CNOOC 863 Deepwater Technology

Overview of Deepwater Pipeline and Riser Technology State-of-the-Art and Tendency

(深水管道及立管技术综述 – 现状及趋势)

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1.0 SUMMARY

The offshore oil and gas industries started to move into deepwater from early 90s. Since then, tremendous achievements have been made in particular in the Gulf of Mexico, West Africa and Offshore Brazil. It is the general tendency that the whole offshore industries will move to deeper water with no exception of Offshore China. CNOOC is fully aware of this tendency and start to invest in the deepwater offshore technology for the near future offshore exploration and production.

This report summarizes the state-of-the-art and the tendency of deepwater technology with particular attention to the risers and pipelines, which are the keys to unlock the deepwater resources.

2.0 INTRODUCTION

In recent years, the exploration and production activities of offshore oil and gas in deepwater development are numerous, nearly doubling the water depth compared to the activities 10 years ago. Offshore industry is building systems today for production from even deeper water, progressively using new technology, and significantly extending existing technologies. This is the general trend in the offshore oil and gas industries such as Gulf of Mexico (GoM), West of Africa (WoA), Brazil and North Sea.

Figure 2-1 below illustrates the deepwater development trend in Brazil, from which it tells that the offshore development goes into deeper and deeper. This is also true for China offshore industries. Back to later 1960s when the offshore industries started in Bohai Bay, the typical water depth in this area is around 20 m. From later 1980s, the joint explorations and productions in the South China Sea started at the water depth from 100 m to 400 m. Recent exploration activities indicate the discovery of hydrocarbon resources in the South China Sea at the water depth of 600 m approximately. The targeted water depths for oil and gas developments are increasing yearly. Considering the technical feasibility and economic factors, the challenges of deepwater development call for novel ideas and concepts, advanced engineering methodology, new materials, and welding techniques.

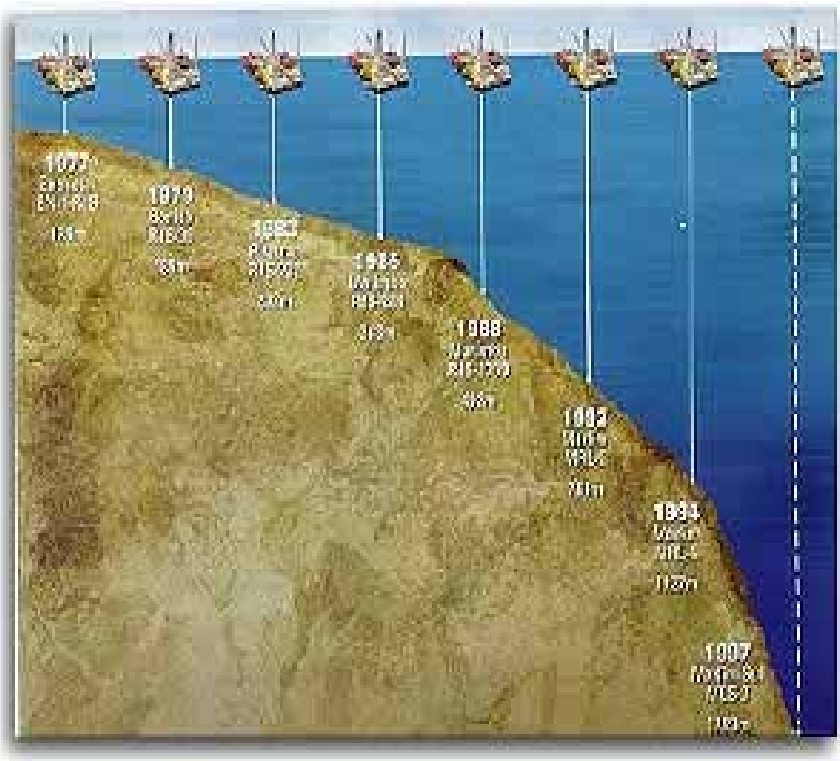

Figure 2-1: Deepwater Development Trend in Brazil

As stand alone deepwater developments are one of the main focuses of the oil and gas industries, it is important to select the development concept at an early stage. Decisions made at the frond end are the most important ones to get right as they are the most costly to change. This is true for all components of the system but in particular for the risers, as these are the key link between the subsea production systems and floating faculties. It is imperative that these decisions are based on a realistic appreciation of the capabilities of the system, rather than pure intuition. This appreciation does not only include understanding the technology issues and each design's functionality limits but also the associated reliability of each design, their interface requirements and their costs, to name but a few.

Regardless of the floater concept adopted for offshore field development, there is always a need of pipelines/flowlines and risers, which form the critical parts of offshore infrastructure. Pipelines and risers are some of the more complex aspects of deepwater developments, as illustrated in Figure 2-2 below.

First of all, basic concepts of deepwater pipelines and risers are outlined in this report with focus on the actual offshore field application, and particular attentions are paid to their potential application in the China Sea. More detailed discussions on deepwater pipelines and risers are presented in three separated sections addressing industrial design standards, engineering solutions and offshore installation. Comparisons are made for different pipeline and riser concepts and pros and cons were also indicated. Different examples are given to demonstrate the outlined concepts. It is concluded that some pipeline and riser concepts are very feasible and attractive for the deepwater oil and gas developments in China Sea.

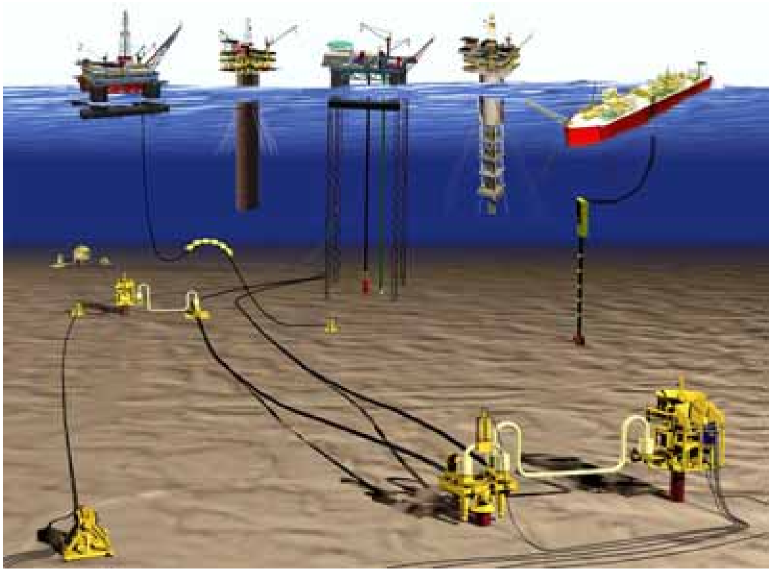

Figure 2-2: Flowlines and Risers in Deepwater Developments

3.0 DEEPWATER CONCEPT SELECTION

3.1 Pipeline/Flowline System

3.1.1 Pipeline Concept Category

Offshore pipelines are used for a number of purposes in the development of offshore hydrocarbon resources. The figure below illustrates the general definition of offshore pipelines, which covers the following

- Transportation pipelines
- Infield product transfer test/production flowlines
- Water and chemical injection flowlines
- Tie-in spool between flowlines and risers

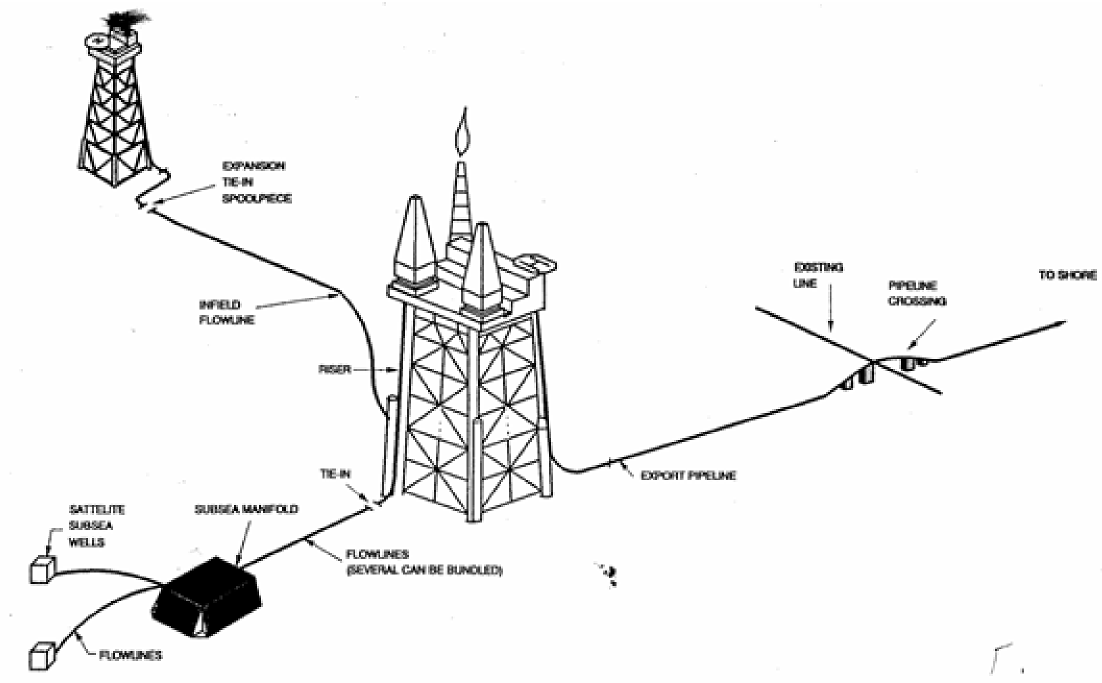

Figure 3-1: Definition of Offshore Pipelines

There are different ways to group pipelines regardless their service purpose. One common way is to categorize the pipelines based on their cross-section configurations, namely single wall pipeline, pipe-in-pipe (PIP) pipeline, and bundle pipeline, as sketched in Figure 3-2 below.

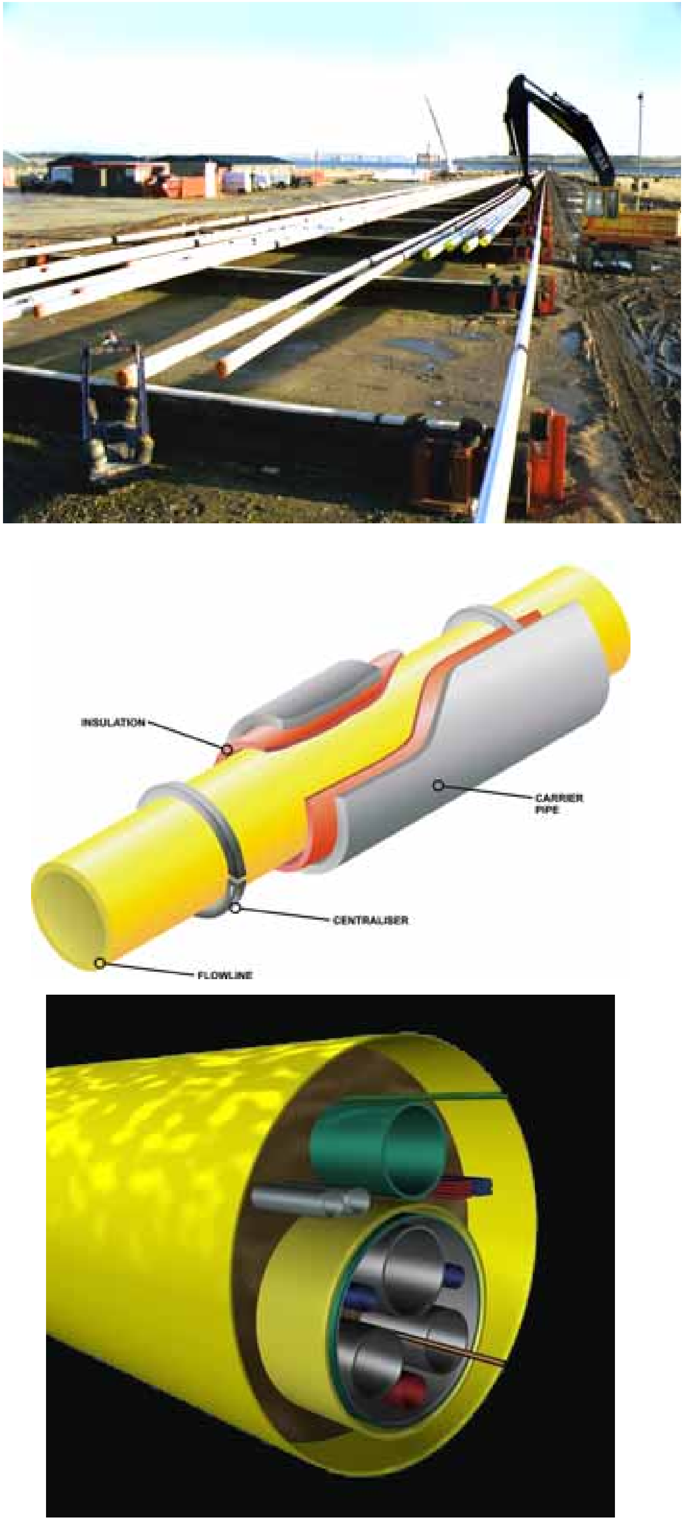

Figure 3-2: Pipeline Category – Single Wall, PIP and Bundle

3.1.2 Pipeline Concept Selection Principles

Among the factors governing the selection of a pipeline/flowline concept, functional requirements, schedule, costs are some of the important issues.

The single wall pipeline is the most common one that is widely used both offshore and onshore for multi-purposes. It can serve export transportation, infield production/test, water injection etc. If single wall pipeline/flowline can satisfy the development requirement, it is always the first choice.

The main feature of PIP systems is that the pipeline is comprised of concentric inner and outer pipes. The inner pipe (flowline) or pipes within jacket pipes carry the production fluids and are thermal insulated, whilst the outer pipe (or carrier/jacket pipe) provides mechanical protection.

Many of the newly emerging generation of high pressure high temperature (HP/HT) reservoirs in the North Sea and GoM are being exploited using PIP system as part of subsea tie-backs to existing platforms, in particular for cases when there is a strong thermal insulation requirement. Not only are reservoir conditions more harsh but there is a need to insulate the flowlines to prevent wax and hydrate formation as the product cools along the length of the pipeline. Such kinds of flowlines are also widely used in China Sea, e.g. in Bohai Bay.

Pipeline bundle system is widely used in North Sea, Gulf of Mexico and West of Africa both in shallow and deepwater. A few unique features of pipeline bundles are

- Several lines can be bundled together including umbilical
- Excellent thermal insulation performance
- Quick and cost-effective installation

With the use of PIP and pipeline bundle systems come additional design features that are not present in conventional single wall pipeline design. Engineering challenges rang from structural design of spacers, internal bulkheads, and thermal insulation design to the understanding of the structural behavior both globally and locally under a variety of loading regimes. Due to the increased number of components in such systems compared with conventional pipelines, the design process is therefore more iterative in nature as the interactions of the components may necessitate design alteration.

3.1.3 Deepwater Pipeline Challenges

Even though lots of similarities are observed between shallow water and deepwater pipelines, there are still some unique challenges of deepwater pipelines including

- High external hydrostatic pressure could cause pipeline collapse
- HP/HT from deepwater reservoirs cause pipeline thermal expansion and global buckling
- High thermal performance requirements, e.g. PIP
- On-bottom stability due to high bottom current
- Non-trench due to water depth
- All diverless operation (installation and maintenance)
- Very high tension drives installation method changes, e.g. from S-lay to J-lay

3.2 Deepwater Riser System

3.2.1 Riser Concept Category

A riser system is essentially conductor pipes connected between floaters on the surface and the subsea facilities (e.g. wellheads, PLETs, manifolds) at the seabed. There are essentially two kinds of risers, namely rigid riser and flexible riser. A hybrid riser is the combination of these two.

There are a variety of possible configurations for marine risers, such as free hanging steel catenary riser (SCR), top tensioned riser (TTR), lazy S riser, steep S riser, lazy wave riser, steep wave riser, etc. Due to the requirement of deepwater production, new configurations are also available, such as Compliant Vertical Access Riser (CVAR), (multibore) hybrid riser.

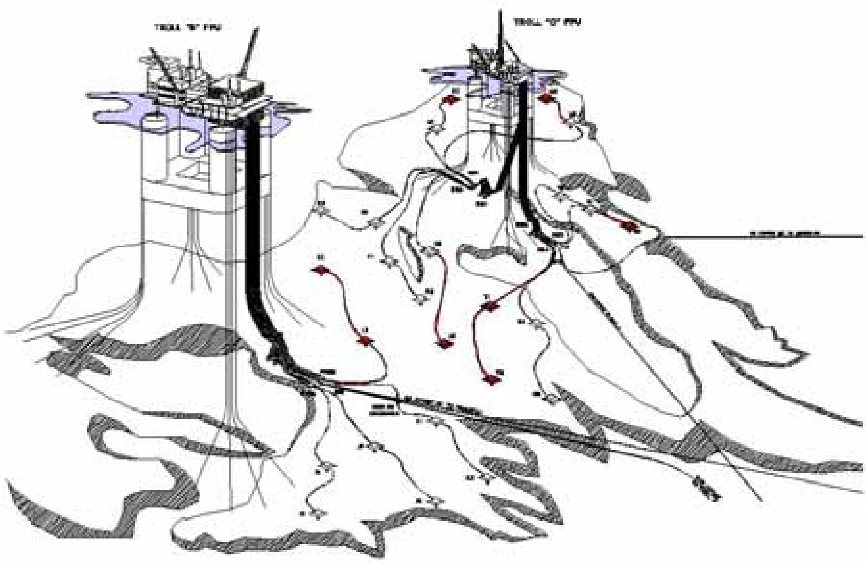

Figure 3-3: Flexible Riser Project Example in North Sea

Figure 3-3 above illustrates the flexible riser concepts used in a Norwegian North Sea. Large amount of flexibles were used for both risers and subsea flowlines in this field development.

Figure 3-4 below shows an artist sketch describing the field architecture of a deepwater development project in Angola, West of Africa. It covers quite wide range of riser concepts such as TTR, SCR, tower riser, flexible risers, flexible offloading jumpers.

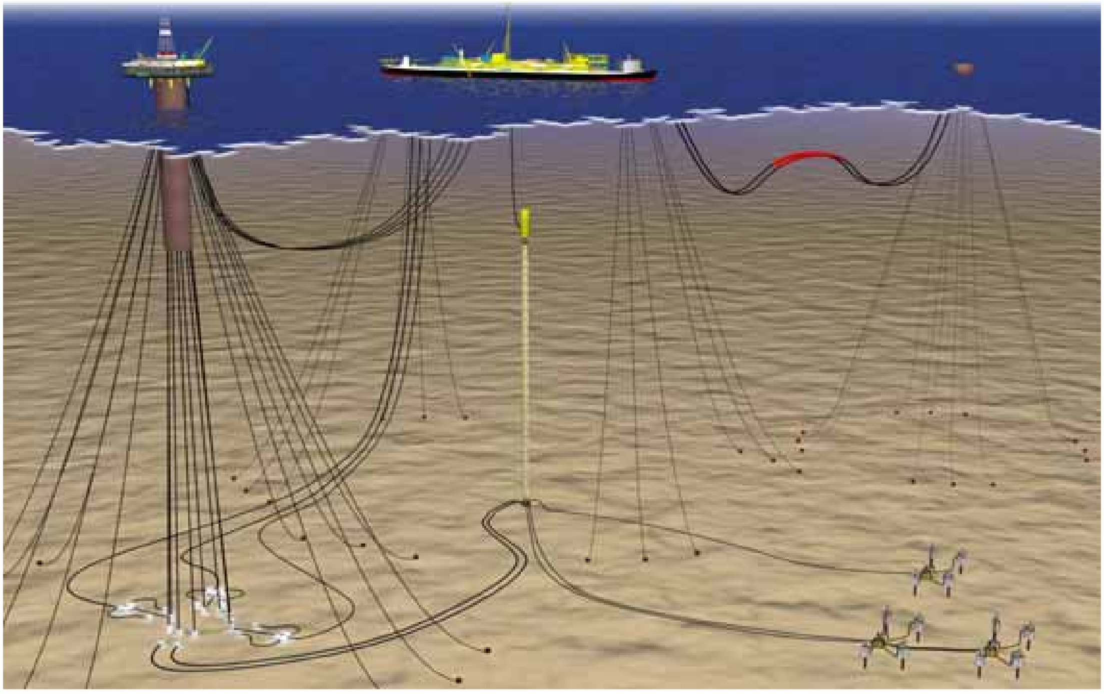

Figure 3-4: Riser Concepts for a Deepwater Development in WoA

3.2.2 Riser Concept Selection Principles

Deepwater riser is relative ‘new’ concept and very much ‘dynamic’, which is totally different from traditional shallow water risers, e.g. rigid pipe clamped to fixed jacket platform. As the development goes on, various riser concepts are developed to fit the practical need.

In general, rigid riser should be used compared to flexible riser if possible. This is mainly driven by cost. Flexible riser can be considered as an alternative considering technical, tree concept and other non-cost issue, e.g. schedule and operator’s preference.

Basically, TTRs are used for SPAR and TLP floaters as production. SCRs are generally used as a minimum for export for all floaters. Flexible can be used for production, water injection, and export.

In addition to cost, there are some limitations to flexible riser including water depth, design pressure and temperature, and diameter.

SCRs are being used widely worldwide including for traditional Spar project, e.g. Tahiti. Recent deepwater development shows that SCR is the most preferred option as long as it is feasible.

While Figure 3-5 shows SCR concept adopted in a GoM deepwater development project.

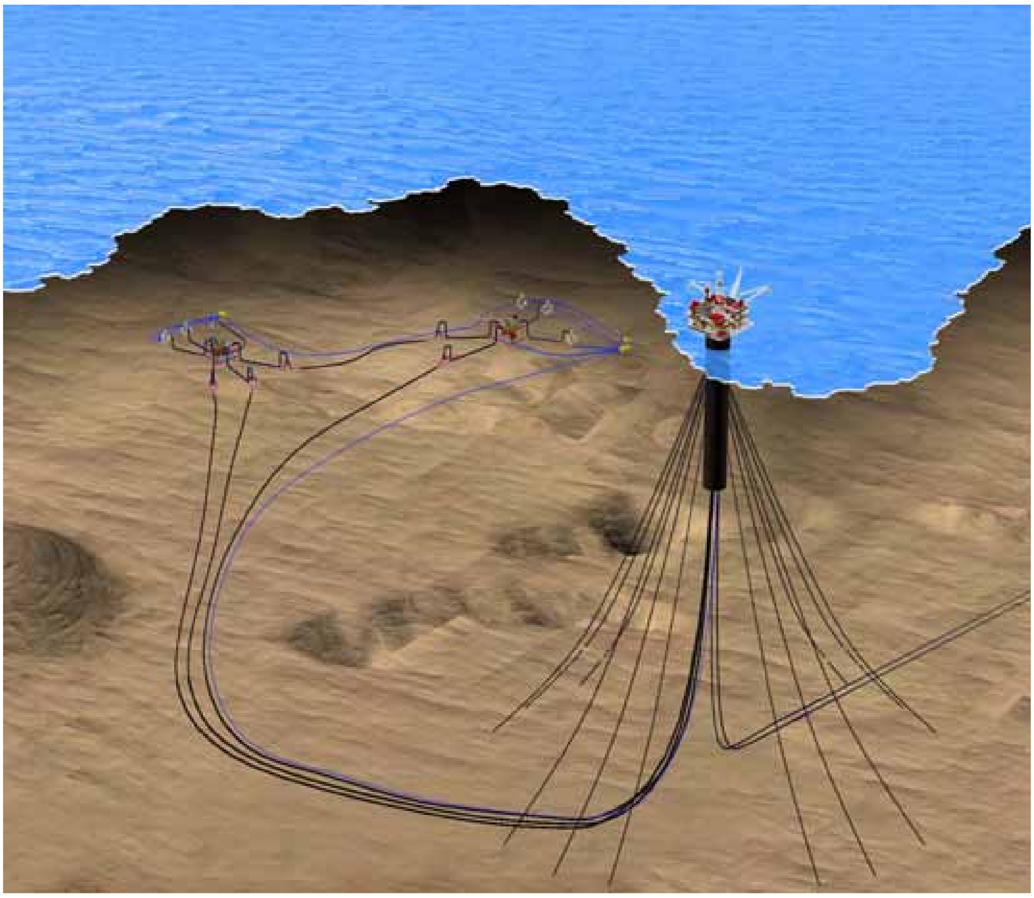

Figure 3-5: SCRs Deepwater Development in GOM

3.2.3 Deepwater Riser Challenges

Compared to traditional shallow water riser, the challenges are quite unique and often require innovative solutions. The following bullets summarize the primary difference of deepwater risers:

- Prolific wells
- Total cost is very high
- Consequence of failure is very high
- Dynamic fatigue often dominates the design
- Riser top tension and payloads at floater is high
- Exposed to deepwater complex current causing VIV problem
- HP/HT often drives the technology to the edge
- Global and local analysis is complicated and is often coupled with floater
- Pipe soil interaction is complex.
- Less feedback from offshore operation experience
- Technology stretch

4.0 INDUSTRIAL DESIGN CODES AND SOFTWARE

4.1 General

The selection of design codes for pipelines and risers mainly depends upon the following

- Governmental requirements
- Regulatory body requirements
- Client's preference
- Geographical location of the field development

4.2 Design Codes for Pipelines

The most commonly used design codes for offshore pipelines include the following

- DNV OS F101 (2000): "Submarine Pipeline Systems"
- API RP 1111 (1998): "Design, Construction, Operation, and Maintenance of Offshore Hydrocarbon Pipelines – Limit State Design"
- BSI BS 8010 (1993): "Code of Practice for Pipeline – Part 3. Pipeline Subsea: Design, Construction and Installation"
- ASME B31.8 (1992): "Code for Gas Transmission and Distribution Piping Systems" (1994 Addendum)
- ASME B31.4 (1992): "Code for Liquid Trans Transportation System for Hydrocarbons, Liquid Petroleum Gas, Anhydrous Ammonia and Alcohol's"
- ABS (2001): "Guide for Building and Classing Undersea Pipelines and Risers"

In principles, the design codes can be grouped into two namely

- Reliability based limit state design (Load Resistance Factored Design – LRFD)
- Conventional allowable stress design (Working Stress Design – WSD)

The most successful and worldwide commonly used limit state design code is DNV OS F101, which was based on a Joint Industry Program (JIP) of SUPERB (Jiao, et al, 1996) conducted at Norwegian Marine Technology Center with offshore industry sponsors. The first such kind of design code was released formally by DNV in 1996.

LRFD approach introduces a couple of safety factors for different parameters for different failure modes. WSD approach only uses one safety factor covering all the uncertainties. In principle, the LRFD approach is less conservative, which could lead to the thinner wall thickness of the pipe and reduce the material cost accordingly. This is on the condition that the same or higher safety level is still maintained in a consistent manner. There are numerous papers addressing this issues, e.g. Song, et al (1998, 1999), Zimmerman, et al (1992), Bai and Song (1998) and Sotberg, et al (1992, 1994)

4.3 Design Codes for Risers

Even though risers exist for many decades, it only makes tremendous progress in recent years with the development of deepwater technology. The major configuration of previous risers is the simple extension of steel pipe flowline, which was commonly clamped to, e.g. jacket legs. Previous risers design was based on solely pipeline codes with different safety factor.

Deepwater development calls for novel concept and new technology to handle the challenges which could not meet from shallow water development. There is also a need for a new industrial riser design code to cope with the deepwater riser technology. The first riser design code is API RP 2RD followed by DNV OS F201. These two codes are still the only design codes dedicated to marine risers, which are listed below.

- API RP 2RD (1998): “Design of Risers for Floating Production Systems and Tension Leg Platforms”, First Edition
- DNV OS F201 (2001): “Dynamic Risers”

Besides, some codes released by regulatory bodies address riser design to a certain extend, e.g. ABS (2001).

4.4 Industrial Software

4.4.1 Generic Software

The most commonly used general purpose non-linear finite element analysis (FEA) software include

- ABAQUS: General purpose FEA program
- ANSYS: General purpose FEA program

4.4.2 Pipeline Software

Besides, there are quite a few specially developed pipeline software, such as

- PIPSIM and OLGA: Multi-phase flow assurance programs
- PIPSTAB: Pipeline on bottom stability analysis program
- PONDUS: Pipeline dynamic response on seabed due to wave and current (APA)
- OFFPIPE: Offshore pipeline installation analysis program

4.4.3 Riser Software

The following are well commercialized and well known industrial software for riser analysis

- Riflex : Norwegian Marine Technology Center (Marintek)
- Flexcom 3D : MCS International (Ireland)
- Orcaflex : Orcina Ltd. (UK)
- SHEAR7 : MIT (USA)
- VIVA : MIT (USA)
- VIVANA : Marintek (Norway)

The selection of software depends upon the engineering requirements. Nowadays, the software interface is design so user friendly that a new user can run the programs within a short time. However, it is not easy task to have the insight knowledge about the software and the pipeline and riser engineering.

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5.0 ENGINEERING DESIGN OF PIPELINES AND RISERS

5.1 General

The design of offshore pipelines and risers normally is conducted at the following stages

Conceptual Engineering

The major purpose of this engineering at this stage is to establish the technical feasibility, identify the required information for the next design phase and to allow the cost and schedule estimation. This is often referred to as "concept selection".

Preliminary Engineering

The primary tasks at this stage is to perform material selection and wall thickness sizing; determine the dimensions of the flowlines and risers; perform design code checks; prepare MTO and prepare authority applications. The basic concept needs to be finalized at this stage, which is also referred to as "define phase".

Detail Engineering

All the engineering work at this stage need to be detailed enough for procurement and fabrication. Further more, project procedures, specifications, MTOs, testing, survey and drawings need to be fully developed. This phase is also referred to as project "execute phase".

5.2 Design Procedure

5.2.1 Primary Design Parameters

The primary goal of the design procedure is to determine the optimized pipeline and riser design parameters based on operational data (e.g. design pressure and temperature, field data, and processing data). Among those parameters, the following are most important

- Pipeline and riser dimensions (internal diameter) based on flow assurance analysis
- Pipe material grade based on pipe availability, cost, and welding (e.g. API 5L pipe, CRA pipe, cladding pipe, and liner pipe)
- Pipe wall thickness sizing based on design codes (e.g. pressure containment calculation, DNV OS F101, API RP 2RD)
- Pipeline routing and riser top and subsea arrangement (e.g. pipeline alignment sheets, riser hang-off system)
- Pipeline and riser length for MTOs
- Pipe coating types and thickness (e.g. anti-corrosion coating, weight coating,

thermal insulation coating)

- Pipe cathodic production (CP) system (e.g. anode type, amount, attachment to pipes)

5.2.2 Design Procedure for Pipelines

Normally, the design procedure is an interactive process and those parameters cannot be isolated. This procedure for pipeline design is illustrated by the Figure 5-1 below.

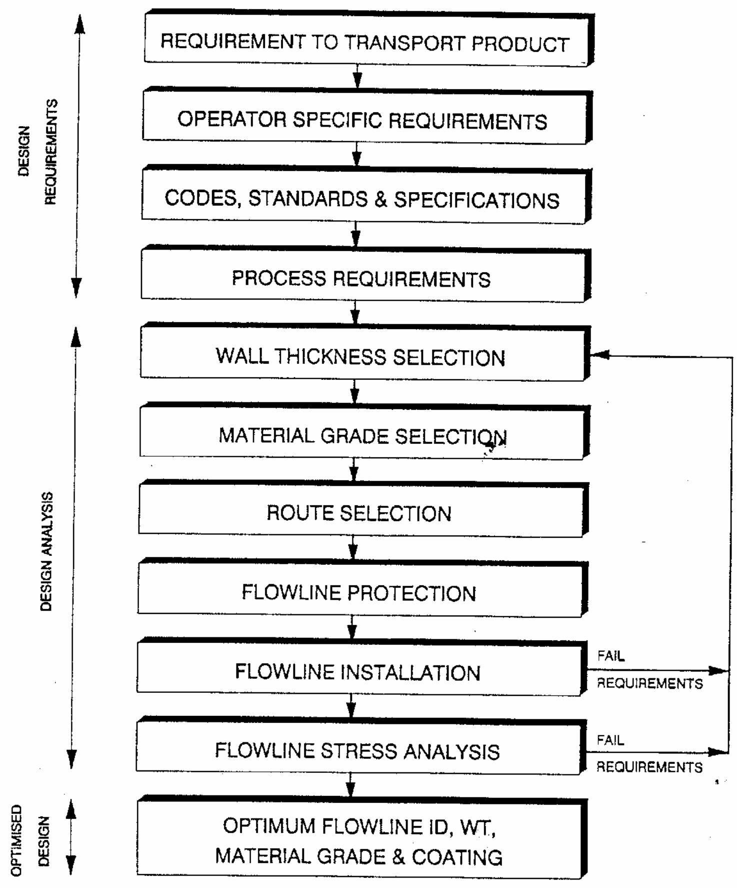

Figure 5-1: Pipeline Design Procedure

5.2.3 Design Procedure for Risers

Below is the brief summary of TLP riser global analysis steps:

- Select and define the characteristic of the proposed riser system.
- Prepare a preliminary design based on installation requirements, hydrotest requirements, internal design pressure, O.D. collapse pressure, materials selection and tensioning device.

- Prepare a preliminary riser system layout configuration. The system layout should include topsides interface, stress joint requirements, offset distance and direction and mooring pattern.
- Prepare a TLP riser design project execution plan. This plan should include software selection, requirements for quasi-static analysis and dynamic analysis, load cases, deliverables and cost and schedule summaries.
- Prepare analysis model.
- Run analysis according to TLP riser design project execution plan.
- Verify results of model.
- Iterate model selection and analysis if necessary.
- Prepare results for client review. The results should include a static strength table, dynamic strength table and a fatigue strength table.
- Finalize results for client in a report.

5.3 Design Basis Document

Design basis document (DBD) provides the means for managing the design of the pipeline and riser systems and the focus for controlling design changes. The purpose of the design basis is to provide the basic philosophy, a consistent set of data, requirements and design rational to be applied for the specified project development.

The DBD serves as the foundation of the pipeline and riser engineering, which will be continuously monitored and updated throughout the project as additional design data become available. If there is any variation of design data, a deviation request will be issued to client for approval.

A typical design basis for pipeline and riser should consist of the following as minimum

- System Description and Functional Requirements: which describes the arrangement and key components of pipeline and riser systems and defines general project design requirements. This part also defines the way in which changes in data related to pipeline and riser engineering are to be managed through the different groups in the project organisation;
- Requirements for Design and Analysis: which defines the loading conditions to be considered and criteria to be used to assess response of pipelines and risers.
- Design Data: which provides numerical relevant data on the pipeline and riser systems. This includes, but not limited to, the following:
  - ✓ Field layout and site location data
  - ✓ System design life and well production data

- ✓ Pipeline and riser data
- ✓ Vessel data and motions (for riser engineering only)
- ✓ Metocean, geotechnical data, and soil data
- ✓ Pressure and temperature data
- ✓ Load cases (pressures, fluid contents, environmental criteria)

In addition to design data, the DBD should also include the identification of key design interfaces between production system components.

5.4 Material Selection

The most commonly used materials for offshore pipelines and risers are steels varying from carbon steels (e.g. American Petroleum Institute (API) – 5L Specification, Grade X52 – X70 and higher) to exotic steels (i.e. duplex, e.g. 13% Cr.). The following factors are governing the material selection

- Cost
- Resistance to corrosion effects
- Weight requirements
- Weldability

The higher the grade of steel (up to exotic steels) the more expensive per volume (weight). However, as the cost of producing high grade steels has reduced, the general trend in the offshore industry is to use these steel of high grades.

Material selection probably is one of the first steps in offshore pipeline and riser engineering, which forms a critical element of the system design. Besides, material selection has the following cost implications on fabrication, installation and operations as explained below.

Fabrication: The cost of steels increases for the higher grades. However, the increase in grade normally will reduce the pipe wall thickness. This results in the overall fabrication cost probably becoming lower when using a high grade steel compared with a lower grade steel.

Installation: High grade steels are difficult to weld and consequently result in slower lay rate compared to the lower grade steels. However, should the pipeline be laid in very deep water and a vessel is laying at its maximum lay tension, then the use of high grade steel may be more suitable, as the reduction in pipe weight would result in lower lay tension. In general, from an installation aspect, the lower grade steel pipelines cost less to install than higher grade steels.

Operation: Depending on the product being transported, the pipeline may be subjected to:

- Corrosion (internal)
- Internal erosion;
- H_2S induced corrosion.

Designing for no corrosion can be performed by either material selection or modifying operation procedures (i.e. chemical corrosion inhibitors).

5.5 Pipeline Routing Design

Pipeline routing design is a complex procedure, which can be governed by several factors. In principle, the shortest distance between the terminal points is likely to be the most economic from a material standpoint, but possible overriding factors must be considered. Typically the route selection will be affected by:

- Offshore installation;
- End point locations;
- Water depths;
- Uneven seabed;
- Subsidence;
- Presence of adverse environmental features such as high currents, shoaling waves;
- Presence of other fields, pipelines, structures, prohibited zones (e.g. naval exercise areas);
- Presence of unfavorable shipping or fishing activity;
- Suitability of landfall sites, where applicable.

A significant proportion of the total cost to install a pipeline which is directly affected by the chosen route is incurred during fabrication and installation. The associated activities are:

- Length of fabricated pipeline pipe (coated);
- Pre sweeping of route;
- Pre lay installed freespan correction supports;
- Post lay installed freespan correction supports;
- Trenching, burying or rockdumping.

Some or all of these activities will be present within the selected pipeline route. As a general rule the design should be performed to:

- Minimize length of pipeline required;
- Avoid requirement for presweeping;
- Avoid pre-lay installed freespan correction supports;
- Minimize post-lay freespan correction supports;
- Minimize trenching, burying and rock dumping.

Figure 5-2 shows the pipeline routing for a pipeline net work in the Norwegian sector, North Sea.

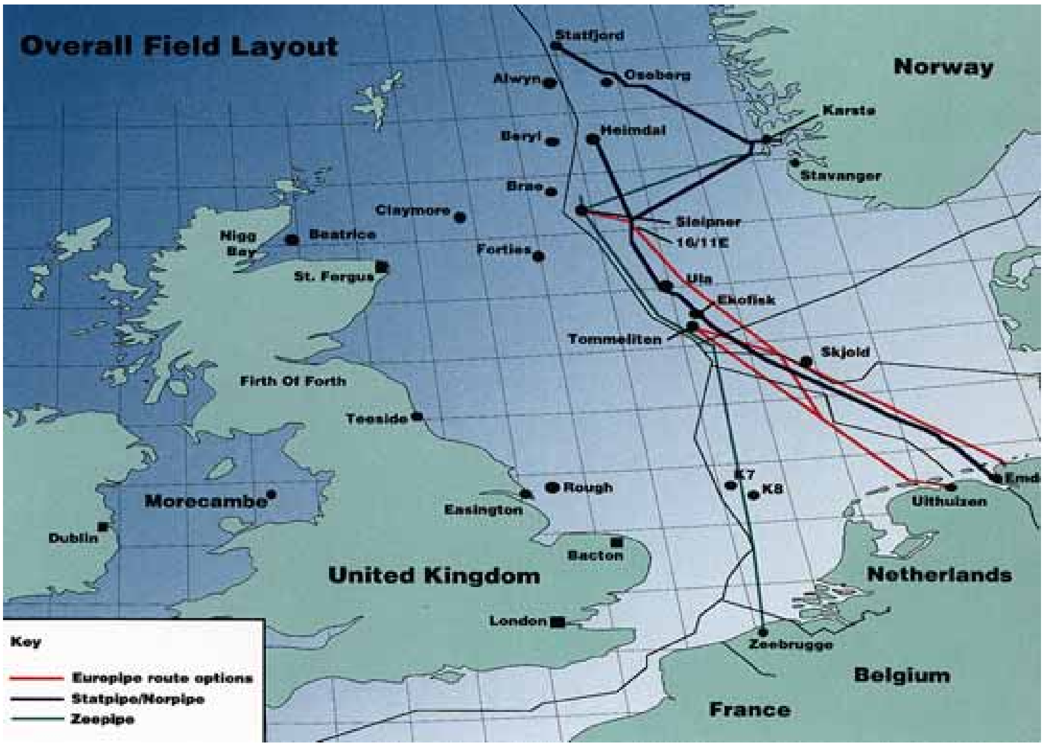

Figure 5-2: STATOIL – EUROPIPE Project

5.6 Thermal Insulation Design

Thermal insulation design is playing more and more important role in the deepwater development in order to prevent hydrates and wax formation. Flow assurance is to ensure successful operations in reliably, manageably, and profitably flowing oil and gas from the reservoir to their destinations. The following figures show the cross section of a pipeline showing the blockage effect on the product flow.

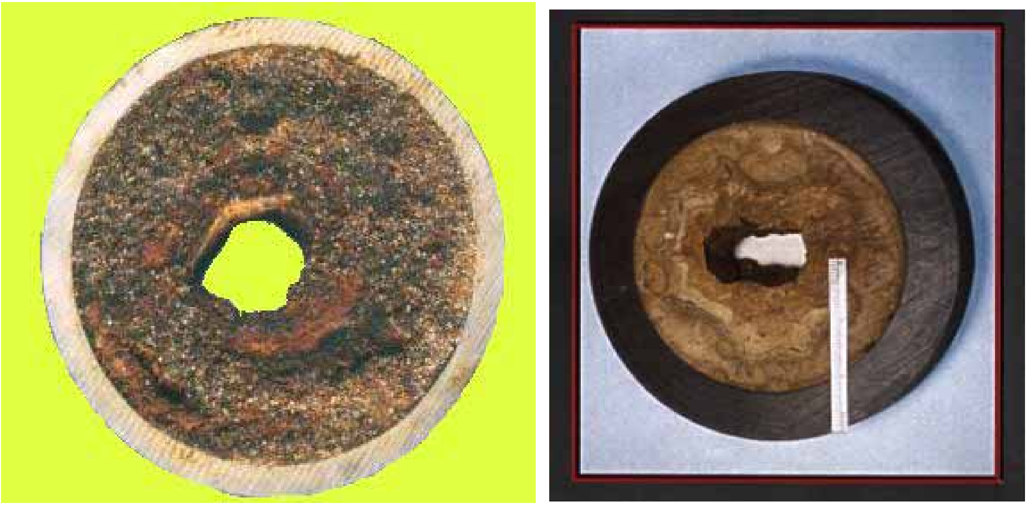

Figure 5-3: Wax Formation/Paraffin in a Pipeline

Generally, there are two types of thermal insulation namely

- Passive insulation
- Active heating

One of the main advantages of pipeline bundle system is to provide excellent thermal insulation performance. Pipeline bundles are integral to production and flow assurance strategies. Figure 5-4 below shows the thermal performance analysis (Song and Knutsen, 1999).

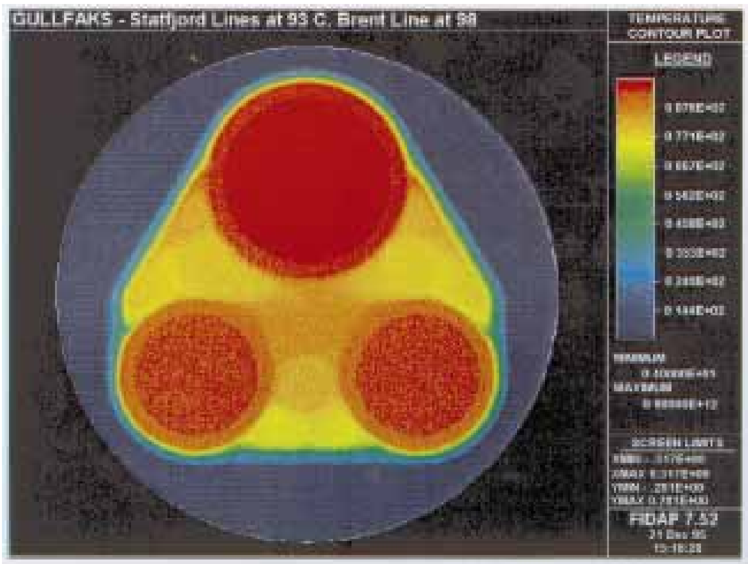

Figure 5-4: Example of Pipeline Bundle Thermal Performance Analysis

5.7 Pipeline and Riser Analysis

5.7.1 General

The finite element model is a very powerful tool for analyzing the in-situ behavior of pipelines and risers, e.g. by using the programs described above. The in-situ analysis covers a pipeline or riser over its whole field design life load history, which can consist of several sequential load cases, for example:

- Temporary installation phase
- Pressure testing (water filling and hydrotest pressure)
- Operating condition (content filling, design pressure, and temperature)
- Shut down/cool down cycles of pipeline
- Upheaval and lateral buckling of a pipeline
- Dynamic environmental loading
- Pipeline and riser subject to impact loads (e.g. fishing gear, dropped object, etc)
- Floater motion effect on riser dynamic behavior

Special attention should be paid to the following nonlinearities in the global FEA modeling for pipelines and risers

- Material non-linearity.
- Geometric non-linearity.
- Boundary non-linearity (friction, sliding, pipe soil interaction, etc).

5.7.2 Pipeline Analysis

Pipeline analysis covers both global and local. Global in-situ analysis address pipeline global response behavior during the entire anticipated service loading conditions. Local analysis is normally used to check local response including local loading, e.g. finshing grear impact, and local component design, e.g. bulkhead for PIP.

The following Figure 5-5 illustrates the in-situ modeling of a pipeline bundle system showing the stress variation along the very uneven seabed. This analysis was used for seabed intervention design.

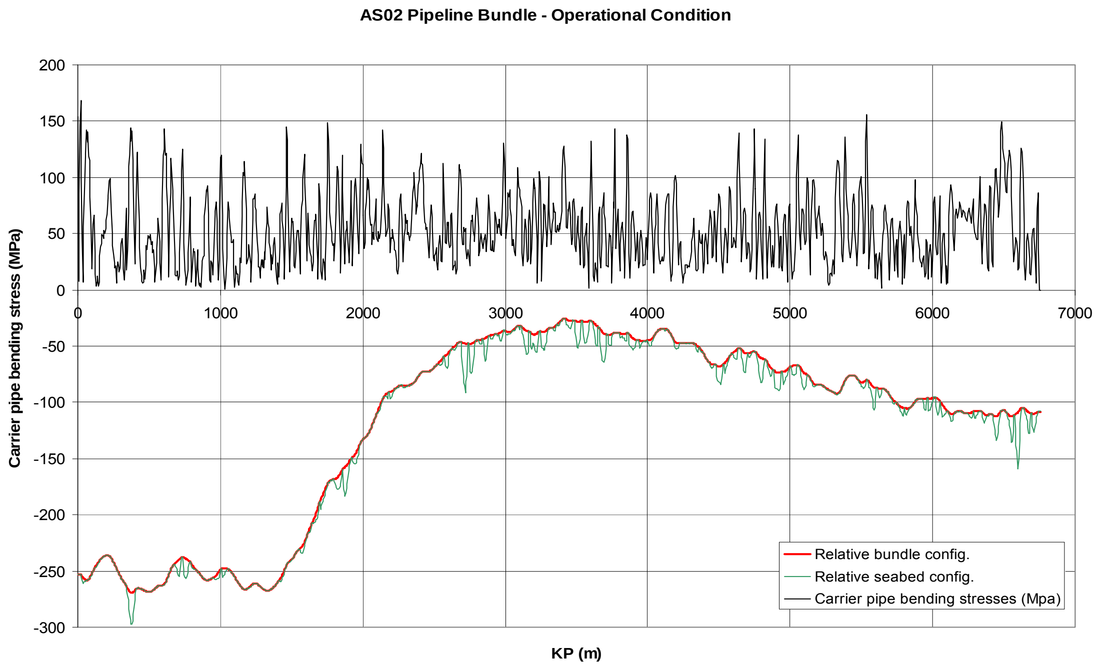

Figure 5-5: Pipeline Bundle System In-Situ Behavior

5.7.3 Riser Analysis

Regardless the load cases, the analysis of deepwater riser can be grouped into static and dynamic analyses.

- *Static Analysis:* The static analysis for riser available from e.g. Orcaflex or Flexcom that is used in the model handles non-linearity's from large-displacements effects, material non-linearity, and boundary non-linearity's such as contact, sliding, and friction (pipe/seabed interaction). For riser system, the static analysis defined the global configuration such as top hang off angles, total suspended length, touch down point (TDP).

- *Dynamic Analysis:* A general dynamic analysis must be used to study the non-linear dynamic response of the riser system. General non-linear dynamic analysis uses implicit integration of the entire model to calculate the transient dynamic response of the system. Dynamic analysis should be conducted for the deepwater riser where dynamic effects exist always due to floater motion and dynamic environmental conditions (wind, wave, current). The riser system behavior and their response can be determined from such an analysis.

Figure 5-6 shows a computer model of a deepwater Spar SCR using Flexcom-3D.

Figure 5-6: Spar SCR Global Computer Model

5.8 LRFD Based Structural Strength Design

All relevant failure modes formulated in terms of limit states should be considered in the design of pipelines and risers. The classification of limit states can be as below

- Service limit state (SLS): a condition which if exceeded, renders the pipelines unsuitable for normal operations. This includes ovalizatoin, ratcheting, accumulated plastic strain, and damage due to loss of weight coating for pipelines.

- Ultimate limit state (ULS): a condition which, if exceeded, compromises the integrity of the pipeline and risers. This includes bursting, local buckling, global buckling, unstable fracture and plastic collapse.

- Fatigue limit state (FLS): accounting for accumulated cyclic loads due to, e.g. environmental loading, operational conditions, VIV, floater motion, etc.

- Accidental limit state (ALS): due to accidental loads, e.g. trawl board impact, dropped objects, etc.

Different phases and considerations should be taken into consideration when conducting the limit state design check. This includes

- Installation
- Hydro-testing
- Operation
- Shut-down

Normally, the limit state can be expressed for a specified failure mode as

$$L_d \leq R_d$$

Where, L_d is the design load effect and R_d is the structural design resistance.

A typical example of a bursting limit state can be expressed as

$$(P_i - P_e)*(D-t)/2t \leq \eta_u*SMYS$$

where, P_i is the internal design pressure, P_e is the external hydrostatic pressure, D is the normal diameter of the pipe, t is the nominal wall thickness of the pipe, η_u is the safety factor, SMYS is the specified min yield strength of the pipe material.

6.0 OFFSHORE INSTALLATION

6.1 Installation Methods

Offshore pipeline and riser installation is conducted by using specialized installation vessels. The most commonly used offshore installation methods include

- J – Lay
- Reel – Lay
- S – Lay
- Towing

Depending upon the selection of the installation methods, offshore pipelines and risers could be exposed to different installation loads from the installation vessel. These loads include pressure, tension, bending, fatigue, etc. The installation engineering is performed to estimate the load effects in a pipeline or riser to ensure that the effects are within the strength design criteria.

To conduct installation engineering, the most commonly used programs are OFFPIPE for pipeline and ORCAFLEX for riser. Those programs can give indicative global results for mot situations during the installation phase.

The following figures sketch the different installation methods, and general descriptions for each installation method are summarized in the table below.

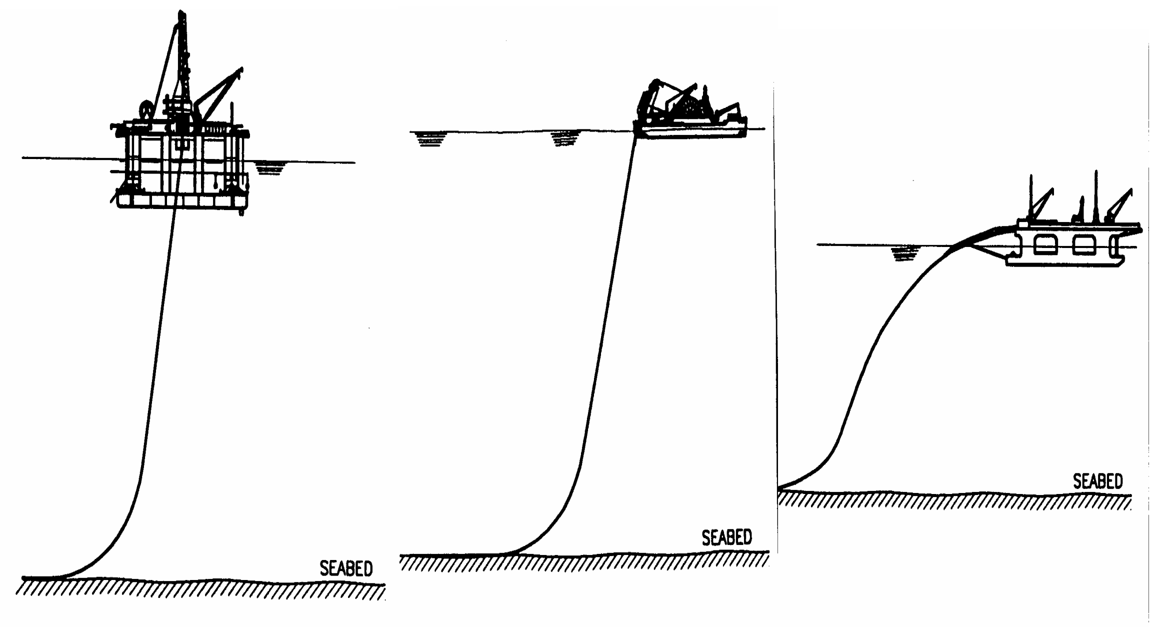

Figure 6-1: Pipeline and Riser Installation Illustration – J Lay, Reel Lay and S Lay

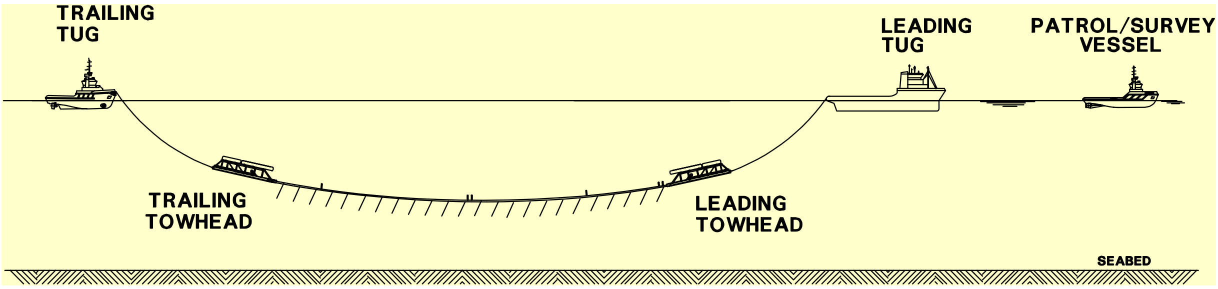

Figure 6-2: Pipeline and Riser Installation Illustration – Towing

6.2 Installation Fleets

In general, there are three kinds of installation vessels for pipeline and riser installation namely semi-submersible, ship shaped vessel and tugs. The selection of the installation vessel is governed by the installation method selected. Their pros and cons are summarized in the table below.

Table 6-2: Installation Vessel Summary

Vessel Type	Pros	Cons
Semi-submersible	▪ Excellent weather capabilities ▪ Stable platform for pipe-laying ▪ Wide range of pipeline diameters ▪ Suitable for deepwater	▪ Costly ▪ More personnel (typically 200 - 400) ▪ Two anchor handling vessels ▪ Survey vessel ▪ Supply barge for pipe transportation
Ship Shaped	▪ Excellent weather capabilities ▪ Fast transit (V=12 - 16 knots) ▪ Longer pipes ▪ Fast installation	▪ Not good sea keeping capabilities
Tugs	▪ Very low equipment cost ▪ Onshore fabrication ▪ Schedule flexibility	▪ Limited fabrication length of pipe strings ▪ Only straight pipe ▪ Temporary buoyancy could be required

Figure 6-3 shows a semi-based installation barge named Balder from HMC. This vessel is designed for J-lay installation. While, Figure 6-4 shows a ship-based installation vessel named Deep Blue from Technip and designed for both J-lay and reel-lay methods.

Figure 6-3: HMC Balder Installation Vessel – J-Lay

Figure 6-4: Technip Deep Blue Installation Vessel – Reel-Lay and J-Lay

6.3 Installation Example

6.3.1 Towing Installation

To demonstrate the installation method, a towing installation project (Song, et al, 2001) was selected to show the procedure and solutions. This was based on a North Sea riser bundle project executed in year 2000 in the offshore Norwegian Sector, which is completely applicable for any towing installed pipelines and risers.

The bundled riser system was fabricated and tested at the fabrication yard onshore. It was assembled using 20 flat pack arrangements including buoyancy tanks evenly distributed over the total riser length. Figure 6-5 shows the assembled bundled riser system on the fabrication site and one larger buoyancy tank connected to the four integrated riser bases. Upon the completion of fabrication, test and pre-launch checks, the bundled riser was ready for launch and Figure 6-6 shows the panorama view of the on-going launch operation.

Figure 6-5: Fabricated Riser Bundle System at Yard

Figure 6-6: Riser Bundle System at Launch Operation

The tow of bundled riser system consisted of surface tow for the inshore from fabrication site to the open water area, CDTM for the offshore part from open water area the Gullfaks field and off-bottom tow in the field. The following figure shows the CDTM tow.

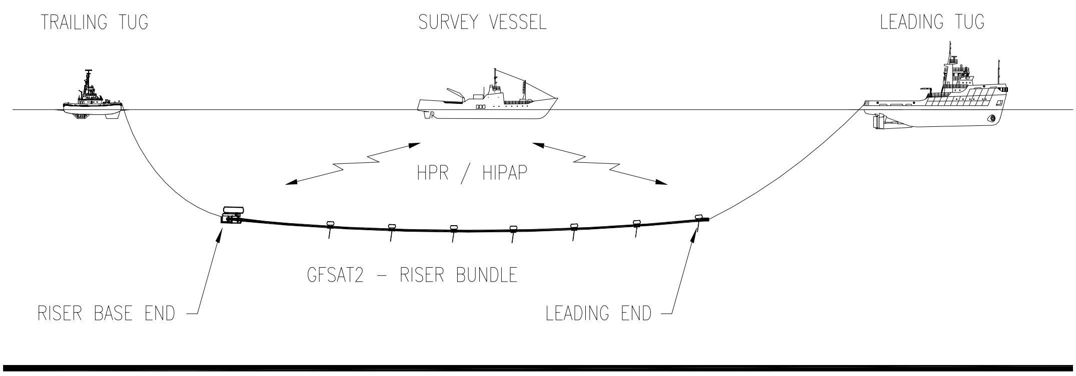

Figure 6-7: CDTM Tow of Riser Bundle System

When the tow reached the installation parking area, the bundled riser was set down to the seabed in a controlled way by reducing speed and paying out wire on the tugs. When the bundle belly touched the seabed both tugs paid out wire. Once the riser bundle was stable in off bottom mode at 2.5m above the seabed both tugs started to pay out the wire and reduce tension to minimum. Then, the bundled riser was ready for off bottom tow. The off bottom pull brought the bundled riser from the installation parking area to the target area where the buoyancy tanks were flooded and recovered.

The pull-in operation started by applying tension through the winch at GFC platform topside and reducing back tension from tug. ROV was available to monitor the J-tube entrance, riser base and pull head as required. Care was taken to ensure the riser base neither rotating nor snagging during the operation through ROV monitoring. The pull-in operation was stopped when the riser base was in the target box. The riser system was surveyed. When the riser was pulled in into position, the temporary hang off clamp was installed to the riser at GFC platform topside so that the riser could rest on the seal housing.

6.3.2 J-Lay Installation

Below outlines the primary J-lay installation method for a 2nd installation of an SCR.

a) The installation vessel will transit to the field with pipe of double or quad joints.

b) A pipeline initiation anchor / pile will be installed along the pipeline route and the pipe lay will commence as the straightened pipe is lowered and attached to the initiation rigging. The correct catenary and pipe tension are obtained and the pipe is installed along the route.

c) The installation vessel will continue to pay-out pipe and lay-away along the riser route. The calculated length of the riser sections will be cut to length per design.

d) The VIV strake sections will be installed on the required area of the riser pipe and the flexjoint assembly head will be welded to the end of the riser pipe.

e) The riser will be lowered down to the transfer depth utilizing the installation vessel pipe follower.

f) The host platform pull-in winch will be deployed to the transfer depth at designed elevation.

g) The installation vessel ROV will connect the platoform winch wire to the riser pipe flexjoint assembly head rigging at the transfer depth.

h) The installation vessel will continue to lower the riser. The riser load will be transferred to the platform winch and the pull-in of the riser will begin.

i) The platform will continue to pull-in the riser flexjoint head assembly; a horizontal force component will be applied to the riser until it is hung-off in the platform hang-off clamp and secured.

Figure 6-8 shows an installation vessel J-lay tower.

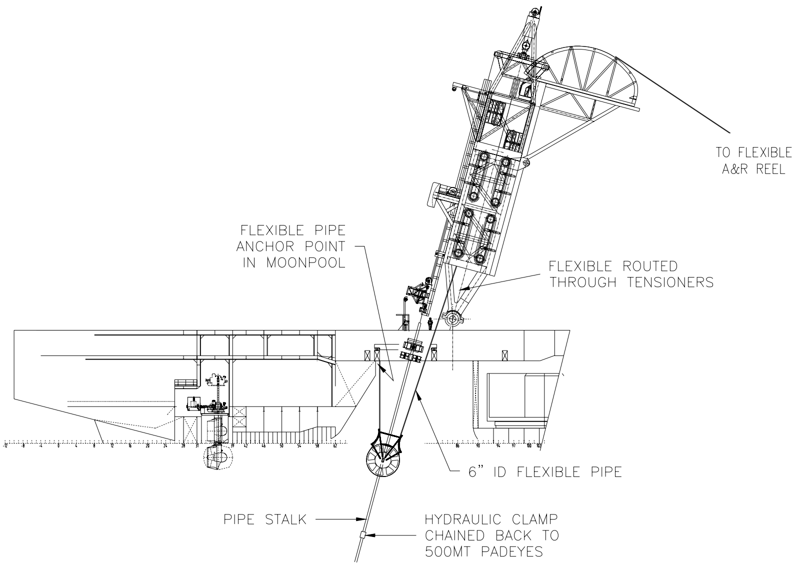

Figure 6-8: J-Lay Tower

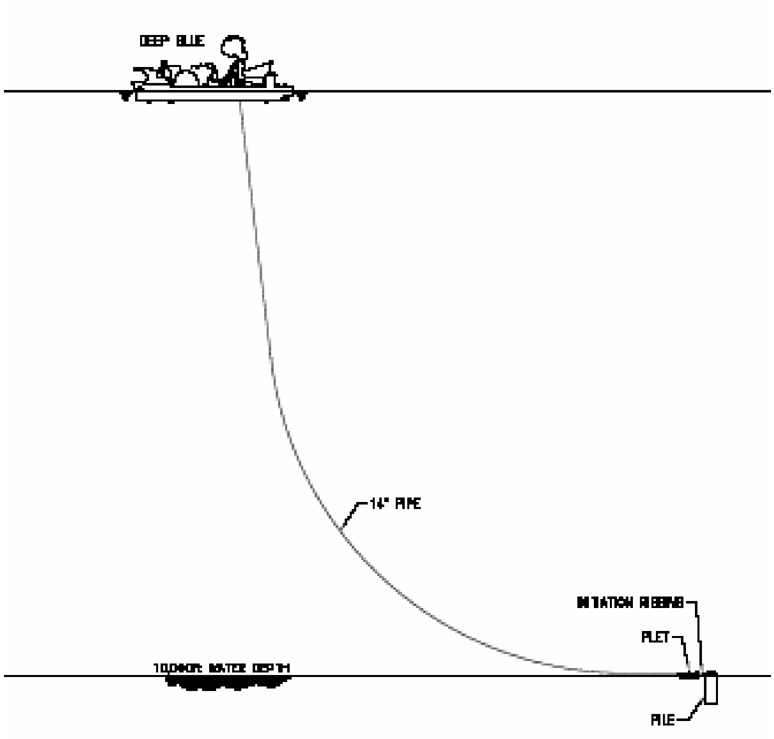

Figure 6-9: Initiation of Riser J-Lay

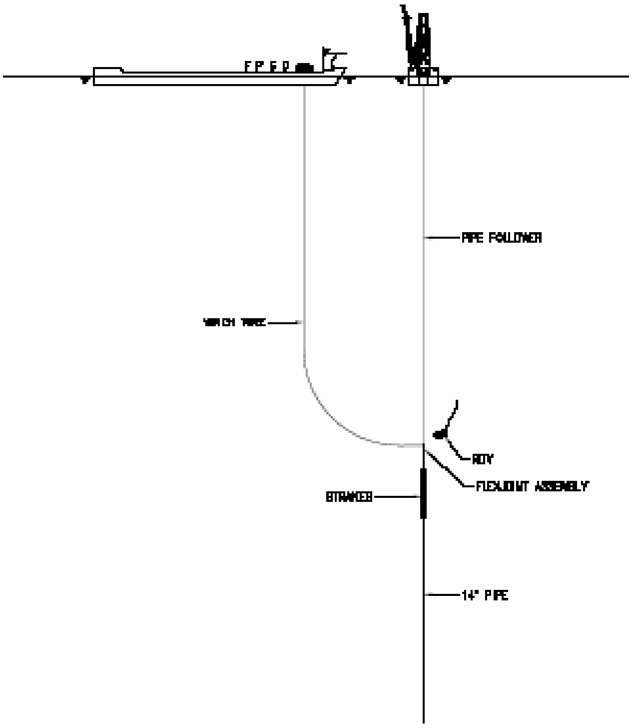

Figure 6-10: Connection Pull-In Wire

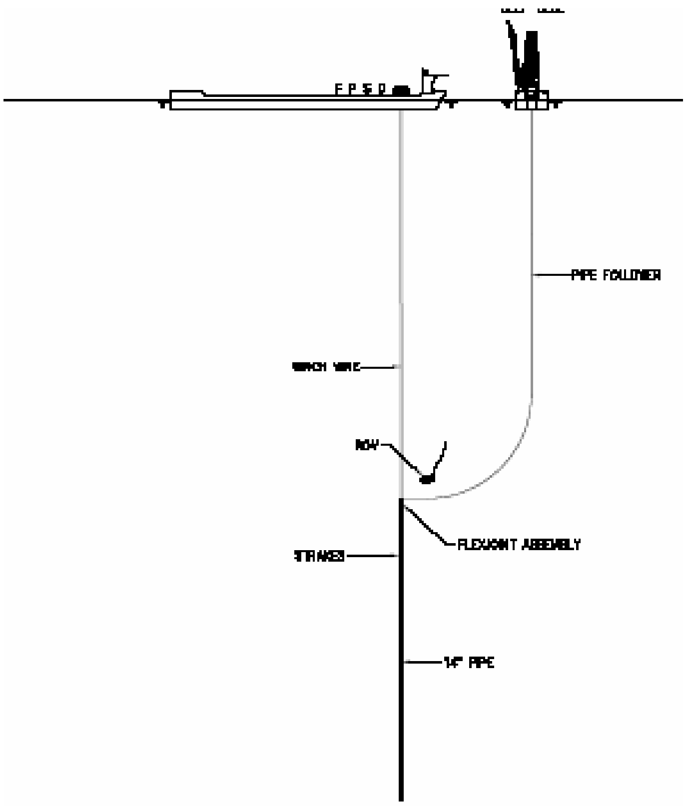

Figure 6-11: Transfer and Pull-In

7.0 CONCLUSIONS

In this report, the deepwater technology of offshore pipelines and risers are reviewed considering the potential application to the China offshore development. For water depth about 500m in the near future offshore development in China, the following suggestions are made

- Rigid pipes should be used for pipelines if possible, rather than flexibles;
- For short distance (about 15 km) infield transportation, flowline bundle system should be considered seriously.
- For strong thermal performance required flowlines, pipe-in-pipe and flowline bundle system should be taken into account.
- Flexibles and SCRs should be the most attractive riser concepts.
- Towing and reel lay installation methods should be evaluated carefully in the project. For large diameter pipelines (larger than 16”), J-lay should be prioritized.

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