Introduction to
Offshore Pipelines and Risers

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Jaeyoung Lee, P.E.
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PREFACE

This lecture note is prepared to introduce how to design and install offshore petroleum pipelines and risers including key considerations, general requirements, and terminologies, etc. The author’s nearly twenty years of experience on offshore pipelines along with the enthusiasm to share his knowledge have aided the preparation of this note. Readers are encouraged to refer to the references listed at the end of each section for more information.

Unlike other text books, many pictures and illustrations are enclosed in this note to assist the readers’ understanding. It should be noted that some pictures and contents are borrowed from other companies’ websites and brochures, without written permit. Even though the exact sources are quoted and listed in the references, please use this note for engineering education purposes only.

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Jaeyoung Lee, P.E.
Houston, Texas
jlee@jylpipeline.com
Revision Log

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General:    Reformatted Figure/Table titles, bullet points, etc.
Chapter 1: Updated with new project records. Added Figures 1.3.2 and 1.3.3.
Chapter 2: Added required MMS permit application documents.
Chapter 3: Added Section numbers 3.1 and 3.2. Added typical deepwater flowline engineering design procedures and flowchart. Updated with latest codes and added some codes (DIN, DNV, ISO, etc.).
Chapter 4: Modified route curvature radius formula. Added positioning systems.
Chapter 7: Added/modified material property definitions and testing methods, yield stress definition, pipe grades per API-5L 44th edition (2007), line pipe types, and steel pipe manufacturing process. Modified insulation coating types and added PU and PP coating system comparisons table. Added U value examples of PIP systems. Modified CRA pipe material selection guideline, Table 7.2.2. Added an offshore coiled tubing operation picture, Fig. 7.7.1.
Chapter 8: Replaced waterstop picture and modified waterstop descriptions.
Chapter 10: Added virtual anchor length calculation formula.
Chapter 13: Added non-tapered bracelet anode dimensions table.
Chapter 14: Added a J-lay vessel picture. Added more pictures of S-lay and J-lay operation and equipment. Modified J-lay schematic sketch.
Chapter 17: Added welding symbols and fundamentals on welding inspections.
Chapter 20: Overall revision.
Chapter 22: Added Figure 22.2.1 and a pig launching picture in Figure 22.2.3.
Appendix A: Modified the ovality definition and added some more terminologies.
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1 INTRODUCTION

Deepwater means water depths greater than 1,000 ft or 305 m by US MMS (Minerals Management Service) definition. Deepwater developments outrun the onshore and shallow water field developments. The reasons are:

- Limited onshore gas/oil sources (reservoirs)
- Relatively larger (~20 times (oil) and 8 times (gas)) offshore reservoirs than onshore
- More investment cost (>~20 times) but more returns
- Improved geology survey and E&P technologies

A total of 175,000 km (108,740 mi.) or 4.4 times of the earth’s circumference of subsea pipelines have been installed by 2006. The deepest water depth that pipelines have been installed is 2,414 m (7,918 ft) in the Gulf of Mexico (GOM) by Anadarko for the Independence Hub project in 2007. The record is broken by Petrobras Cascade flowlines which are installed in 2,689 m (8,820 ft) of water in GOM in 2009 [10].

The longest oil subsea tieback flowline length is 43.4 miles (69.8 km) from the Shell’s Penguin A-E and the longest gas subsea tieback flowline length is 74.6 miles (120 km) of Norsk Hydro’s Ormen Lange, by 2006 [1]. The deepwater flowlines are getting high pressures and high temperatures (HP/HT). Currently, subsea systems of 15,000 psi and 350°F (177°C) have been developed. By the year 2005, Statoil’s Kristin Field in Norway holds the HP/HT record of 13,212 psi (911 bar) and 333°F (167°C), in 1,066 ft of water.

The deepwater exploration and production (E&P) is currently very active in West Africa which occupies approximately 40% of the world E&P (see Figure 1.1).

![Figure 1.1 Worldwide Deepwater Exploration and Production][1]

[1] Figure 1.1 Worldwide Deepwater Exploration and Production [1]
Offshore field development normally requires four elements as below and as shown in Figure 1.2. Each element (system) is briefly described in the following sub-sections.

- Subsea system
- Flowline/Pipeline/Riser system
- Fixed/Floating structures
- Topside processing system

If the wellhead is located on the seafloor, it is called a wet tree; if the wellhead is located on the surface structure, it is called a dry tree. Wet trees are commonly used for subsea tiebacks using long flowlines to save cycle time (sanction to first production). Dry trees are useful for top tension risers (TTRs) or fixed platform risers and provide reliable well control system, low workover cost, and better maintenance.
1.1 Subsea System

The subsea system can be broken into three parts as follows:

- Wellhead structure (Christmas tree) and manifold,
- Control system – subsea control module (SCM), umbilical, umbilical termination assembly (UTA), flying leads, sensors, etc., and
- Connection system – jumper and pipeline end termination (PLET).

![Subsea System](image)

**Figure 1.1.1 Subsea System**

Wellhead (typically 28-in. diameter) is a topside structure of the drilling casing (typically 36-in. diameter) above the mudline, which is used to mount a control panel with valves. The shape of the wellhead structure with valves looks like a pine tree so the wellhead is also called as “Christmas tree”. The manifold is placed to gather productions from multiple wellheads and send the productions using a smaller number of flowlines.

The control system includes SCM, umbilical, UTA, flying leads, and sensors. SCM is a retrievable component used to control chokes, valves, and monitor pressure, temperature, position sensing devices, etc. that is mounted on the tree and/or manifold. UTA allows the use of flying leads to control equipment. Flying leads connect UTAs to subsea trees. Sensors include sand detectors, erosion detectors, pig detectors, etc.

For details on connection system, please see Subsea Tie-in Methods in Section 15.
1.2 Flowline/Pipeline/Riser System

Oil was transported by wooden barrels until 1870s. As the volume was increased, the product was transported by tank cars or trains and eventually by pipelines. Although oil is sometimes shipped in 55 (US) gallon drums, the measurement of oil in barrels is based on 42 (US) gallon wooden barrels of the 1870s.

Flowlines transport unprocessed fluid – crude oil or gas. The conveyed fluid can be a multi-phase fluid possibly with paraffin, asphaltene, and other solids like sand, etc. The flowline is sometimes called a “production line” or “import line”. Most deepwater flowlines carry very high pressure and high temperature (HP/HT) fluid.

Pipelines transport processed oil or gas. The conveyed fluid is a single phase fluid after separation from oil, gas, water, and other solids. The pipeline is also called an “export line”. The pipeline has moderately low (ambient) temperature and low pressure just enough to export the fluid to the destination. Generally, the size of the pipeline is greater than the flowline.

It is important to distinguish between flowlines and pipelines since the required design codes are different. In America, the flowline is called a “DOI line” since flowlines are regulated by the Department of Interior (DOI 30 CFR Part 250: Code of Federal Regulations). And the pipeline is called a “DOT line” since pipelines are regulated by the Department of Transportation (DOT 49 CFR Part 195 for oil and Part 192 for gas).

Figure 1.2.1 Flowline/Pipeline/Riser System
1.3 Fixed/Floating Structures

The transported crude fluids are normally treated by topside processing facility above the water surface, before being sent to the onshore refinery facilities. If the water depth is relatively shallow, the surface structure can be fixed on the sea floor. If the water depth is relatively deep, the floating structures moored by tendons or chains are recommended (see Figure 1.3.1).

Fixed platforms, steel jacket or concrete gravity platform, are installed in up to 1,353 ft water depth (Shell Bullwinkle in 1988). Four (4) compliant piled towers (CPTs) have been installed worldwide in water depths 1,000 ft to 1,754 ft by 2008 (one more CPT will be installed in 366 m (1,200 ft) of water in offshore Angola, west Africa, in 2009). It is known that the material and fabrication costs for CPT are lower but the design cost is higher than conventional fixed jacket platform.

Tension leg platforms (TLPs) have been installed in water depths 482 ft to 4,674 ft (ConocoPhillips’ Magnolia in 2005).

Spar also called DDCV (deep draft caisson vessel), DDF (deep draft floater), or SCF (single column floater) is originally invented by Deep Oil Technology (later changed to Spar International, a consortium between Aker Maritime (later Technip) and J. Ray McDermott (later FloaTEC)). Total 16 spars, including 15 in GOM, have been installed worldwide in water depths 1,950 ft to 5,610 ft (Dominion’s Devils Tower) by 2007. A new spar installed in late 2008 in 2,383 m (7,816 ft) of water in GOM for Shell’s Perdido project set up a new water depth record.

Semi-floating production systems (semi-FPSs) or semi-submersibles have been installed in water depths ranging from 262 ft to 7,920 ft (Anadarko’s Independence Hub in 2007).

Floating production storage and offloading (FPSO) has advantages for moderate environment with no local markets for the product, no pipeline infra (remote) areas, and short life fields. No FPSO has been installed in GOM by 2008, even though its concept for GOM environment application was approved by MMS in 2000. The first FPSO in GOM will be installed by Petrobras for Cascade and Chinook field development in 2,600 m (8,530 ft) of water in 2010 (see Figure 1.3.3). FPSOs have been installed in water depths between 66 ft to 4,796 ft (Chevron Agbami in 2008).

Floating structure types should be selected based on water depth, metocean data, topside equipment requirements, fabrication schedule, and workover frequencies. Figure 1.3.2 shows the floating systems development trend between 1977 to 2009.
Table 1.3.1 shows total number of deepwater surface structures installed worldwide by 2009. Subsea tieback means that the production lines are connected to the existing subsea or surface facilities, without building a new surface structure. The advantages of the subsea tiebacks are lower capital cost and shorter cycle time by 70% (sanction to first production) compared to implementing a new surface structure.

Table 1.3.1  Number of Surface Structures Worldwide [2] & [11]

<table>
<thead>
<tr>
<th>Structure Types</th>
<th>No. of Structures</th>
<th>Water Depths (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed Platforms (WD&gt;1,000’)</td>
<td>~6,000</td>
<td>40 - 1,353</td>
</tr>
<tr>
<td>Compliant Towers</td>
<td>4</td>
<td>1,000 – 1,754</td>
</tr>
<tr>
<td>TLPs</td>
<td>22</td>
<td>482 - 4,674</td>
</tr>
<tr>
<td>Spars</td>
<td>17</td>
<td>1,950 - 5,610</td>
</tr>
<tr>
<td>Semi-FPSs (Semi-submersibles)</td>
<td>45</td>
<td>262 – 7,920</td>
</tr>
<tr>
<td>FPSOs</td>
<td>159</td>
<td>66 – 4,796</td>
</tr>
<tr>
<td>Subsea Tiebacks</td>
<td>3,622+</td>
<td>49 – 7,600</td>
</tr>
</tbody>
</table>

Figure 1.3.1  Fixed & Floating Structures [3]
Figure 1.3.2 Development of Deepwater Floating Systems, 1977 to 2009 [11]

Figure 1.3.3 Application of FPSO - Petrobras Cascade and Chinook Project [12]
1.4 Topside Processing System

As mentioned earlier, the crude is normally treated by topside processing facilities before being sent to the onshore. Due to space and weight limit on the platform deck, topside processing facility is required to be compact, so its design is more complicated than that of an onshore process facility.

Requirements on topside processing systems depend on well conditions and future extension plan. General topside processing systems required for typical deepwater field developments are:

- Well control unit
- Hydraulic power unit (HPU)
- Uninterruptible power supply (UPS)
- Control valves
- Multiphase meter
- Umbilical termination panel
- Crude oil separation
- Emulsion breaking
- Pumping and metering system
- Heat exchanger (crude to crude and gas)
- Electric heater
- Gas compression
- Condensate stabilization unit
- Subsea chemical injection package
- Pigging launcher and receiver
- Pigging pump, etc.
References


