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Abstract

The oil and gas industry is currently facing unprecedented challenges because of a negative impact from a declined commodity pricing trend. As the industry tackles deeper and more complex projects, the use of innovative technology to resolve technical challenges becomes an essential project enabler. Integrating proven designs and products with new technologies is a basic requirement in present business environment.

Companies are also underestimating the costs of completing projects, therefore they need to re-think established ways of working in order to better handle increasing project costs and complexity. This is now the time for companies to focus on efficiency to better insulate themselves from the runaway costs that have been a feature up until the oil price crash.

Cost efficiency of the project is driven by both technological breakthroughs and project management performance. A holistic approach to project management is now of paramount importance, meaning that all aspects of the project are to be taken into consideration from the beginning, ensuring that the project can be delivered on time, on cost and with certainty.

The aim of this thesis is to provide insights into multiple factors, which exert influence on a successful riser project delivery in the challenging conditions of deepwater, since it represents the largest source of energy supply growth in the near future. The best industry practices from recent major riser projects have been emphasized.

Acknowledgements

There are two very respected persons who empowered me to materialize this project. I hold them in great honor:

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My family is my treasure. I am much obliged to my parents, brother and sister and their families for energizing and keeping me going, for love and support. I am especially grateful to my parents, who have been helping me in all my initiatives along the life. Thank you!

In addition to all, I want to express my gratitude to Shyam Krishna Ramanan for the contribution to this project that he has made as an outstanding editor, adviser and friend.

This project finalizes the study in the University of Stavanger but kicks off the university of life that I feel extremely ambitious of!

Maxim Belik

Nomenclature

Abbreviations

3D	3-dimensional
ACM	Angular Connection Module
A&R	Abandon and Recovery
ALARP	As Low As Reasonably Practical
API	American Petroleum Institute
AUT	Automated Ultrasonic Testing
BG	British Gas
BP	British Petroleum
BSLM	Bend Stiffener Latching Mechanism
BSR	Buoyancy Supported Riser
BTM	Buoyant Turret Mooring
CAPEX	Capital Expenditures
CEO	Chief Executive Officer
CFD	Computational Fluid Dynamics
CMT	Cold Metal Transfer
COBRA	Catenary Offset Buoyant Riser Assembly
CRA	Corrosion Resistant Alloy
CS	Carbon Steel
CTQ	Critical To Quality
DFA	Design For Assembly
DFM	Design For Manufacturing
DFSS	Design For Six Sigma
DNV	Det Norske Veritas
ECA	Engineering Criticality Assessment
EDXA	Energy Dispersive X-ray Analysis
EPCI	Engineering, Procurement, Construction and Installation
FEA	Finite Element Analysis
FEED	Front-End Engineering Design
FiLeTS	Finance, Legal, Tax and Supply Chain

FMEA	Failure Mode and Effect Analysis
FPSO	Floating Production Storage and Offloading unit
FPU	Floating Production Unit
FSHR	Free Standing Hybrid Riser
GoM	Gulf of Mexico
HAZID	Hazard Identification
HAZOP	Hazard and Operability Study
HLV	Heavy Lift Vessel
HRT	Hybrid Riser Tower
HSSE	Health, Safety, Security and Environmental
ICT	Information and Communication Technologies
ITT	Invitation To Tender
LRTA	Lower Riser Tower Assembly
MOC	Management of Change
NCF	Norwegian Continental Shelf
NDT	Non-Destructive Testing
OMA	Operational Modal Analysis
OTC	Offshore Technology Conference
PA	Phased Array
PGMAW	Pulsed Gas Metal Arc Welding
PLET	Pipeline End Termination
PMCD	Pressurized Mud-Cap Drilling
PSA	Petroleum Safety Authority
PU	Polyurethane
RIM	Riser Integrity Management
RIT	Riser Installation Tool
RMS	Riser Monitoring System
ROV	Remote Operated Vehicle
RTM	Real Time Monitoring
SCR	Steel Catenary Riser
SIMOPs	Simultaneous Operations
SHR	Single Hybrid Riser
SLOR	Single Line Offset Riser
SLWR	Steel Lazy Wave Riser

SMYS	Specified Minimum Yield Strength
SPS	Subsea Production and Processing System
SSW	Spiral Strand Wire
SURF	Subsea Umbilical, Riser and Flowline
TDP	Touchdown Point
TDZ	Touchdown Zone
TIG	Tungsten-arc Inert Gas
TMIT	Top Mounted Internal Turret
URTA	Upper Riser Tower Assembly
US	United States
VIM	Vortex-Induced Motions
VIV	Vortex-Induced Vibrations
WAG	Water Alternating Gas

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1 INTRODUCTION

1.1 Background

Growing world energy demand will continue keeping oil and gas producers on the track of technology developments in order to enable successful discoveries of new production regions. It will be required of engineers to stay up-to-date with innovative technologies that could be applied in challenging deepwater regions with extreme environmental conditions. Technological breakthroughs and achievements would make the development of frontier areas possible.

The *frontier* nature can relate to the deeper reservoirs characterized by higher pressure and temperature. Alternatively, the *frontier* can be driven by location: remoteness from existing infrastructure or due to offshore projects commencing in the countries with a limited oil and gas experience. Very often a combination of these *frontier* aspects is represented in a single project that makes the execution more complicated.

Through the last decade the oil and gas industry has successfully explored and produced from water depths up to 2500 m. But with the Shell's Stones project expected to produce first oil in 2016 in 2900 m water depth, the industry has closely approached to new frontier areas with water depths exceeding 3000 m. The emerging deepwater frontier areas, which represent an operating environment in the near future include:

- The Western Gulf of Mexico;
- Offshore Brazil;
- East of Canada;
- Areas of Western and Eastern Africa, which are additionally challenged by significant local content requirements;
- New gas production regions of offshore Australia;
- Offshore Eastern India and Malaysia.

The successful development of frontier projects is in great dependence on innovative technologies and the competence of companies.

- More challenging environment require high technical requirements imposed on the subsea system elements. Thus, breakthrough technologies are highly desired for engineering of robust elements to enable new fields to come on-stream in the coming decades.
- The frontier's specifics add to the project complexity, which leads to facing unavoidable challenges during the project execution. Hence, for companies to handle these challenges, considerable engineering experience, expertise and managerial capabilities are required.

1.2 State of Art

1.2.1 Technical constituent

When oil is discovered, the technical and economical feasibility study of the field is initiated. It necessitates a reservoir data acquisition campaign in order to form a database for the oil field development study. Oil field development study comprises the following conceptual considerations: subsea production system, flowlines, riser system and Floating Production Storage and Offloading (FPSO) unit.

A subsea production system consists of wells completed below the sea surface, seabed wellheads, subsea production trees, subsea tie-ins to flowline systems, subsea equipment and control facilities to operate the well (Bai & Bai, 2012). The well system configuration is a core aspect of field development plan. Production and injection wells are drilled to establish a suitable layout to enable efficient field productivity and are designed for field specifics to fulfill operational requirements. Multiple jumper connections, manifolds and in-field flowlines are coupled with the arrangement of wells to form a subsea network.

An FPSO is a ship-shaped vessel held in location by a mooring system, the topside facilities consist of independent modules and auxiliary structures, which make up one or several process trains. The FPSO is considered to be a suitable field development solution for the deepwater areas in environments, which lack for existing marine pipeline infrastructure. The vessel is generally characterized by its processing and storage capabilities.

Subsea production system, flowlines and risers carry the produced fluids from the wells up to the host vessel. The processing starts, when the fluid reaches the deck and enters the FPSO facilities. Once it is processed, the oil is stored in tanks of the hull, await to be offloaded to a shuttle tanker, while the gas is transported through a single line to the shore or injected back to the reservoir in order to maintain the pressure or used for the energy needs of the vessel.

Flowlines and risers are major components of the subsea transportation system, which link the wells to the FPSO. Depending on the field requirements the system may need to transfer the following to or from the vessel:

- Well fluids;
- Injection fluids including gas, water and chemicals;
- Export gas (and possibly export oil);
- Utility and control fluids including hydraulics, air and heating media;
- Electric power, communication and control signals.

1.2.2 Current demands

Over the last 15 years, the industry has developed and implemented plenty of riser systems all over the world. The systems can significantly vary from one project to another, since a wide range of parameters drives the riser configuration. Offshore projects of Brazil can serve as a good example of how a number of challenging projects came into existence within just a couple of years, thanks to innovative technologies and advanced managerial approach. Pre-salt field developments have incorporated a plenty of "know-how" solutions, which allowed Petrobras to get recognized and become a corporate award winner at Offshore Technology Conference (OTC) in 2015 (Otcnet.org, 2016). The oil and gas production in this challenging environment demanded the development of different riser systems, which were successfully applied and are now available for the industry.

Risers are ducts leading oil or gas from the seabed to the platform. Buoyancy Supported Riser (BSR) is a riser concept with a higher fatigue performance than conventional risers. The buoys are installed at a point about 250 meters below the sea surface in order to sustain the risers that are connected to subsea pipelines. With this configuration, the movement of the floating platform is not transferred fully to the rigid risers, reducing the damage because of fatigue and ensuring longer life span in severe conditions. The first four buoys of this type were installed in the pre-salt Sapinhoá and Lula fields in 2013/2014 (Fig. 1.1).

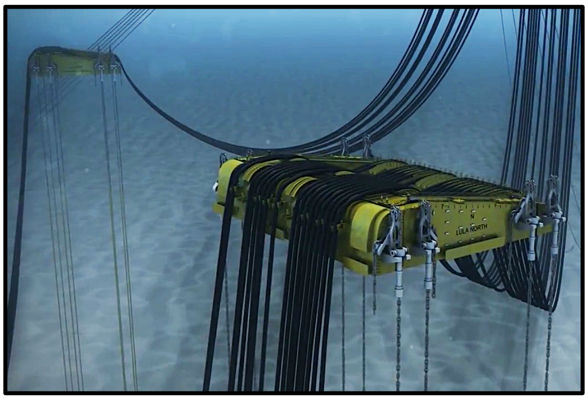

Fig. 1.1 Two BSR systems, Lula field (Petrobras.com, 2016)

The flexible riser is a multilayer pipe comprised of metallic and polymer materials placed one on top of another. In 2014 thirty-five flexible risers were successfully installed in the Lula field (Iracema South project) in a very challenging water depth of 2220 m (Fig. 1.2) (Petrobras.com, 2016). The project development was accomplished with the first application of highly

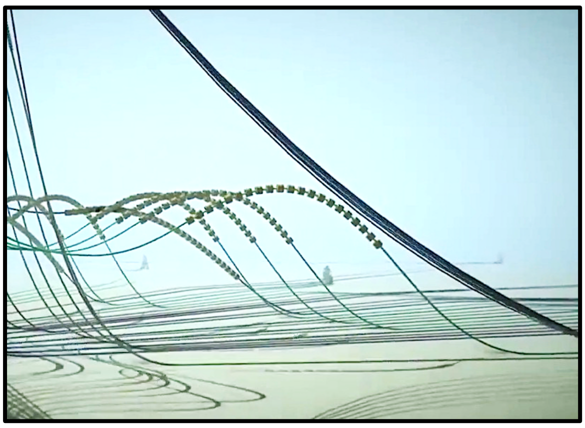

Fig. 1.2 Flexibles, Sapinhoá field (Petrobras.com, 2016)

technological flexible pipes with integrated monitoring system. Flexibles are inherently designed to be maintenance free, whereas incorporated monitoring technologies facilitate a prediction of future performance.

Another pre-salt field, Sapinhoá North, was developed with application of Steel Lazy Wave Risers (SLWR) for production and gas injection lines. SLWRs are steel risers installed with a set of mid-water buoyant elements that form a humped configuration and are connected directly to the floater. This is the first system of its kind in the world to be connected to a spread-moored FPSO. Moreover, 2140 m was the greatest water depth ever achieved for this type of riser installation at that time – Q1 2015.

Additionally, the Sapinhoá North's gas export system utilized a Free Standing Hybrid Riser (FSHR) concept for the first time in the pre-salt cluster. The FSHR consists of a vertical steel pipe tensioned by a near-surface buoyancy can. The connections to the floater and Pipeline End Termination (PLET) at the seabed are established through the flexible and rigid jumpers respectively (Fig. 1.3).

Successful developments achieved by Petrobras are not only a combination of innovative solutions with field-proven technologies, but most of all, an approach of all stakeholder companies to re-think the way projects are implemented and find the balance between direct and indirect activities influencing the project delivery.

Recently in the pre-salt layer, the production records have been frequent. The annual average production in the pre-salt in 2015 was the largest in the Petrobras's history: 767 000 barrels per day, exceeding production in 2014 by 56%. In May 2016, Petrobras reached the mark of 1 000 000 barrels of oil produced in a single day (Petrobras.com, 2016). These represent a significant milestone in the oil industry, since the fields are located in deep and ultradeep waters.

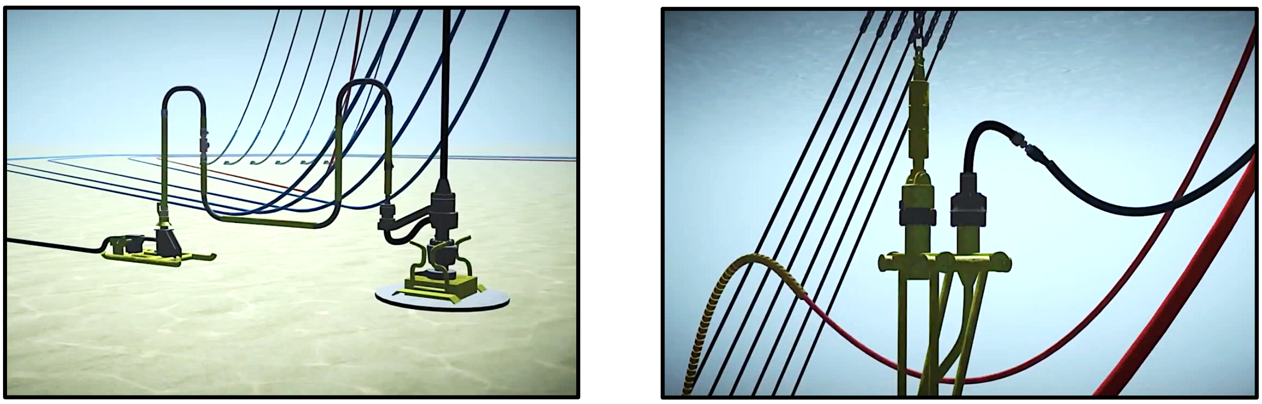

Fig. 1.3 Lower and upper arrangement of FSHR, Sapinhoá North (Petrobras.com, 2016)

1.3 Scope and Objectives

The scope of this thesis project includes:

- Literature review of recent projects: fully covering the tendering stages and project execution activities;
- Study of recent projects: seeking for the best industrial practices and establishing typical challenges encountered during the project delivery;
- Identification of core execution activities, with the focus on engineering and managerial aspects;
- Analysis of industry current demands and needs.

The main objectives are:

- Understand the parameters, which influence the selection of a riser concept;
- With reference to recent projects, identify the principal activities and decisions that took place in order to successfully follow the projects up;
- Highlight the key factors, which lead a riser project delivery to success, in terms of managerial and engineering practices.

2 RISER SYSTEMS

Riser system is designed to serve as a conduit for transporting gases and fluids either coming from the marine production facilities up to the floater or pumped down for injection purposes.

All riser concepts can be roughly split in two groups: coupled and uncoupled. The group of coupled systems comprises risers, which directly connect seabed facilities to the floater, where the floater's dynamics is transferred directly to the riser. On the other hand, the uncoupled risers are linked to the floater through intermediate mid-water structures, which reduce the impact of the floater motions on the riser.

2.1 Coupled concepts

2.1.1 Flexible riser

A flexible pipe is one comprised of layers of different materials where each layer serves a certain function while working together to be leak-proof and provide a reliable conduit for well fluids. Hence, a flexible pipe is more technologically complex than a rigid metallic pipe.

A flexible pipe is made up of several different layers (Fig. 2.1). The main components are leakproof thermoplastic barriers and pressure-resistant steel wires. An internal interlocked carcass serves as a resistance to sand erosion and hydrostatic collapse. Helically wound steel wires provide with excellent bending characteristics and strengthen the structure to resist against high-pressure. Anti-wear tapes are laid between the steel layers to prevent excessive wear. Two thermoplastic sheaths serve to ensure fluid containment (internal layer) and to protect metallic layers from seawater ingress (external layer). This modular construction, where the layers are independent, means that each layer can be made fit-for-purpose to optimize structural design according to field's specific operational requirements. In most cases the flexible risers are configured in some form of "hump" to absorb the platform motions (Fig. 2.2).

Fig. 2.1 Cross-section of flexible riser (Muren et al., 2013)

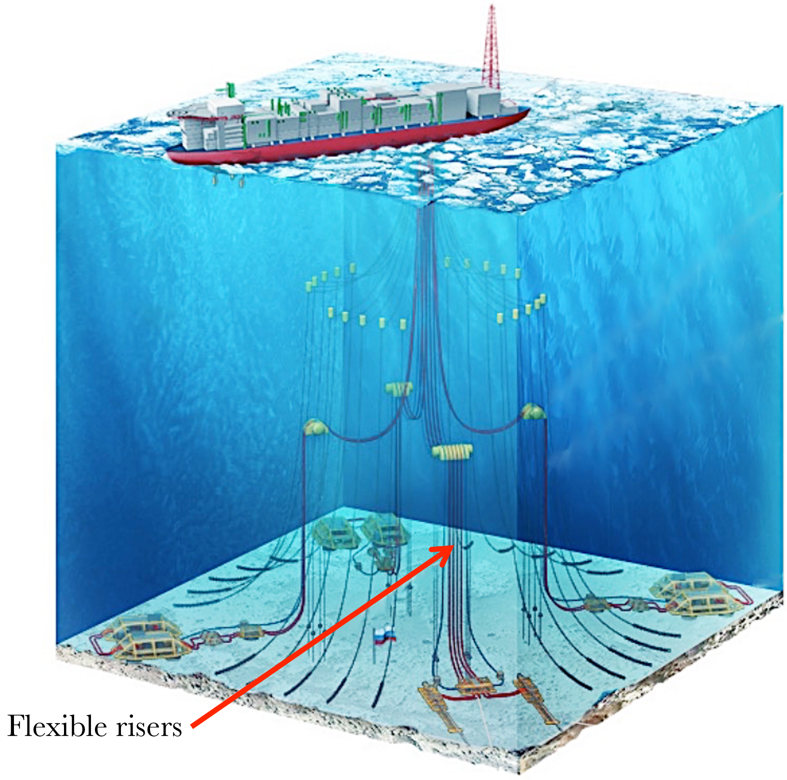

Fig. 2.2 Shtokman field concept, Barents Sea (Russia) (Shtokman.ru, 2016)

In a report delivered to the Petroleum Safety Authority Norway (PSA) by 4Subsea company, it is emphasized that the failure rate is substantially higher for flexible risers compared to rigid steel risers. Referring to the statistics for 2010-2013, as of 2013 in the Norwegian Continental Shelf (NCF) there were 326 flexible risers operating with a 1.5% probability of failure per riser per operational year (Muren et al., 2013). Thus, the field experiences clearly demonstrate that there are good reasons to be concerned about the robustness of flexible risers. Due to these problems, integrated monitoring methods such as an integrated "fiber optic system" for monitoring of tensile wire rupture are under development, and some of these innovation solutions being relatively new have a limited operational experience and are yet to gain full acceptance; once such integrated technology was utilized in the pre-salt field development in offshore Brazil (Leira et al., 2015).

The current deepest installation of flexibles is about 2200 m, but the water depth applicable for the use of flexible risers is up to 2500 meters (Clevelario et al., 2010) - the study was carried out by Wellstream as part of its research and development program established in 2008, which focused on the development of a new generation of flexible pipes specifically designed for the Brazilian pre-salt cluster. Besides, very shallow waters pose a challenge as well. In Vietnam, where water depths of less than 50 m is often encountered, vessels are subject to more significant relative displacements, which lead to the excessive riser motions and high tensions induced in the risers (Hanonge & Luppi, 2010).

2.1.2 Steel Catenary Riser (SCR)

SCR is a relatively simple system where the riser hangs off the floater and extends to the bottom, where it is in continuity with the flowline. At the top, a flexible joint represents the hang off interface, as part of the hull, to connect the riser to the platform. On-bottom configuration can be represented as a piled foundation with the integrated riser-flowline connection, but often a SCR is just an extension of a flowline, hence it is easier to fabricate and install. SCR is made of rigid pipes of standard length welded in a line.

The resultant riser configuration is a compromise between tension at the top, maximum bending stress at the touch down point and risk of interference with adjacent structures (Quintin et al., 2007). The design is additionally optimized by major fatigue considerations of Vortex-Induced Vibrations (VIV), soil-riser interactions and flow assurance requirements.

The concept is attractive for its simplicity and cost effectiveness based on considerable industrial experience. The major disadvantages are high sensitivity to fatigue due to extensive dynamics and hang-off loads significantly increasing with the water depth. Moreover, there are potentially buckling issues in the Touchdown Point (TDP) area induced by the downward vertical motion and hydrodynamic reaction. These design challenges can be successfully addressed by introducing a SCR concept with varying weight along the riser (Karunakaran et al., 2013).

The Weight Distributed SCR is a concept, which enhances the applicability of SCRs to harsher environments. In this concept, ballast elements are attached to certain near-bottom sections to reduce stresses around the TDP and hence enhance the fatigue resistance to avoid buckling.

2.1.3 Steel Lazy Wave Riser

SLWR is a compliant form of SCR fitted with the buoyancy modules at its lower section to form the “wave” configuration. The use of buoyant elements improves the fatigue performance making it less susceptible to the heave motions of a host platform, which extends the utility of SCRs for deepwater harsh environment.

The first SLWRs were installed in 2007/2008 at BC-10 in Brazil, and then the Caesar-Tonga oil field was developed with application of steel lazy wave risers tied back to the spar platform in 2011/2012 to be the first of its kind in the Gulf of Mexico (GoM) (Fig. 2.3). The Shell’s Stones is an ongoing project with the SLWR system designed for 2900 m water depth (van Beurden, 2016).

Since the fatigue issues are one of the major design concerns, a number of various fatigue sources must be considered. For instance, with regards to the Caesar-Tonga field development case, the major design issues are: waves and wave related vessel motions, hull Vortex-Induced Motions (VIM), heave-induced VIV, riser VIV and installation-induced fatigue (Lahey et al., 2013).

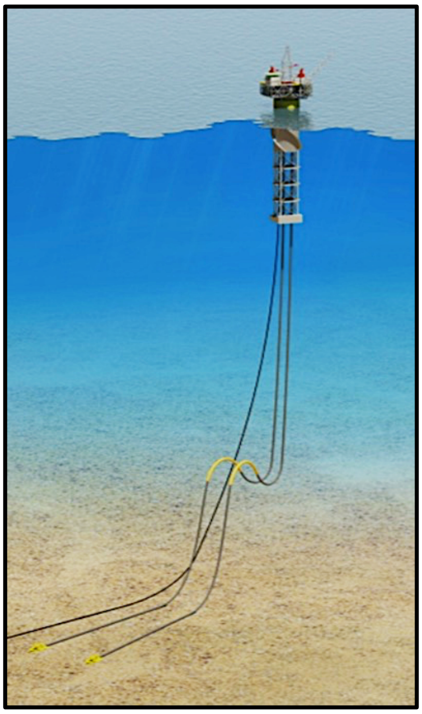

Fig. 2.3 Two SLWRs, Caesar-Tonga (GoM) (Lahey et al., 2013)

The SLWR concept is one of the most attractive riser systems for a turret-moored FPSO development for the following reasons:

- The ability to withstand large floater motions;
- SLWR is less sensitive to floater offsets;
- Reduced loads on the turret compared to free hanging SCR or flexible riser;
- More robust design strength and fatigue.

The shortcomings:

- Large footprint; it raises interference issues and adds potential risk of damage by fishing gears;
- The riser requires interfacing at the top-end and fatigue of the "hump" section because of slugging; this needs to be addressed very early in the design.

2.2 Uncoupled concepts

The key feature is a decoupling between Floating Production Unit (FPU) and the riser itself, it allows for reduction of the loads transmitted onto FPU, whilst the fatigue cycling at the steel riser components is significantly reduced, thus, a greater fatigue performance is achieved.

The first campaign for the development of a new "decoupled" concept dates back to early 90's, when DeepStar, a joint industry initiative, was established. Since that time, a considerable growth in the number of deep and ultradeep water oil and gas fields has complemented the existing portfolio of technical riser solutions. Being inspired by new discoveries the industry has extended the application of steel catenary risers in harsh environment and developed a number of hybrid riser concepts incorporating both steel pipe and flexible pipe technologies.

2.2.1 Single Hybrid Riser (SHR)

SHR incorporates only one steel riser of vertical geometry provided by the buoyancy tank (Fig. 1.3, 2.4). Connection to FPSO is made up by a flexible jumper, which is attached to upper assembly. Lower assembly provides connections to flowlines and is attached to foundation.

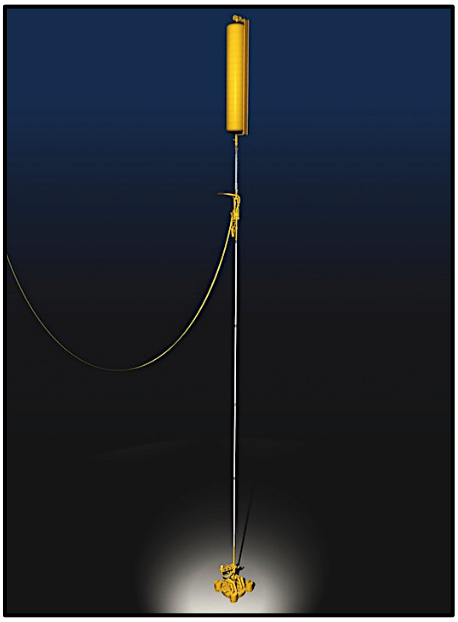

Fig. 2.4 SHR (Subsea7.com, 2016)

If SCR concept is compared to SHR concept in a typical application in West Africa in 1700 m water depth, than SHR concept is of higher cost than SCR by a factor of about 2, but it has lower hang-off loads than SCR by a factor of about 4. SHR system is more complex with a high degree of interaction with the FPSO. SHR also poses delivery challenges due to long lead forged items and qualification testing. The riser support buoy is typically large and usually requires Heavy Lift Vessel (HLV) for installation. Besides, the safety requirements add the following limitations: the buoy should not be located under the vessel or in corridors used for offloading or support boat operations. (Seguin et al., 2016)

2.2.2. Hybrid Riser Tower (HRT)

HRT consists of a number of steel risers bundled together and straightened up, it is opposite to SHR, which incorporates only one steel riser but with all remaining configurations being essentially the same. The buoyancy tank provides uplift load to the riser-tower and makes it self-standing. The bundle allows 6 risers (recommended maximum, but up to 11 as on the Greater Plutonio project) to be gathered and fixed by guiding frames. Upper and Lower Riser

Fig. 2.5 URTA and LRTA, CLOV project (Subsea7.com, 2016), (Proust et al., 2015)

Tower Assemblies (URTA and LRTA) ensure reliable connections with all flowlines, with the buoyancy tank and the suction anchors (Fig. 2.5-2.6, 3.3). Flexible jumpers make up the fluid connection of each rigid riser to the vessel, while effectively isolating the riser tower from the

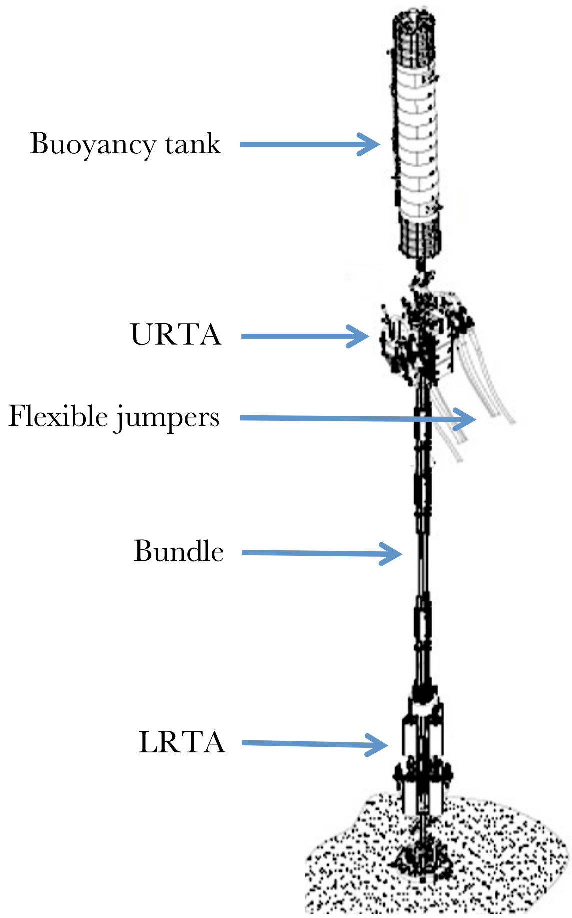

Fig. 2.6 HRT assembly, CLOV project (Proust et al., 2015)

vessel dynamics.

The concept has a clear advantage of a compact field layout that reduces the risks of interferences. The HRT is fully fabricated onshore, but a specific fabrication site is required. Usually there is no mandatory requirement for a more expensive construction vessel, since a towing installation method is used for installing the tower, but a HLV may be required for a buoyancy tank installation. All existing HRTs have been manufactured by sections, which were fabricated and stored floating in a sheltered bay until a final tie-in operation takes place.

The HRT concept was pioneered by Cameron Offshore Engineering for the Green Canyon 29 installation in the Gulf of Mexico in the late eighties (Fisher & Berner, 1988) and further developed in 2000's. By the time a HRT configuration was sanctioned for the CLOV project and delivered by Total in 2014, five Hybrid Riser Towers had already come into operation – at Girassol (2001), Rosa (2007) and Greater Plutonio (2008) fields. Meanwhile, the first SHR system was developed for the Kizomba field that has been on-stream since 2004. All five of the HRT projects mentioned above are from the Angolan oil fields. SHRs are also notable for their successful applications in projects in West Africa.

2.2.3 Grouped SLOR (Single Line Offset Riser)

The SLOR is another modified concept of the Single Hybrid Riser concept. The grouped SLOR concept (Fig. 2.7) consists of 2 or more SHRs extending from the seabed arrangements and with upthrust provided by air cans (or syntactic foam) placed on their tops. The risers are closely grouped and connected together by a buoyant guide frame constraining them to move collectively. The flexible jumpers enable a FPU connection to the top of each SHR assembly. About a decade ago Subsea 7 performed a qualification program and confirmed the robustness of the grouped SLOR concept and design, which is applicable for deepwater environment (Karunakaran et al., 2009).

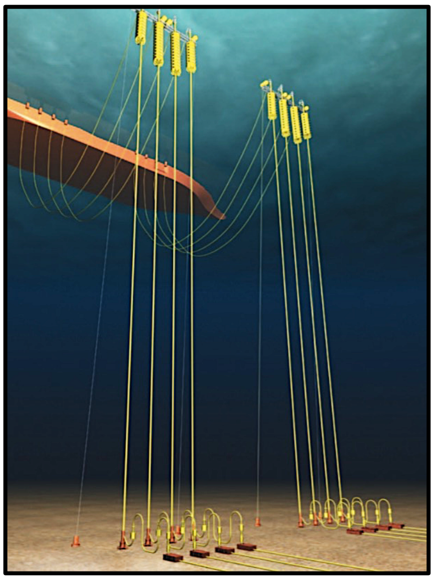

Fig. 2.7 Grouped SLOR concept (Offshore Engineer journal, 2007)

It is a well-developed arrangement and an appropriate riser solution for congested fields, where space is limited but high productivity is of paramount importance. The materials and technology, which are in use at the present moment, provide sufficient field proven validation for the Grouped SLOR concept in being a robust design concept. The installation starts from the guide frame: it is towed to the location and then tethered to seabed via suction piles. The installation of risers follows next; they can be installed by a number of methods: tow-out, reel-lay or J-lay. The connection jumpers can be pre-installed prior to the floater arrival, which is a beneficial advantage. Further, the concept offers the flexibility to install and remove risers individually.

2.2.4 Buoy Supporting Risers

In mid 90's Petrobras initiated its own "decoupled" concept development program and in 2001 the company filed a patent. Later on, in 2009 the first prototype was successfully installed in the water depth of 500 meters in Congo (Hiller et al., 2015). The resultant concept was fully engineered within the scope of Sapinhoá and Lula projects (Fig. 1.1, 3.7-3.8). The final concept utilizes a submerged buoy for hanging SCRs at a certain level of 250 meters below the sea surface. The buoy is an intermediate interface to link steel risers with flexible jumpers extending from the buoy up to the floater. It accommodates the hang-off arrangement of steel risers coming from a seabed and various connection facilities of the jumpers providing a smooth joining to floater processing installations. The system has the advantages of improved fatigue performance because flexible jumpers effectively absorb the floater motions that allow the SCRs and tendon to have a reduced dynamic excitation.

In 2013/2014 the first four BSR systems were installed in more than 2100 m water depth, bringing to life a novel riser system for ultradeep water field developments (Cruz et al, 2015).

2.2.5 Catenary Offset Buoyant Riser Assembly (COBRA)

The concept consists of a catenary riser section with a sub-surface buoy arranged on top, which is tethered down to a suction anchor with an inclination of 7^0 (Fig. 2.8). The buoy is positioned at appropriate depth of 100-200 m, depending on field environment, to reduce

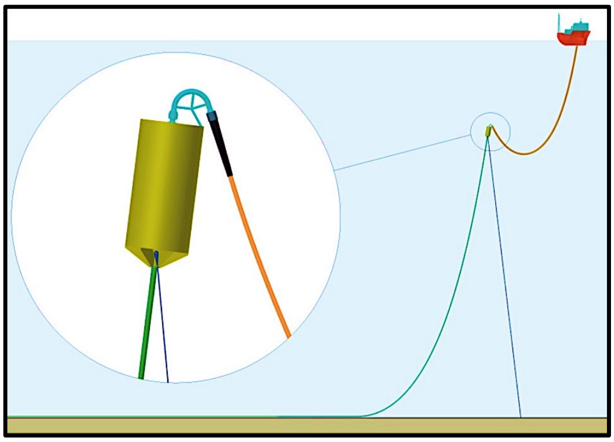

Fig. 2.8 COBRA arrangement (Karunakaran & Baarholm, 2013)

surface wave and current effects on the catenary section, whilst a flexible jumper connects the top of catenary riser section to the host platform. The concept combines the advantages of SCR and hybrid riser towers: it eliminates fatigue and buckling problems at TDP that is peculiar to SCR and avoids complicated bottom assemblies, which are specific for hybrid riser towers.

COBRA was developed by Subsea 7 in cooperation with Statoil for the harsh Northern North Sea conditions. Through extensive dynamic response analyses it was found that this riser concept has robust strength and fatigue behavior: it has been developed to be deployed at the three depths of 750, 1500 and 3000 m and has been proved to be feasible for application. (Karunakaran & Baarholm, 2013)

Offshore oil field conditions vary from one location to another, in terms of water depth and environment. Thus, the decoupled hybrid riser systems can be adaptable for various parameters such as water depth, prevailing waves and currents and different velocities over the whole water column. The main hybrid riser parameters that allow adaptation are the following:

- Depth of buoyancy modules: larger depth assures a better protection from effects of waves and surface current;
- Upthrust of buoyancy modules: larger tension increases the resistance to horizontal loads induced by the floater offsets and deep currents.

Hybrid riser concepts have been an attractive choice for recent deepwater field developments and still represent a vital interest for future application.

Subsea riser design is the most challenging engineering aspect of a deepwater field development. The variety of technical and commercial parameters for given metocean conditions, production and local content requirements drive the selection process. A well performing riser system is a result of the comprehensive analyses of influencing factors based on thorough studies and optimization processes.

3 REMARKABLE DEEP WATER PROJECTS

A decade ago there were a few fields operating in ultradeep water with the depth exceeding 1860 m (a depth threshold, when the water is already considered as ultradeep, as per API 2006). But much has changed since then owing to furthering of technological frontiers and industrial developments, which are driven by oil and gas industry among other industries. At the present, depths over 2000 m already do not seem to be so untypical for offshore projects.

After major discoveries made in the pre-salt fields offshore Brazil (2000-2500 m) the industry has extended its interest in deepwater: from Guyana to Uruguay in the Western Atlantic and from Ivory Coast to Angola and even Namibia in the Eastern Atlantic. The Western Gulf of Mexico, Offshore Eastern India and Malaysia are other attractive regions with already ongoing or planned exploration campaigns. The following review of four projects, three of which have been completed and the fourth, the Stones project, is under way, will demonstrate the achievements of industry, which have found a proper base for future projects.

3.1 BC-10

Parque das Conchas (BC-10) project is a major milestone in the development and commercialization of Brazil's deepwater oil. The project comprises four fields tied back to a centrally located FPSO vessel, the Espírito Santo (Fig. 3.1), moored in water depths of about 1800 meters. In 2009 Subsea 7 successfully installed 7 steel catenary lazy wave risers of total length 21 km completing phase 1 of the field development. The third phase of this project was put into operation in March 2016.

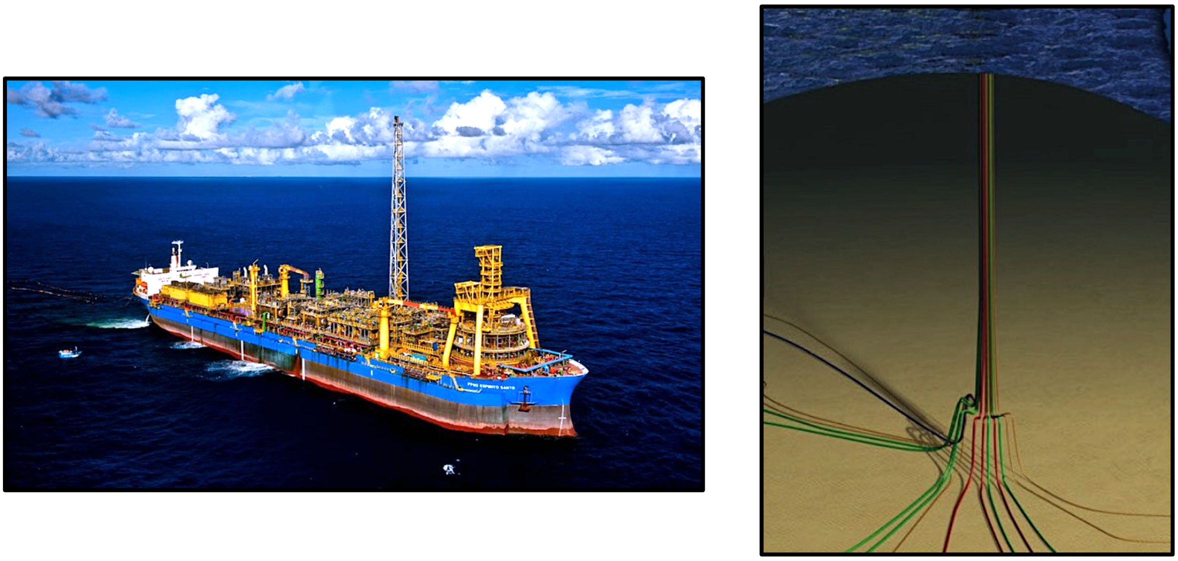

Fig. 3.1 FPSO Espírito Santo and BC-10 riser system scheme (Stingl et al., 2010)

The project is notable for its first use of SLWR in the industry, and the first time a steel riser system of any configuration has been used with an internal turret mooring system. The FPSO began oil production in July 2009, and now has over six year's optional experience. During this period, inspection of the riser system and the associated flexjoints has confirmed the integrity of the design, giving further confidence in the use of steel risers in turret-moored systems (Newport et al., 2014).

The challenging conditions of ultradeep waters in the Campos Basin initiated the study to improve fatigue performance of steel risers and to reduce loads imposed on the FPSO. Shell successfully developed the design of risers and umbilicals with a "world's first" configuration, where the buoyancy elements were to be attached to the sagbend region of risers to achieve a "lazy wave" configuration providing better responses to FPSO motion in harsh environmental conditions, thereby improving the fatigue life of risers.

The design process used for SCR risers was also employed for the SLWR. Riser design is complicated by nature and with the addition of the buoyancy the analyses become even more challenging. Through the investigation of main parameters such as riser stresses, top angular rotations, VIV response, fatigue, amount of distributed buoyancy required and interference, the buoyancy length of risers has been determined using numerical methods to be about 350 meters for two of the risers and 500 meters for last five with the strakes length 800 and 1000 meters respectively. Simultaneously, a new riser termination interface was designed (described in Chapter 4). (Thomas et al., 2010)

3.1.1 Fabrication and installation phases

The pipeline, flowline and riser installation method selected for the project was the reel-lay method. A significant feature of this method is that the preparatory works are completed onshore where weather is not critical. At the spoolbase (Fig. 3.2), insulated pipes were welded to form "stalks", the pipe strings of predetermined lengths, following which all stalks were

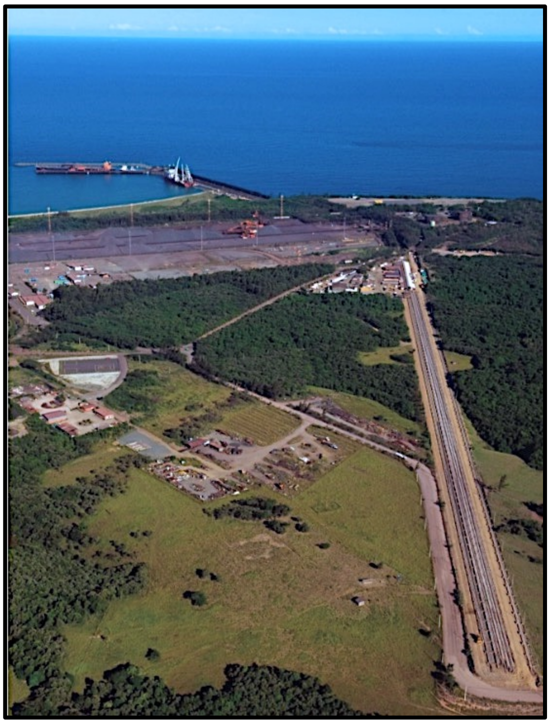

Fig. 3.2 Subsea 7's Ubu spoolbase (Hoffman et al., 2010)

piled up and kept ready for loading operation upon arrival of the pipelay vessel. As one stalk is reeled onto the pipelay vessel, a consecutive stalk is lined up and welded to the first one. The process is repeated until the desired pipeline length has been loaded onto the reel. (Thomas et al., 2010)

The welding process was one of the major challenges faced in this project. The overall scope was excessive: 11 000 welds and 15 months of total stalk fabrication were required during the project. The welding process was complicated because of the utilization of various diameters (6-10 inch), wall thicknesses (15.9-25.4 mm) and coating types, which required differing requirements for initial allowable flaws and inspection procedures. The welding process selected for the risers was fully automatic. The chosen Tungsten-arc Inert Gas (TIG) welding was not the fastest one, but it was deemed to have a better overall quality when compared to other possible welding processes. (Thomas et al., 2010)

The extensive demands for fabrication and installation procedures extended the required weather window and provided with better technical opportunities to abandon the riser in case of adverse weather conditions. Another advantage of the SLWR was that the installation of risers did not require the presence of FPSO nearby ensuring field development to be continued in case of late arrival of FPSO.

The entire pipelay campaign was completed in nine months including time for transits, mobilizations for pipe spooling, loading equipment, deck reconfiguration, re-fuelling and delays due to weather. Performing extensive up-front analyses and specific detailed analyses based on actual site observations and short-term weather forecasting helped mitigate delays due to weather. Some risers were installed full of water to improve vessel weather performance. (Thomas et al., 2010)

3.1.2 Execution challenges

The installation phase of the BC-10 project experienced the following challenges (Thomas et al., 2010):

- Demand for development of a detailed subsea layout description and installation sequence to reduce risks of potential clashes;
- Stability control of the "hump" section when laid down on the seabed. Since SLWR has a very long buoyant section, it requires the "hump" section to be cautiously managed based on lay tension and soil friction during installation;
- Identification of potential difficulties in respect of the induced fatigue of SLWRs during installation and the strength assurance of flexjoints.

Indeed, the installation was a highly demanding phase due to the concept novelty and the lack of industry experience, and it required multiple analyses coupled with a careful execution planning. Thus, to adequately address all technical issues, uncertainties and risks in order to subsequently enable a successful project delivery, the following matters were considered: (Thomas et al., 2010)

- Pre-abandonment layout, recovery and transfer sequence of SLWRs and umbilicals;
- Possible interferences and minimum clearances with mooring lines, risers and umbilicals during the operations;
- Detailed static and dynamic analyses for the laydown, recovery and transfer of the SLWRs and umbilicals assuming the construction vessel parameters.

During the pipe lay operations, there were two major installation challenges that included the rigging failure and the failure of pull-in winch onboard the FPSO. Successful outcomes of the two incidents were achieved because of the response of all parties involved. Key learning's from the incidents were the proper contingency planning and developing a clearly aligned culture regarding safety and technical integrity across all companies involved in the project. This allowed the project to achieve the best possible outcome especially during unexpected situations. (Thomas et al., 2010)

The recovery-and-transfer method applied for accomplishing major offshore operations proved the robustness of analysis techniques jointly developed by Shell and Subsea 7. Through the multiple analyses the early mitigation measures were elaborated and put in-place in good time, that helped in reducing vessels' standby time and improved the overall efficiency of installation process and followed up the satisfactory installation of SLWRs.

3.1.3 BC-10 learning's

The following high-level learning's have been compiled during the design and execution of the project. They are mostly the validation of basic good project management practices (Stingl & Paardekam, 2010):

- Superior Health, Safety, Security and Environmental (HSSE) performance can only be realized by getting complete and undivided individual commitment from all project team members, contract staff and their senior management;
- Significant offshore campaign savings can be realized by using fit for purpose vessels and standard hardware;
- The proactive and systematic coordination of the offshore construction vessels and commissioning activities is essential to reduce cost, minimize interference and maintain schedule;
- A contractor owned and operated FPSO is a robust contracting strategy when safety concerns, technical integrity and interdependencies in relation to the riser system are jointly identified and managed during early design phase;
- Strict project management control processes such as change management, risk management, cost, schedule and quality are essential to ensure value optimization;
- The development of a comprehensive stakeholder engagement plan is vital to identify potential issues and plan timely resolutions.

3.2 CLOV

This project is the fourth large-scale development in Block 17 within the Angolan offshore sector executed by Total, it entered into production in 2014. CLOV consists of the four separate oil and gas accumulations located in waters up to 1400 meters and tied back to a large spread moored FPSO 200 km off the shore. The installation of two Hybrid Riser Towers (CL HRT and OV HRT) took place in the third quarter of 2013, about 3 years after the project tender was awarded (Proust et al., 2015).

The "hybrid" terminology originates from the use of mixed technologies of the rigid and flexible pipelines within the riser concept. A Hybrid Riser Tower consists of a bundle of several risers, anchored to the seabed and tensioned by means of a buoyancy tank (Fig. 2.5-2.6, 3.3). The top of steel risers is connected to the FPSO via six flexible jumpers, while the buoyancy tank is connected to the top of tower through a flexible joint. Both upper and lower riser tower assemblies provide interfaces to connect risers to the flexible jumpers and to the rigid spools at the top and the seabed levels respectively. Rigid spools are to accommodate the HRT inclinations caused mainly by the FPSO excursions. The last key element is a suction pile, which serves as a tower foundation: LRTA interface incorporates a connection of tower to the pile. (Proust et al., 2015)

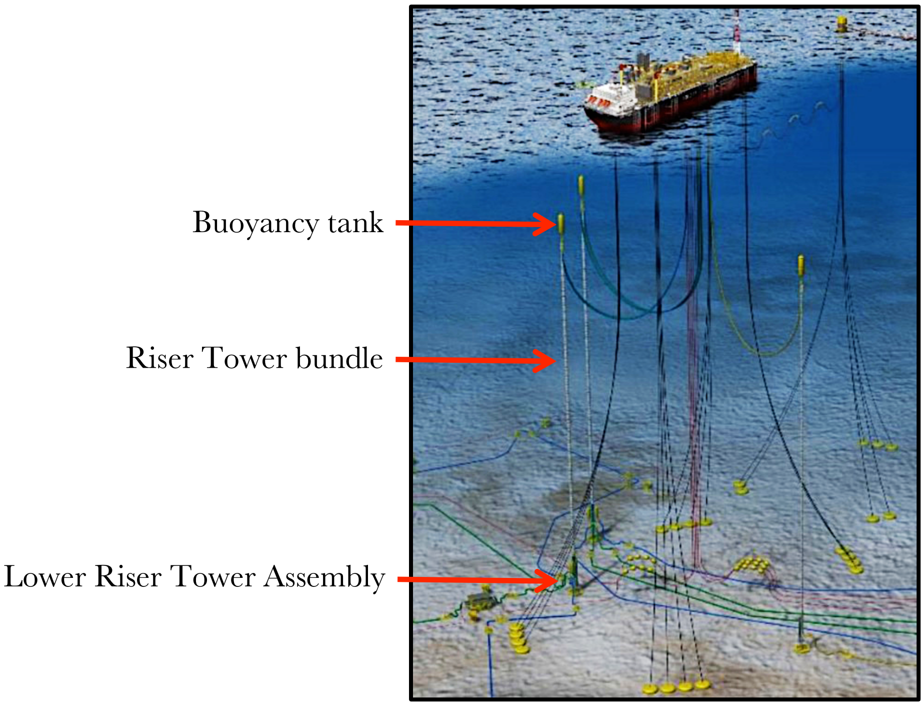

Fig. 3.3 CLOV Hybrid Riser Tower, field overview (Proust et al., 2015)

The CLOV project is noteworthy: it serves as a good example of how the experience from previous similar projects can be very beneficial in new similar projects; as well, the project incorporated a number of useful managerial practices.

3.2.1 Updated methodologies

The resultant riser system is a system of "a new generation" (Mouillerat & Silva, 2015). The riser architecture, which was finally delivered, greatly benefited from the experience gained during Girassol and Greater Plutonio projects, which were earlier completed in offshore Angola. Based on the past projects, significant updates to the design, fabrication and installation methodologies were achieved through comprehensive engineering analyses. (Proust et al., 2015)

In reference to the past concept developments, the design optimization undertaken at different phases of CLOV project delivery yielded a number of improvements (Proust et al., 2015):

- Bundle guide frames made of polyurethane (PU) instead of steel: they are arranged at regular intervals along the tower, where the risers are placed on their periphery (Fig. 3.4). The use of PU material provided with the following benefits: lighter weight; reduced quantity of needed buoyancy foam; easier and quicker fabrication; no geometrical inaccuracy, since the fabrication is based on the molding process;
- Buoyancy modules are not used to thermally isolate steel risers any more: thermal insulation is integrated with production risers;
- Buoyancy tank and URTA are not integrated into a single element: the concept is of a standalone buoyancy tank and URTA. The solution simplifies both designing and fabrication processes;
- Hybrid buoyancy tank is designed with higher buoyant capacity: no risks of uncontrolled flooding involved during towing or upending operations.

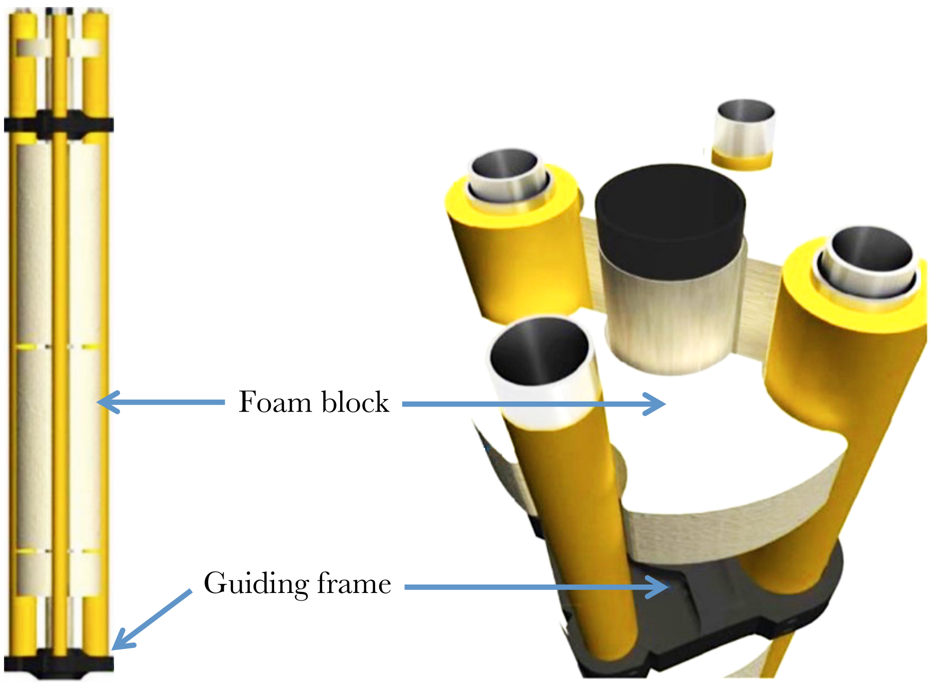

Fig. 3.4 CLOV Riser Tower bundle (Proust et al., 2015)

The experience gained during Girassol and Greater Plutonio projects considerably helped in finalizing a practical installation methodology. Prior experience was used extensively to determine which combination of activities had worked well and could be conducted again in a similar manner and which activities were to be improved. (Proust et al., 2015)

3.2.2 Continuous collaboration

When the CLOV project was executed, the collaboration between the engineering and fabrication teams started well ahead of the HRT fabrication campaign. As soon as the design of the HRT kicked off in the Total engineering office in Paris, the presence of the fabrication subcontractor's team within the engineering office made it easy to integrate the fabrication subcontractor's expertise in the HRT design and develop a concept as fabrication-friendly as possible. Hence, the teams successfully accomplished two important principles: Design For Manufacturing and Assembly (DFM, DFA), which reduced the risks of cost and schedule delays. (Proust et al., 2015)

Similarly, when the fabrication activities kicked off at the Angolan yard, some of the Design Engineers from Paris were transferred to Africa to supervise the HRT fabrication. This decision ensured a good transfer of knowledge from the engineering team to the fabrication team. Thus, the established communication between the engineering and fabrication teams was highly beneficial and even crucial to the success of the HRT delivery. The following challenges greatly exemplify the practicality of such collaboration principles. (Proust et al., 2015)

Thus, the proceedings of the design engineering activities and installation engineering activities were tightly integrated so as to ensure that the engineering team responsible for design would take any input from the engineering team responsible for installation and make the offshore installation campaign as easy as possible, while the installation procedures would not jeopardize the HRT integrity. (Proust et al., 2015)

3.2.3 Execution challenges

Very early during the HRT design, it became clear that the URTA and LRTA would be too wide to go through the existing wet dock, which the Lobito yard inherited from the Greater Plutonio project. In cooperation with the fabrication subcontractor, various options were considered with strengths and weaknesses identified (Proust et al., 2015):

- Enlarging the existing wet dock and performing the tie-ins of URTA and LRTA onshore. The modification of the wet dock represented a significant investment, but would provide significant benefits in terms of safety of tie-in operations and generate opportunities for saving time later on;
- Applying the methodology used to fabricate the Greater Plutonio project HRT: performing the tie-in operations in water using a dedicated floating welding chamber, cofferdam, to work in dry environment (Fig. 3.5). The strength of this solution was in using proven methodology from past projects, which was already perfected and known to be efficient;

- Other solutions were analyzed jointly with the fabrication team, but including them involved an additional level of technical risk or complexity.

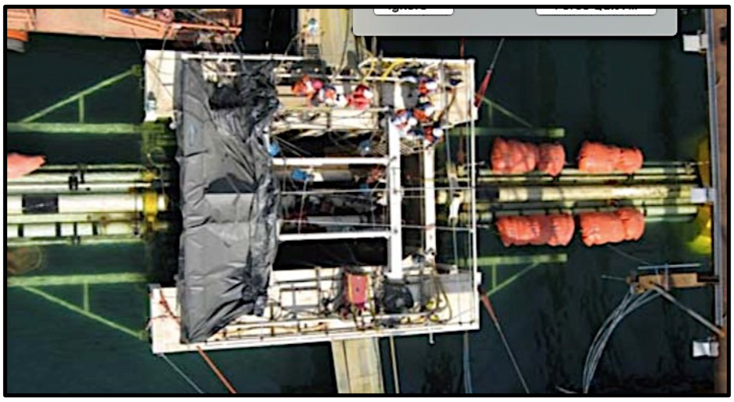

Fig. 3.5 Tie-in operation using cofferdam, Greater Plutonio (de la Cruz et al., 2009)

After a careful review of the various proposals, the decision was made to proceed with the solution that would minimize the delivery schedule risk and provide a safe working environment, despite the significant investment involved. The performance of the HRT fabrication activities then showed how this decision was important in the successful riser project delivery. (Proust et al., 2015)

Another area of focus identified by the engineering team was the capability to control the linear upthrust of the HRT bundle. The installation analyses showed that this parameter was very sensitive and needed to be maintained within a narrow range during the towing and upending operations. Bearing this in mind, the engineers designed the foam blocks with a recess to further provide an opportunity for an optional insert. Then, the fabrication subcontractor was required to re-weight all the elements during the assembly of each bundle section (pipes, foam blocks, PU guide frames) and the engineering team needed to compute the as-built weight of the bundle section and determine the blocks, which the inserts should be installed in to enable upthrust adjustment of the tower. The good management of the HRT bundle weight could be only achieved through the constant collaboration between the engineering and fabrication teams. (Proust et al., 2015)

3.2.4 Potential time saving

The tie-ins of the 220 m long bundle sections were to be repeated 10 times (5 times for OV tower and 5 times for CL tower). These operations were identified as one of the activities with significant potential for time-saving. A lot of energy had been invested to make sure this potential did materialize. Both OV and CL towers were developed based on a very similar design, so that the experience from the OV tower assembly would greatly guide the CL tower assembly activities. (Proust et al., 2015)

Additionally, to assure right assembly operations, very early in the project life, a simulation of and training for assembling the HRT bundle sections were organized at a workshop in France, involving key personnel from the fabrication subcontractor's organisation (Proust et al., 2015).

The duration of assembly and tie-in of one bundle section was initially estimated to be 15 days, but there was a consensus that this duration could be significantly reduced if the lessons learnt during the assembly and tie-in of the first bundle sections were quickly integrated. The actual fabrication timing is illustrated in Fig. 3.6. The figure shows an efficient learning curve with a considerable time reduction achieved during the CL HRT assembly and tie-in operations that is well below the initial estimate of 15 days. (Proust et al., 2015)

The Hybrid Riser Tower is now a well-known solution in the oil and gas industry and can be implemented worldwide. The strengths of the HRT solution for ultradeep water developments are already well identified (Seguin et al., 2015) and it is now ready and mature for new demanding projects.

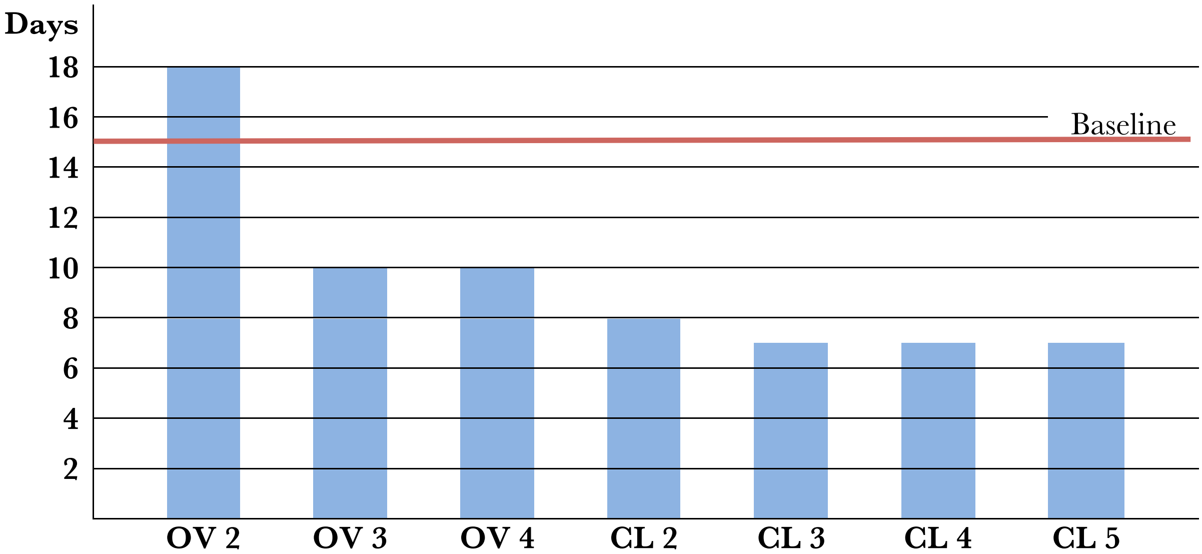

Fig. 3.6 Duration of HRT bundle section assembly and tie-in operations (Proust et al., 2015)

3.3 Sapinhoá-Lula NE

Buoy Supporting Risers concept was selected as the most effective riser system for the development of two fields in Offshore Brazil: Sapinhoá and Lula Northeast. Each field comprises one FPSO vessel and two tethered BSR systems (Fig. 3.7-3.8) with the overall scope of 27 steel catenary risers. The first buoy was installed in December 2013, the first oil took place early in 2014. The four BSR systems installed in more than 2100 m water depth brought to life a novel riser system opening new frontiers for ultradeep water projects all around the world.

The concept has emerged from the assessment process as the most suitable and robust concept to be applied, considering the overall criteria and identifying the main advantages (Hiller et al., 2015):

- Versatile solution from the design and configuration perspectives: well-established SCR design methods; fewer connections and simpler integration of the various main components; the buoy can be easily reconfigured for a larger number of risers; the requirements for future risers and umbilicals can be readily incorporated into the design;
- Versatile solution from the assets perspective: no requirement for major modification of fabrication bases; no installation requirements for unconventional vessels;
- Versatile solution from the overall schedule perspective: allowing procurement and fabrication of different items to be proceed in parallel without excessive interdependence;
- Less complex subsea layout: each riser gradually splays out from the buoy like a fan (Fig. 3.7) towards the individual wells avoiding crossings and reducing congestion on the seabed;
- System requires less complex and less costly monitoring and integrity management: allowing a direct access for inspection and maintenance of lines and independent replacement of any line;
- Good potential for local content: granting a fair share of supply to the local industry.

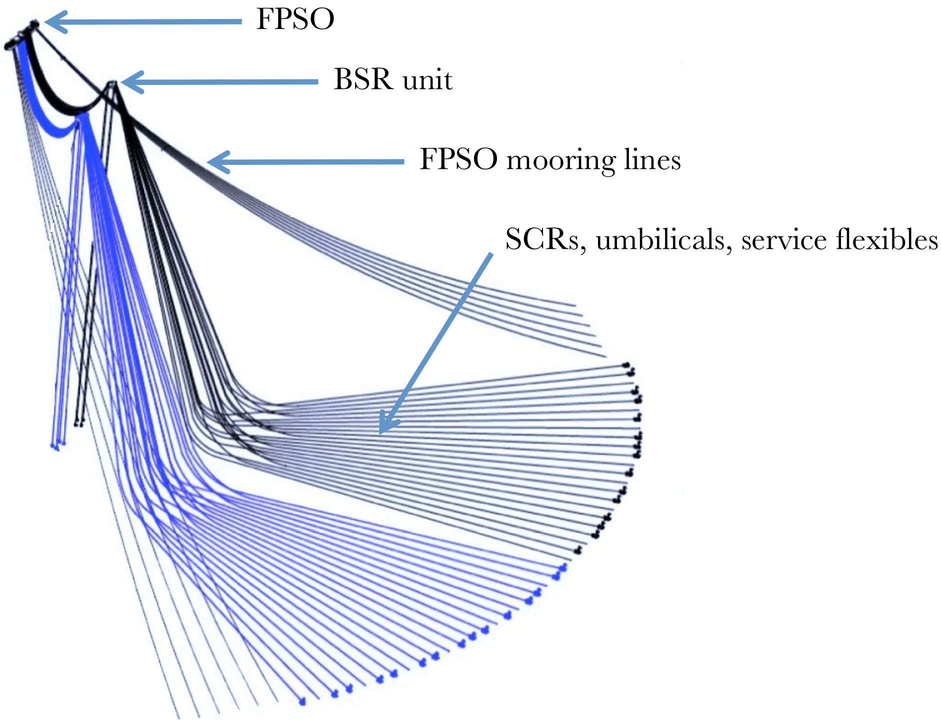

Fig. 3.7 Sapinhoá-Lula NE riser system overview (Cruz et al., 2015)

3.3.1 Pre-salt cluster

Sapinhoá-Lula NE project is a part of the outstanding development of the area known as Santos Basin pre-salt cluster. Petrobras with their partners and suppliers evolved their

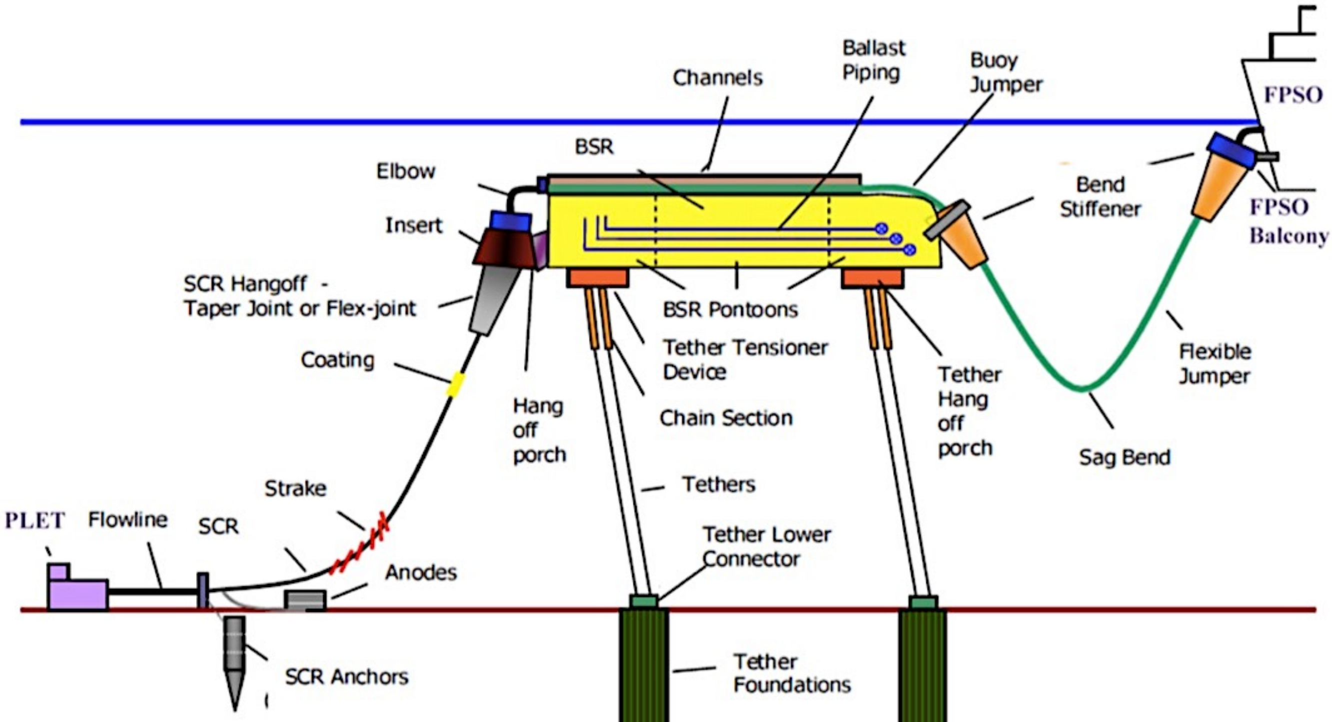

Fig. 3.8 BSR key elements (Cruz et al., 2015)

technologies into several breakthroughs, which enabled the development of pre-salt cluster. Most of them are listed bellow (da Costa Fraga et al., 2015):

- First deployment of BSRs in Sapinhoá and Lula NE;
- First 60 km of SCRs with lined pipes installed by reel-lay method in Sapinhoá and Lula NE;
- Deepest SLWR (2140 m). It was the first to be connected to a spread moored FPSO and the first riser to be fully composed of lined pipes and metallurgically clad pipes;
- Deepest 35 flexible risers (2220 m) with the approximate length of 100 km (installed by July 2014);
- First application of flexible risers with integrated tensile armor wire monitoring system (commissioned by mid 2015);
- Water depth record (2103 m) for a subsea well drilled with the Pressurized Mud-Cap Drilling (PMCD) technology;
- First CO_2 separation from associated natural gas in an ultradeep water environment with CO_2 re-injection into producing reservoirs;
- Deepest offshore well (2220 m) injecting gas with CO_2;
- First use of Water Alternating Gas (WAG) injection method in ultradeep water.

The pre-salt annual average production in 2015 was the largest in Brazilian history: 767 000 barrels per day, exceeding production in 2014 by 56%. Further, in May 2016 the benchmark record of 1 000 000 barrels of oil produced in a single day was reached. As a whole, the pre-salt development is a milestone in the petroleum industry, while the related projects including Buoy Supporting Risers serve as a great example of innovative execution environment and present a meaningful experience for future developments.

3.3.2 Encountered challenges and applied innovations

Sapinhoá-Lula NE BSR execution happened to be a challenging fast-track project, which required some engineering solutions to be devised and implemented "on the fly" (Cruz et al., 2015). To allow the project to come to life multiple resolutions were required to cope with the following challenges (Camozzato et al., 2015):

- Tight execution schedule;
- Changes: the threat of delays forced a proper revision of relevant input data to be performed;
- Weather: scarce available metocean data;
- Technical challenges, which required innovations in the design;
- Inspections: fabrication novelty required a quality control of fabrication processes;
- Logistics: challenges caused by an extensive number of suppliers and their widely spread locations;
- Offshore operations: challenges due to weather uncertainties scaled up by the management complexity of offshore operations performed by a high number of vessels, closely located;
- Contractual structure: twenty-four contracts proved to be quite difficult to manage.

To overcome technical challenges and successfully perform the project delivery, a number of innovative developments were realized (Cruz et al., 2015):

- Reeled-lay method was qualified to install Corrosion Resistant Alloy (CRA) mechanically lined pipe;
- The first use CRA mechanically lined pipes on risers;
- Angular Connection Module (ACM), a novel connection system. It facilitates the procedure of connecting and minimizes the number of connections and their potential leak paths;
- Riser Installation Tool (RIT) capable of withstanding up to 400 tons tension;
- A new Engineering Criticality Assessment (ECA) methodology was developed based on Finite Element Analysis (FEA) to perform the assessment of ductile tearing and plastic collapse of the welding cases, which are not covered by the codes;
- The sheathed Spiral Strand Wire (SSW) design was adopted for the buoy's mooring system and designed for the design life of 27 years;
- The mooring top connectors comprised by various elements to handle tension and length variations and to absorb the BSR lateral movements.

Established environment for the productive interaction between contractor and operator enabled the concepts and ideas to be easily shared and rapidly incorporated into the final design, thereby enhancing the reliability of construction and installation operations. In addition to managerial factors, successfully completed multi-vessel offshore operations were based on the numerical prototype tank tests, step-by-step 3D simulation methods and dynamic analysis, which have verified the robustness of all technologies applied to such a large system. The field results, obtained during the first time installation and system operation, allow the BSR concept to be considered as a field proven solution that can be further developed in future projects.

This example greatly demonstrates that the industry can successfully execute projects utilizing innovative technologies on an aggressive schedule.

3.4 Stones

Stones field is located in the Walker Ridge area of the GoM (US), about 300 km off the coast of New Orleans. The ultradeep water project lies in a depth of approximately 2900 meters. The field was discovered in 2005 and has been developed and operated by Shell. The host vessel Turritella is, as of June, 2016 moored to the seabed being in the field with the final tensioning and chain-cutting operations completed (Offshore magazine, 2016). Turritella has nine mooring lines arrayed in three bundles of three (Fig. 3.9), each line is comprised by chain and polyester sections and has in-line tensioning system.

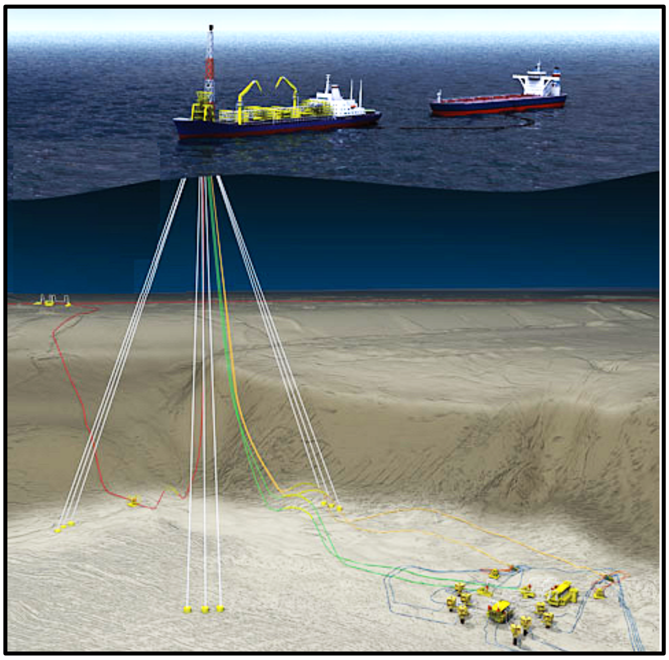

Fig. 3.9 Stones riser system, field overview (Musarra, 2016)

When installed, the Stones FPSO will be the second FPSO in the GoM and the deepest FPSO development in the world. Stones is a phased development that will start with two subsea production wells tied back to FPSO. In later phases Shell will add six more wells with multiphase pumping. As of June, 2016 the project status is almost 100% delivered (van Beurden, 2016).

3.4.1 New technology

The disconnectable turret is configured with lazy wave risers for the first time in industry using Buoyant Turret Mooring (BTM) technology, so that if a heavy storm or hurricane approaches, the FPSO can disconnect its mooring lines and risers from the well system and sail to safe areas. 3D printing technology has allowed the Stones project team for very rapid prototyping of the buoy, which has a complex geometry. Hands-on interaction with the scaled-down 222 components of the foam blocks (Fig. 3.10) helped to assure the correct

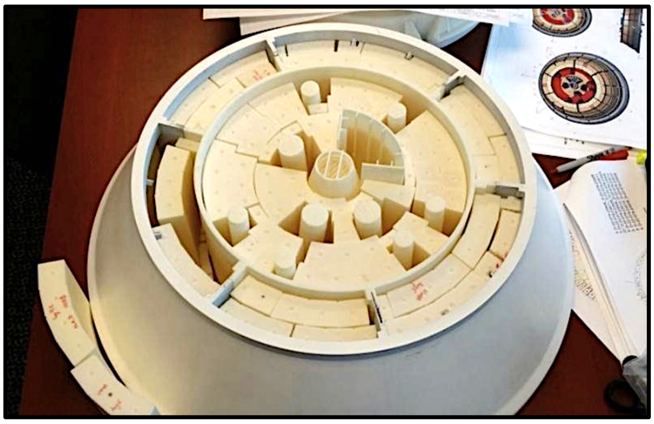

Fig. 3.10 Buoy prototype, Stones (Shell.com, 2016)

dimension parameters, improve components before they are built and how best to do the installation work in the construction yard with the associated safety risks evaluated. Using 3D printing technology, Shell could reduce the gap between the design and fabrication, accelerate the assembly activities, reduce the costs and improve the safety concerns towards delivering an end product of high quality. (Shell.com, 2016)

3.4.2 Near future

The following two cases demonstrate the existing industry challenges, which demand innovations and new development approaches to reduce the capital expenditures in order to attract investments for new deepwater frontiers in near future:

- Shell's intention to put into operation the deepest development with a number of "world's first" solutions in addition to other two ultradeep water projects (over 2250 meters), which are phase 2 of the Coulomb project and phase 2 of the Perdido project (Musarra, 2015);
- On the other hand, current oil market conditions have led to multiple delays and cancellations of greenfield project developments: in mid-2015 ConocoPhillips announced that they would reduce future spending on deepwater exploration and exit some deepwater projects in favour of shorter cycle time assets (ConocoPhillips, 2016).

4 STEEL LAZY WAVE RISER CONCEPT

A typical SLWR consists of the four sections: upper catenary section, middle buoyant section, lower catenary section and bottom section. The upper catenary section usually constitutes the largest part of the riser length and it interfaces with the host. The buoyant section is fitted with syntactic foam buoyancy modules and with the achieved negative weight creates the riser's "wave". The lower catenary is a short section below the buoyant length and it interfaces with the sea floor. The bottom section lays on the sea floor most of the time and it extends to the flowline-riser transition point.

In 2009 Shell pioneered a SLWR concept in the Parque das Conchas fields (offshore Brazil) in the conditions of ultradeep water and constant swell, dynamic sands and under certain metocean uncertainties, which all posed huge technical challenges on the engineers. SLWR remains an attractive riser concept for future developments, because of a relatively short delivery time and reduced risks to the delivery schedule due to fewer components required; lower cost and lower payload in comparison to the hybrid systems and flexibles respectively and advanced fatigue performance (Seguin et al., 2015), (Newport et al., 2014).

In March, 2016 Shell announced that the production from the third phase of BC-10 development commenced. It can be hereby concluded that the riser and turret technologies deployed for operation at BC-10 in 2009 have proven to be robust and reliable.

4.1 Riser design

A SLWR system is generally customized to the specific project based on the floater design and its characteristics, turret constraints, hang-off payload, internal fluid properties, environment conditions and field life. The design process involves a large number of iterations on the buoyancy distribution to determine configurations, which would satisfy the strength and fatigue requirements of risers and flexjoints; to meet interference requirements and establish installation requirements. Thus, the main areas of design are strength, fatigue, interference and installation.

The riser strength is to be analyzed first to give a preliminary configuration to determine TDP location, buoyancy distribution and stress joint design. Interference analysis between the risers and preliminary fatigue analysis can then be started to provide input into the riser configuration. As well, preliminary installation analysis can concurrently be performed to satisfy all strength, fatigue and interference requirements, which will be expected to be experienced during operations. Throughout the design process the cooperation with manufacturers and fabricators must be maintained to ensure all design requirements are met.

4.1.1 Spatial interference

The SLWRs are modeled along with the adjacent umbilicals and mooring lines in order to determine the minimum clearance between them. The models interpret the dynamic behaviour of lines under different metocean conditions (10-year and 100-year waves, currents and hurricanes) and help in establishing the recommended lengths for straked, faired and buoyancy sections to avoid potential clashes. Sensitivity analyses are to be performed to investigate the effect on the clearance due to:

- Changes in seabed friction coefficient;
- Loss of buoyancy modules;
- Change in TDP water depth;
- Placement of strakes below the riser buoyancy.

4.1.2 Riser strength design

To perform strength analyses a finite element package is to be used with an appropriate type of a finite element and stiffness (2-noded hybrid beam elements were used in Caesar-Tonga project (Lahey et al., 2013), which would allow for accurate modeling. High meshes are to be used in high stress gradient areas such as the stress joint and touch down zone.

The API 2RD design criteria can be used to check the riser strength. In reference to the Caesar-Tonga project, the riser strength unity checks were performed using the following relation:

Unity Check = Computed Von-Mises Stress / (A x SMYS)

Where ***A = K x (2 / 3)***, ***K*** is the design case factor, and ***SMYS*** is the Specified Minimum Yield Strength. ***K*** was taken as 1.0 for operating conditions, 1.2 for extreme conditions and 1.5 for survival conditions.

The load cases can be based on the combination of all three conditions and various scenarios such as winter storm, current, hurricane or/and any extreme damages such as a mooring line failure.

4.1.3 Fatigue

Fatigue is commonly analyzed for first and second order vessel motions, VIV (and hull VIM if applicable) for both long-term day-to-day conditions and single extreme events. Cumulative fatigue design is performed based on the considerations of sources of fatigue damage given the riser service lifespan, and the fatigue criterion is given by:

$$[\, M \times (D_{wave} + D_{heave} + D_{vim}) + N \times D_{viv} \,] < [\, 1 - D_i \,]$$

Where ***M*** and ***N*** are safety factors applied to long-term wave fatigue and VIM, and long term VIV respectively; could be taken as 10;

D wave – local damage, accumulated over service life, due to waves and wave related vessel motions;

D heave – local damage due to heave-induced VIV, evaluated to be negligible;

D vim – local damage due to hull VIM;

D viv – local damage due to riser VIV;

D i – installation damage, could be taken as 0.1.

To assess total fatigue damages, each fatigue source is to be computed using individual calculating methods, which are beyond the scope of this thesis.

4.1.4 Installation

Analyses are to be performed to ensure riser pipe integrity during offshore installation. Operational parameters for the analyses could be based on the pipe allowable stresses and strains, system physical properties, equipment limitations, catenary configuration and weather conditions.

In static analyses the discrete steps are defined from the vessel movements, winch wire and host wire lengths. Thereafter, the related nominal loads, von Mises stress, bending strain of the riser and anchor/wire loads are to be checked against installation constraints.

Dynamic analyses are performed for the critical static steps in the installation sequence in which maximum allowable sea states, maximum and minimum riser pipe loads, stresses and strains are determined. Both vessel and floater motions are to be considered.

Besides, because of a lazy wave shape the length of riser can be increased by 25-50 percent that requires more riser quality welds when compared to a SCR design. But despite the increase in riser length the overall length of the system (riser and flowline) remains relatively the same when compared to a SCR design, while the top tensions are reduced by 10% or more.

4.2 Floater mooring system impact

Spread and turret mooring systems are two major alternatives for anchoring FPSO. A choice between turret-moored FPSO and spread-moored FPSO is primarily dictated by metocean conditions. In the past, West African projects were mainly based on the use of FPSOs with spread mooring systems, while the Brazilian projects more often resorted to FPSOs fitted with turret mooring systems. The situation has been rapidly changing with ultradeep water developments coming on-stream: as of 2014 there was one turret-moored FPSO among projects in West Africa, while 3 out of 5 ultradeep water projects in Brazil were based on the utilization of spread-moored vessels (Mahoney, 2013). Disconnectable turrets are to be designed for the projects, where the floater must be able to detach a riser system from the floater to prevent it from transferring significant dynamics.

Mooring system and riser system must be mutually elaborated to achieve high operation performance. Successful engineering is based on the early addressing of interdependent factors in design, since the type and characteristics of mooring system affect the design considerations of riser system:

- Spatial limitations restrain the overall number of risers and installation of additional risers in case of field expansion some time in the future. Turret-moored FPSOs are

more limited in terms of available space;
- Different layouts influence the configuration of each riser. Hence, interference analyses coupled with multiple iterations must be performed to determine the length of buoyancy section, TDP location, strakes allocation etc;
- Because of different layouts the flow assurance must be addressed early in design;
- The riser terminations are principally divergent for two anchoring systems: FPSO interface and resultant pull-in operations and exploitation philosophies.

Additional requirements could be posed on the riser system in case of a new mooring system concept like a taut-moored spar-like buoy (Fig. 4.1), developed by BP Americas. In a nutshell,

Fig. 4.1 Disconnectable MoorSpar FPSO System (Banon et al., 2012)

there are a number of advantages for ultradeep water applications; the concept is robust and allows FPSO to disconnect from the spar-like buoy and sail away, while the system remaining in location is designed to survive a 1000-year hurricane, which is a lower probability of exceedance compared to FPSOs designed for a 100-year maximum hurricane (Banon et al., 2012).

4.3 Turret assembly. Riser-to-turret interface

If the turret concept has been sanctioned to be an FPSO anchoring system, then it can be designed on the basis of a typical Top Mounted Internal Turret (TMIT) for flexible risers. Referring to the BC-10 project, Shell incorporated a number of modifications to the turret (Fig. 4.2) to enable its application with SLWRs (Newport et al., 2014):

- A new mechanism to connect SLWRs to I-tubes;
- To avoid clashes between the inclined I-tubes the termination of risers and umbilicals is designed to be located in the turret cylinder rather than at the collar deck;
- To easily situate the winch in line with each of the I-tubes and facilitate a straight pull-in

of the inclined risers the winch is centrally located on the movable platform of the collar deck. This differs from a typical TMIT, where a travelling winch is located close to the perimeter of the upper deck to allow a straight pull-in.

In TMIT designed for flexible risers, the risers run through vertical I-tubes, whilst in the turret designed for BC-10 FPSO the SLWRs and umbilicals enter at an angle ranging from 4° to 10° to the vertical. The riser I-tubes have a non-radial arrangement and are terminated at the riser deck allowing the risers to be hung off with split collars in a dry installation environment. The umbilical I-tubes are terminated on the umbilical deck, still within the lower turret but elevated in order to have a dry operating environment. Installation deck is located between the riser and umbilical decks; it provides an access to the chain sheaves required for the

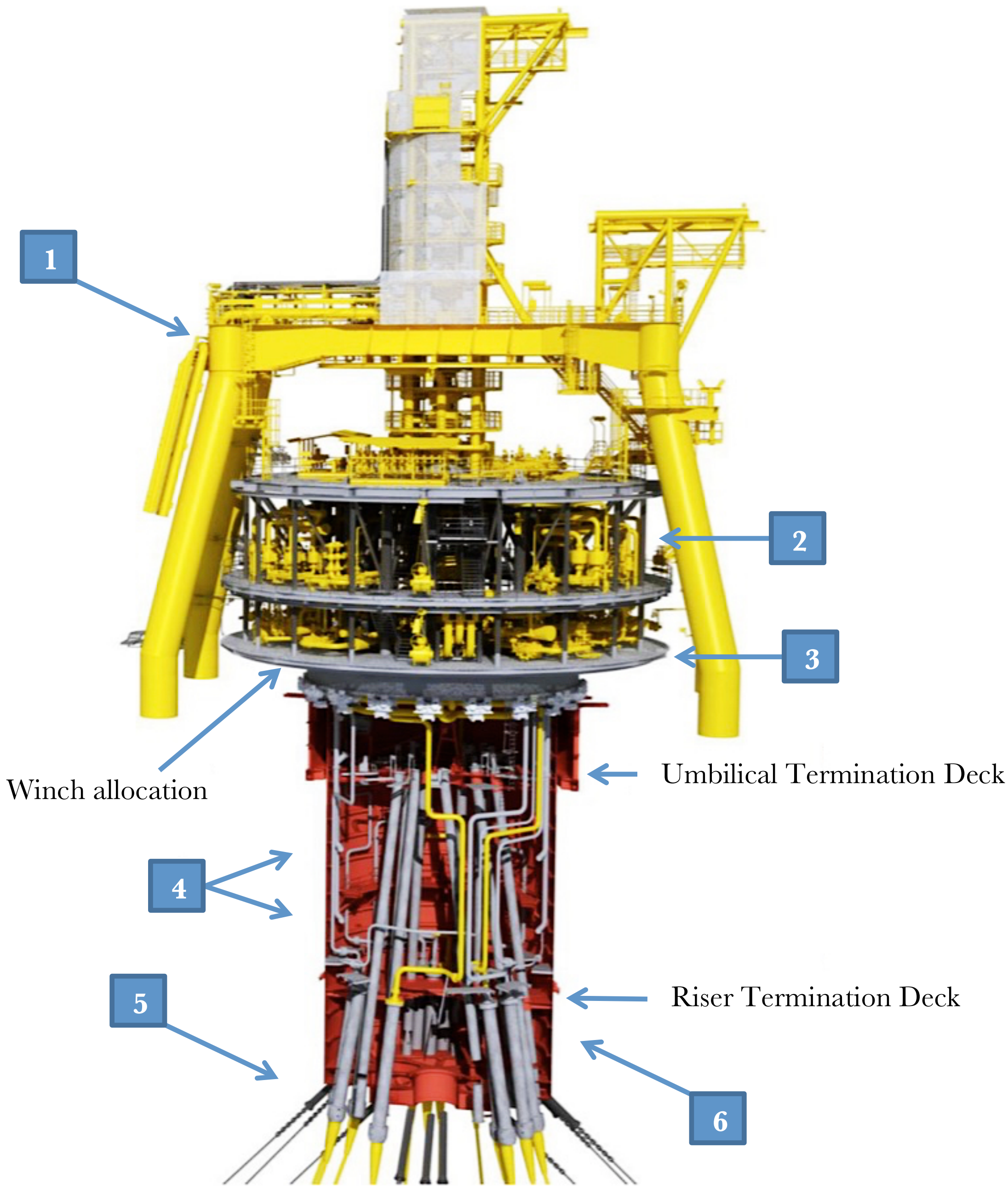

Fig. 4.2 TMIT, BC-10 (Newport et al., 2014)

mooring line pull-in. (Newport et al., 2014)

Figure 4.2 depicts the major components and their locations:

1) Gantry structure, which is supported on the vessel deck;
2) Manifold structure;
3) Collar deck;
4) Fluid transfer system incorporates piping, risers, manifolds, and swivels;
5) Mooring lines;
6) Turret cylinder, the load transfer path from anchor lines to the vessel.

A flexjoint connected to a journal forging terminates the riser (Fig. 4.3). The flexjoint allows for angular rotations of the riser up to 20°. The journal forging is attached to the top of the flex joint and interfaces with the I-tube clamp casting: clamp casting is assembled with eight locking plugs to centralize the riser in the guide tube. Clamp casting transmits the bending moments (and a portion of the riser tension) to the chain table. The top of the journal forging is fitted with a hang-off collar to transmit the riser tensions to the guide tube. It should be noted that the interface for the BC-10 umbilicals is not affected by the use of SLWR: it consists of a standard Bend Stiffener Latching Mechanism (BSLM). (Newport et al., 2014), (Hoffman et al., 2010)

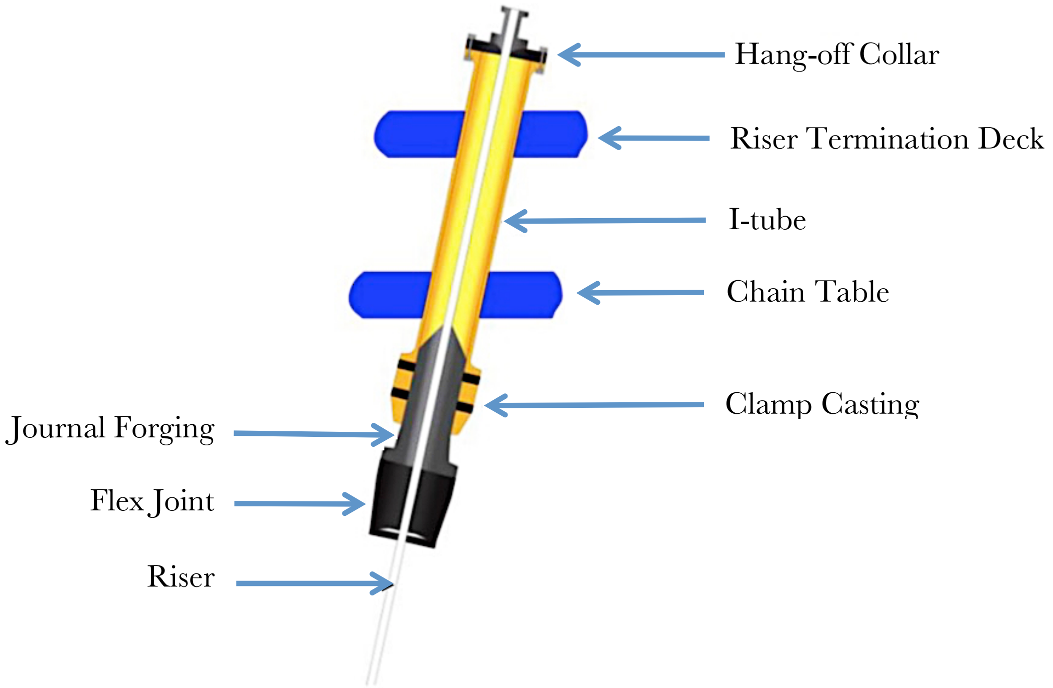

Fig. 4.3 SLWR / turret interface (Newport et al., 2014)

4.4 Tethered configuration

In 2016 Subsea 7 presented the study on a tethered configuration of SLWR that tends to improve the riser respond in the conditions of extreme FPSO offset positions and dramatic fluid density changes, since the performance of hang-off and TDZ riser sections remain critical in case of disconnectable turret-moored FPSO (Karunakaran et al., 2016), (Cheng & Cao, 2013).

SLWR is designed with large net buoyancy and a long suspended length to reduce the stress in Touchdown Zone (TDZ), when FPSO is in the "near offset position". However, if the vessel moves to the "far offset position" and the fluid density drastically decreases, than the large net buoyancy causes the flexjoint to get significantly angled. To handle it a clamping tether can be applied (Karunakaran et al., 2016); which will hold the riser at its low position and keep the hang off angle deviation acceptable, whilst a low-density fluid is being produced. This is one of the primary factors driving the tethered SLWR design (Fig. 4.4).

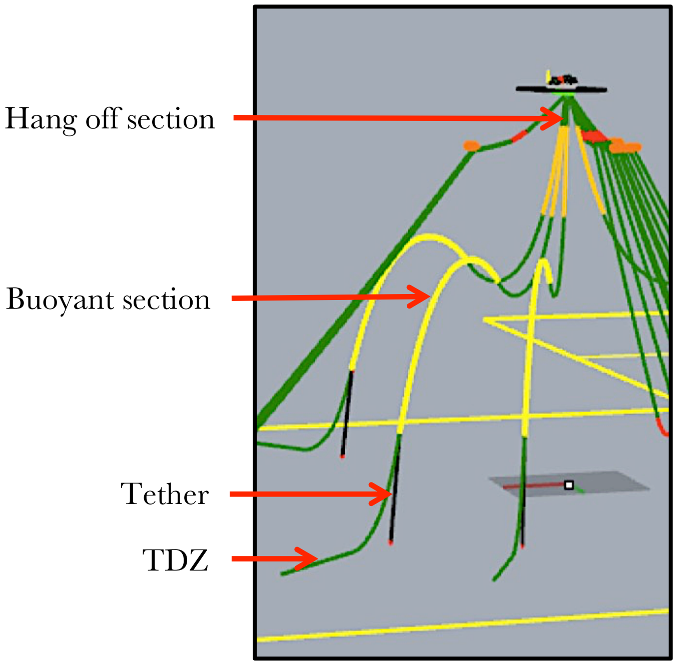

Fig. 4.4 Tethered SLWR (Karunakaran et al., 2016)

Subsea 7 states that there are nearly 12 controlling parameters, such that a change in one of these parameters affects a number of others: tether length, axial stiffness of tether, flexjoint properties, net buoyancy and number of buoyancy modules etc. This complicates the design of the system and much iteration is required to optimize the configuration.

4.5 Buoyancy modules

In the design of the "wave", there is a crucial trade-off between the amount of buoyancy and the increased fatigue performance of the riser. The larger wave, the longer the fatigue life of riser. However buoyancy modules and their installation are expensive, hence requiring iterations to manage the incorporation of minimum amount of buoyancy, while sufficiently decoupling the vessel motions. The following principle is also applicable: the closer the buoyant section to the seabed, the more effective the decoupling is. But this increases the horizontal instability of the bottom section in the presence of deepwater currents. Because of this sensitivity, additional analyses are to be performed.

In reference to the BC-10 project, the design of risers additionally assumed a 5% loss of buoyancy over the project life due to the compression affects from possible water ingress and creep (Hoffman et al., 2010). As well, in case of a disconnectable turret, extra foam modules might be needed to achieve a required upthrust of the middle buoyance section in order to enable keeping a disconnected buoyant turret floating.

4.6 Monitoring system

The uncertainties in deepwater environment and the shortfalls in riser design methodologies may pose challenges to the riser system integrity. SLWRs are critical dynamic structures with a complex fatigue response, thus to enhance an operational safety the Real Time Monitoring (RTM) technology can be applied as part of the Riser Integrity Management (RIM) practice.

A Riser Monitoring System (RMS) will improve the visibility to the riser's actual operational loads and can provide opportunities for optimization of the vessel's positioning during operation to minimize the operational loads on the riser system. The riser monitoring data can also be used to improve the equipment's maintenance and life-cycle cost.

The monitoring system is based on measuring riser response (strain or accelerations) at discrete points along the hang-off and TDZ critical locations. The dominant source of riser excitation is expected from VIV and wave induced vessel motions. Hereby, the primary objectives for the monitoring system are set to be the following (Zhang et al., 2014), (Karayaka et al., 2009):

- Assist in integrity assessment of the risers;
- Characterize the riser response and associated fatigue damage due to VIV and wave loading, first and second order floater motions;
- Characterize the riser-soil interaction;
- Characterize buckling behavior along the TDZ critical location;
- Characterize the flex joint rotation by measuring angles above and below the joint;
- Characterize the flex joint bending strain and stiffness by measuring bending strain below the joint.

The objectives are accomplished by installing multiple monitoring devices: motion, strain, inclinometer sensors. An optimal monitoring system configuration is determined by the cost, installation principles (before or after the installation of risers), sensor sensitivity, sensor types (accelerometer or strain based devices), communication methods with topside facilities (online or remote access) and integration with the project team. The required number of measurement locations depends upon the range of modes expected to be excited, level of accuracy required and overall system costs. To increase the reliability of monitoring system in critical areas the redundancy can be introduced by considering the following aspects: placement of back-up sensors; separating communication and power cables; employment of field proven instruments; enabling regular inspection and maintenance. (Karayaka et al., 2009)

Filtering of raw data and turning it into useful information for operators is very critical to understand and identify problems in the riser operations. This process is challenged by the fact that if noise or “false” data in digital signals cannot be removed, riser response cannot be identified correctly. The use of Operational Modal Analysis (OMA) technique can diminish noise and provide with real information without “false” data. (Zhang et al., 2014)

The monitoring system comprises (Pulse-monitoring.com, 2016):

- A topside data acquisition system that gathers data from the sensor packages;
- Various measured parameters, which are displayed on a screen and checked against preset thresholds;
- Alarms, which are raised by the software when the preset thresholds are exceeded.

The monitoring data gathered real time is aimed to provide a real time operational assistance using topside alerts coupled with the on-shore analysis to better understand the system responses. The motions recorded at the hang-off zone and TDZ tend to interpret the response along the entire length of the riser.

4.6.1 Riser monitoring devices

Typical motion sensors arrangement strapped onto the SCR is shown in Figure 4.5. The motion sensor resolution, sensitivity, spacing between the devices and their allocation along the riser shall be adequately chosen to enable capturing the entire range of modes the risers are subject to during their service life. The motion sensors measure 3 axis accelerations, 2 axis angular rates and 1 axis inclination.

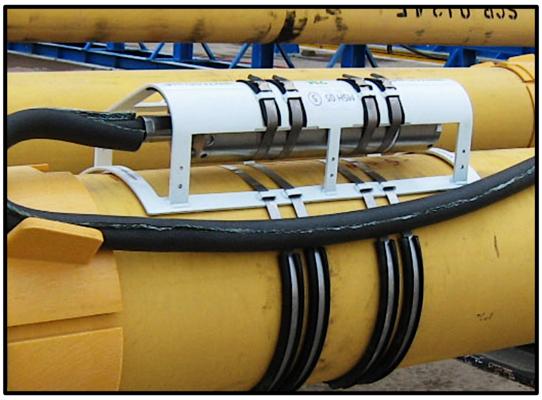

Fig. 4.5 Motion Sensor (Karayaka et al., 2009)

A typical strain (and motion) sensor arrangement is shown in Figure 4.6. The strain stick is installed directly on top of the insulation and near the fatigue critical location of the riser. The sensors are attached to the riser with the engineered compensation straps to accommodate shrinkage of the insulation layer due to the hydrostatics at the depths. The measurement resolution of 2 micro-strain, the high sensitivity, allows capturing the smallest dynamic curvature changes when the riser is subjected to bending. The strain sensors are to be placed as close to the pull tube exit as possible, because the strain level increases close to the riser pull tube. The strain distribution at the touchdown region is more complex, and it requires a thorough technical analysis for a suitable sensors allocation.

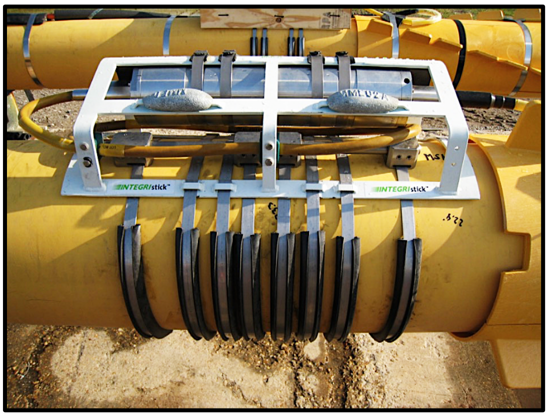

Fig. 4.6 Dynamic Curvature Sensor (Karayaka et al., 2009)

The inclinometer sensors are installed above and below the flex joint.

4.7 Safety

Safety must be recognized as the highest priority in the designing, installation and operation phases. A conservative approach to the design and outfitting can be exercised to ensure safe long-term operation of the riser system. To reduce probability of vortex induced vibrations the riser string is to be fitted with strakes and fairings covering maximum length. Extra coverage with fatigue reducing devices can be provided beyond the predicted VIV sensitive regions. The umbilicals adjacent to the SLWRs are to be outfitted with fairings to reduce probability of clashing.

The riser inspection, maintenance and repair program must be appropriately elaborated in light of the complexity and all innovative technologies used. A comprehensive program is to be developed based on the input of the design team: preventive approaches called Hazard and Operability Study (HAZOP) and Hazard Identification (HAZID) are to be used for identification and evaluation of problems that may represent risks to personnel, equipment or overall project efficiency.

5 SLWR PROJECT DELIVERY

In the current market conditions the discussions on project optimization, innovative technologies and new approaches to the project management have gained greater importance and have become very vivid. At the last OTC 2016 in Houston, Subsea 7 and KBR suggested an improved type of industry alliance between the installation contractor and the engineering contractor (Seguin et al., 2016) – it implies the early involvement of the installation contractor in the project front-end activities (concept and Front-End Engineering Design (FEED)), which are typically performed by the engineering contractor. The rationale behind why the industry should rethink the way deepwater and ultradeep water projects are currently managed is due to (Seguin et al., 2016):

- Project cost overruns;
- Frequent project schedule slippages;
- Unsatisfactory interface management;
- Challenges associated with risk management and risk sharing;
- Increasing project complexity (deeper waters, harsher environments, geopolitical constraints);
- The oncoming skills shortage in the subsea industry;
- Current market conditions requiring significant cost savings;
- A lot of potential developments now considered as not economically viable.

As it was mentioned earlier in the Chapter 1, Petrobras shares the same ideas about a new approach desired in the current industry realities. Further, at OTC 2016 the representatives from such leading companies as Shell Oil, Anadarko, Maersk Oil, McKinsey and Technip presented their group report (Dekker et al., 2016) on how to manage the deepwater development costs in the lower-for-longer price current environment, which currently prevails; one of the key points among others was that in order to enhance project performance and reduce cost, an early engagement with Engineering, Procurement, Construction and Installation (EPCI) contractors paired with consistency of project management personnel was required.

Thus, major project executors have multiple of perspectives to improve their current approaches to the performance of riser project delivery to eventually bring to life a well performing riser system and stay economically viable.

5.1 Concept

Subsea industry has been constantly searching for novel technologies, which would allow Steel Catenary Risers to have higher performance. SLWR concept emerged as an improved SCR solution applicable for deepwaters. After its first successful installation in 2008, the concept became attractive for frontier regions. SLWR is relatively new technology with just a few applications in Offshore Brazil and GoM.

Riser system is an essential part of the overall field development. The riser concept selection process is carried out along with conceptual studies of the field development. Field specific requirements remain the major drivers for any subsea system including the riser system (Fig. 5.1). In addition, the riser system is closely interconnected with the floater and production system, which both create multiple interfaces and impose additional requirements on the riser concept; that shall be addressed in the concept development as early as possible, since any late change results in project schedule delays and negative financial consequences.

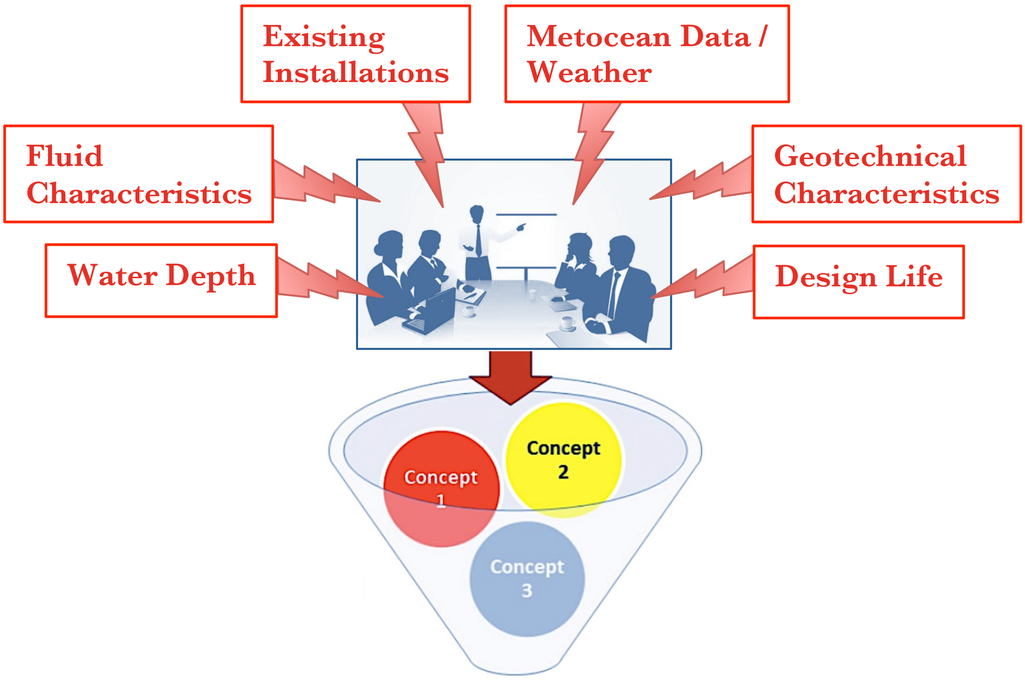

Fig. 5.1 Concept development process

If the operating company has decided to develop the riser system by contracting, then it commonly organizes a tendering process either by openly advertising the scope, specifications, terms and conditions of the proposed contract or through a competitive negotiation. In case of the latter, requests for proposals are sent only to contractors, which are considered to be qualified enough to manage the project.

Having full freedom in the development process, proponents are to individually decide how extensive they are going to develop the concept and how much resources shall be brought to the process in order to achieve a desired level of concept detailing. Through rigorous analyses and reasoning work the proponents are to demonstrate the validity of technical solutions to convince a client and successfully proceed to FEED studies. Fig. 5.2 depicts the project's early phase activities starting from the call for tenders, or Invitation To Tender (ITT), and ending up with the contract award. (In the graph: the blue and red symmetric figures characterize the overall scope of preliminary proposals; the scope of preliminary proposals is narrowed down while the proposals are subjected to screening and selection processes).

Referring to the Sapinhoá-Lula NE project, before tendering started Petrobras had clearly stated the objective of having a decoupled riser system and specified all technical requirements, so as to allow the proposals on most efficient technology solution to be centered

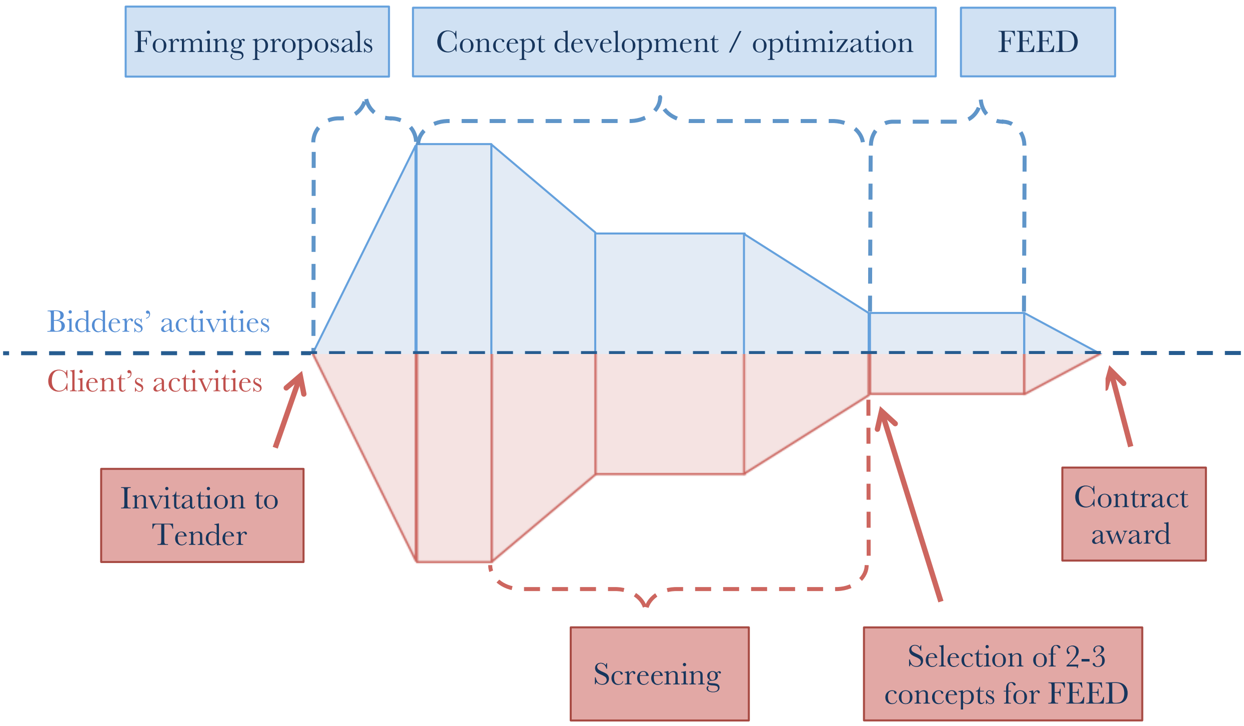

Fig. 5.2 Activities at the early stages of project development process

on it. The shortlisting process performed by Petrobras was based on the following studies (Hiller et al., 2015):

- Configuration feasibility analysis. Layout and flowline approach studies;
- Description of main components and materials, as well as description of onshore construction and offshore installation operations;
- System operation; inspection, repair and maintenance of components;
- Qualification considerations; system and sub-assemblies track records;
- Contractor capabilities and track records;
- Preliminary schedule and CAPEX cost estimate.

The key concept selection criteria were set as follows (Hiller et al., 2015):

- Risk of chosen system; application of field proven components;
- Availability and characteristics of required fleet and infrastructure to build the system;
- To rely on experience from previous projects to construct and install similar systems and use of specified materials and technologies;
- Team experience from executing similar projects and familiarity and experience of working within the relevant country;
- Onshore construction and offshore installation complexity;
- Level of complexity to install, maintain and replace critical components. Cost of integrity (considering monitoring, inspection and maintenance);
- The system flexibility of being installed before the FPSO arrival;
- Subsea layout (flexibility and interference);

- Schedule risk associated with the EPCI phases;
- Additionally, some regions demand significant local content requirements: high level of local industry involvement, which is critical for the project.

The screening process typically concludes with the most advantageous concepts and a few proponents (typically a maximum of three) elected to perform FEED studies.

5.2 FEED

At this phase the objective for each company participating in the tendering process is to describe their concepts in more detail: identifying and introducing improvements to the initial concept in order to reduce costs and improve operability while ensuring integrity and constructability. Whereas, the conceptual design and development plan are used as a starting point for the FEED. Thus, the primary objectives to achieve are to:

- Define basic design details for the riser configurations (parameters of straked, faired and buoyant sections), FPSO balcony/turret configuration and all associated hardware;
- Verify material selection and specify final corrosion allowance;
- Perform further studies to optimize the systems layouts and clearances in relation to the designed and future risers, mooring lines and flowline interfaces;
- Demonstrate compliance with the schedule requirements and technical specification;
- Maximize confidence in the execution strategy to facilitate a fast track transition from FEED into project execution, minimizing design changes to allow early start on procurement;
- Further define the fabrication and installation methodologies and timing schedule for all main structures;
- Further define the integrity management plan for the risers;
- Define the cost base for engineering, procurement, fabrication, onshore testing, installation and final pre-commissioning, sufficient for preparing a commercial offer.

It must be acknowledged that there might be some uncertainties about production parameters, monitoring system, tethers solution or any other technical dependencies, so that certain parameters might need to be fine-tuned early in the detailed engineering stage after clarifications (if any) are required.

Qualification programs for new technologies and computer simulations for innovative installation methodologies are to be planned during the FEED study to undertake without delays upon start of the EPCI project.

At the end of FEED study the proposals are to be presented by each company participating in the tendering process to let the final negotiation and evaluation to take place to enable awarding a contract. Proposals are to be considered according to established primary criteria with a financial estimate as a central part of the evaluation process. Despite the fact that Sapinhoá-Lula project is conceptually different relative to the SLWR concept, the estimates used in Sapinhoá-Lula project can be considered as typical and are to be evaluated within SLWR project (Hiller et al., 2015):

- Key time periods and timing schedule:
  - Period of qualification of critical components;
  - Period of supplies;
  - Complexity of the system construction (required time period);
  - Period of mobilization of the site;
  - Efficiency of the installation spread;
- Costs of the RIM, including monitoring, inspection and maintenance;
- Level of definition and robustness of the basic project

The Sapinhoá-Lula NE design competition process ended up with a number of lessons, which can be deemed as typical for a large deepwater project and therefore should be considered in future SLWR projects (Hiller et al., 2015):

- The involvement of a larger number of companies enriches the research and development process and gives the opportunity to increase the technical knowledge of each proposed riser system;
- The engagement with leading companies in the industry allows a wide screening of the market for best solutions and provides with better access to the pool of experts;
- Close collaboration with companies accelerates long lead partnership and leads to the effective design process of new assets and technologies;
- The establishment of efficient partnerships is a critical activity to handle tight design and supply schedules; exclusive partnership could be beneficial;
- The use of formal tender clarifications visible to all bidders coupled with technical workshops and clarifications privative to specific competitor has a good balance of flexibility, organization and transparency;
- Clear goals and evaluation criteria set a neutral environment and promote a great deal of collaboration; this permits a fast tracking of the basic design and facilitates a bidding process. In addition, unnecessary interactions between the supply chain in search for feasible and best technical options are eliminated;
- Integrating design and construction engineering with constant trade-offs results in better-optimized solutions;
- Various communication and interfacing tools are in demand to effectively coordinate expertise pools, which are spread globally;
- The tendering and execution planning activities are time consuming, thus the assessment procedures to cover the 2nd order costing items (logistics, tax and finance, risks and mitigation plans) in greater depth are to be properly planned.

The design of offshore facilities should be favourable to the end-users or operators of the facilities; this is fundamental (Chandrasegaran et al., 2016).

5.3 Engineering

The project execution starts off with the engineering phase, which predetermines the success of all subsequent phases. This fact increases the importance of the engineering phase posing additional considerations to be thoroughly elaborated. Many challenges, from technical to managerial, expose the project to high risks are to be taken into account/analyzed early in detail design and considered throughout the execution phases. The challenges have a cascading effect: any delays in installation, fabrication, supplies, procurement or design will push an offshore campaign to the winter time with less frequent suitable weather window that, in turn, postpones the production start.

The challenges encountered in the Sapinhoá-Lula NE project execution can be deemed as typical for a large deepwater project and therefore should be not underestimated in future SLWR projects. They are grouped into the following major categories (Camozzato et al., 2015):

- Schedule
  The schedule is typically tightened by the time planned for the first oil, so that all components are to be designed, procured and fabricated to allow an offshore campaign to start by a certain date;
- Changes
  Relevant input data needs to be systematically revised. It is critical, because the process results in multiple adjustments iterations, which are required to finalize the project specifications, which are time-consuming and could lead to the project delays;
- Weather
  The frontier regions have scarce available data that gets renewed when the FEED stage is ongoing or later during the detailed engineering. It imposes uncertainties on the design process and requires certain envelopes in designing components to absorb the changes. Besides, upon weather revision the expected offshore operation ability is tuned and the campaign duration is repeatedly planned;
- Technical
  Frontier regions force the project team to develop new components that have been non-existent but are required to enable a project execution. This makes great demands of the project team to have high engineering competences. In addition, the project execution unavoidably faces a significant number of technical changes, which must be handled;
- Inspections
  The procedures of on-site inspection must be elaborated and implemented at the fabrication sites to allow perfect matching of components built by different suppliers at different locations;
- Logistics
  Because of the extended procurement plan and worldwide-spread of the suppliers, a massive task of handling international logistics of goods and complex customs

processes is to be managed. An appropriate control of all processes is core to avoid project delays. Associated logistics difficulties such as sizing, shipping weight, tax regulation must be accounted during the engineering process;

- Offshore operations
  Installation criticalities must be established by the engineering team to accomplish successful offshore operations depending on the weather conditions, capabilities of construction vessels, safety installation requirements, presence of neighboring fleet etc. Detailed planning, coordination and 24/7 presence should be partially accounted during the engineering phase;
- Contractual
  Contractual structure comprised by dozens of individual contracts is complex to manage. To implement any changes to the execution plan certain procedures are required to get an agreement from the contractor.

A rigorous design program shall be elaborated to ensure the risers could be safely installed and would allow for robust operations in accordance with the design requirements. Additional steps shall be undertaken to provide increased assurance of the riser design, if the innovative technologies to be employed. The overall scope of the engineering phase includes the following key design aspects:

- Materials and corrosion engineering;
- Global riser analysis;
- Computational Fluid Dynamics (CFD);
- Local FEA and ECA;
- Weld qualification and specification;
- Specification development.

A riser system must be designed such that no single failure will cause any unacceptable incident taking into account the most unfavorable combination of functional, environment and accidental loads. The potential causes of failure shall be identified by analyses and measures implemented during the design to remove or minimize the probability of occurrence. (Suresh et al., 2015)

5.3.1 Materials and corrosion engineering

Proper material selection is a complex engineering function and is one of the most important factors during the design phase; it involves careful analysis of a large amount of information to provide a riser system with high performance.

Material selection is generally a balance between reliability and cost. A proper matching of the materials characteristics with service application is essential for good operability. In order to make the best material choice decision the following factors should be analyzed as a whole (Yanes, 2012):

- Detailed operational conditions, which the riser system is going to operate in;
- Detailed composition of the fluid;
- Life expectancy defined by the operating company depending on the economic feasibility;
- Most probable corrosion phenomena expected during the service life with identification of critical SLWR components;
- Performance records of materials used for similar services;
- Screening of different materials accordingly with main properties, behaviour in contact with different fluids, manufacturing characteristics, cost, delivery time and availability.

A coherent system engineering approach should be adopted incorporating a standardized selection process based on application of cross-discipline experience along with the corrosion rates and inhibition requirements to reduce the number of iterations.

5.3.2 Global analysis

Global analysis is an essential tool to optimize the entire riser system configuration, predict operating envelope and fatigue life. Moreover, the global model is used as a base case for detailed analysis of each particular component. The objective is to determine the critical loads on system components under varying vessel positions and environment loading using static and dynamic analyses.

The focus of static analyses is to assess the static response of SLWR system due to the current loading and determine critical design parameters under operational, extreme and accidental conditions as well as the varying fluid densities. Results from static analysis clearly define the extreme current loading and directions that produce the worst response for each given critical design parameter. Each main result from the static analyses identifies the load case to run dynamic analysis. Two cases – 10year wave/100year current and 100year wave/10year current are modeled for various combinations of wave heights and peak periods for up to 5 wave directions. This method of static and dynamic analyses shall be conducted for each SLWR system key component identifying each design parameter for critical loads. Ad locum the fatigue assessment shall be performed.

Strakes optimization as a part of VIV calculations and interference study are performed using global model: the clearance between all major components must remain at a safe minimum considering all extreme and operational scenarios.

5.3.3 Finite Element Analysis

FEA is a structural analysis intending to simulate the actual working conditions of the system elements in different installation and operational scenarios. FEA models predict the component behavior and, through various design iterations, result in optimized design. It is one of the key methods to validate a system design as per latest industry standards.

Design validation is required to ensure the equipment will work as expected before it is put into operation. As well, extensive tests are part of the qualification program, they involve significant amount of cost and time to develop test set-up to simulate the exposure of novel riser system components to actual installation and operational conditions. Hence, it is important to simplify the design validation procedures to reduce expenses without compromising the purpose of the tests. It is prudent to replace some of the tests by finite element analysis with conservative approach using field proven data, since the cost of FEA simulations is significantly lower than if extensive tests are to be performed (Suresh et al., 2015).

5.3.4 Engineering Criticality Assessment

ECA is conducted to confirm that failure from possible weld flaws will not occur, based upon the principles of fracture mechanics, during the installation and operation of the pipeline. Normal ECA methodology described in DNV-OS-F101 performs the assessment of ductile tearing and plastic collapse by determining the extent of crack driving force.

The Sapinhoá-Lula NE project has demonstrated that there may be a lack of formalized standards in the industry to assess the welding scenario (Gouveia et al., 2015), where the weld metal does not overmatch the parent material (partially over-matching or under-matching of the girth weld, where the parent pipe yield strength is lower than the weld metal counterpart). This overmatching is requested in order to avoid strain concentration on the pipeline girth weld, where defects are likely to occur and lower fracture toughness is expected. Therefore, a new ECA methodology should be developed with an involvement of significant amount of testing procedures and authorized resources from certification and classification companies such as DNV, ABS or Lloyds.

5.3.5 Design advancement

The riser system equipment is subjected to various forces throughout the lifetime from installation and operation to decommissioning. A failure at any of these stages can lead to catastrophic consequences to human lives, environment and structures integrity. Design advancement techniques are the measures intending to improve the components reliability and control their development costs (Suresh et al., 2015):

- Design For Six Sigma (DFSS)
  To provide a framework for robust design the DFSS methodology includes a number of techniques such as Critical To Quality (CTQ) Flow Down, Fish Bone Diagram, Failure Mode and Effect Analysis (FMEA), tolerance analysis and various optimization and verification techniques. Design for reliability involves identification of failure modes for specific equipment and design cases, definition of limit states, uncertainty measurement of random variables, calculation of failure probabilities, etc;
- Design For Manufacture
  DFM is an approach to engineering, when the components are designed keeping in mind their subsequent manufacturing activities in order to facilitate them and avoid

additional manufacture expenses and time-consuming operations. DFM identifies potential problems and address them during the design phase;

- Design For Assembly
  DFA is an approach to engineering, when the components are designed with ease-of-assembly in mind. If the component contains fewer parts and if the parts are provided with features, which make them easier to grasp, move and orient, this will take less time to assemble, thereby reducing the costs;

- Design validation
  System design must be validated based on the latest industry standards to ensure the riser components will work as expected. This is generally achieved through the extensive qualification testing and structural analyses like FEA, where an appropriate simulation environment must be developed to be close to the actual conditions covering phases from manufacturing to decommissioning. Multiple design iterations based on the testing results lead to the best riser configuration;

- Design validation using measuring equipment (motion and dynamic curvature sensors, Fig. 4.5-4.6) placed at critical locations on the riser. The SLWR has a novel configuration with which the industry has limited design and field experience. Thus, installing motion and strain sensors to track the riser's infield behavior through measurement of motions and strains enables a comparison of observed performance to analytically predicted performance made during design. Such design validation practice has been successfully applied to the Caesar-Tonga SLWR project; (Kumar Das et al., 2014)

- 3D printing
  Any assembly or functionality complications identified at the final stage result in huge financial losses and project delays. This can be potentially avoided using 3D printing technologies and performing indicative tests on the scaled-down models. By adopting 3D printing technologies the models of specific components can be printed in a short time and with low costs to provide engineers with quick and clear understanding on the functionality of components and represent their assembly activities. Such design validation practice has been successfully applied to the Stones BTM key components (Fig. 3.10).

5.4 Procurement and integrated supply chain

All procurement activities must be conducted by contracting company in close cooperation with the client. The procurement responsibilities shall be reasonably divided between them to secure timely deliveries of all riser system components. The long-lead items can be procured by the client before the contract is awarded, so that manufacture of these items could commence and later on they could be delivered in time for the assembly and installation operations. The marshaling and mobilization of components shall be carefully planned by the contractor, so that all items could be fabricated, inspected and ready for transportation with all specifications satisfied.

When the early procurement is to be organized, there is a need to have an early definition of the interfaces for each procured component, otherwise remaining design uncertainties will result in delays and jeopardize the overall project delivery.

Establishing a dedicated organization is key to ensure timely placement of purchase orders, comprehensive awarding processing, appropriate post award management (engineering, expediting, quality control and transportation to the fabrication sites). When procuring the items the following matters are to be considered: (de la Cruz et al., 2009)

- Risks of having a period of overheated market: the required raw materials and equipment are in deficit. Thus, the decisions must be taken early in the engineering phase to allow placement of orders for reservation of production slots;
- Schedule constraints. The fabrication sequence imposes constraints on the delivery of items, which are required in fabricating. Some deliveries shall be organized in batches (i.e. partial deliveries) to allow fabrication to progress;
- Quality issues. The quality control of all components is a major challenge for the project. Maintaining the required quality level for numerous suppliers of different sizes, at different locations with tight schedule constraints, while they were already busy on many other demands, takes a lot of efforts to the team. The items of first delivery priority (critical path items) shall be determined in order that the team could particularly focus on them. Obtaining of final documentation matching the specifications remains crucial for the overall process.

In addition to the major riser system components, the provision of installation aids distributed around the world requires significant efforts to follow up the deliveries: riggings, temporary structures, hang-offs, transportation frames, tools for Remote Operated Vehicles (ROV), etc.

Referring to the Sapinhoá-Lula NE project, more than 2500 purchase orders have been placed with over 600 different suppliers involved in the process. The following map provides a vivid illustration of the worldwide spread of suppliers showing the diversity of countries (Fig. 5.3), this is a typical scope for recent riser system projects.

5.4.1 Tax and Legal requirements

An extensive global supply chain creates a complex logistics of goods as well as complex customs processes to be managed during the project execution.

Finance, Legal, Tax and Supply Chain ("FiLeTS") management must be organized by means of forming a FiLeTS team, so as to free up the engineering team to allow them to focus their expertise on technical matters. Some of the FiLeTS team's responsibilities are the following (Stingl & Paardekam, 2010):

- Communicating with suppliers during ITT to clarify the tax regimes; individual approach has to be adopted;
- Structuring the contracts to ensure full compliance with tax and legal requirements;
- Communicating with internal Tender Boards to verify they have a clear

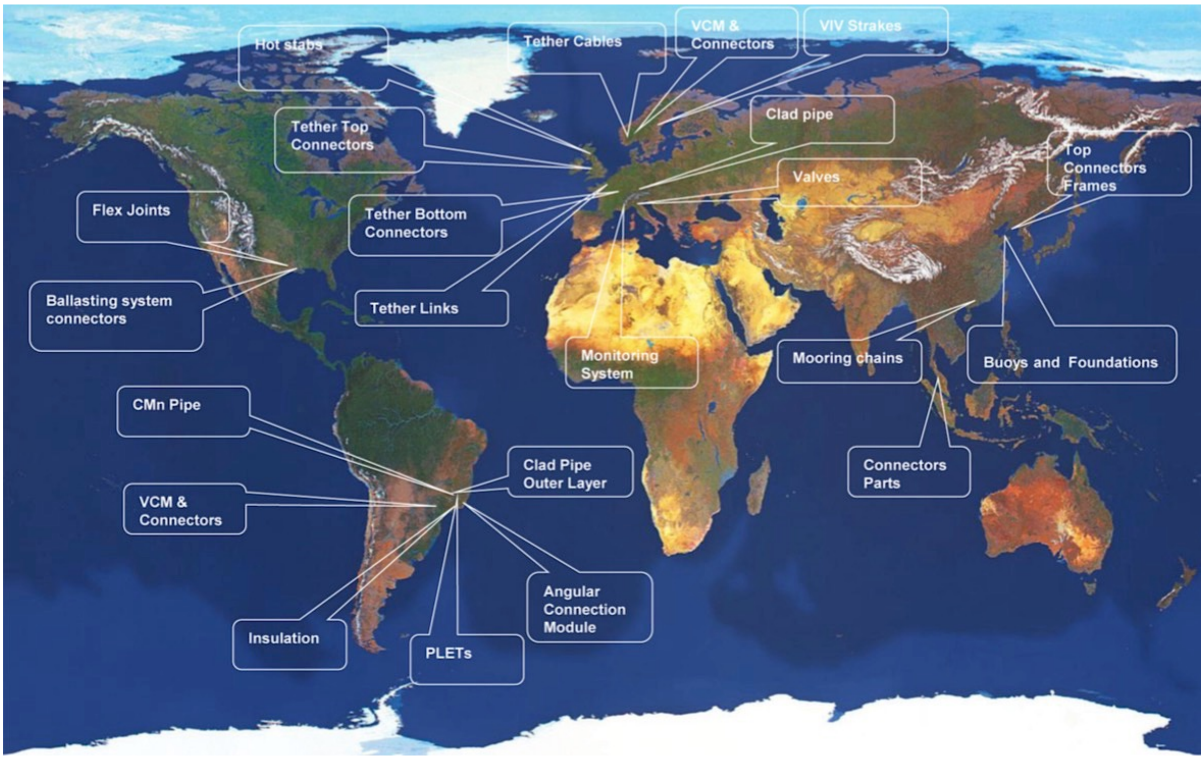

Fig. 5.3 Main suppliers by country of origin, Sapinhoá-Lula NE (Camozzato et al., 2015)

understanding of the legal structures in the contracts, etc.

5.4.2 Additional procurement challenges

The future SLWR projects have to take up the gauntlet to manage the following typical challenges that were encountered during BC-10, CLOV and Sapinhoá-Lula NE projects:

- Innovative and pioneer characteristics of riser system components can face the difficulties in terms of limited number of suppliers that have capabilities to fabricate and deliver components within the required quality and schedule;
- World-spread suppliers create the difficulty of overcoming different languages and time zones;
- Multiple logistics bases must be mobilized for storing materials as well as for pre-assembly activities. A dedicated team must be established in each base to manage on-site operations and ensure HSE priority in all activities;
- To carry the cargoes around the world freighters are to be used. Matching the planned delivery dates with the availability of cargo ships is critical.

5.4.3 Supply chain management

To effectively execute large and complex SLWR project some management principles can be introduced into the organization of supply chain. Referring to the CLOV's project experience, engineers with different competencies are to be mobilized to expedite the deliveries: e.g. material engineer is to be made responsible for specialized material like forged pieces and line pipes, or an electronic engineer is to be made responsible for the riser tower monitoring system, which requires a high competency to deal with cutting edge technology equipment, etc. Applying this experience the following management features can be adopted (Proust et al., 2015):

- Each purchase order is to have its dedicated supply chain management engineer, whose duty is to deliver the goods in time and with the required level of quality;
- A dedicated technical engineer is to be assigned to follow up the technical progress of the supplier, ensure the products are being delivered in line with the requisition and identify any potential technical issue in advance;
- For large orders, the supply chain engineer becomes a project manager accountable for the schedule, budget and quality of the package and being closely assisted by technical engineer.

5.5 Fabrication

This project manufacture phase has two principal concerns:

- Availability of plant capacity to manufacture large quantities of pipe given the supply chain constraints;
- Assurance of pipeline integrity during reeling and installation operations.

The riser serves as a physical boundary between the production fluid and environment. Any disruption in the structural integrity during operation phase will lead to the tremendous consequences for the operating company and environment. Thus, the process for producing welds must be developed and qualified to minimize the potential of fracture during the reeling and installation operations and through the entire lifespan.

5.5.1 Production of risers

Production of risers proved to be technically very demanding, hence the following challenges and difficulties experienced by previous riser projects can be considered:

- Qualification program (if unconventional materials or novel technologies are to be used): the program must be properly planned to be completed prior to the commencement of riser fabrication. It is recommended that the project team plan a dedicated qualification program in advance (van der Ent et al., 2006);
- Material selection and evaluation of properties: evaluation of as-welded properties and their changes during the following reeling and installation operations;
- Optimization of fabrication productivity and quality: the choice of welding and Non-Destructive Testing (NDT) equipment is mainly a trade-off between the production rate and quality. Besides, root, fill and cap welding passes can be produced using different welding techniques;
- Quality control supervision: selection and testing of equipment, adjustment of equipment for various requirements, elaboration of quality control procedures;
- Workforce criticality, local requirements: there may be a lack of qualified specialists to

perform technically advanced welding procedures using specific equipment. Training program is required. This was one of the most significant challenges encountered in Sapinhoá-Lula NE project;

- High competency requirements to the operators: Automated Ultrasonic Testing (AUT) interpretation is substantially operator dependent. Thus, it is necessary to perform an extensive review of operator's experience to assure his competence and permit him to work on the firing line. Specifically trained AUT operators are of vital importance to a successful inspection (van der Ent et al., 2006);
- Production scope: large number of welds to be completed given the overall length of all risers;
- Changes in the welding procedure. The practical example: initially the weld caps can be left intact during fabrication, but fatigue testing may reveal that it will be virtually impossible to meet the project requirements without sanding the caps. Thus, the testing procedures will have to be reorganized, cap removed and post cap removal inspection stations will have to be additionally arranged. Removing of caps is a relatively exhaustive process with high requirements to the final surface profile, therefore a training is required for this key function as well;
- Conducting full-scale tests to validate new methodologies. Spooling trials as an example (Maneschy et al., 2015): after completing spooling trials, the pipes are to be removed from the vessel and inspected in order to evaluate the internal roughness and verify if wrinkles have occurred during the reeling process. The inspection of internal surface can be performed using the crawling video and laser equipment to identify discoloration developed after welding and for hi/lo gauging and measurements of concavity (Fig. 5.4)

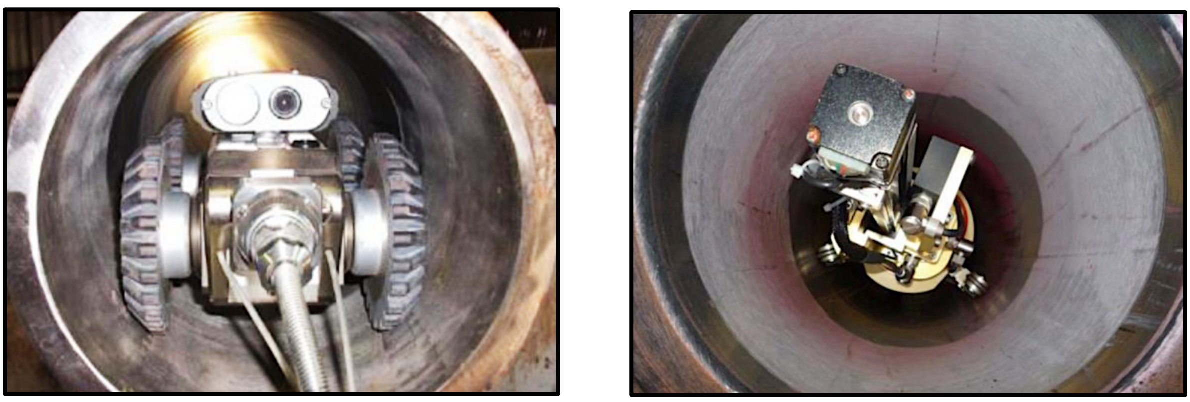

Fig. 5.4 Crawling video (left) and laser equipment (right) (Maneschy et al., 2015)

5.5.2 Inspection method

ApplusRTD provides oil and gas industry with world leading inspection and NDT services, it holds extensive global accreditations and recognitions, thus cooperation with them can be advantageous. The onshore (and offshore) girth welds can be examined using Phased Array (PA) AUT method, performed by Applus using their proprietary Rotoscan PA AUT system.

The Rotoscan AUT system is a patented system, which utilizes the conventional Rotoscan hardware but introduces the use of PA probes configured to produce angled compression waves instead of conventional shear wave probes. This wave concept is required to overcome the ultrasonic difficulties associated with transmission of conventional waves through the CRA welds, which are known to be a challenge due to noisy grain microstructure (anisotropic) (Fig. 5.5).

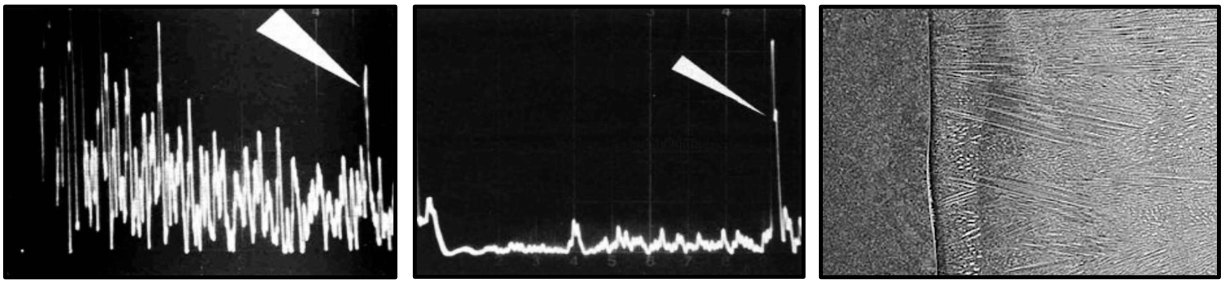

Fig. 5.5 Conventional shear waves (left) and compression waves; CRA weld filler to base material interface (right) (van der Ent et al., 2006) (Hu & Tsai, 2007)

Prior to the commencement of riser production, the AUT system must be qualified. Qualification is highly critical for the entire project, since any missing system malfunctions could put the project at risk. The following activities comprise a comprehensive qualification study (Jones et al., 2016):

- Review of historical data from previous projects, establishing a pre-qualified basis;
- Elaboration of decision flow charts for defect interpretation and sizing in order to provide greater clarity for AUT operators and ensure the correct process is consistently followed when evaluating indications;
- Development of interpretation guidelines: revised software and interpretation rules are required for each type of pipe material;
- Customization of equipment: as part of the AUT validation process. Occurrence of false indications will require correction actions in order to adjust equipment and improve the sensitivity for indications in certain areas of weld;
- Performance of additional testing may be required in some cases of false indications: Dye Penetrant Inspection and Energy Dispersive X-ray Analysis (EDXA);
- Investigation of Partially Mixed Zones formations will be required in case of their occurrence.

5.5.3 Production experience. Aasta Hansteen project

Welding development work completed prior to the fabrication campaign allows production team to concentrate on improving general efficiency and overcoming specific technical challenges, which are always expected to encounter during fabrication.

The on-going Aasta Hansteen project demonstrates the scope of activities required to organize a proper fabrication campaign. It serves as a good example to emphasize that the production experience from previous projects shall be taken into account when preparing a new project's risers production. Moreover, a technical partnership between Subsea 7 and CRC-Evans has yielded a number of novel and cost effective welding solutions, demonstrating the importance of industry knowledge consolidation.

The time period of early 2013 associates with the first implementation of the Cold Metal Transfer/Pulsed Gas Metal Arc Welding (CMT/PGMAW) solutions for the fabrication of SCRs in both Carbon Steel (CS), clad and lined pipe for Sapinhoá-Lula NE project – on the base of the Ubu spoolbase (Fig. 3.2). Within the project, the fabrication campaign encountered a number of technical and operational challenges (Jones et al., 2016):

- Camera/laser inspection difficulty: control of the root profile to ensure avoidance of a concavity. This was a demanding technical test, as the camera images were not always reliably interpreted by the inspector for NDT of the clad/lined welds;
- The execution of cap sanding. With regard to control of material removal and meeting stringent final visual inspection criterion, the procedure proved to be challenging;
- High residual magnetism in both the clad and lined pipe materials. Normal pipe end demagnetization procedures proved to be ineffective in completely eliminating the magnetic fields.

As for Vigra spoolbase (Norway) CMT/PGMAW processes took place for the first time in 2012 (for clad pipe). The first use resulted in a significant improvement in productivity over the clad pipe welding technology based on TIG welding. During the following 3 years, the process was deployed for several North Sea projects before the Aasta Hansteen fabrication campaign kicked off later in 2015. By that time, operators had considerable experience and a high efficiency in executing operations. Subsea 7 and CRC-Evans have performed an extensive investigation to introduce technical and procedure developments into the Aasta Hansteen fabrication campaign.

5.5.3.1 Introducing developments

When reviewing industry experience, it was identified that the use of PGMAW in recent years had proven to be problematic in achieving the high weld integrity requirements on some projects in the GoM. Taking all available experience into account, Subsea 7 identified the following areas to be developed (Jones et al., 2016):

- Improvements in CMT/PGMAW performance for both CS and clad/lined heavy-wall pipe;
- Capability for performing full pipe body demagnetization. (Subsequently, in order to minimize the risks of re-occurrence of a residual magnetism problem to such extent as experienced during the Sapinhoá-Lula NE fabrication campaign, Subsea 7 installed a full pipe body demagnetization facility at the Vigra spoolbase).

With regards to the CMT/ PGMAW welding solution for clad/lined pipe the following technical improvements were achieved (Jones et al., 2016):

- Use of an improved CMT waveform in combination with an optimized Ar-He-CO2 shielding gas composition. This results in better process stability and, in combination with the use of tighter root bevel tolerances, gives fewer burn-through flaws;
- The bevel angle. Reduction from 10° to 5° gives fewer welding passes to complete the weld. Additional optimization of welding parameters reduces risks of lack of fusion flaws;
- Optimization of composition of shielding gas used for the PGMAW fill and cap passes minimizes oxidizing potential necessary to maintain arc stability whilst avoiding excessive oxidation of the weld metal;
- The use of tighter contact tip dimensional tolerances facilitates more reliable current pick up and consistent welding parameters;
- Besides, following the Sapinhoá-Lula NE experience, the internal inspection has been greatly improved with utilization of CRC V Root Internal Inspection System (Fig. 5.6), which was made available through the partnership with CRC-Evans.

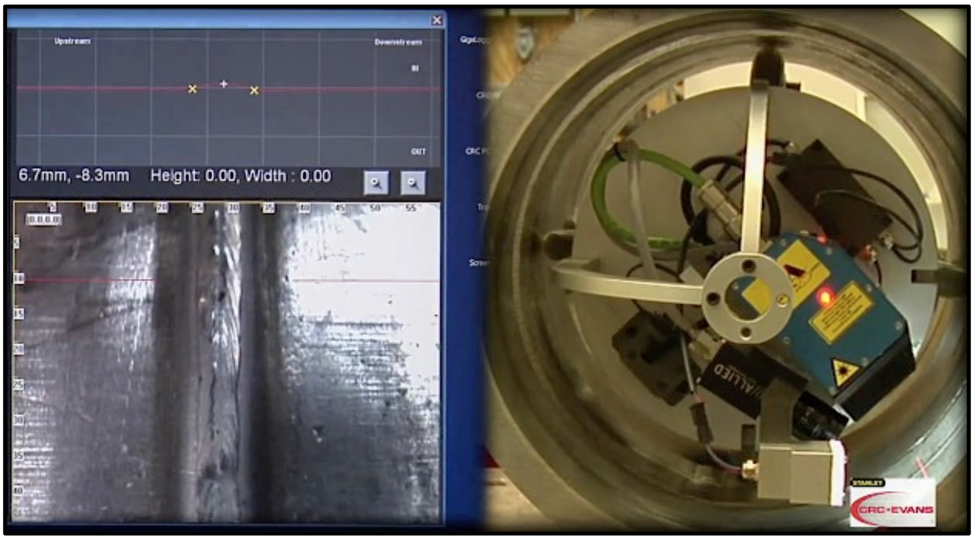

Fig. 5.6 Vision Root Scanning System. Results can be seen in real time (Crc-evans.com, 2016a)

In 2012, prior to the Aasta Hansteen development program, an industry review of PGMAW performance highlighted limitations relative to the achievement of stringent weld quality requirements. CRC-Evans and Subsea 7 recognized that a substantial improvement in technology would be required. The fundamental cause of small lack-of-fusion flaws was an issue to investigate. Thus, to improve the ability to monitor and evaluate what is happening in the arc and weld pool in real time and to visually observe the effect of changes in parameters, the following items became key to achieve a successful result (Jones et al., 2016):

- The CRC-Evans P-625 (computerized external welding machine, Fig. 5.7) fully integrated into the Fronius welding power supply. The major benefit of this system is that it allows for real time manipulation of pulse waveform through the use of the remote control unit;

- Data acquisition system capable of recording pulse waveform characteristics. The system provides with real time feedback and enables ongoing changes to ensure that a stable arc is being produced;

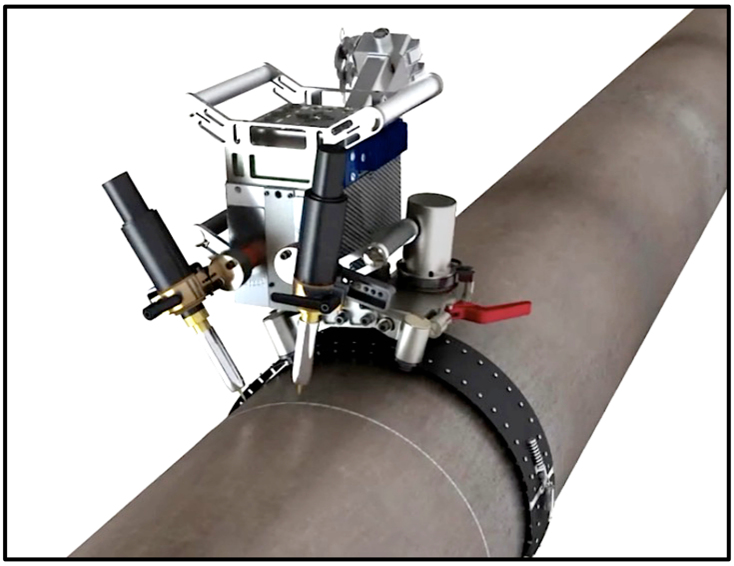

Fig. 5.7 CRC-Evans P-625 (Crc-evans.com, 2016b)

- High speed video camera for viewing of the arc. Coupling the above with a high-speed camera allows for a visualization of what is happening in the weld pool and associated arc and droplet detachment (Fig. 5.8). This permits a quick validation of the effect of each parameter change.

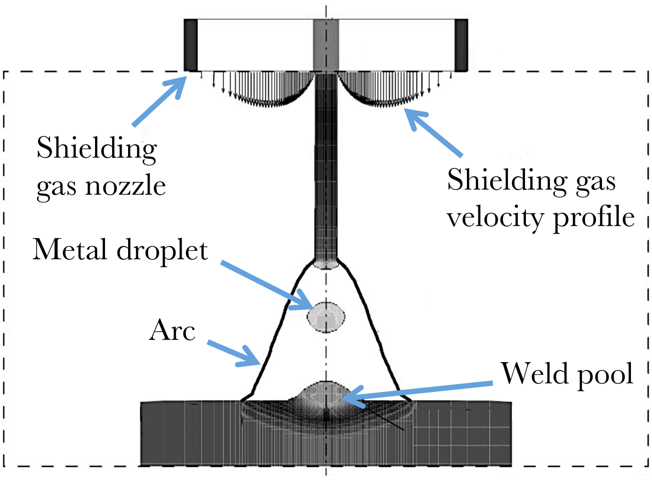

Fig. 5.8 Schematic representation of GMAW system (Hu & Tsai, 2007)

In addition to all, the following basic principles are important to consider, when the fabrication efficiency is paramount:

- Less complexity of equipment leads to reduced number of process interruptions, while greater continuity of welders' operations is achieved;
- Elimination of changeovers of equipment between fatigue and non-fatigue critical

zones improves welding cycle time.

Since the spoolbase typically accommodates all required facility for production of lines of various kinds (gas export SCRs, production flowlines, production SCRs), than the fabrication campaign is to be organized in certain order to optimize efficiency and learning curve.

5.6 Installation

The installation engineering is to be carefully integrated into the detailed design of the riser system. The project team should evaluate first and second-end installation methods and ultimately decide on preferable method keeping in mind the installation of buoyancy modules and strakes and hang-off joint handling during the process. When choosing installation strategy factors, factors such as availability, procurement and installation costs inevitably drive the selection.

5.6.1 Installation procedures

Riser installation is normally performed by direct transfer from an installation vessel to the FPSO. However, pre-installation, subsequent recovery and transfer offers a beneficial alternative method for installation of SLWRs. This reduces the requirement for long installation weather windows normally associated with direct transfer methods, more freedom to abandon the riser in case of adverse weather conditions and allows for field development to continue in case of late arrival of the FPSO. (Thomas et al., 2010)

But these advantages bring some associated challenges. The biggest challenge is the requirement for the development of a detailed subsea layout description, an installation sequence and the engineering of pre-abandoned risers to ensure that the installation vessel and the SLWR maintain an adequate clearance with the FPSO mooring lines, risers and umbilicals. Moreover, SLWR has a long buoyant section that forms a "hump" when laid down on the seabed, the height of which has to be managed based on a lay tension and soil friction. (Thomas et al., 2010)

Installation analyses are to be performed in order to adequately address all technical issues, uncertainties and risks:

- Pre-abandonment layout and recovery and transfer sequences of risers considering possible interferences and existing clearances with mooring lines, risers and umbilicals during operations;
- Detailed static and dynamic analyses for the laydown, recovery and transfer of risers considering the construction vessel parameters.

The core BC-10 project activities when installing SLWRs with the deployment of pre-abandonment and recovery method are the following:

- Development of pre-lay configuration;
- Pre-abandonment;

- Recovery;
- Transfer after recovery;
- Direct transfer.

5.6.1.1 Development of pre-lay configuration

A key consideration in developing the pre-lay configuration is to have maximum flexibility in laying the risers and to maintain the riser configuration in the final in-place condition as per design. To maintain flexibility for installation, the crossings of risers in the pre-lay condition shall be avoided. If the risers are to be attached to a turret-moored FPSO, where the riser headings converge to a point, the pre-lay route of the risers has to deviate from its final in-place design heading. Introducing a curve in the pre-lay route after the TDP and avoiding crossings at the same time is not possible. In addition, the buoyant section of the riser starts immediately after the TDP and therefore introducing a curve just after TDP is not practical. Therefore, based on the maximum bottom tension the installation vessel is able to provide and the riser pipe that can be lifted off the seabed at the maximum available bottom tension, the pre-lay route curve is to be introduced before the TDP. The intent is to lift the pipe off the seabed up to this curve initiation point by stretching the riser prior to the transfer operation whilst keeping the vessel heading in the design riser heading. (Thomas et al., 2010)

Several iterations involving various laydown configurations and recovery sequences may be required to arrive at the optimum pre-lay configuration and recovery sequence.

5.6.1.2 Pre-abandonment

A key consideration in developing the pre-abandonment procedure is the formation and maintenance of the hump stability. This involves selecting a suitable lay tension that optimizes the hump height of the pre-laid risers and balancing the friction force developed by the pipe on the seabed for stability of the pre-lay route curve and hump. The optimization of tension required to lay down the flexjoint is an important part of the design of this stage. At the abandonment stage the flexjoint has to have sufficient bottom tension to prevent overstraining ensuring curve and hump stability. The pre-abandonment layout should be designed carefully, considering the recovery sequence and potential clashes during recovery and transfer operations (Fig. 5.9). (Thomas et al., 2010)

5.6.1.3 Recovery

Like pre-abandonment, recovery also needs to consider hump and curve stability and possible overstraining of the flexjoint. The main concern during this stage is the optimization of the vessel route during recovery such that adequate clearance can be maintained from existing laid/transferred risers, umbilicals and FPSO mooring lines. The success of the installation process by the pre-abandonment-and-recovery method is largely due to successful recovery without clash or interference, whilst maintaining hump and curve stability and integrity of the flexjoint and SLWR. Other important factors during the recovery phase are the monitoring of the touchdown point and optimizing the positioning of ROVs, which are to provide the monitoring of activities. (Thomas et al., 2010)

5.6.1.4 Transfer after recovery

Main issues of this stage are optimization of the positioning of the installation vessel with respect to the FPSO within the constraints of the FPSO pull-in winch wire length and the requirement to have specified minimum clearance levels (Fig. 5.10). The vessel needs to be

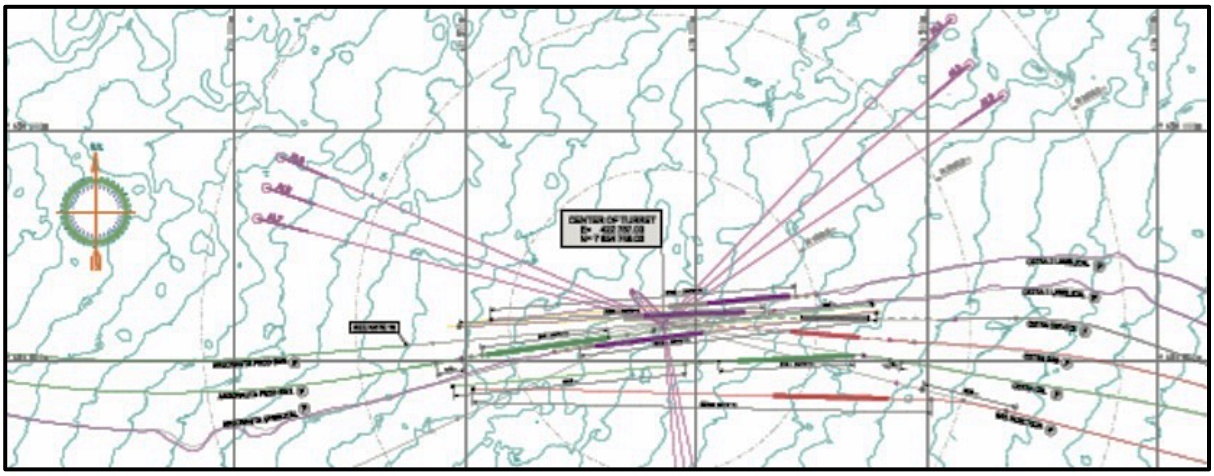

Fig. 5.9 SLWR pre-abandonment layout, BC-10 (Thomas et al., 2010)

positioned to avoid high top tension of the FPSO and Abandon and Recovery (A&R) winches, overstraining of the riser and flexjoint and the formation of a second touchdown point. In addition, monitoring of touchdown, particularly for out-of-plane transfers and clash or interference are also concerns during this stage. (Thomas et al., 2010)

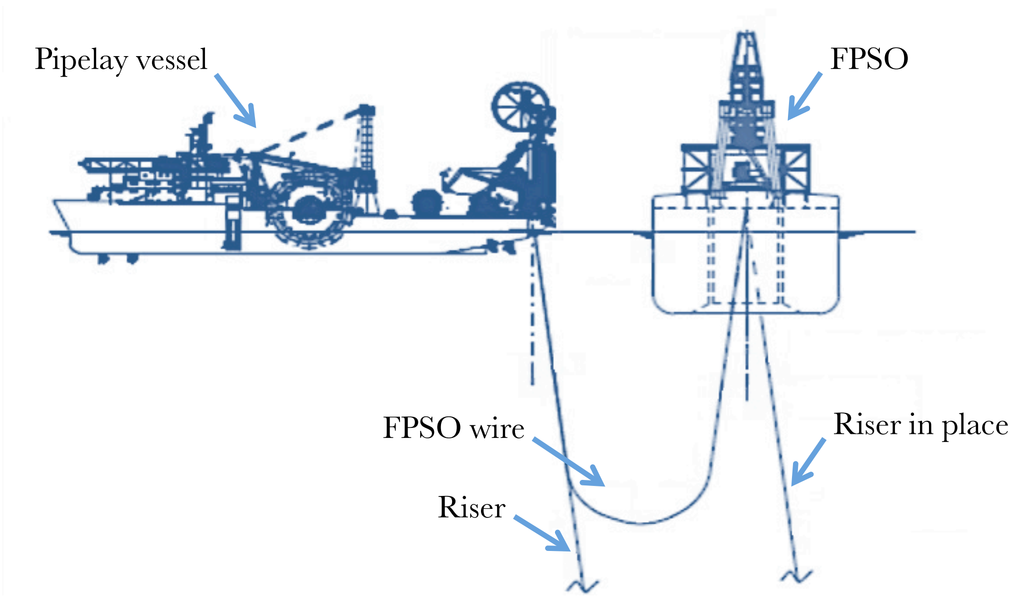

Fig. 5.10 Typical position of vessels during pull-in operation (Thomas et al., 2010)

5.6.1.5 Direct transfer

Some of the SLWRs can be transferred directly to the FPSO. During the operation, the construction vessel has to stay outside of the FPSO swing radius to avoid the potential risk of clashing in case of deteriorating weather conditions. Therefore, finding a suitable position for flexjoint welding to minimize fatigue damage without infringing on the exclusion zone around the FPSO and not overstraining the riser during welding are key concerns of this stage. Other important issues are maintaining the FPSO and A&R winch loads within allowable limits during handover. (Thomas et al., 2010)

5.6.2 Contingency planning

The success of developing offshore construction procedures and plans is very much related to identifying key risks and developing contingency plans to mitigate such risks. The SLWR pre-lay configuration is to be developed such that the recovery and transfer could be reversed if a riser, in case of an unforeseen event, has to be recovered back from the FPSO and laid down on the seabed. Contingency planning is to be considered as an essential element when developing installation procedures. (Thomas et al., 2010)

5.6.3 Additional challenges

The challenges encountered during the Sapinhoá-Lula NE project execution can be deemed as typical for a large deepwater project and therefore should be analyzed in future SLWR projects based on the existing experience (Camozzato et al., 2015):

- To avoid conflicting with local onshore and offshore activities the project team needs to establish an extensive interface with navy and local authorities;
- The weather can be rough and can dynamically change in short periods of time. Since there is no sheltered location anywhere closer than the coast itself, the only way to escape is to sail back to the coast. The distance to the coast may be extensive resulting in higher schedule and cost losses. Thus, the offshore operation risks are to be evaluated, optimized and reduced to As Low As Reasonably Practical (ALARP);
- To increase the offshore operation predictability, the weather forecast discussions and model interpretation are to be performed on a daily basis;
- If the field development plan has been sanctioned with the pilot FPSO production, the presence of the producing FPSO in the field will create an extra challenge to the offshore activities. If the installation of flowlines starts as soon as the first riser is in place, then it will similarly complicate the operations. Therefore, to coordinate the fleet a SIMOPs matrix to be developed, which is discussed next.

5.6.4 SIMOPs

Simultaneous Operations (SIMOPs) are described as the potential clash of activities, which could bring about an undesired event or set of circumstances: safety, environment, damage to assets, schedule, commercial, financial etc (IMCA, 2010).

The following project demands lead to very tight schedule of offshore operations: a fast-track nature of the project, engagement of multiple vessel contractors, high interdependency of marine operations, high cost rates of offshore activities. Considering the amount of installation operations and a number of involved vessels, the occurrence of Simultaneous Operations is unavoidable. Hence, the activities are to be prioritized using SIMOPs matrix to diminish non-productive time of installation units and improve the safety of operations, which is a major concern during the installation phase.

Management of SIMOPs requires close coordination between the project team and vessels contractors to carefully plan all activities in the field. Re-evaluation and revision of the matrix needs to be done on a daily basis through a proactive partnering with all contractors, since an interruption in any operation could significantly affect other offshore operations in a chain reaction.

Thus, the most important task for SIMOPs mitigation is the monitoring of planned vessels activities in order to identify all possible SIMOPs and priorities in operations in advance with cost and schedule impact taken into account. Having identified the operations, which are to take place at the same time and at the same installation area, adjustments in the offshore activities must be found to mitigate or eliminate risks. If the clashing cannot be eliminated, then the priority is to be defined through the communication of involved parties. To get a better and complete understanding of operations the communication could be effectively organized deploying a "war room" concept: the physical room equipped with the latest Information and Communication Technologies (ICT) to enhance the collaboration between different teams and companies (Fig. 5.11).

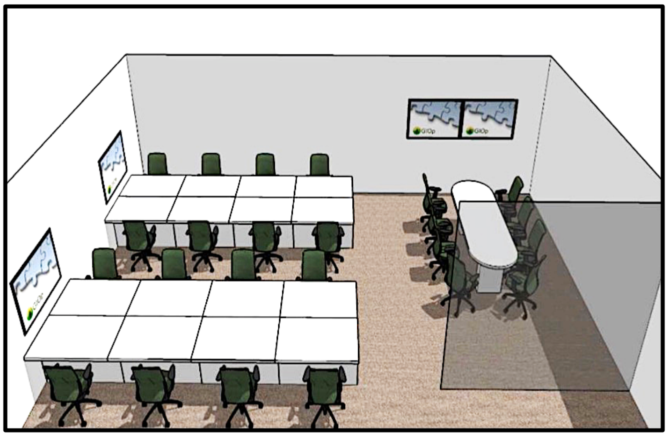

Fig. 5.11 War room layout, Lula NE pilot project (de Moraes Cruz et al., 2016)

6 PROJECT MANAGEMENT

The success of riser project delivery is dependent on effective integration of execution processes, level of team's expertise, multiple internal and external interactions and relationships, solid management principles and strong leadership. This is especially true for deepwater projects where the costs are high, the schedules are critical and the technologies are novel and have limited application records.

Managing project is a highly sophisticated process that is built on a simultaneous managing of different project sectors. To enable project to succeed none of the project sectors should fail.

6.1 Human resources management

The delivery of SLWR riser system is typically accomplished through the EPCI contract. To facilitate interfacing, improve partnering and manage the project complexity a dedicated project team should be based close to the client team. The team can be split between packages, for instance: SCR package and riser/FPSO interface package or another relevant for the project. Each package can have one manager in charge, who reports to the project director. Packages should have team of specialists from different disciplines (one discipline has one dedicated manager) accordingly with their demands. The reporting can be based on the principles of matrix structure of organization.

The riser delivery project typically has a global outreach due to:

- Extensive project scope variety;
- Expertise requirements;
- Worldwide spread of suppliers, fabrication sites and bases locations;
- Logistics requirements.

Thus, dedicated teams can be located in remote locations accordingly with identified needs in order to optimize the execution process herein meeting project demands (cost, schedule, quality). As examples, fabrication management team can be organized in China, an intermediate logistic base can be set up in Europe, while the major project team is to be located in Brazil or in Angola, if it is a Brazilian or Angolan project respectively. The contractor's worldwide offices are to serve as support providers to major project team, in case if additional professional qualifications are required.

6.1.1 Local content

Local content is a socio-economic improvement of local society based on a significant increase in the amount of project related activities performed in a project-based country. If a corporate management and growth policy built around sustainable development has been adopted, than a local content issue is of high significance to the company. This obligates company to initiate a support for the advancement of local economies.

Back to CLOV's execution activities: having identified local content challenges at early stage of the project Total appointed its first ever local content coordinator who would report directly to the project director. The local content policy was based on identifying what was required to assist the Angolans and then recommending a solution that would meet the needs of both the local population and the project. (François & Antonio, 2015)

The capabilities of country to accomplish various execution activities at all phases of the project are to be analyzed in order to maximize involved resources of country, both human and industrial. Significant efforts are required within the evaluation process to identify local production needs in terms of:

- Additional costs, which are required to train and qualify local workforce and to upgrade existing fabrication yards (which are to be involved in the project delivery): to recondition riser/umbilical assembly lines, extend fabrication and storage areas, install new cranes or/and to expand and equip the quay to accommodate larger vessels and enable future activities (for instance, loading modules onto FPSO or mobilization of construction vessel for offshore campaign), etc;
- Quality requirements to meet project expectations: it is of importance that if the yards are to perform extensive fabrication and assembly work during the project execution, they have to be manned with a skilled local workforce, therefore, appropriate training programs must be elaborated.

6.2 Interface management

A well-established interface management process is an excellent enabler of co-operation and collaboration among the companies involved in a project. Awareness and understanding of project interface must be assured when dealing with large and multinational projects. The interfaces can be generalized into four major groups, which should be preliminary identified and listed in the master schedule with responsibilities assigned (Sterling, 2013):

- Physical: consists of structural interfaces between system components;
- Technical: compatibility of codes and specification, which different companies follow;
- Commercial: fulfillment of agreements on payment schedules;
- Organizational: coherent performance in line with the decisions made and the established timeline.

Thus, ways to avoid or mitigate conflicts within any of these generic interfaces must be dealt with managerial principles. Effective interface management requires both the organizational setting and the communication processes to be of an appropriate level. Hence, the following decisions can be made by the project team aiming for a well-performing interface management process:

- Allocate committed staff in key contractors' offices to ensure that the right messages are sent, received and understood (Sterling, 2013);
- Form a FiLeTS team to communicate internally within the project team and

externally with contractors on the matters of finance, legal, tax and supply chain issues throughout various project stages (Stingl & Paardekam, 2010);

- Integrate engineering and fabrication teams adapting the experience from CLOV project: where the engineering is performed with close cooperation with fabrication team, afterwards the fabrication process is assisted by project engineers, who are present at the fabrication yard (Proust et al., 2015);
- Initiate a "war room" concept to facilitate interfacing within a multidisciplinary project team and with contractors and stakeholders. Efficient integration, communication, planning and assessment of the execution phases can be accomplished through regular meetings held in a war room. It consists in a physical room (Fig. 5.11), where representatives of several stakeholders can meet for real time monitoring and controlling of the project additionally using videoconference facility. In particular, such meetings are useful during the installation phase when many resources are involved.

The main benefits of the "war room" (de Moraes Cruz et al., 2016):

- Prompt decision making process;
- Effective daily control of activities regarding resources, time and deliveries;
- Mitigation of delays in material and services deliveries;
- Continuous schedule updating;
- Prioritization of activities;
- Focus on the critical path activities;
- Risk monitoring and controlling;
- SIMOPs mitigation;
- Higher commitment among the participating organizations;
- Enhanced control of activities in terms of legal compliance.

Multiple interfacing is an extremely important element that needs management and proper planning. Because of the increased size and complexity of projects, an ad hoc approach to handling of interface management is in demand as has never been before. Poorly defined interfaces between design aspects, disciplines, execution teams, regional cultures and contract scopes must be avoided.

6.3 Risk Management

Planning of a project includes a detailed risk assessment and risk management planning. The risk management plan can be elaborated through a workshop with a multidisciplinary team of different specialists. The typical workshop objectives could be:

- Identify uncertainties that could pose a negative (risk) or positive (opportunity) impact in the project outcomes;
- Rank qualitatively the risks and opportunities regarding its impacts and probabilities;
- Plan an appropriate response for each risk or opportunity.

As deepwater projects expand globally into new areas, the challenges related to the frontier environment increase. Managing technical and non-technical risks in an integrated fashion (as per risk management strategy) becomes critical. An overview of some common deepwater technical and non-technical risks are given below.

Technical risks:

- Limited industrial records
  A shortage of companies' experience of SLWR system delivery and a lack of SLWR systems, which could have been in operation for more than 10-15 years, limits the industrial data. Even though there have been no major failures in the existing riser systems could conceal hidden flaws in the engineered design or flaws accumulated during manufacturing;
- Water depth
  Innovative riser solutions are being developed to go into deeper waters, but they carry technology maturation and equipment qualification risks (Dekker & Reid, 2014);
- Physical location
  The risks relate to the metocean conditions, seabed topography and various seabed hazards. As well, significant remoteness involves additional concerns about getting personnel and equipment to the location during the installation phase;
- Safety and environment
  New designs result in a technically enhanced working environment that subjects the personnel to higher risks due to unfamiliarity. In turn, the risks of failure causing environmental consequences are higher.

Non-technical risks (Dekker & Reid, 2014):

- Qualified resources
  If the application of novel technologies requires adequate staffing capable of performing newly-designed functions, than the risks related to the availability of qualified people and experienced contractors become significant. When quality resources are in short demand, more conventional technology may prove to be a more robust approach. Therefore, a proper analysis is required to assess the alternatives in order to make the right decision;
- Local content
  The constraints in local capacity, in terms of human and hardware resource availability or the ability to meet the project technical requirements. Local content engagement has recently become an inherent requirement for the delivery of large projects, especially the projects, which are based in regions like Brazil and West Africa with a fewer number of experienced companies and the lack of developed oil and gas large-scale infrastructures;
- Highly aware stakeholders
  In today's information society, transparency and availability of information has

increased significantly. The demands for engaging and listening to local stakeholders may be a cause of the project delay. The Lula NE pilot project can serve as an example of typical case when the number of audience has grown from expected one to actual five, each one located in a different place (de Moraes Cruz et al., 2016);

- Political threats
  Geopolitical stability could be vulnerable. Prohibiting sanctions may be applied to the state-controlled contractors that will make them cease the contract inevitably leading to the project being suspended;
- Legal framework
  Uncertainty of state, local and international regulations, which could change on short notice. For example the stringent regulations, which came into place shortly after the major and catastrophic offshore disasters such as the Alexander Kielland incident in the North Sea or the Macondo blowout incident in GoM.

The third attribute that poses a challenge to deepwater riser project delivery is the schedule element. Presently, all projects are executed in the conditions of shortage of time. This drives the project efficiency, but increases the risks of occurrence of slips in the decisions.

When these risks and schedule drivers are managed properly, the projects can be very successful for all parties and stakeholders involved including the host country's government and people. Hence, to handle the risks the sequence of primary actions is the following:

- First, the overall strategy should be elaborated to guide a risk management process;
- Second, the multidisciplinary team should gain proper insights into every type of risk during the workshop in order to decide on the tools, which would best suit to deal with the risk, and elaborate risk mitigation actions along with the contingency plans;
- Third, kick off risk mitigation plans: implementation of planned risk mitigation actions;
- Finally, deploy contingency plans if risky scenarios start to materialize.

6.3.1 HSSE

The HSSE management must be a priority in every sector of execution activities within a SLWR project. The goal of zero incidents can be achieved only if the teams share a commitment to safety and take it most seriously. To maximize the effectiveness of a zero incident performance the following steps should be undertaken (Stingl & Paardekam, 2010):

- Form and follow strategic HSSE objectives;
- Plan, organize and execute the project activities in a way to ensure that risks to health and safety of people are As Low As Reasonably Practical. Ensure all activities are in compliance with health standards;
- Ensure all staff is aware of critical HSSE tasks. Enhancement in HSSE culture of main contractors is important for the project success: personnel training should to be mandatory;

- Conduct senior management alignment workshops: gather and get all major contractors to know the specifics of design and construction activities before they commence. The objectives are to achieve a complete and undivided commitment of senior management to superior HSSE performance. During the BC-10 fabrication and installation phases, these meetings proved to be invaluable when investigating incidents and sharing learning's;
- Establish relationships and communication channels to enable the teams to monitor performance and share best practices;
- Ensure HSSE is an integral part of the total project.

To facilitate the introducing of HSSE principles into the team's activities, initially the project team should be committed to (Stingl & Paardekam, 2010):

- Manage HSSE as any other critical business activity;
- Pursue the goal of no harm to people;
- Promote a shared HSSE culture of commitment;
- Play a leading role in promoting best industry practice;
- Protect the environment;
- Use material and energy efficiently.

6.3.2 Risk response planning

Contingency planning, or it could be also called Management of Change (MOC), is a very important part of the overall project accomplishment. The planning should be performed in order to avoid any interruptions in the execution activities because of the undesired events like adverse environmental conditions, breakdown or rupture of installation equipment, delays, etc.

Possible cases for contingency planning:

- Deployment of new technology
  At the engineering phase, the risks of unsuccessful application of new technology shall be understood;

- Procurement challenges
  Various purchase risks shall be considered in order to secure a procurement stage. Contingency plans shall be elaborated for the risks related to critical components or materials (for instance, shortage of supplies on request due to the overheated market, when the required goods are in short supply);

- Fabrication delays
  The fabrication of any sophisticated riser component is dependent on multiple supplies. Similarly to the previous case, the supplies of component parts might be suspended, thus leading to the delivery delays of key riser system elements. Therefore, the contingency plans are necessary;

- Installation operations

Risk assessment sessions should be carried out to identify main installation risks. Once the results from the sessions are achieved, they could be further used for developing installation procedures and contingency plans. During the installation, if the risky scenario seems to materialize or has already happened, than a back-up procedure should be immediately mobilized enabling the operation to be continued as per plan. In case of SLWR riser system, some schedule slips could be faced during the installation, due to the first use of some installation techniques, it may shift the following activities, hereby necessitating the application of contingency plans;

- Pre-lay configuration method should be developed in a way that the recovery and transfer operations could be reversed in case of an unforeseen event.

The general risk responses could be:

- Utilize more conventional technical solutions and field-proven components;
- Establish new partnering relationships;
- Outsource part of the work;
- Prepare back-up components, procedures, vessels, etc.

Every late change needs a proper consideration of schedule consequences, quality influence, human needs and involvement of other resources, which are all required to enable a project change.

7 INDUSTRY CURRENT TRENDS AND NEEDS

New commercial approaches, innovative cost measures and technological advances on the part of operators, suppliers, contractors and governments are required in order to reduce the project cost and lower an oil breakeven price making a greenfield project less risky to invest in. To reach this new level of competitiveness, the industry players need to draw their attention to the identified set of opportunities that the industry is beginning to capitalize on (Dekker et al., 2016):

- Supply chain efficiencies;
- Common standard project design solutions;
- Innovations in field developments;
- Supply chain alliances;
- Improved fiscal terms with governments.

Thus, the industry needs to (Dekker et al., 2016):

- Reduce deepwater project costs by 30% through equipment, project design and field efficiencies;
- Create supplier alliances and novel ways of collaboration throughout the industry;
- Create shared value amongst operators and host governments: a balancing act of resource, capital and knowledge holders;
- Promote deepwater projects as the largest source of supply growth to 2030.

7.1 Industry alliances

New alliances and partnership models are getting underway in the industry. Establishing close industry relationships enables capitalization on the synergies between partners' technology portfolios that, in turn, facilitates the development of new technologies. Industry alliances strengthen a holistic approach to development of subsea facility. Integration of expertise from key areas reduces the project risks and uncertainties and delivers optimized solutions for the clients. Strategic partnership of recent alliances has the potential to improve project performance and better address the client's challenges resulting in significant cost savings.

Examples of major industry alliances are as follows:

- OneSubsea, it is initially established in 2015 between Schlumberger and Cameron, subsequently involving Subsea 7;
- Forsys Subsea, it is a joint venture established in 2015 between FMC Technologies and Technip that is currently making progress to merge;
- Saipem and Aker Solutions cooperation that kicked off in December, 2015.

By combining the industry-leading technologies of the parent companies, the interfacing of the Subsea Umbilical, Riser and Flowline (SURF) systems and Subsea Production and Processing Systems (SPS) will be reduced. The early and closer collaboration in designing and execution of SPS and SURF systems will lead to the integration of solutions enhancing schedule and cost performance indicators (Fig. 7.1).

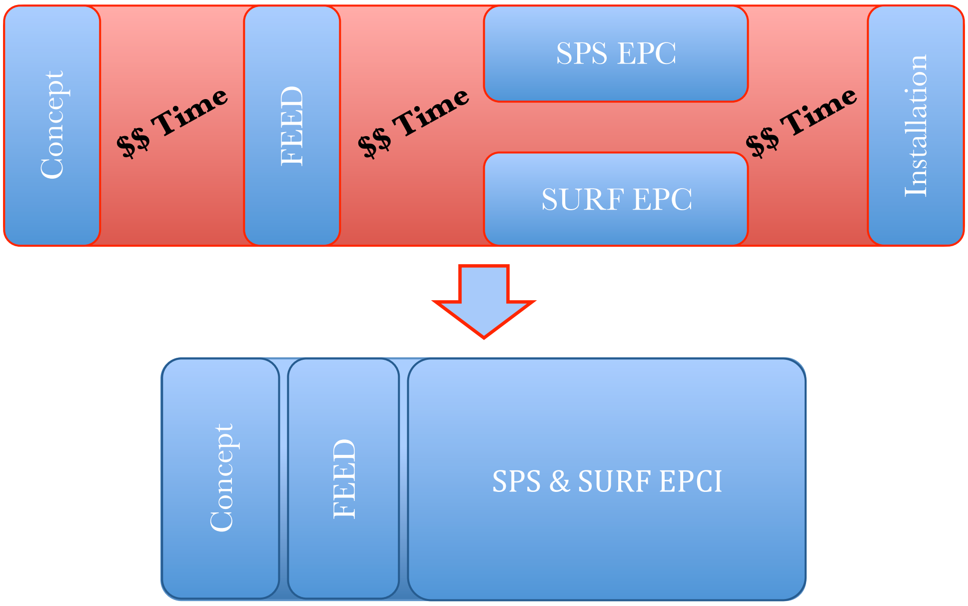

Fig. 7.1 From traditional execution model to an integrated SURF/SPS execution (Cormell et al., 2016)

7.1.1 Integrated project execution: a SURF/SPS engagement

This new approach is part of a global trend within the industry, in response to the current low oil prices and degraded business environment. SPS and SURF contractors are now developing and engaging in coordinated activities much earlier. The intent is to exploit the contractors' knowledge and insights for the system definition to bring more value at early stage of concept formulation based on their experience, drivers and vision. An efficient SURF/SPS partnership brings additional benefit during the project execution phase as well.

Figure 7.1 highlights additional costs and delays that in the traditional execution model with SPS and SURF contractors working separately are typically resulted from (Cormell, 2016):

- Gaps in scope definition and boundary limits;
- Late resolution of some technical interfaces;
- Non-conformance or performance issues;
- Misalignment in quantities.

In recent projects, which are considered to be successful, the cost overruns have been in the order of 5-10% of the overall SPS and SURF contracts with associated schedule impacts of 3-6 months. Poorly defined and executed interface issues can lead projects to even higher cost and schedule consequences. (Cormell, 2016)

To benefit from an integrated SURF/SPS project execution, the three key success factors must be thought-out (Cormell, 2016):

- Goal alignment
  It is of utmost importance that SPS and SURF contractors have a clear and common understanding of the overall system;
- Convergence management
  Interconnection of SPS and SURF processes shall be thoroughly understood: a clear identification and tracking of key interface data;
- Rationalization
  Before starting the execution phase, the interface and boundary limits between SPS and SURF have to be rationalized. Procurement, fabrication, logistics and installation scopes of SPS and SURF systems shall be subjected to proper study (design for vessel, integration of schedules, interfacing are possible issues to rationalize).

Figure 7.2 illustrates the importance of early alignment and convergence planning. In a traditional execution model, activities inefficiency is mainly coming from misalignments and late resolution of interfaces that will materialize risks and hence generate additional costs and

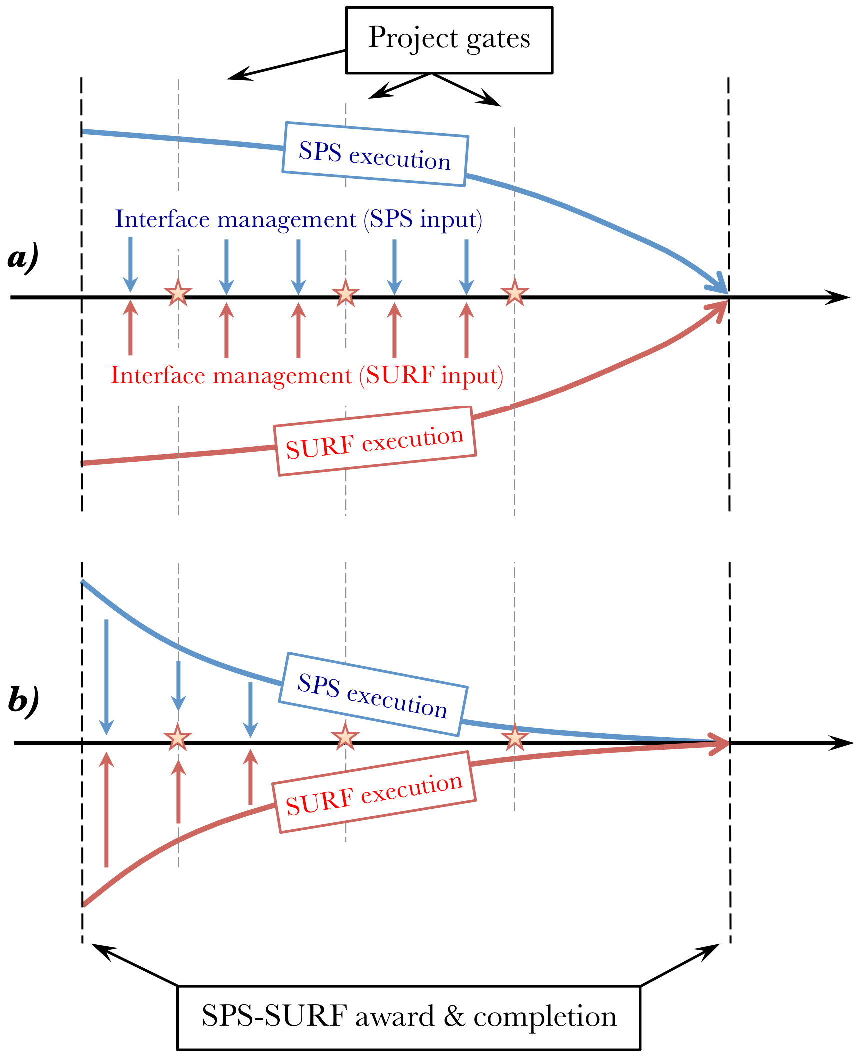

Fig. 7.2 Convergence planning. Traditional model (a) and integrated model (b) (Cormell et al., 2016)

delays. Through an integrated execution model, early alignment of critical milestones and early resolution of interfaces will allow the mitigation of most of the risks. Resolution of an interface at engineering stage is always cheaper than the resolution of the same interface when fabrication is about to start or the offshore campaign is about to be mobilized. (Cormell, 2016)

7.1.2 Honest communication and collaboration

The key to success at the early engagement stage and throughout the execution process is trust built in the context of a true operator/contractor partnership. Building this trust often works best in a small, integrated team over a number of months and years and requires commitment to the relationship. The integrated team creates an atmosphere, which allows problems to surface and be elevated quickly and then resolved within the team with aligned goals. Honest communication and collaboration contribute to robust value creation. (Dekker et al., 2016)

7.2 Common standard project design solutions

There is substantial potential for additional cost savings through common design innovations at the project level. The standardization of equipment, design and installation improves project economics through enhanced delivery schedules, reduction in engineering, manufacturing and installation costs and reduction of project execution risks.

- The steps of specification, tendering and evaluation of proposals for the components are eliminated as well as most engineering activities;
- Delivery times from the equipment supplier may also be improved as repeat deliveries promote consistency and better understanding of specifications;
- Standardized installation tools and installation procedures help avoid trouble time;
- A standardization program enables cost savings through the reduction of spare parts and spare assemblies. With a standardization program, a single purchased component can serve as a stand-by component for multiple projects.

Standardization can be extended to the full FPSO (as well as turret and riser system) designs. For example, standardization of 8 FPSOs was a successful strategy applied by Petrobras to the development of Brazilian pre-salt cluster (Nunes et al., 2016). A "design one, build many" strategy achieves significant cost savings in every execution phase: engineering, procurement, fabrication and installation (Dekker et al., 2016):

- Engineering man-hours are reduced through the use of a previously completed design;
- Design changes should be greatly reduced as the various analyses and code checks are completed;
- Fabrication based on experience and lessons learnt from previous activities leads to time and cost savings.

Hereby, the industry can make great progress in reducing development costs through a strategy of standardization.

7.3 Time to reshape. Promoting deepwater projects

Royal Dutch Shell has over the years proved to be a pioneer in many of the innovations developed in the offshore industry. In this regard, in June, 2016 following Shell's acquisition of British Gas Group (BG), Shell provided an update on the company's strategy indicating the existing industry needs for changes. (van Beurden, 2016)

Shell has identified deepwater as a growth priority with projects in Brazil and the Gulf of Mexico projected to become "cash engines" early in the next decade (van Beurden, 2016). Shell's focus on ultradeep water GoM play does not end with Stones: 52 fields that have been scheduled to come on-stream in the GoM during 2015-2016, three fields among those are in water depths of or surpassing 2250 meters are scheduled to come on-stream in 2016, and all three are Shell's projects (Musarra, 2015).

The industry needs to re-think established ways of working in order to better handle increasing project costs and complexity. In regard to Shell, the BG deal triggered off Shell's reshaping. It turned out to be transformational for the company. It hereby promotes the present business conditions as suitable in order to undertake actions to enhance the performance and become more competitive.

7.4 OTC 2016 as an industry indicator

The CEO of *io Oil & Gas consulting* (a venture that has been resulted from the industry alliance between GE and McDermott), has described the last Offshore Technology Conference in Houston from the following perspectives, which are meaningful:

- Creative innovation
  "Creative innovation and use of new digital technologies is one of the key things to help the industry work differently in near future" (Jackson, 2016);
- New ways of working
  "The opportunities are still there for the taking but it is up to companies to make the most of new ways of working and the latest technology in order to survive and thrive" (Jackson, 2016).

The statements are great indicators of the topicality of problems addressed in this thesis.

8 SUMMARY AND CONCLUSIONS

The thesis has provided an overview of various riser systems, described their core elements and determined key characteristics. Projects insights, which were obtained by reviewing OTC papers, have clarified riser systems' features and established typical delivery challenges, which are of importance to be analyzed in the future projects.

SLWR riser system concept has been selected as one of the most attractive riser solutions to be applied to deepwater projects and has been discussed in more detail covering design peculiarities and execution procedures. Challenges related to deepwater environment have been stressed.

A number of remarkable riser system projects have been subjected to thorough study so as to distinguish the best engineering and managerial practices and identify the principal activities and decisions that took place during the projects delivery and which successfully assisted in projects follow-ups. Introduced innovative developments as well as related activities and adopted well-performing managerial principles have been accented.

Project management section has brought essential aspects of successful riser system project delivery for discussion. Key matters, which improve the project delivery performance, have been distinguished and described with some details.

Since a riser system project, as part of the overall offshore field development, demands certain economic conditions in order to become an attractive investment case, the current industry state has been depicted in the last chapters of this paper.

Finalizing the Master's thesis the following conclusions can be made up:

1. Industry expertise, engineering experience and managerial capabilities are important to deliver greater certainty into the riser system design and project delivery planning.

2. The management of riser system project delivery is a highly sophisticated process that is built on a simultaneous managing of different project sectors.

3. Greenfield projects can be made more commercially viable through the higher performance efficiency and project cost savings based on best industry practices.

4. Engineering and managerial aspects should be effectively managed to successfully deliver a riser system project. Combining innovative developments and proven managerial practices enables a project delivery in the demanding conditions of frontiers.

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