from a potentially dangerous area when releasing a wire under tension.
- Both ALMs were transported in a vertical position on the A-frame, which reduced manual rigging and thus personnel exposure. It also meant that upending operations were performed in a controlled environment in port, further reducing project and personnel exposure.
- All sub-contractors, working on the AHV, were issued Personnel Protective Equipment (PPE) by the Contractor to ensure a consistent high standard for personnel arriving from both in- and outside Brazil.
- Audits were carried out on the barge and AHV to ensure that both were certified, all documentation was in place and that both provided a safe working environment for the project personnel.
- All launching and recovery techniques (with the exception of the conductor launch) were practiced in a controlled environment, in port, and fine tuned before going to an offshore environment to perform such operations. This provided all personnel the chance to witness and control the operation without the effect of vessel motion, and make any adjustments required.
- A strong emphasis on Management of Change (MOC) was implemented for the project. The reason for this was to track and evaluate/analyze/re-calculate each and every change, as well as the thought process behind the change, required.

Quality Plan Highlights

A Quality Plan was developed, ensuring that only the correct equipment would be utilized at any time of the project, reducing the project exposure. The following are highlights of the Quality Plan:

- All equipment was new (except the hammer), and supplied with a copy of all certificates.
- All equipment was coded to ensure there could be no confusion with rigging equipment.
- All equipment was tracked through the entire project, and any damage recorded so such item was not re-used.
- All equipment was sourced through trusted vendors, themselves subjected to pre-qualification.

Preparation phase

Conductor fabrication

The conductors were fabricated in Vitoria, at Vitoria Offshore Logistics’ (VOL) waterfront area. This area was chosen because of the following:

- Ample area available for the welding operations to be completed safely without a cluttered work site.
- Easy access to the waterfront for load out operations.

The welding operation was subcontracted to local specialists, with the Contractor responsible for the supervision, logistics and coordination of welding inspections and any subsequent repair work required before acceptance.

All conductors were inspected for ovality and straightness before and after welding to ensure drivability and fit.

- Ovality – the difference between major and minor outside diameters -required to be less than 1%
- Straightness – The maximum straightness deviation required to be less than 3/8” per 40 ft length

Welding procedures for the girth welds on the conductors were developed according to ASME Section IX ed.2004. Charpy impact testing was conducted on test specimens from a qualifying weld. Each girth weld was set with a spacing of 1/3mm and a ceramic backing strip was tacked on the inside of each joint preventing the necessity of welders working from inside the pipe. The pipe was pre-heated to a temperature of 150°C and the following welds applied

- Root Pass - FCAW at 40cm/min
- Fill weld - Submerged Arc @ 46cm/min
- Finishing weld - Submerged Arc @ 41cm/min
Ultrasonic inspection was conducted on each weld to verify there were no inclusions. A third party inspector witnessed all welding operations.

**Conductor Load Out**
A detailed load out and lifting plan was developed for the entire operation, covering all aspects of the pipe movement across the staging area and loading to the barge.

Two 200t mobile cranes performed the actual load out operation. The following steps were performed during the load out:
- Onsite Job Safety Analysis for responsible parties.
- Specific safety briefing for crane drivers and banksmen.
- Facility load out area secured to keep unauthorized personnel out of danger.
- Cranes connected and made the lift using basket slings.
- Lowered the conductor onto support beams on the barge.
- Conductor moved into final position with the shuttle system.
- Sea fastened the conductor in final position.

By using the shuttle system for load out, there was no requirement for the cranes to reach across the barge during loading nor was it necessary to turn the barge. The cranes loaded the conductors onto the closest part of the barge; the shuttles moved the conductors to their final position on the barge. Using the hydraulic shuttle system during the load out provided the opportunity to test them in circumstances similar to those offshore.

**Barge construction**
The barge was built in Rio Nave Shipyard, Rio de Janeiro, between February and August 2007. It was built and operated by a 100% Brazilian owned company and complied with all local and international regulations both during the building process and when operational. The barge had the following main characteristics:
- Classification Society – RBNA (Registro Brasileiro Navios e Aeronaves) – A1 O2 5 – Cargo Barge.
- Dimensions were 75m x 22.40m, with a maximum draft of 3.5m
- Accommodation for 8 persons, with full kitchen and mess facilities.
- Primary and Auxiliary Generators.
- Full Compliance with SOLAS, MARPOL and local regulations.
- Three deck support beams for supporting 18 conductors.
- Winch specification: 10 ton
- Crane capacity: 15 ton
- Launch system & support beams designed for up to 5deg rolls at 10 second periods.

**Location Survey**
A survey operation was carried out as part of the BC-10 Project covering all sub-sea installation sites. As part of the survey the locations for both ALMs and the wellhead conductors were investigated for any obstructions and four marker buoys were placed at each of the installation site. This would minimize the time spent during the conductor installation to confirm the final location.

**Offshore Installation Phase**

**ALM Installation**
With the AHV on location and the template deployed vertically in the water, the next step was to rotate the template 90’ to a horizontal position for lowering and installation on the seabed.

In the vertical position the template was supported by two winch wires connected to the AHV’s 600 ton towing winch and 150 ton secondary winch. These were attached to the top corners of the template with 150 ton and 85 ton ROV shackles. The attachment points were designed to counteract any rotational forces the template might be subjected to due to vessel motion and subsea currents. The template was lowered to a depth of approximately 50 m, where the following steps were performed:
- AHV anchor handling winch wire, already connected to a four-way bridle, was lowered with the template. Two 150 ton passive heave compensators connected in series were connected in this line above the bridle. The compensators were not under load at this stage.
- The ROV performed an inspection of all the rigging and confirmed that everything was in place and no tangling issues were evident.
- The AHV heaved slowly on the anchor handling winch until the weight transferred to the four-way bridle in the horizontal position, leaving the two original lowering lines slack. At this point the single lowering line on the four-way bridle and the heave compensators supported the template and the vessel motions were being compensated.
At this point, the ROV attempted to release the two original lowering lines where they were connected to the template via 150 ton ROV-releasable shackles. The ROV was unable to release the shackles; in order to provide some extra slack, the bridle wire was raised inadvertently allowing the top compensator to contact the stern roller. Eventually, the original lowering lines had to be released via the backup 85 ton ROV-releasable shackles.

With the two initial lowering lines recovered to deck, and the template being lowered through the water column, the project team decided that it would be best practice to land the template in a predetermined safe zone and disconnect from the bridle via an ROV hook. This was accomplished without incident, and allowed the damaged compensator to be recovered, removed, and the remaining compensator re-calibrated for optimal performance at the seabed.

The compensated lowering line was then lowered again, reconnected using the ROV hook and the template lifted clear from the seabed in a safe and controlled manner.

Approximately 200m from the intended drop location, the template was lowered to allow a 3 in. x 30 m drag chain, which was pre-attached to the template centerline, to land on the seabed and assist in correctly orienting the template as the AHV slowly continued ahead in DP mode towards the drop point.

As the template approached the drop point, the heading was continually monitored and the AHV course line altered to ensure the heading stability was maintained.

At the drop point, the template heading was once again confirmed and the template lowered in a safe and controlled manner on to the sea floor.

The ROV hook was then disconnected and utilized as a recovery hook for the drag chain section and the four-way bridle when they were disconnected by the ROV. The template was left clean of any rigging.

The same procedure was repeated for the second ALM spacer template installation, with the exception of new ROV shackles made from existing 55 ton shackles for the four-way bridle; these replaced the original 85 ton ROV-releasable shackles.

The shackles were changed out because the original 85 ton ROV shackles were thought to be defective due to pre-mature release of the bridle on the first ALM installation. A later investigation concluded that the bridle, alternating between slack and tight due to vessel motion, simply snagged and triggered some of the spring loaded shackles when the ROV was carrying out the visual inspection on the template.

Conductor launch and self-weight penetration
The project plan was to batch set all 17 conductors in one field visit. During the process of drivability and lateral load analysis in the procedural development stages it was determined that the well conductors each had to reach minimum embedment of 14.0 m and the ALM conductors 14.5 m. At these depths, the conductors had sufficient lateral and structural stability such that the hammer could later be docked on top for the hammer phase of installation. As there was a chance of encountering shallow sand deposits at the BC-10 site, self-weight penetration analysis indicated some conductors would penetrate only 12 m. Contingency measures, described below, were developed to deal with such an event.

Once the barge arrived on at the BC-10 location, the AHV came alongside and began the conductor launching sequence. The basic installation steps were as follows (Fig. 7 and 8):

- AHV came alongside close to the barge and held position while the deck crew passed the work wire across to the barge.
- With the AHV work wire secured on the barge, the barge crew attached it to the STS head utilizing the barge tugger and barge crane to reduce handling. In a further effort to reduce handling risk/exposure for the barge crew, a much lighter 5m Spectra sling on the end of the work wire was used.
- Once the AHV work wire was connected to the STS head, the work wire securing arrangement on the barge was released, leaving the work wire weight now on the shackle connected to the STS Head.
- The conductor sea fastenings were then released and the conductor secured and picked up by the shuttle system for moving to the launching ramp.
- The shuttle system then transported the conductor to the ramp on the starboard side, and lowered it onto the ramp, at which point the conductor rolled down the ramp and into the water.
- The conductor flooded instantaneously and swung under the AHV, until it was suspended by the work wire in the vertical position, connected to only the STS Head.
- The conductor was then lowered to depth on the AHV’s 600 ton winch, and once the coordinates were confirmed, was landed between the marker buoys placed on the seabed during the initial survey operation under visual observation by ROV.
- The conductor was continually lowered and self-penetrated until the heave was damped by the soils. The verticality was then checked by the ROV and confirmed to be within acceptable limits, at which point lowering continued until the self-weight penetration limit was reached.
- Verticality was again verified by the ROV, after which the ROV closed the vent valves on the STS head and connected to the suction port.
- The ROV commenced pumping. This produced an underpressure across the STS head, embedding the conductor further into the soil in the same way a traditional suction pile is installed. This suction embedment technique added up to an extra 5 m of penetration, significantly adding to the lateral and structural stability of the conductors.
- The ROV then disconnected the STS head, which was released by the ROV and recovered to the surface on the lowering line. In a subsequent operation, the STS was passed back to the barge for re-use.

The above sequence of events was successfully repeated for all 17 conductors, thereby batch setting all the conductors.

**Contingencies**

To ensure that the minimum required conductor penetration would be achieved, two contingencies developed:

- Increased penetration with suction force. The STS head acted as both a lifting/lowering head and a suction head. It was designed to suction penetrate the conductors from their minimum expected self-weight penetration depth of 12 m if shallow sand was encountered to the minimum allowable penetration depth of 14 m to 14.5 m. In practice, the STS heads were able to increase the penetration depth up to 5 m.
- Increased penetration by adding dead weight ballast. A dead weight ballast assembly that was designed to be rigged up and lowered over the conductor (in a donut type arrangement) with a head section that landed on the conductor head to centralize the weight distribution. This added 45 tons of low Center of Gravity (CoG) weight that would aid penetration. It was designed to allow suction to be applied simultaneously. This unit was not required during conductor installation.
- A spare (7th) ALM conductor was available in case of a problem or loss during the launch. No spare 36” conductors were prepared; an unsuccessful installation would be mitigated by jetting this conductor with the MODU.

All conductors were successfully installed, achieving an average self penetration of 17 m to 18 m, and an additional average penetration of 4 m to 5 m utilizing suction, therefore achieving an overall average initial penetration of 21 m to 23 m. **Table 1** provides the data sheet of the conductor installations.

**Hammer Mobilization**

The next step was to mobilize the deepwater hammer spread onto the AHV. The deepwater hammer spread had never been deployed from an AHV, main reasons being the limited deck space and the absence of a large crane. To overcome these issues the following equipment was designed, developed and fabricated:

- A stacking system that allowed standard containers to be loaded on the AHV deck two tiers high and secured safely, at the same time designing access/escape walkways into the frames to provide a safe working area.
- A deployment skid which was used to both store the hammer on deck and act as a safe means for deployment and recovery over the stern roller.
- A foundation frame to raise the large umbilical winch off the main deck and deploy the umbilical over the port side crash rail and bulwark.
- An anti-twist clump weight system.

In addition:

- Detailed procedures were developed for upending the hammer and deployment over the stern roller.
- A detailed deck plan was developed, with the emphasis on minimizing equipment handling by personnel and creating safe working areas and safe havens for retreat in the case of any incidents.

**Driving Operation**

The vessel arrived at the BC-10 location and carried out the normal DP checks, then over-boarded the hammer without incident. This operation was intended to happen only once, but due to several small technical problems the deployment and recovery operation was performed several times. The problems were caused mainly by the vessel motion in an unusually large seaway (4 m to 5 m of swell) for the time of year and the standard heave compensators used being unable to isolate the hammer from the unpredicted long swell periods. This made it very difficult at times to land the hammer on the WHH (Fig. 9), and at times some minor impact damages were inflicted on the hammer appurtenances.

The following improvements were made to increase the control over the hammer movements at depth:

- Increasing the bell housing width. This made the hammer easier to land on the WHH by providing a larger catchment area.
- Continually monitoring, re-calculating and re-evaluating the effectiveness of the compensator units. This allowed adjustments to be made, altering the system stiffness to account for any changing environmental conditions, which reduced vessel motion amplification that was present at depth.
- Visual aids were added to the bottom of the hammer, hung off on ropes to allow the ROV to visually monitor and add an element of depth perception during the landing process.
With the landing issues resolved and the weather returning to more predictable states, the hammering phase was carried out without further incident. Each conductor was hammered to the specified grade within the set limits. The 48 in. diameter foundation conductors were the biggest challenge, as the penetration limit was set at a maximum of +/- 3 in. difference in height between other conductors in the template. By using the hydraulic hammer’s single-stroke mode of operation, the height requirement was met. Table 2 provides the data sheet for the driving operation.

**Key Learnings**

A number of operations were conducted off shore for the first time in the industry. Key learnings from the installation phase:

- During the first conductor launch, as the shuttle system was laying the conductor on the ramp for launching, the AHV was moved forward away from the barge too early. This introduced some longitudinal forces in addition to the planned transverse movement of the conductor, and resulted in some damage to the center launching ramp as well as some damage to the heave compensator in the lowering line. The conductor was installed as planned, but these changes were implemented to improve the launch process:
  - The AHV for all subsequent launches was kept closer to the barge until the conductor entered the water. The conductor trip through the water column after launch was re-modeled and it was established that the vessel being closer to the barge, meaning more slack line in the water column, would not have an impact on the anticipated loads during the transition from horizontal to vertical. This eliminated any risk of shock longitudinal loads during launch.
  - Damage to the barge itself was non-existent, but the end of the center ramp was damaged beyond repair. A load distribution calculation was performed which showed that the remaining two ramps would support the subsequent conductor launches adequately. The damaged area was then cut away so as not to become a hazard to further operations.
  - The vessel heave and conductor heave was closely monitored during the installation of the first conductor, and sea states recorded throughout. This allowed evaluating the true effectiveness of the passive heave compensator in the line. It was established that the subsequent launches could be performed safely without the use of a heave compensator in the line, eliminating the risk of further damage.

- AHV Winch Peak Loads: The launching models anticipated a peak load on the AHV winch of no more than 10% over the payload weight. This was estimated onsite to be fairly accurate but unfortunately, due to technical problems with the AHV winch load cells the actual loads could not be determined.

- A problem with the AHV secondary winch caused a runaway failure (uncontrolled release of wire) and the total loss of one 48” conductor. Because of the good work practices of the rigging crew and the detailed procedures in place, there were no personnel present on deck during this operation, and therefore no injuries. This should not distract from the fact that this was still treated as a very serious incident, and a full investigation was held to determine the fault with the AHV winch. The damage was limited to a heave compensator, a lost wire, rail damage on the ‘A’ frame and some other minor material damage. All damage was rectified and the operation continued without the use of the secondary winches, which did not have a remote operated emergency brake system.

- Heave Compensation: It was known from the early design phase of the project that standard passive heave compensators would not perform well in long-period wave conditions (i.e. swell). Since met-ocean data indicated that persistent swell conditions were forecast for only 18% of the time, the risk was accepted. With this experience in mind, a prototype of a passive compensator was developed that will address the long period wave issue and adds a number of other enhancements including hydraulic rod lock, one-the-fly damping and spring stiffness adjustments plus automatic depth compensation and stern roller deployability.

- The launch method for the hammer: A dedicated launch frame for the hammer, instead of using the A-frame, can be developed that can withstand harsher launch / sea conditions.
Conclusions

12 March 2008 marked the completion of the installation of two (2) ALM spacer templates and seventeen (17) conductors in the BC-10 Block in 1600m to 1950m of water depth. All installations were accepted within the predetermined tolerances. The conductor installation campaign achieved many industry first, in water depths ranging between 1650 and 1920m in harsh met ocean conditions. The industry firsts were:

- Template transportation and installation from AHV
- Deepwater hammer spread deployed and operated from AHV
- Deepwater hammering in up to 1920 m water depth

With the installations in Brazil the operating envelope of deepwater conductor installation with a hydraulic hammer has been significantly increased and provides a viable alternative to installations with a deepwater drilling rig.

For the Parque das Conchas Project the successful conclusion of the conductor installation campaign marked the start of it’s Field Development. The achievements and impact can be summarized as follows.

- Installation of 2 ALM spacer templates with an AHV without the use of a MODU or a construction vessel.
- Installation of 11 @ 36 in. well conductors, taking it off the work scope of well delivery with a MODU.
- Installation of 6 @ 48 in. ALM conductors. No alternative installation method, with either a MODU or a construction, was identified. This novel installation method was critical to the successful construction of the Parque das Conchas artificial lift system as a whole.

The conductor installation campaign was planned to have some cost savings compared to a MODU installation. However, when the overall project size was reduced from 33 to 11 well conductors this target was not met. Installation of the ALM template early in the BC-10 Field Development construction does now allow for the required flexibility for the subsequent construction phases of the ALM by both the construction vessel (main manifold installation) and the MODU (Liner installation in the conductor and ESP modules). Up to a month of MODU time was freed up for other well activities; 1-2 days saved per well conductor installation and 2-3 days per ALM conductor.

The campaign was concluded with no Lost Time Incidents or harm to people.

Acknowledgements

The authors wish to thank the BC-10 Project Team, co-venturers Petrobras and ONGC, Shell Brasil E&P, Shell International E&P and InterMoor for permission to publish this paper.

The implementation of the deepwater conductor installations would not have been possible without the support provided by many vendors who supplied key components, including Menck, FMC Energy Systems, Vetco Gray, Norwegian Geotechnical Institute, Premium Solutions and Tidewater.

Nomenclature

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>AHV</td>
<td>Anchor Handling Vessel</td>
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<tr>
<td>ALM</td>
<td>Artificial Lift Manifold</td>
</tr>
<tr>
<td>CoG</td>
<td>Center of Gravity</td>
</tr>
<tr>
<td>DP</td>
<td>Dynamic Positioning</td>
</tr>
<tr>
<td>ESP</td>
<td>Electrical Submersible Pump</td>
</tr>
<tr>
<td>MOC</td>
<td>Management Of Change</td>
</tr>
<tr>
<td>MODU</td>
<td>Mobile Offshore Drilling Unit</td>
</tr>
<tr>
<td>OD</td>
<td>Outer Diameter</td>
</tr>
<tr>
<td>PPE</td>
<td>Personal Protective Equipment</td>
</tr>
<tr>
<td>ROV</td>
<td>Remotely Operated Vehicle</td>
</tr>
<tr>
<td>STS</td>
<td>Suction To Stability</td>
</tr>
<tr>
<td>WHH</td>
<td>Well Head Housing</td>
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<thead>
<tr>
<th>Unit</th>
<th>Symbol</th>
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<tr>
<td>inch</td>
<td>in.</td>
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<tr>
<td>meter</td>
<td>m</td>
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<tr>
<td>short ton (2000 lb)</td>
<td>ton</td>
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References
### Tables

#### Conductor Installation Phase - Batch Setting (No Hammering)

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<thead>
<tr>
<th>Well Location</th>
<th>Conductor ID</th>
<th>Subsea Heave</th>
<th>Initial Penetration</th>
<th>Slabbing Verticality</th>
<th>Time to Dock ROV</th>
<th>Pumping Time</th>
<th>Final Penetration</th>
<th>Final Verticality</th>
<th>Total Time (Launch &amp; Install)</th>
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<td>36&quot; - B6</td>
<td>2 - 3m</td>
<td>17.0m</td>
<td>0.5 deg</td>
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<td>15 mins</td>
<td>22.5m</td>
<td>0.5 deg</td>
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<td>15 mins</td>
<td>21.5m</td>
<td>0.79 deg</td>
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<td>0.5 deg</td>
<td>15 mins</td>
<td>15 mins</td>
<td>21.0m</td>
<td>0.5 deg</td>
<td>3h 35 mins</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>36&quot; - B3</td>
<td>2 - 3m</td>
<td>17.0m</td>
<td>1.0 deg</td>
<td>30 mins</td>
<td>10 mins</td>
<td>21.5m</td>
<td>0.8 deg</td>
<td>3h 55 mins</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>36&quot; - B10</td>
<td>1 - 2m</td>
<td>18.5m</td>
<td>0.75 deg</td>
<td>10 mins</td>
<td>20 mins</td>
<td>24.0m</td>
<td>0.75 deg</td>
<td>4h 35 mins</td>
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<tr>
<td></td>
<td>36&quot; - B8</td>
<td>2 - 3m</td>
<td>17.0m</td>
<td>0.9 deg</td>
<td>10 mins</td>
<td>15 mins</td>
<td>20.5m</td>
<td>0.5 deg</td>
<td>7h 30 mins</td>
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<tr>
<td></td>
<td>36&quot; - B9</td>
<td>2 - 3m</td>
<td>19.0m</td>
<td>0.25 deg</td>
<td>30 mins</td>
<td>20 mins</td>
<td>19.0m</td>
<td>0.25 deg</td>
<td>5h 17 mins</td>
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<td>2 - 3m</td>
<td>20.0m</td>
<td>0.5 deg</td>
<td>20 mins</td>
<td>15 mins</td>
<td>21.7m</td>
<td>0.5 deg</td>
<td>4h 35 mins</td>
</tr>
<tr>
<td></td>
<td>36&quot; - B4</td>
<td>2 - 3m</td>
<td>20.0m</td>
<td>0.9 deg</td>
<td>15 mins</td>
<td>15 mins</td>
<td>22.5m</td>
<td>0.8 deg</td>
<td>3h 30 mins</td>
</tr>
<tr>
<td></td>
<td>36&quot; - B2</td>
<td>2 - 3m</td>
<td>18.0m</td>
<td>0.5 deg</td>
<td>5 mins</td>
<td>20 mins</td>
<td>21.0m</td>
<td>0.5 deg</td>
<td>3h 35 mins</td>
</tr>
<tr>
<td></td>
<td>36&quot; - B11</td>
<td>2 - 3m</td>
<td>19.0m</td>
<td>0.6 deg</td>
<td>5 mins</td>
<td>15 mins</td>
<td>23.0m</td>
<td>0.8 deg</td>
<td>4h 10 mins</td>
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#### Conductor Installation Phase - Driving Operation

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<tr>
<th>Well Location</th>
<th>Conductor ID</th>
<th>Length [m]</th>
<th>Water Depth [m]</th>
<th>SWP Pile + Hammer Distance [m]</th>
<th>Stick up [m]</th>
<th>Driven Distance [m]</th>
<th>Final Penetration [m]</th>
<th>Total Blows [No.]</th>
<th>Net Driving Time [hh:mm]</th>
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<td>48</td>
<td>1943.7</td>
<td>21.2</td>
<td>4.5</td>
<td>23.3</td>
<td>44.5</td>
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<tr>
<td></td>
<td>36&quot; - B6</td>
<td>49</td>
<td>1894.9</td>
<td>27</td>
<td>4</td>
<td>24</td>
<td>45</td>
<td>774</td>
<td>0:23</td>
</tr>
<tr>
<td></td>
<td>36&quot; - B5</td>
<td>50</td>
<td>1893.3</td>
<td>21.7</td>
<td>5.1</td>
<td>22.2</td>
<td>43.9</td>
<td>1388</td>
<td>0:39</td>
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<tr>
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<td>36&quot; - B4</td>
<td>48</td>
<td>1889.5</td>
<td>22.5</td>
<td>4.09</td>
<td>22.4</td>
<td>44.9</td>
<td>552</td>
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<tr>
<td><strong>Abelone</strong></td>
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<td>62</td>
<td>1894.6</td>
<td>22.5</td>
<td>34.3</td>
<td>58</td>
<td>3063</td>
<td>1:31</td>
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<td>36&quot; - B3</td>
<td>49</td>
<td>1867.9</td>
<td>27</td>
<td>1.8</td>
<td>33.4</td>
<td>58.4</td>
<td>1235</td>
<td>0:48</td>
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<td>33.2</td>
<td>58.2</td>
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### Table 1 – Conductor installation performance – initial installation

#### Table 2 – Conductor installation performance – Driving operation
Figures

Figure 1 – Location Map, Block BC-10

Figure 2 – Parque das Conchas Field Layout, Block BC-10
Figure 3 – Artificial Lift Manifold Template

Figure 4 – Conductor through ALM

Figure 5 – Artificial Lift Manifold Template rigged to AHV

Figure 6 – Conductor Launch Barge
Figure 7 – Conductor launch – Plan View

Figure 8 – Conductor launch – Side View
Figure 9 – Conductor driving

MENCK 270T HAMMER INSTALLATION PROCEDURES
(USING AHTS)