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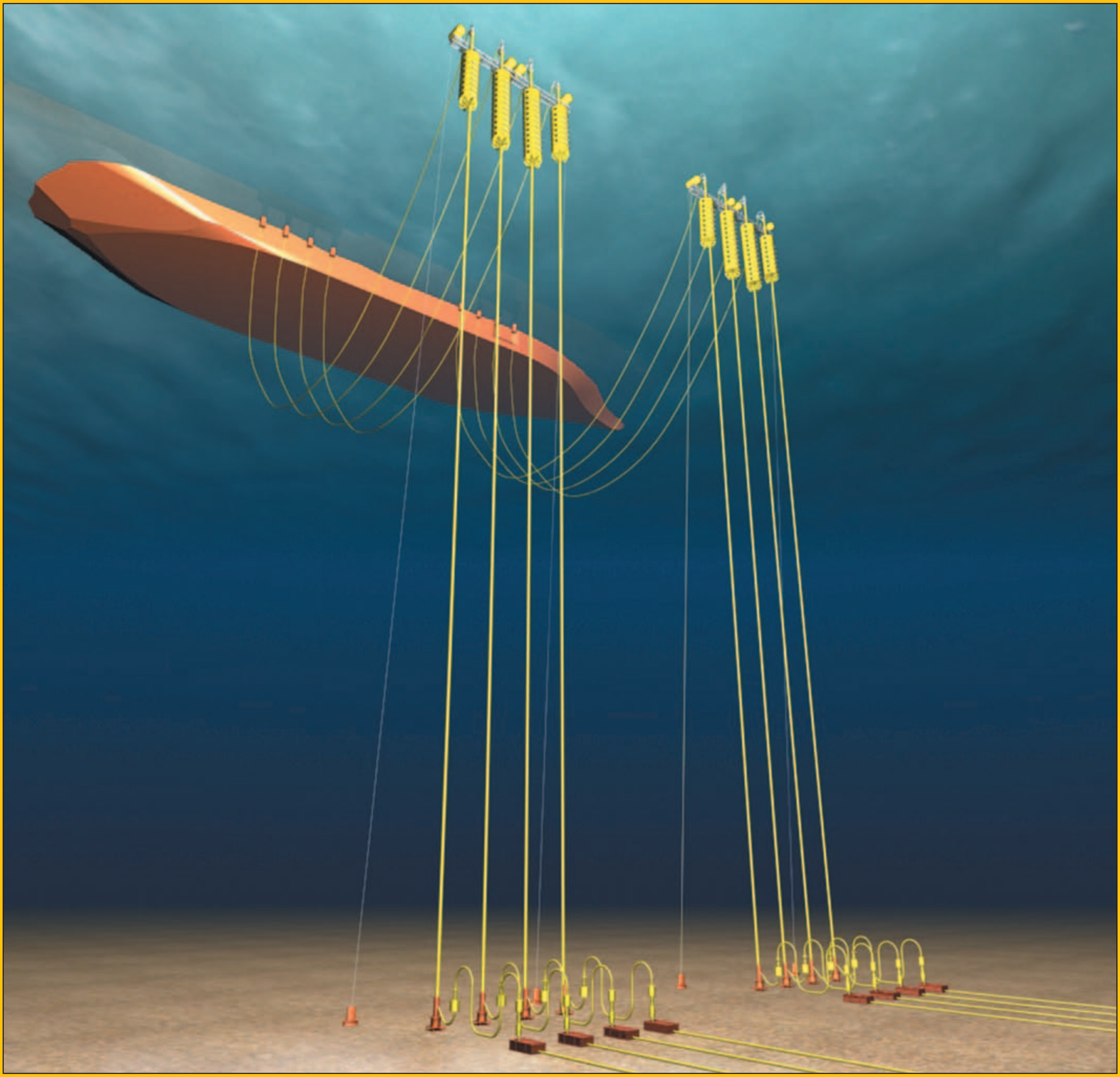
Making more of SLOR



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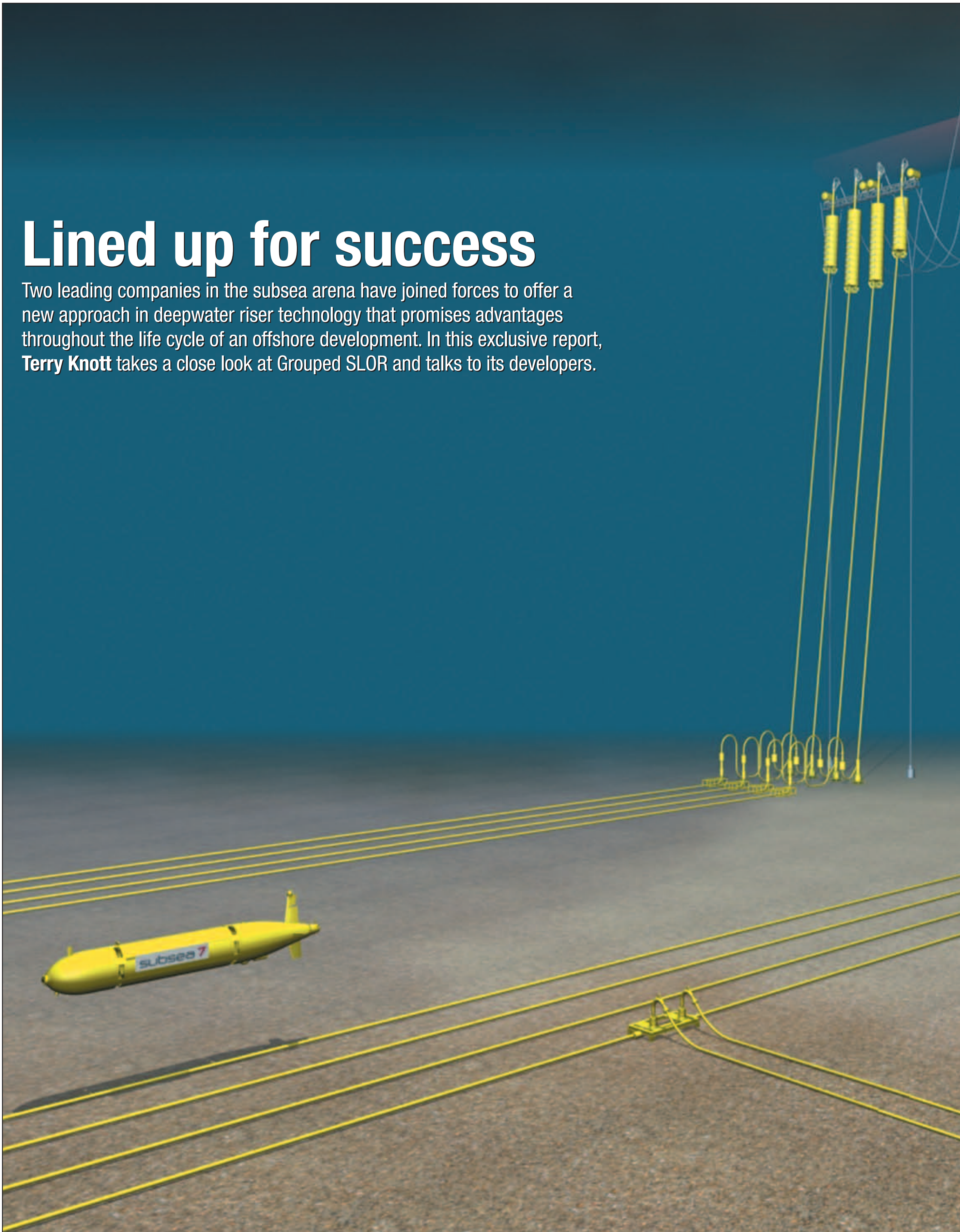
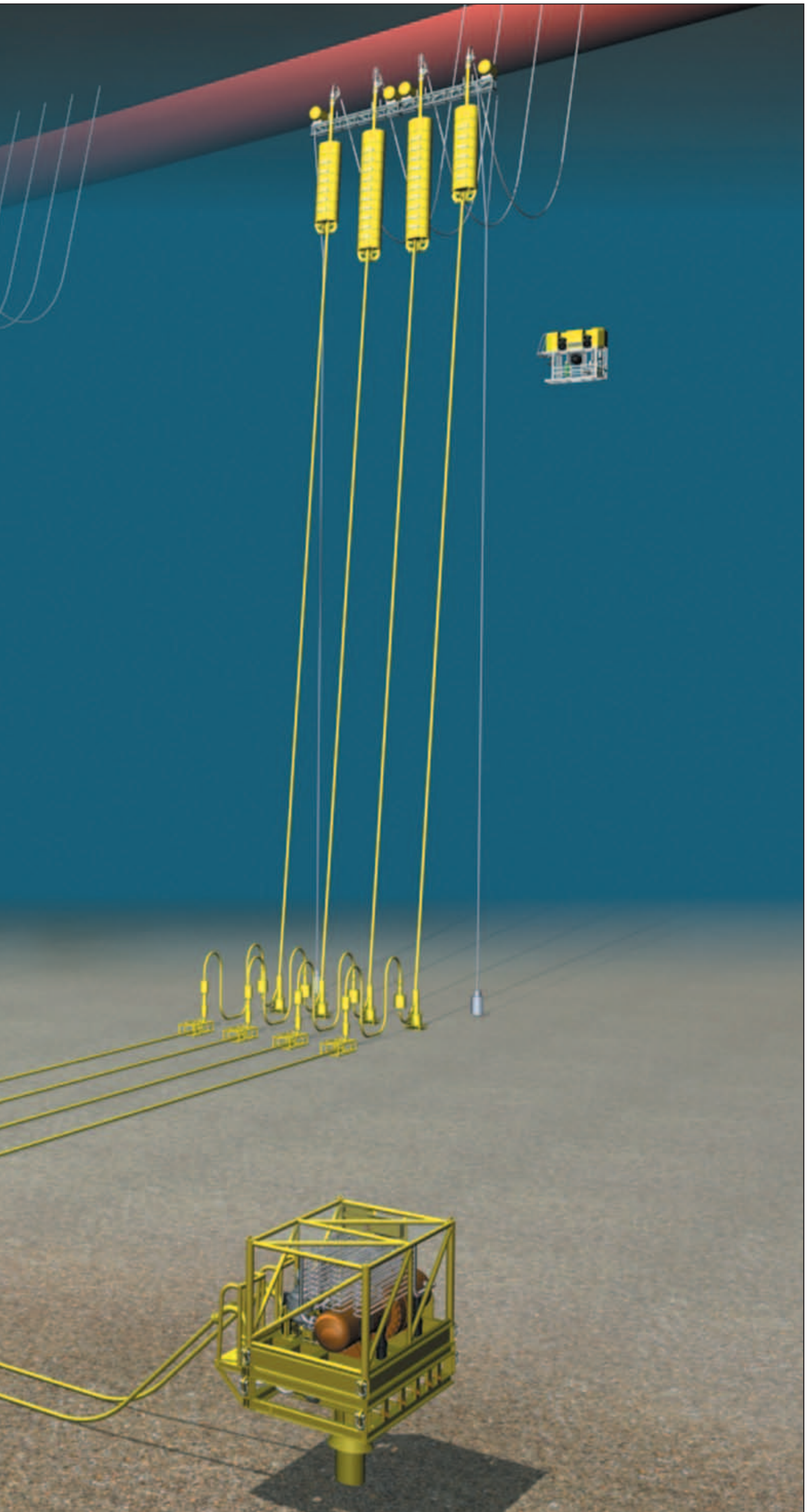
Lined up for success

Two leading companies in the subsea arena have joined forces to offer a new approach in deepwater riser technology that promises advantages throughout the life cycle of an offshore development. In this exclusive report, **Terry Knott** takes a close look at Grouped SLOR and talks to its developers.





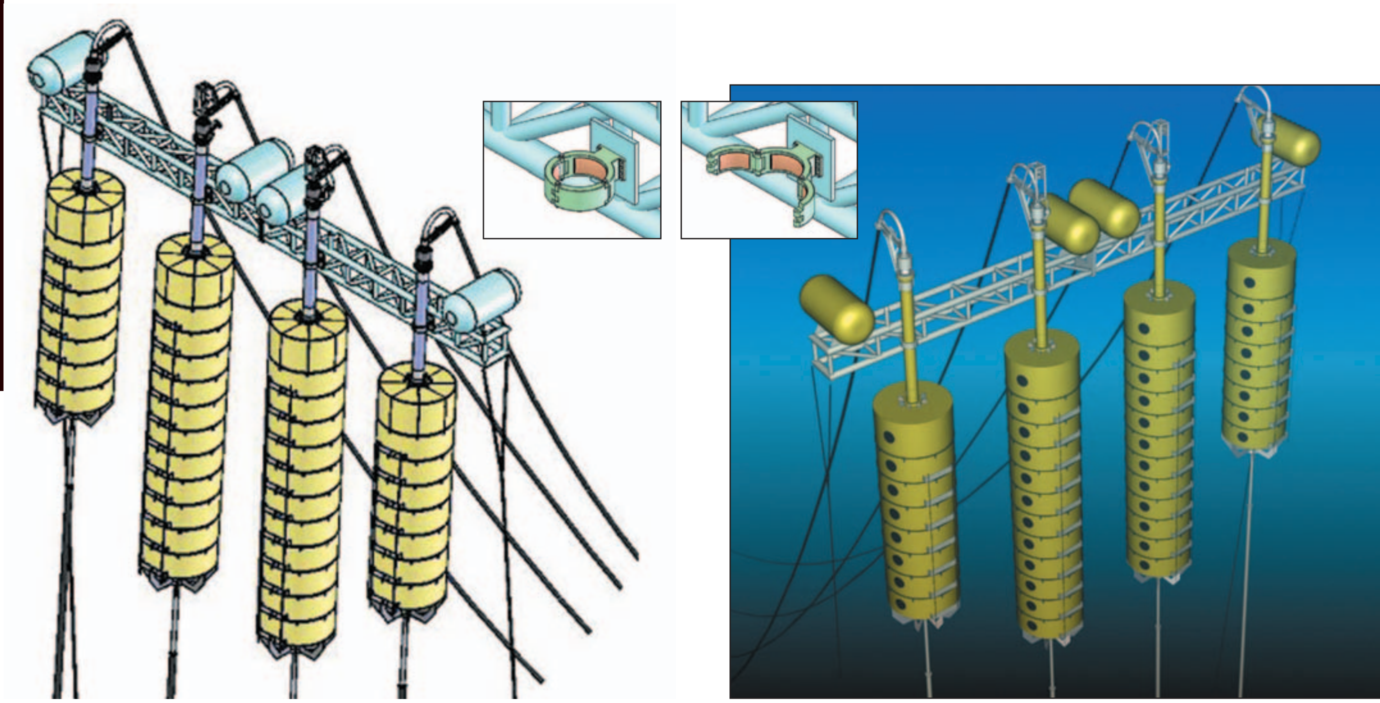
On occasion, an idea emerges in the offshore industry which by its apparent simplicity seems destined to succeed. It may be an absolute breakthrough, it may be an evolution of an existing concept, but either way it stands out. And when that idea is targeted at a technically complex and challenging operation – and retains its robustness as a solution – a quizzical 'why didn't we do it this way before' is likely to pass through the minds of seasoned observers.

One such innovation that is currently attracting increasing interest among operating companies is focused on deepwater risers. Developed over the past two years by riser specialist 2H Offshore in collaboration with subsea engineering and construction company Subsea 7, the concept – known as Grouped SLOR – has already rapidly advanced to the commercial stage of being actively considered for upcoming projects in the world's key deepwater producing regions.

'The Grouped SLOR concept is targeted at solving underwater congestion problems for offshore developments involving multiple risers connecting to an FPSO or semisubmersible,' explains Steve Hatton, managing director of 2H Offshore. 'Today's deepwater developments are using increasing numbers of risers and umbilicals to meet production and export requirements, which along with mooring lines and FPSO offsets, are imposing constraints on the location of risers. The essential goal is to avoid risking clashes or interference between them.'

By way of background, he points to the success that has been enjoyed by free standing hybrid risers in recent years, in both bundled and single line arrangements, which have been widely used in West Africa. Free standing risers decouple FPSO motions from the risers by using flexible jumpers between risers and vessel, providing good fatigue performance and the ability to be preinstalled, thereby taking riser installation off the project's critical path. But despite their many positive benefits, bundles and single line risers have some drawbacks when riser numbers start to head upwards – and riser numbers measured in dozens, connected to a single FPSO, are not uncommon now.

'Bundled risers can accommodate up to a dozen lines in a single structure, but practical problems arise at the top and bottom ends of the bundle,' Hatton observes. 'The large number of lines terminating in a small envelope presents problems in finding routes for flowlines and their associated rigid jumpers on the seabed, while also allowing for pipe expansion, movement and installation



A lightweight buoyant guideframe is used to align the risers in a close grouping such that no clashing can occur between aircans on the risers. Inset: An rov-operated receptacle clamp connects the risers to the frame, allowing the stem of each riser to move up and down within the receptacle to give independence of movement to the risers.

tolerances. For the dynamic flexible jumpers above the bundle, a spatial arrangement is needed not only for installation, but also for avoiding clashing between jumpers during operation as ocean currents impinge on the jumpers and the FPSO moves around. And during the field's life, getting access to any one of the risers in the bundle can mean that the whole bundle might need to be taken out of service.'

He speaks from experience, 2H having assisted in the design of the three riser bundle 'towers' for Total's Girassol field offshore Angola and also on the industry's first riser bundle in Placid Oil's Green Canyon block 29 project in the Gulf of Mexico almost 20 years ago.

When it comes to standalone risers, 2H has an undisputed pedigree since developing the concept – now trademarked – of the single line offset riser (SLOR) and its pipe-in-pipe variant, the concentric offset riser (COR), in the late 1990s. To date, 12 SLORs have been installed in ExxonMobil's Kizomba A and B developments offshore Angola with another due for installation this year for Petrobras' *P-52* semisubmersible platform in the Roncador field off Brazil. SLORs are presently in the running for another half dozen deepwater developments around the world.

'The SLOR has been very successful,' adds Hatton. 'But these too can present challenges as each one requires a large clearance between it and adjacent risers, umbilicals or mooring lines, sometimes limiting the number of risers that can be used. Compared with bundles, SLORs do provide easy access for operational intervention if required, but the space available can limit the addition of more risers for future staged development of the field.'

Group know-how

Driven by the industry's subsea layout challenges, 2H began working on a new way to bring together multiple free standing risers around two years ago. The concept that emerged – Grouped SLOR – appears eminently simple at first sight, but much engineering analysis, testing and know-how have gone into the idea.

In essence, Grouped SLOR optimises the riser/vessel interface and seabed layout by using a lightweight buoyant frame, tethered below the sea surface, to link together in close proximity an aligned group of single risers. This collectively constrains riser movement and eliminates the risk of clashing (*see diagram*). Bringing the risers together significantly reduces the overall space required compared to individual SLORs and removes many of the problems of routing of flowlines and jumpers associated with bundles, but preserves the advantages of the free standing riser concept in giving easy access to individual risers throughout the life of field.

'Grouped SLOR, which is now patented, could be called an open bundle hybrid,' Hatton points out. 'It is based on components which are field-proven already, and as such it is proving very attractive to operators as a solution for mid to ultra-deep waters.'

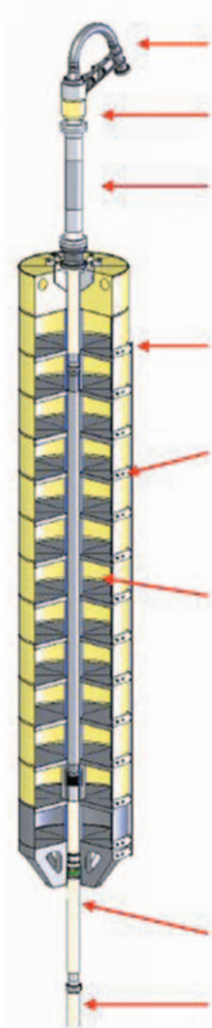
Soon after 2H began its conceptual development work, subsea contractor Subsea 7 came onboard to contribute its expertise in subsea installation, helping to ensure the design was both flexible and practical.

'We see Grouped SLOR to be a robust alternative to conventional riser bundles,' says John Mair, global technology manager for Subsea 7, who in February was personally acknowledged by industry body Subsea UK with an award for his individual contribution to the subsea industry (*OE* March).

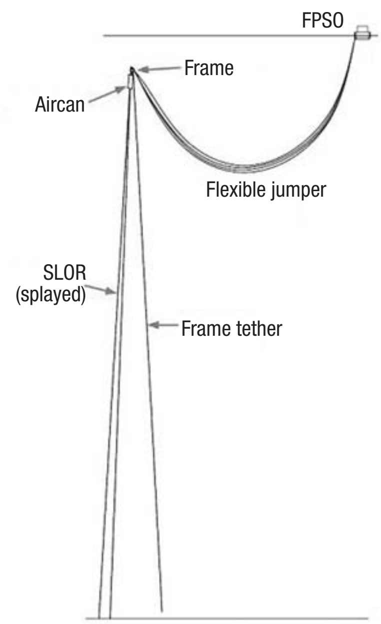
'It expands our existing portfolio of subsea riser solutions and provides us with a competitive edge in the free standing riser market. We have a collaboration agreement with 2H for the Grouped SLOR technology, and already this has allowed us to offer the concept for bids on several projects in the Golden Triangle – that is Africa, the Gulf of Mexico and Brazil.'

Subsea 7's participation accelerated the detailed development of Grouped SLOR, maturing the design and making it ready for inclusion in commercial bids within six months. The Grouped SLOR configuration for one of those projects – which presently must remain unidentified for commercial reasons – provides a typical description of the subsea hardware involved.

A lightweight tubular guideframe is the main differentiator between Grouped SLOR and individual SLOR installations. The frame, weighing 115t in air and measuring around 45m long by a few metres wide, is tethered by either spiral strand steel wire or polyester ropes, secured to suction piles in the seabed. The frame is fitted with horizontal buoyancy tanks, typically four, either air or syntactic foam-filled, which give the frame buoyancy to allow it to be stationed



LEFT: *Section through a compartmented aircan. The steel riser passes through the aircan and is fixed at the top of the stem. This transfers the buoyancy upthrust of the aircan to the riser to keep this upright and in tension. A gooseneck is used to make the connection between the riser and the flexible jumper leading to the FPSO.*



ABOVE: *Arrangement of risers, guideframe and tethers, and jumpers in a Grouped SLOR installation.*

50-100m below the sea surface – avoiding the faster ocean currents above. The buoyancy imparted by the tanks keeps the tethers taught, giving around 50t of tension at their base. Because the frame is buoyant, it can also be towed to the field, whole or in sections, and is easily installed by a light duty vessel.

Lined up along one side of the frame is a series of SLORs – four would be a typical number, although 12 risers in a line have been shown to be feasible by analysis. The SLORs are principally of the same design as individual SLORs – that is, a steel riser held vertically and kept taught by a large buoyant aircan at its top end. As an example, a 10in diameter riser – weighing around 400t in air – sitting in relatively shallow water of 800m, would be fitted with an aircan of 5-6m in diameter. The can would be 10-25m long, depending on the duty of the riser, with the aircan being sized to provide a tension of 150t at the base of the riser.

The riser passes through the centre of the compartmented aircan and into an elongated stem, around 0.8m in diameter and 10m long – a departure from the design of individual SLORs (*see diagram above*). The riser pipe is terminated inside at the top of the stem, which is where the aircan upthrust is transferred to the riser string to hold it upright.

'It is important to realise that the guideframe is not giving any support to the risers,' explains Nick Dale, senior engineer with 2H. 'If you removed the frame the risers would still be in position, held up by the aircans. A key feature of the design is the way that the elongated stem is connected to the frame, allowing the risers to stroke up and down individually in relation to the frame and one another, enabling the system to respond to vessel movement, temperature and pressure changes, and during the installation of the risers to the frame.'

Each aircan stem is held in a receptacle, bolted onto the frame and having two arms which close around the stem like a clamp. But the fit is such that the stem can slide up and down in the receptacle, its inner face being lined with wear-resistant ultra-high molecular weight polyethylene – similar to the upper stem design for a riser in a spar platform. Should the removal or replacement of a riser be required, the receptacle can be opened or locked closed by rov, without disturbing the adjacent risers.

Other components of the system – used already on individual SLORs – have also been proven in spar or top tensioned riser designs, says Dale, including the tapered keel joint and keel ball at the base of the aircan where large bending loads are experienced.

At the seabed, a latch assembly on each riser connects the riser to a foundation pile, like that for a SLOR, with an offtake arrangement connecting the riser to a rigid jumper and then to the subsea flowline. The fact that the riser is fixed at its base causes any expansion in the line to be upwards, taken up as the stroke in the aircan stem. Expansion in bundled risers is downwards, making design more difficult.

'The Grouped SLOR design gives a spacing between risers at the seabed of around 25m – aiding layout and installation – compared with only 2-3m for risers going into a bundle,' Hatton observes.

At the top of the riser at the aircan stem, a steel gooseneck reaching over the guideframe connects the riser to the flexible jumper leading to the FPSO, around 300m away – again similar to the offtake from a standard SLOR.

Testing times

Given that the main object of the exercise is to bring the risers into close proximity without clashing, how did 2H determine the spacing of the risers on the frame that would give clash free operation under all conditions?

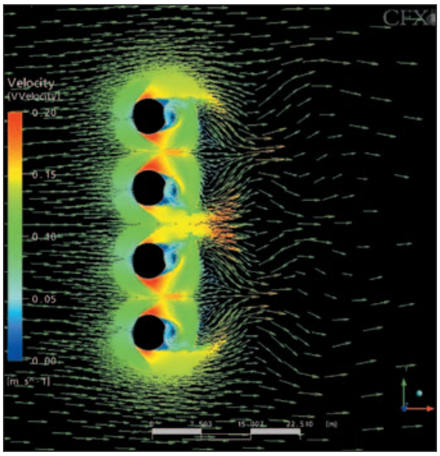
'We used three tools to prove the concept and determine critical parameters such as riser spacing,' explains Dale, 'namely structural finite element analysis, computational fluid dynamics, and model testing.'

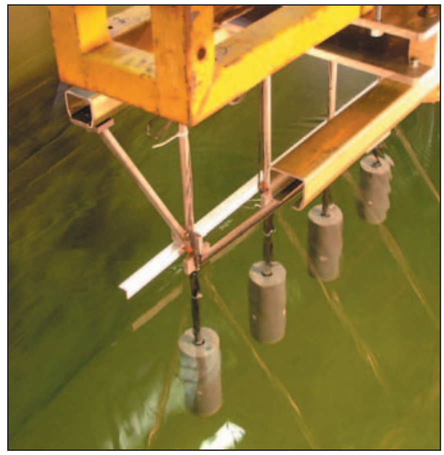
Finite element analysis of the Grouped SLOR structure demonstrated that the system is more stable than a standalone SLOR or COR, which have already been proven in operation to show excellent fatigue performance.

'If you take the combination of an extreme current loading and a failed mooring on the FPSO in 800m of water, the Grouped SLOR will experience a maximum displacement of 18m, compared with 20m for one SLOR,' says Dale. 'In 2000m of water, the frame moves laterally 120m, compared with 140m for a single riser. Furthermore, even in extreme conditions such as these, the greatest load which could be transferred to the guideframe is less than 10t, well within the bearing capacity of the polyethylene bearings.'

When connected, the risers 'lean' towards the frame at an angle of around 3.5°. This, plus the tension in the tethers, creates a stiff triangle that reduces the lateral movement of the frame.

Computational fluid dynamics (CFD) was used to evaluate the effects of the





*Testing and verification of the Grouped SLOR design included computational fluid dynamics modelling (*left*) and tank testing.*

aircans being close to one another, looking at the possibility of vortex induced vibration, random 'galloping' and other hydrodynamic effects. The CFD analysis confirmed that the maximum drag coefficient that can be experienced by the cans is less the 2.0, even assuming an infinitely long aircan – it requires a drag coefficient of 16.0 to cause the cans to clash, hence there is no possibility of this occurring in practice. The results were used to set the spacing between risers such that there is a gap between aircans equivalent to one diameter – around 11m between the centrelines of the aircans – compared to a space of perhaps 70m between individual SLORs.

Model tests of the riser grouping followed in November last year to confirm the finite element and CFD findings. The tests were carried out in a test tank by Marin in the Netherlands – Subsea 7 funding helped with these. Scaled tow tests were conducted for a range of current velocities up to critical Reynolds numbers, with the spacing of the aircans being varied too, revealing that the maximum drag coefficient likely to be experienced is 1.0-1.5 with an aircan spacing of one diameter, well within the values used in the finite element analysis. Should Grouped SLOR be selected for one of the deepwater projects now on the table, further tank tests will be performed to confirm the response of the entire system to wave and current loading.

Out in the field

When it comes to the fabrication of a Grouped SLOR system, the 'fabrication friendly' components lend themselves well to being built locally, says Subsea 7's Mair.

'Most of the components are welded, and items such as the riser pipeline, aircans, guide frame and bottom assemblies could be fabricated at local sites, perhaps more easily than those involved in riser bundles,' he notes. 'Typically these would be fabricated at any one of Subsea 7's spool bases globally. The more critical components, such as the taper stress joints for the keel and the connection latches, would probably be overseen by 2H, although the two companies will decide on the fabrication split on a project by project basis.'

At the end of 2006, Subsea 7 acquired specialist welding company Petrology, which is currently working on the steel catenary risers for the Blind Faith project in the Gulf of Mexico, and would very likely be involved with welding operations on Grouped SLOR developments.

The Grouped SLOR concept is particularly flexible for the installation phase too, as the risers could be towed to the offshore site, or reeled into place, or J-laid.

'We have considerable experience of towing long structures offshore, such as pipeline bundles,' adds David Bloom, Subsea 7 global business manager. 'Our new state-of-the-art rigid pipelay reel ship the *Seven Oceans* will be completed in June this year with the capability for reeling up to 16in diameter lines in 3000m of water and could install SLORs by reeling, and our newbuild pipelay vessel *Seven Seas* will include a J-lay tower that can also lay in up to 3000m, plus it has two underdeck reels for flexibles. This could carry the aircans on the deck and so the entire Grouped SLOR installation could be achieved with one vessel. *Seven Seas* will be ready in June 2008. As the installation phase of the earliest of the projects coming up in the Golden Triangle is 2009, we will be well placed to offer the full EPCI package in conjunction with 2H. The structure of the commercial tenders we are seeing these days requires us to have all flexibility in tailoring our bids to meet them.'

The *Seven Seas* was on the drawing board when Subsea 7 joined with 2H for development of Grouped SLOR. The vessel's design was influenced by the new riser method, notably in its moonpool and J-lay tower configuration. The company has also put much effort into making the connection between aircans and risers as 'hands off' a possible to enhance the safety of this part of the offshore operation.

On the question of cost, the developers point to the fact that the total installed cost makes the Grouped SLOR a highly competitive option. This cost represents a relatively small fraction of the overall subsea system including umbilicals, risers, flowlines and tie-ins, and is very small when compared with overall project costs.

'The real attraction of Grouped SLOR for operators lies in the operations phase,' concludes Mair.

'Unlike hybrid bundles, you now have the option to take a SLOR out of the group if, say, reservoir conditions change and a reconfiguration of the risers is desired. You can intervene for maintenance if necessary, and you don't have to commit to the life of field design up front – adding more SLORs to the group is possible as you have the layout space and it is a relatively easy operation.'

Subsea 7 and 2H are collaborating on new tenders, many of which appear to be well suited to the Grouped SLOR concept, and the two companies are looking ahead to refinements of the technology. It would appear that this is one of those good ideas that is ready to lay claim to its place in the pantheon of offshore successes. **OE**

Subsea 7's newbuild pipelay vessel Seven Seas *will be ready in June 2008, equipped with a J-lay tower that can lay in up to 3000m, plus two underdeck reels for flexibles. The design was influenced by the installation method for Grouped SLOR.*