Sensur av hovedoppgaver

Høgskolen i Buskerud og Vestfold
Fakultet for teknologi og maritime fag

Prosjektnummer: **2015-02**
For studieåret: **2014/2015**
Emnekode: **SFHO3201**

Prosjektnavn
Dypvanns Riser Studie
Deep Water Riser Pipe Study

Utført i samarbeid med: FMC Technologies i Kongsberg

Ekstern veileder: Sondre Rosfjord Askim

Sammendrag: I dette prosjektet har det blitt gjort en markedsundersøkelse for å kartlegge fremtiden til workover riser systemer. Det har blitt laget et beregningsvektøy i Excel som ingeniører kan bruke i en prosjekttilbudsfase for å få en indikasjon på hvilket riser system de burde velge. Videre har en konseptstudie blitt gjennomført for å undersøke om store vanndyp kan nåes ved hjelp av en stål-riser.

Stikkord:
- Beregningsverktøy
- Markedsanalyse
- Konsept

Tilgjengelig: DELVIS

Prosjekt deltagere og karakter:

Navn	Karakter
David Snarheim	
Line Dyre-Hansen	
Øystein Ulmo	
Kjersti Schrøder Anthonsen	

Dato: 04.juni 2015

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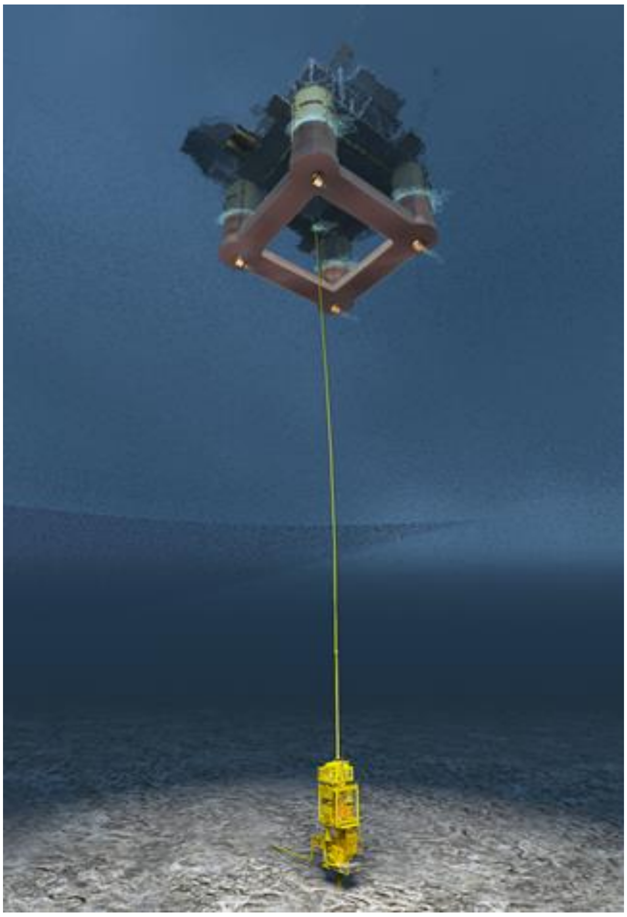
Kjell Enger Intern Veileder	Karoline Moholth Intern Sensor	Anders Wormsen Ekstern Sensor

Final Report

Deep Water Riser Pipe Study



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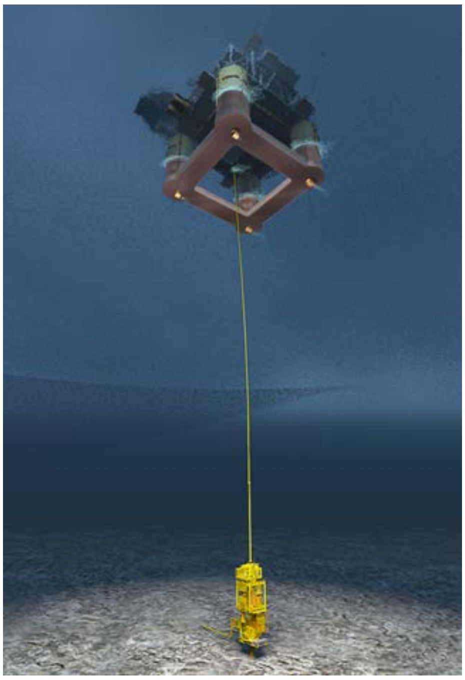
Document And Delivery List

Deep Water Riser Pipe Study



Rev	Date	Prepared By	Reviewed By	Changes
1.0	13.05.2015	Line Dyre-Hansen	Kjersti S Anthonsen	

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Abbreviations

The following abbreviations are used throughout this document.

Abbreviation	Description
G	General
P1	Phase 1
P2	Phase 2
P3	Phase 3

1 Introduction

This document contains an overview of different documents that is created in this project. Table 1, describes the document number, title of the document, which category and phase.

2 Document table list

Table 1: Document list

No.	Document number	Title	Category	Phase	Rev. No	File type	Location CD
1.	1000	Project Control Tool	General	G	-	Excel	Admin
2.	3000	Vision Document	General	G	2.0	Word PDF	Admin
3.	3100	Requirement Specification	General	G	3.0	Word PDF	Tech
4.	3200	Test Specification	General	G	3.0	Word PDF	Tech
5.	3300	Project Plan	General	G	3.0	Word PDF	Admin
6.	3400	Risk Analysis	General	G	2.0	Word PDF	Admin
7.	3600	Post Project Evaluation	General	G	1.0	Word PDF	Admin
8.	3700	Document and Delivery List	General	G	1.0	Word PDF	Admin
9.	4110	Data Collection FMC Deliveries	Data Collection	P1	-	Excel	Tech/Phase 1/Report/Data Collection
10.	4120	Data Collection FMC Tender	Data Collection	P1	-	Excel	Tech/Phase 1/Report/Data Collection
11.	4130	Data Collection Water Depth	Data Collection	P1	-	Excel	Tech/Phase 1/Report/Data Collection
12.	4140	Quest Subsea Database Forecast	Data Collection	P1	-	Excel	Tech/Phase 1/Report/Data Collection
13.	4150	Quest Subsea Trees Global Awarded	Data Collection	P1	-	Excel	Tech/Phase 1/Report/Data Collection
14.	4210	Design Basis Phase 1	Reporting	P1	2.0	Word PDF	Tech/Phase 1
15.	4230	Final Report Phase 1	Reporting	P1	2.0	Word PDF	Tech/Phase 1/Report
16.	4240	Map Phase 1	Reporting	P1	1.0	Word PDF	Tech/Phase 1/Report
17.	4250	Test Report Phase 1	Reporting	P1	2.0	Word PDF	Tech/Phase 1

18.	5210	DWRPS Engineering Tool	Creating tool	P2	1.0	Excel	Tech/Phase 2
19.	5510	User Manual	User documentation	P2	1.0	Word PDF	Tech/Phase 2
20.	5610	Design Basis Phase 2	Reporting	P2	2.0	Word PDF	Tech/Phase 2
21.	5630	Final Report Phase 2	Reporting	P2	1.0	Word PDF	Tech/Phase 2
22.	5650	Test Report Phase 2	Reporting	P2	1.0	Word PDF	Tech/Phase 2
23.	6120	Initial Calculation Phase 3	Define concepts	P3	-	Excel	Tech/Phase 3
24.	6210	Optimizing 5 inch ERC	Evaluate concepts	P3	-	Excel	Tech/Phase 3/Optimizing
25.	6220	Optimizing 5 inch Standard Pipe	Evaluate concepts	P3	-	Excel	Tech/Phase 3/Optimizing
26.	6230	Optimizing 7 inch UN	Evaluate concepts	P3	-	Excel	Tech/Phase 3/Optimizing
27.	6240	Optimizing 7 inch Standard Pipe	Evaluate concepts	P3	-	Excel	Tech/Phase 3/Optimizing
28.	6250	5 inch 3000m Parameter Optimizing	Evaluate concepts	P3	-	Excel	Tech/Phase 3/Optimizing
29.	6260	Cost Analysis	Evaluate concepts	P3	-	Excel	Tech/Phase 3
30.	6410	Design Basis Phase 3	Reporting	P3	1.0	Word PDF	Tech/Phase 3
31.	6420	Final Report Phase 3	Reporting	P3	1.0	Word PDF	Tech/Phase 3
32.	6440	Test Report Phase 3	Reporting	P3	1.0	Word PDF	Tech/Phase 3

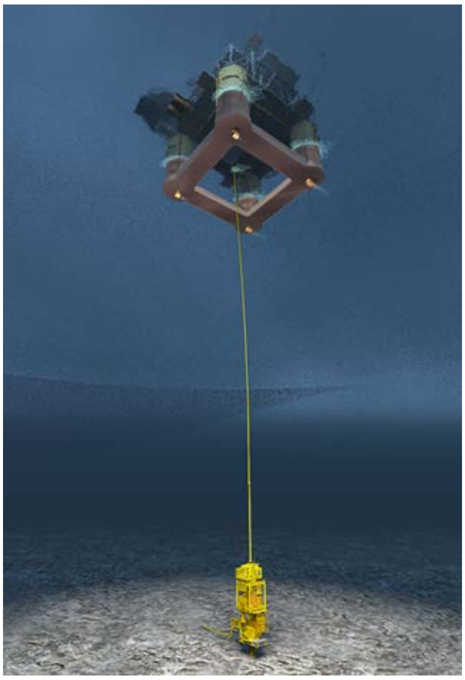
3 Document revision history

Table 2: Document revision history

Rev	Date	Prepared By	Reviewed By	Changes
1.0	13.05.2015	Line Dyre-Hansen	Kjersti S Anthonsen	

Vision Document

Deep Water Riser Pipe Study



Rev	Date	Prepared By	Reviewed By	Changes
2.0	23.03.2015	Kjersti Schrøder Anthonsen	Line Dyre-Hansen	See section 6

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Abbreviations

The following abbreviations are used throughout this document.

Abbreviation	Description
EDP	Emergency Disconnect Package
FMC	FMC technologies in Kongsberg
HBV	Høyskolen i Buskerud og Vestfold (Buskerud and Vestfold university college)
HP	High pressure
HT	High temperature
LRP	Lower Riser Package

1 Introduction

For our bachelor project at HBV, we will be working for FMC Technologies in Kongsberg.

Our project is named **deep water riser pipe study**. FMC wants to be able to propose and evaluate future development needs, have an easier way to take decisions early in a tender phase and to look at next generation riser pipes to meet future deep water projects.

2 Riser systems

Subsea technology is a term used to describe the technology where you produce and use equipment located on the seabed to recover oil and gas. Some key components are manifold, Christmas tree (a valve block), work over riser systems (see Figure 1) and other equipment.

A work over riser system consists of different products, EDP, LRP, stress joints, tension joint, tension frame, and standard joints. Its main purpose is to connect the platform or vessel to the oil/gas well located on the seabed. It is mainly used for a short period of time to do work over tasks such as Christmas tree installation, well maintenance, tubing hanger installation, and can also be used for start-up and test production of a well.

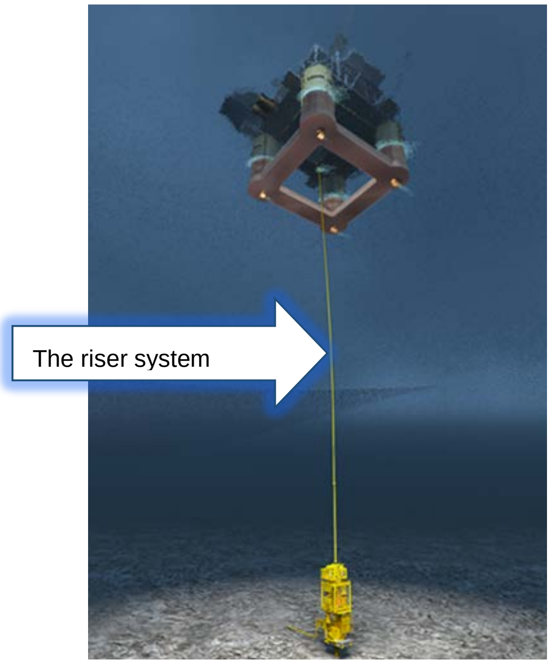


Figure 1 Riser system

3 Challenges with deep water

One of the main challenges for work over riser system in deep water is the external pressure exerted by the water column, as an example at 2000 meter water depth (1 bar per 10 meter) the equipment will have to sustain 200 bars of external pressure. Further, the weight of the total riser system will increase due to the depth. The deeper in the ocean your equipment is, the number of riser joints will increase, therefore the weight of the riser system will increase. The uppermost riser joints will have to sustain the increased weight in addition to the temperature and pressure from the well, along with other factors such as vessel movements.

Deeper water and customers desires to recover oil and gas from more and more challenging wells such as HP/HT, makes new ideas and concepts necessary for FMC in the future.

4 Deep water riser pipe study

As described in section 3 the uppermost riser joint is one of the challenges with deep water, in addition the weight of the equipment. The weight of the riser system is controlled by the weight of the riser joint, because there are more standard riser joints than any other parts, there will be more and more riser joints if you increase the length of the riser. This project will therefore concentrate on the standard riser joints and selection of riser pipes.

The project is divided into three phases as described below.

4.1 Phase 1

This is a study phase where we will get an idea on the future trends in the offshore marked, we will perform this study to identify the main requirements for deep water. Further we will use this as reference for the next phases of our project, and will be used by FMC to understand the future needs and develop strategies for their riser systems. We will also create a map with a visual presentation of the major oceans, subsea regions and their operators.

4.2 Phase 2

In this phase we will develop a new method that FMC can use to take decisions early in a tender phase. This will be a method to choose what kind of riser to use for that project, based on some known parameters.

To do this we have to consider all the different parameters that effects riser pipe design such as:

- Water depth
- Weight of equipment
- Well temperature
- Well pressure
- Others

Then we have to decide which ones who will significantly change the outcome and eliminate the ones who do not. To be able to consider the parameters we have to get an understanding of the effect they have on the riser pipe, for this we also have to gain knowledge on the structure of the riser pipe and the riser system

The method will be implemented in a tool, using Microsoft excel, where you can put in the known parameters and then the tool will calculate what kind of riser to use, and give a visual presentations for that case.

4.3 Phase 3

In this last phase we will create a concept proposal for a deep water riser system focusing on the standard riser joints. The case we will make a proposal for will be chosen based on a trend from phase 1 or a specific tender/project chosen in cooperation with FMC. This concept should be innovative, we may consider alternatives to steel. Further we will use the tool from phase 2 to test the concept. In this phase we may cooperate with some of FMCs pipe suppliers (Vallourec or Tenaris) and with FMCs material technology department.

5 Goals

5.1 Phase 1

Our goals for this phase is to identify trends for work over riser systems in the offshore marked. We will create a map with visual presentation of major oil and gas fields, and a final report.

5.2 Phase 2

The goals for this phase is to develop new method for FMC to take decisions on which riser pipes to use, early in a tender phase. We will make a user friendly tool with possibilities for further development, a user manual, and a final report.

5.3 Phase 3

In this phase our goal is to make a concept proposal for a deep water riser system, specifically the standard riser joints, on a specific case or project and then test it in the tool we developed. We will make a report with a cost analysis.

5.4 Personal goals

At the end of the project we expect to:

- Understand deep water challenges
- Understand material challenges
- Understand design codes and utilization of the equations that they provides, type of approach used etc.
- Understand the effects of loads applied during a work over operation both due to external and environmental loads.

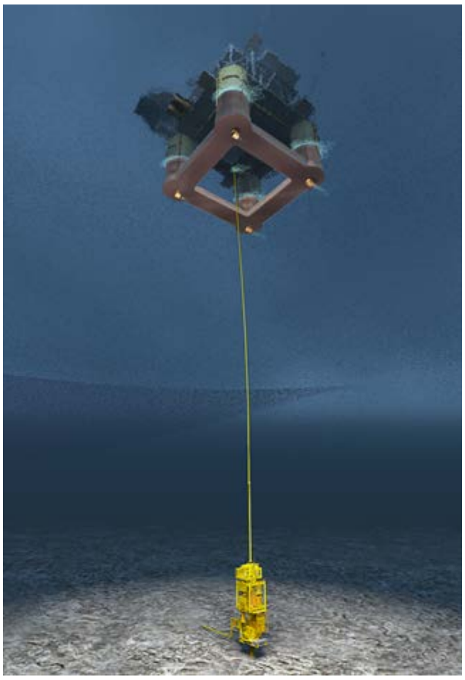
6 Document revision history

Table 1 Revision history

Rev	Date	Prepared By	Reviewed By	Changes
1.0	01.02.2015	Kjersti Schrøder Anthonsen	David Snarheim	
2.0	23.03.2015	Kjersti Schrøder Anthonsen	Line Dyre-Hansen	Spelling mistake, corrected and new setup implemented

Project Plan

Deep Water Riser Pipe Study



Rev	Date	Prepared By	Reviewed By	Changes
3.0	30.04.2015	David Snarheim	Kjersti S. Anthonsen	See section 11

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Abbreviations

The following abbreviations are used throughout this document.

Abbreviation	**Description**
FMC	FMC Kongsberg Subsea
HBV	Høyskolen I Buskerud og Vestfold
SQDC	Saftey Quality Delivery Cost
WBS	Work Breakdown Structure

1 Introduction

This document describes the project plan for the project Deep Water Riser Pipe Study. It contains information related to project setup and planning.

2 Project organization

This section describes the organizational structure utilized by the Deep Water Riser Pipe Study team.

2.1 Organizational chart

The project responsibilities are structured as shown in organizational chart Figure 1, and the project team member's position are described in Table 1.

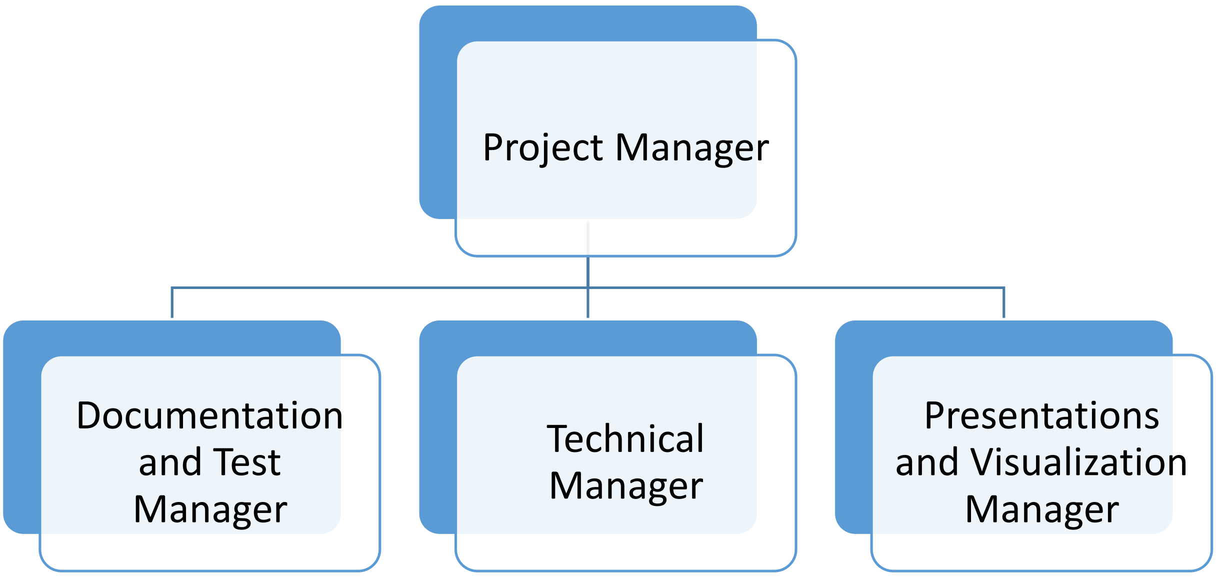


Figure 1: Project organizational chart

2.2 Project team members

Table 1: Project team members

Project team members		
	**Name:**	David Snarheim
	Position:	Project Manager
	Phone Number:	+47 99 25 00 17
	E-mail:	snarhed@gmail.com david.snarheim@fmcti.com
	**Name:**	Line Dyre-Hansen
	Position:	Documentation and Test Manager
	Phone Number:	+47 47 30 42 82
	E-mail:	line_joker@hotmail.com
	**Name:**	Øystein Ulmo
	Position:	Technical Manager
	Phone Number:	+47 48 13 51 19
	E-mail:	oysteinulmo@hotmail.com
	**Name:**	Kjersti Schrøder Anthonsen
	Position:	Presentation and Visualization Manager
	Phone Number:	+47 93 88 72 39
	E-mail:	kjersti_and88@hotmail.com

2.3 Project team members responsibilities

Project Manager

- Establish, control and update project and resource plan
- Establish contract
- Control (If any) financial aspects
- Quality, ensure that the project follows its procedures
- Review documents
- Provide support to Technical Manager, Documentation and Test Manager and Presentation and Visualization manager where required

Technical Manager

- Responsible for the technical solutions and functionality
- Establish plan for solving and completing technical challenges
- Review documents
- Provide support to Project Manager, Documentation and Test manager and Presentation and Visualization manager where required

Documentation and Test Manager

- Establish and update project document plan
- Ensure that correct template are used
- Review documents
- Establish and control project test plan
- Conducting tests and report results
- Provide support to Project Manager, Technical Manager, Presentation and Visualization manager where required

Presentation and Visualization Manager

- Responsible for planning presentations
- Responsible for creating project posters
- Responsible for creating and planning required animations
- Responsible for creating and planning required videos
- Responsible for updating web page
- Review documents
- Provide support to Project manager, Technical manager, Documentation and Test manager where required

3 Project model

For the Deep Water Riser Pipe Study a project specific model has been developed as seen in Figure 2. The model has been developed to suit the project different phases and their difference in work scope, such as.

- Study reports
- Engineering tool

The model idea originates from a standard waterfall model, however the model has been alternated and built up with a vertical and horizontal axis. A short description of the axis are given below.

<u>Vertical axis</u>

The vertical axis identifies the different stages in the project.

<u>Initiate and plan project</u>

This stage is where all project controlling tools are created, ideas are proposed and mapping of user requirements are being conducted, such as.

- Contactor scope of work document review
- Ideas and proposals
- Project control tool
- Timeline plan

<u>Requirement and test specification</u>

At this stage, the project requirements and test specification will be created.

<u>Engineering</u>

This stage will contain the engineering work, as seen the stage have three sub stages which identifies each of the project phases.

<u>Test and verification</u>

This stage will contain the test and verification work, as seen the stage have three sub stages which identifies each of the project phases. The contractor will approve each test.

<u>Horizontal axis</u>

Horizontal axes gives an indication of the project timeline.

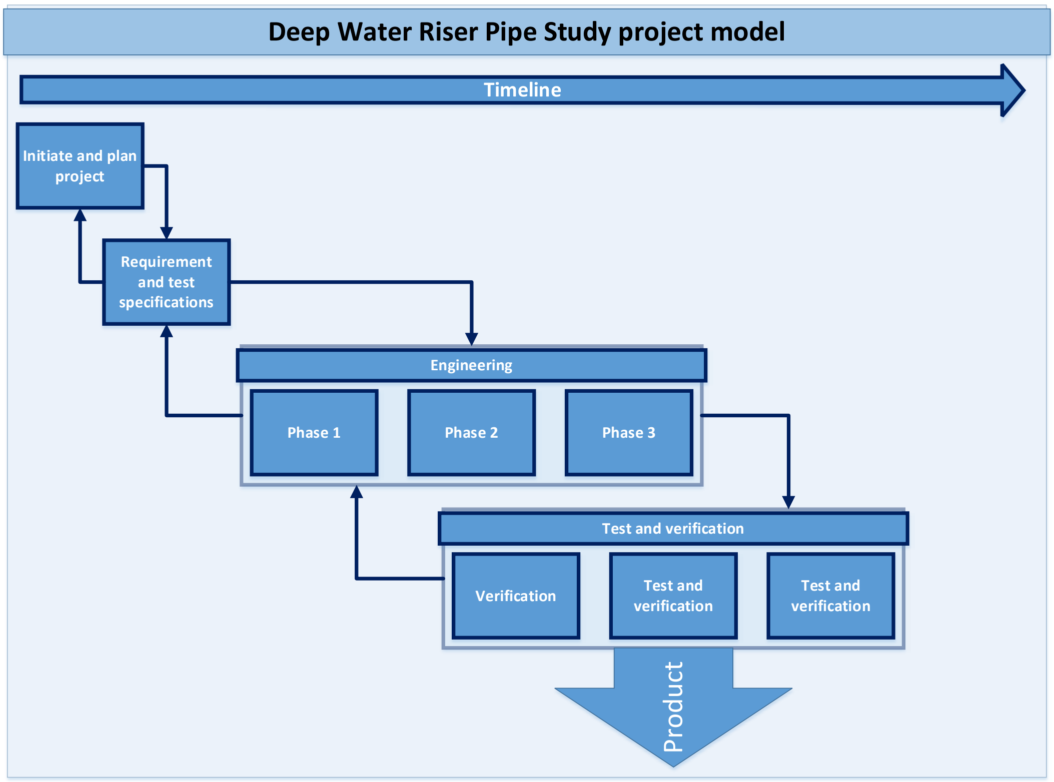


Figure 2: Project model

Quality Iterations

Document control

All documents produced by the project shall as a minimum be revised by the project group, and changes made as necessary. The review process is described in 4.6.

Evaluation of each project stage

Before a phase goes into the next stage, the work performed in the previous stages shall be evaluated as a whole and changes in this stage and previous stages shall be performed as necessary.

Design basis

At each engineering startup for project phase 1-3 there shall be created a design basis document, the document has the function as an iteration where the requirements from requirement and test specification are specified in details.

Phase test and verification

As final quality assurance of the deliverables, each phase shall be verified and tested according to the test specification. The results shall be documented and findings addressed through changes in all project stages as necessary.

Time planning iterations

Project control tool

A project control tool where all work hours are reported, shall be used. Output from this tool shall be continually monitored to uncover deviations from project plan and used as input to weekly follow-up document

Weekly follow up document

A weekly follow up document shall be produced each week, documenting work performed and plan for next weeks work.

In addition this document shall include a project status and deviation from project plan.

Project plan rescheduling

If major deviations is identified on weekly follow up document a re-planning of estimated work hours and work scope shall be performed.

The model developed will provide the project with flexibility and a high quality outcome. In addition, it gives the viewer good visualization of the different stages and project phases.

4 General project guidelines

This section describes the project team guidelines related to project tools that have been created for managing and control.

4.1 Document templates

Document templates are as defined in

Table 2. The templates shall be used for all documentation created for the project.

Table 2: Project document template list

Document template	Format	Storage location Dropbox
Official report template	Word	Administrative/ Doc templates
Minutes of meeting template	Word	Administrative/ Doc templates
Official power point template	Ppt	Administrative/ Doc templates

4.2 Document number and revision control

Document number and revision control shall apply to all official documentation and other documentation where applicable.

Document numbering

- Official document numbers shall always start with their respective WBS number.

Revision control

Official released documents shall follow the structure as described below in ascending order.

- Official revision 1 = 1.0
- Official revision 2 = 2.0

Draft revision control shall follow the structure as described below in ascending order.

- Draft revision 1 = 0.1
- Draft revision 2 = 0,2

4.3 Project control tool

The project tool created by the project team contains the following functions.

- Tracking tasks
- Registration of hours
- Tracking documents status
- Tracking reported hours per activity related to specified task
- Tracking weekly reported hours per team member
- Tracking project total worked hours
- Resource Planning

4.4 Time registration

The project team member shall report their weekly hours in their respective time registration sheet located in the project control tool. One project week lasts from Saturday to Friday. All hours shall be posted within Friday 22:00 each week.

4.5 Minutes of meeting instruction

A minutes of meeting shall be created for each meeting participated in. The minutes shall be written and issued within 24 hours after its respective meeting time. The project members shall alternate on whom to write minutes. The minutes shall be saved in minutes of meeting folder on Dropbox and the document name shall include meeting name and date.

4.6 Review process

The project review process shall in general be as defined in Figure 3 Example: David should review work performed by Kjersti. The project team members may alternate on the review process based on work-teams and workload.

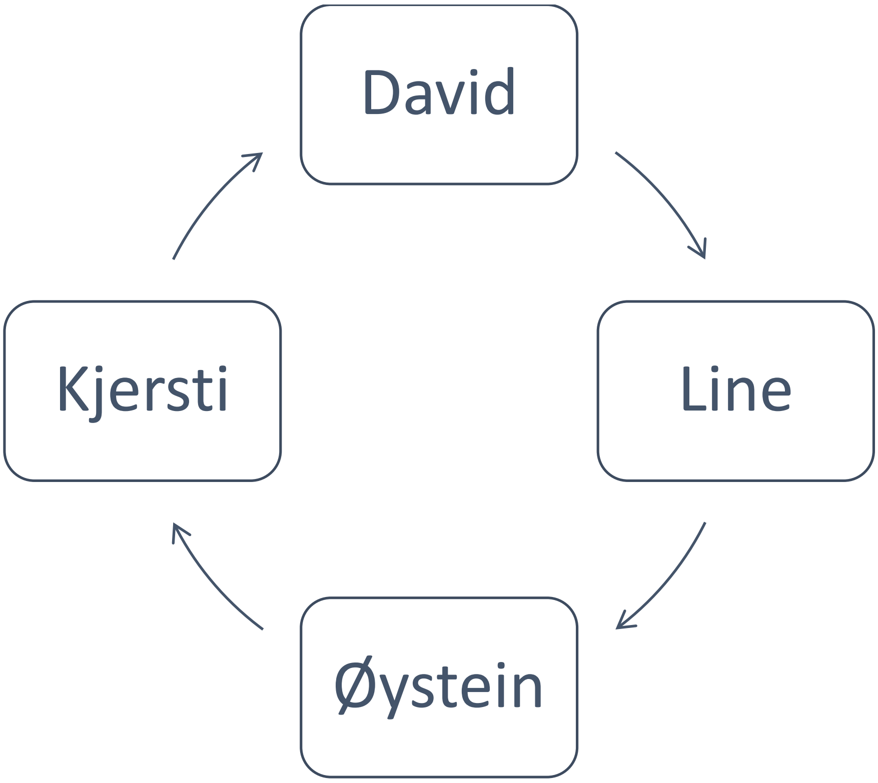


Figure 3: Project review process

5 Project phases description

This section describes responsibilities delegated for each phase of the project. it also contains a description of the work that will be conducted and how it is structured for the main activities in each phase.

5.1 Phase 1

The main responsible for phase 1 will be David Snarheim and Kjersti Schrøder Anthonsen. The other team members will be required to take active part in this phase as well.

Research

Research will consist of gaining information and understanding of deep water work over marked. It shall define a method for presenting trends across regions.

The trends shall mainly be presented based on information as defined below.

- Oil and gas field operator
- Type of subsea tree and tubing hanger drift size
- Type of operation mode preferred
- Water depths
- Well Pressure
- Well Temperature

The research activity will also define requirements for visual presentation map.

Data collection

The data collection activity consist of acquisition and quality assurance of data required for presenting trends.

Reporting

A final report and a visual map identifying trends shall be created as output from phase 1.

5.2 Phase 2

At phase 2 a new method and an engineering tool for rating of riser pipe for deep water shall be developed. The method and engineering tool will be utilized by FMC in tender phase such that an early selection of correct riser pipe design can be performed.

The main responsible for phase 2 will be Øystein Ulmo and Line Dyre-Hansen. The other team members will be required to take active part in this phase as well.

Training

The activity defines a training phase. This is to give the project team members a basic understanding of the methods currently being utilized for estimating and rating of a work over riser systems capabilities. It will also give basic understanding of critical parameters that effects the design criteria of a riser pipe.

Methods and equations

The methods and equations activity will consist of defining the method that shall be used for rating and selection of riser pipe size and material requirement. It shall consider and rate all relevant parameters that effects the design of a riser pipe. Parameters not critical or effecting the design notably should not be implemented such that the method and equations are kept as simple as possible without effecting the accuracy.

Create Engineering tool

The engineering tool activity shall implement the method and equations set into a excel sheet. The engineering tool shall be well structured and provide clear and understandable area for input and reading output. It should also give a visual presentation, however this only a nice to have requirement.

Test Engineering tool

In the activity test engineering tool, the excel sheet shall be tested at a pre-set input data and the output shall be verified by hand calculation. Further the tool shall be tested by a FMC representative for user friendliness and hand calculations or other methods. A test report with recommendations for improvements shall be created.

Refine Enginering tool

The refining activity will consist of implementing improvements identified in the test activity. If any refining is required due to faults originating in methods and equations, redefinition of this activity and subsequent activities will be performed..

User documentation

For the user document activity a user manual shall be created for the engineering tool.

Reporting

The reporting activity will consist of reporting and documenting the method and equations utilized, as well as a conclusion and recommendation for future development possibilities.

5.3 Phase 3

The main responsible for phase 3 will be David Snarheim and Kjersti Schrøder Anthonsen. The other team members will be required to take active part in this phase as well.

Training

The activity defines a training phase, this is to give the project team members a deeper introduction to currently available riser pipes and connectors. The team will also gain information and understanding of the main challenges within the methodology of selecting the preferred riser pipe design and connectors.

Preliminary calculation and evaluation

As part of the Preliminary calculation and evaluation activity the project team will utilize the trends defined in phase 1 and will in cooperation with FMC select on or more deep water cases, where a riser pipe and connector design are currently not available. Based on the specified case or cases a preliminary calculation shall be created to evaluate suitability of steel riser. The project team may be required to approach pipe suppliers such as Tenaris or Vallourec as well as FMC material department for support. The project team stands free to evaluate technology not utilized by the oil and gas industry today.

Material selection or Optimizing design and calculation

In the Material selection or Optimizing design and calculation activity the project team shall evaluate and propose one or several concepts that meets the specified case or cases. A cost estimate may presented but is not a need requirement.

Test concept

In the test concept phase, the proposed concept or concepts shall be tested by utilizing the engineering tool developed in phase 2.

Reporting

For the reporting activity, a final report shall be created documenting all activates defined in phase 3.

6 Project timeline and resource plan

This section contains the project timeline plan and resource plan defined for this project.

6.1 Project timeline plan

The project timeline is created in Microsoft project, a summary of the main activities is presented on timeline in Figure 4. The detailed project plan is presented in Appendix 1.

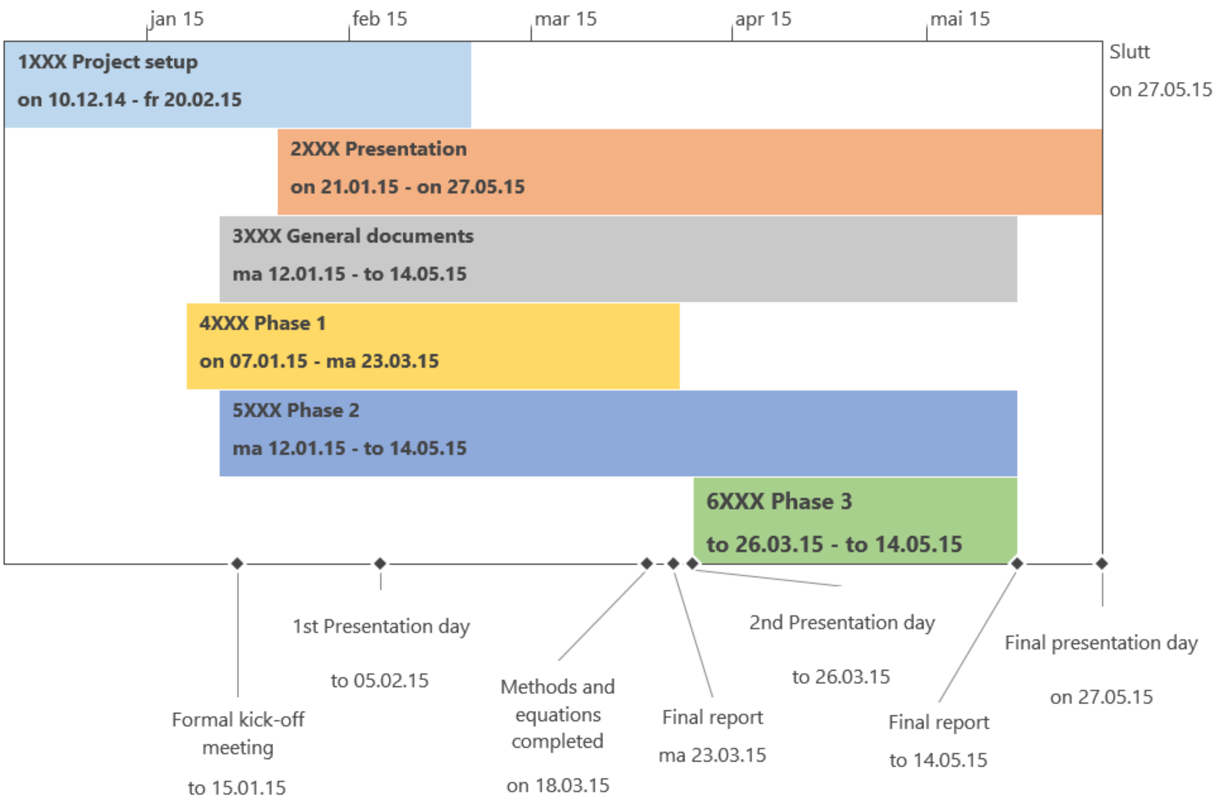


Figure 4: Project plan main activities

In addition to the milestones presented in Figure 4, a full milestone list with dates are presented in Table 3.

Table 3: Project plan milestone list

Milestone	Date
Formal Kick-off HBV and FMC	15.01.2015
Contract signoff	20.02.2015
1st Presentation	05.02.2015
Phase 1 final report	23.03.2015
Method and equations completed Phase 2	18.03.2015
2nd Presentation	26.03.2015
Phase 2 final report	14.05.2015
Phase 3 final report	14.05.2015
Final project report	14.05.2015
Final presentation	27.06.2015

6.2 Work break down structure

A WBS have been created and hours estimated for each activity is as shown in Table 4.

Table 4: Project work break down Structure

WBS	Description	Estimated hours
1XXX	**Administrative**	
1000	Weekly meeting	96
1100	Other meetings	50
1200	Admin tasks (Project tools, Time sheet, Project plan, MOM etc.)	174
1300	General research	14
1400	HBV Friday lecture with Olaf	40
TOTAL		**372**
2XXX	**Presentation**	
2000	1st presentation	125
2100	2nd presentation	117
2200	Final presentation	200
TOTAL		**442**
3XXX	**General documentation**	
3000	Project vision document	19
3100	Requirement specification	57
3200	Test specification	80
3300	Project plan document	50
3400	Project risk analysis document	21
3500	Final thesis report	100
3600	Post project evaluation report	70
TOTAL		**396**
4XXX	**Project phase 1**	
4000	Research phase 1	21
4100	Data collection	50
4200	Reporting	132
TOTAL		**203**
5XXX	**Project phase 2**	
5000	Training	10
5100	Methods and equation	282
5200	Create engineering tool	62
5300	Test engineering tool	45
5400	Refine engineering tool	45
5500	User documentation	40
5600	Reporting	100
TOTAL		**584**
6XXX	**Project phase 3**	
6000	Training	29
6100	Preliminary calculation and evaluation	50
6200	Material selection or Optimizing design and calculation	130
6300	Test concept	30
6400	Reporting	50
TOTAL		**289**
PROJECT TOTAL	**Project**	**2285**

A visualization showing the division of estimated work hours between the activities are shown in Figure 5.

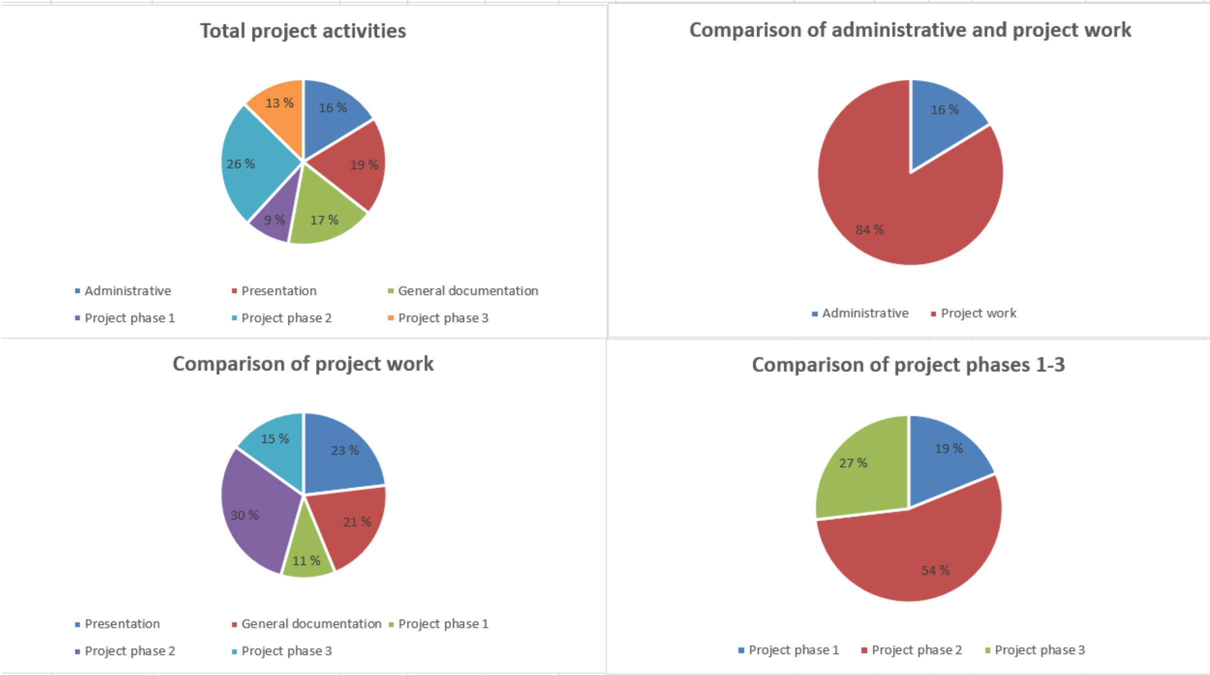


Figure 5: Project percentage visualization

The project is expected to have a high amount of hours related to project planning in the beginning which will eventually flatten out, whereas the hours for main project work will increase. As shown in **Feil! Fant ikke referansekilden.**.

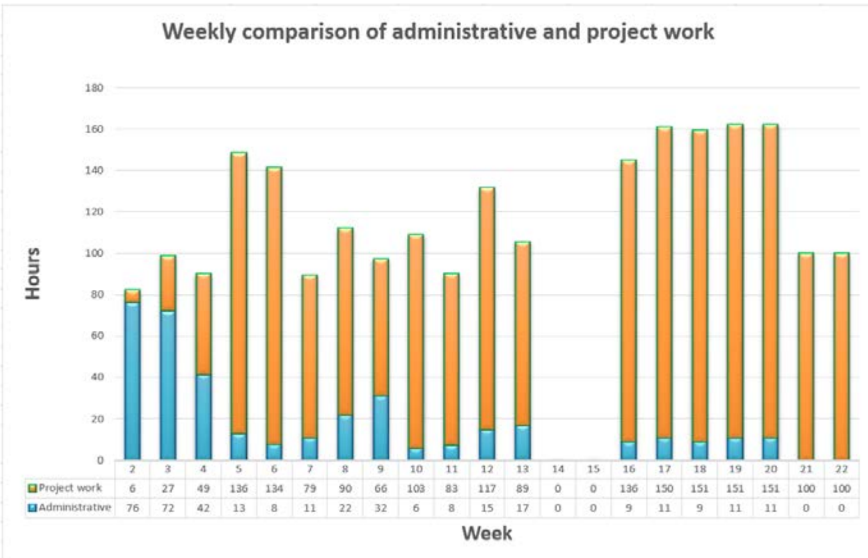


Figure 6: Project resource plan Project planning vs Project work

6.3 Resource plan

The project team have planned for workweeks as estimated in Table 5. Further this has been compared to the resource plan as visualized in Figure 7 where the red line represent the maximum expected hours while the yellow one represents the minimum. The green line represents the estimated work hours. A detailed resource plan is located in Appendix 2.

Table 5: Project weekly work hours estimate

Week	Hours per person	Total hours all members	Comments
2-13	20-30	80-120	4 days' work week
14	0	0	Easter vacation
15	6-10	24-40	Easter vacation, reading and exam day
16-22	35-40	140-160	5 days' work week

Figure 7: Project resource estimation plan

The resource plan is based on regular workweeks with built in range. The range gives the project team members slightly freedom to prioritize their workflow from week to week as long as critical dates are met in accordance with project time plan. Further the resource plan does not calculate work in weekends and Easter vacation, which in combination with re-planning can be used as a buffer in case of unplanned events.

7 Document list

The documents listed in Table 7 are the predefined documents for the project. To keep track of all documentation created, the project control tool as defined in section 4.3 will be used for tracking progress. In addition there will be created a document list report that will be delivered as part of the final project report.

Table 6: Project predefined document list

Document number	Description	WBS
3000	Project vision document	3000
3100	Requirement specification	3100
3200	Test specification	3200
3300	Project plan document	3300
3400	Project risk analysis	3400
3500	Final project report	3500
3600	Post project analysis	3600
4210	Design basis phase 1	4200
4230	Final report phase 1	4200
4240	Visual presentation phase 1	4200
5610	Design basis phase 2	5600
5510	User manual phase 2	5500
5630	Final report phase 2	5600
6410	Design basis phase 3	6400
6420	Final report phase 3	6400

8 Project cost analysis

According to the contract between the students, FMC and HBV, all direct expenses that are directly related to the defined project work shall be covered by FMC. However background literature not directly associated with the product may be covered by the students. If additional expenses outside of the agreed scope of work with FMC a budget shall be created and approved by FMC.

9 Quality and traceability

The project team will follow FMC standards in terms of SQDC whenever applicable and traceability will be highly focused trough all phases of the project.

10 Contract

The project have established a contract with applicable appendixes as defined below. A copy of the contract is found in Appendix 3.

- Main Contract
    - Attachment 1 FMC confidentiality agreement
    - Attachment 2 Internal project team contract

11 Document revision history

Table 7: Document revision history

Rev	Date	Prepared By	Reviewed by	Changes
1.0	02.02.2015	David Snarheim	Kjersti S. Anthonsen	First release
2.0	16.03.2015	David Snarheim	Øystein Ulmo	Updated project model Updated project timeline and hours General update of doc template
3.0	30.04.2015	David Snarheim	Kjersti S. Anthonsen	Updated project model with iteration description and new figure. Updated project timeline and hours. Updated Appendix 1 with iteration phases. Updated Appendix 2 General update of doc template

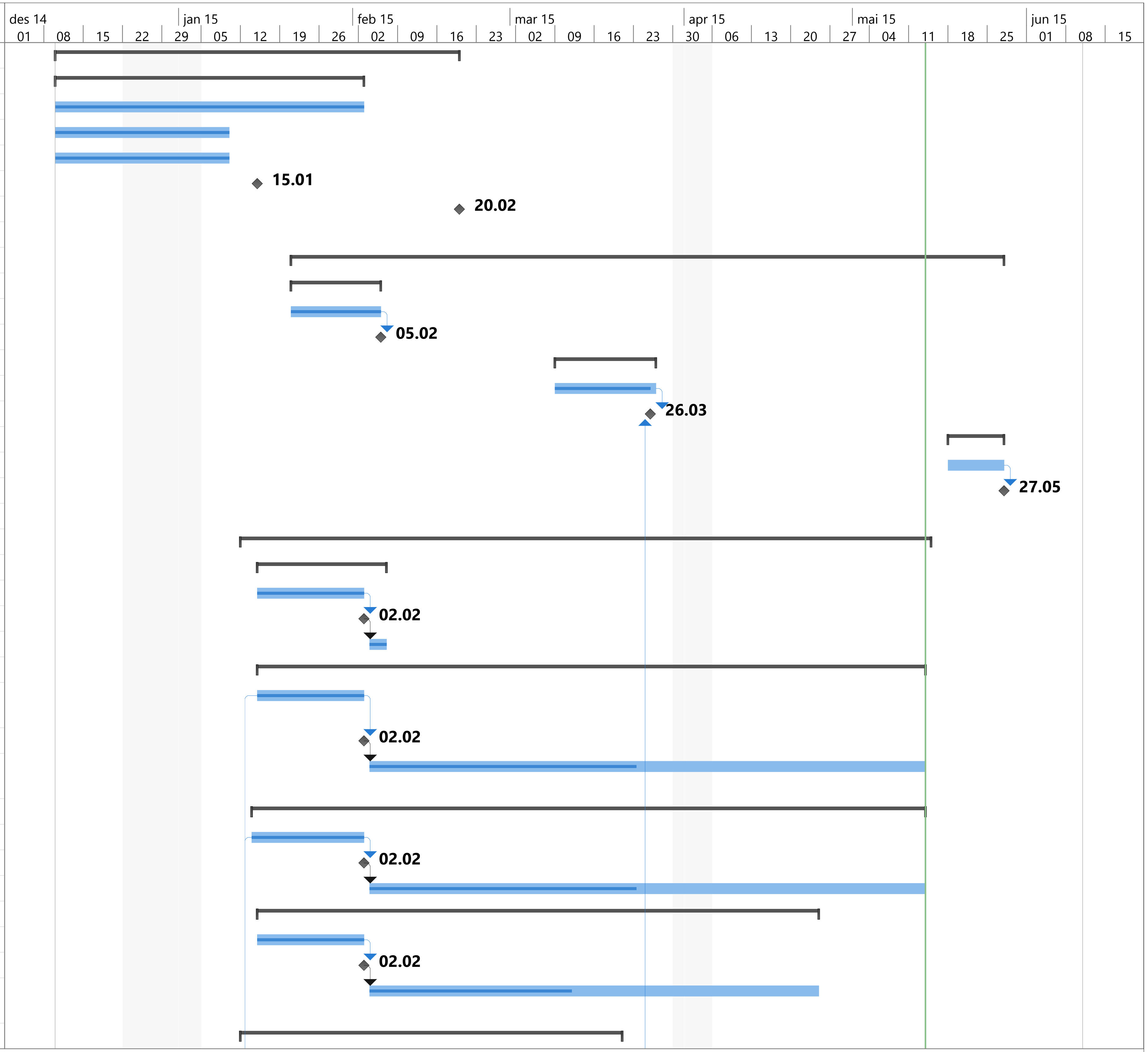
12 Appendix list

Table 8: Document appendix list

Appendix	Revision	Description	Format
1	3.0	Project timeline plan	Pdf
2	3.0	Resource plan	Pdf
3	2.0	Contract	Pdf

Appendix 1 Project timeline plan rev 3.0

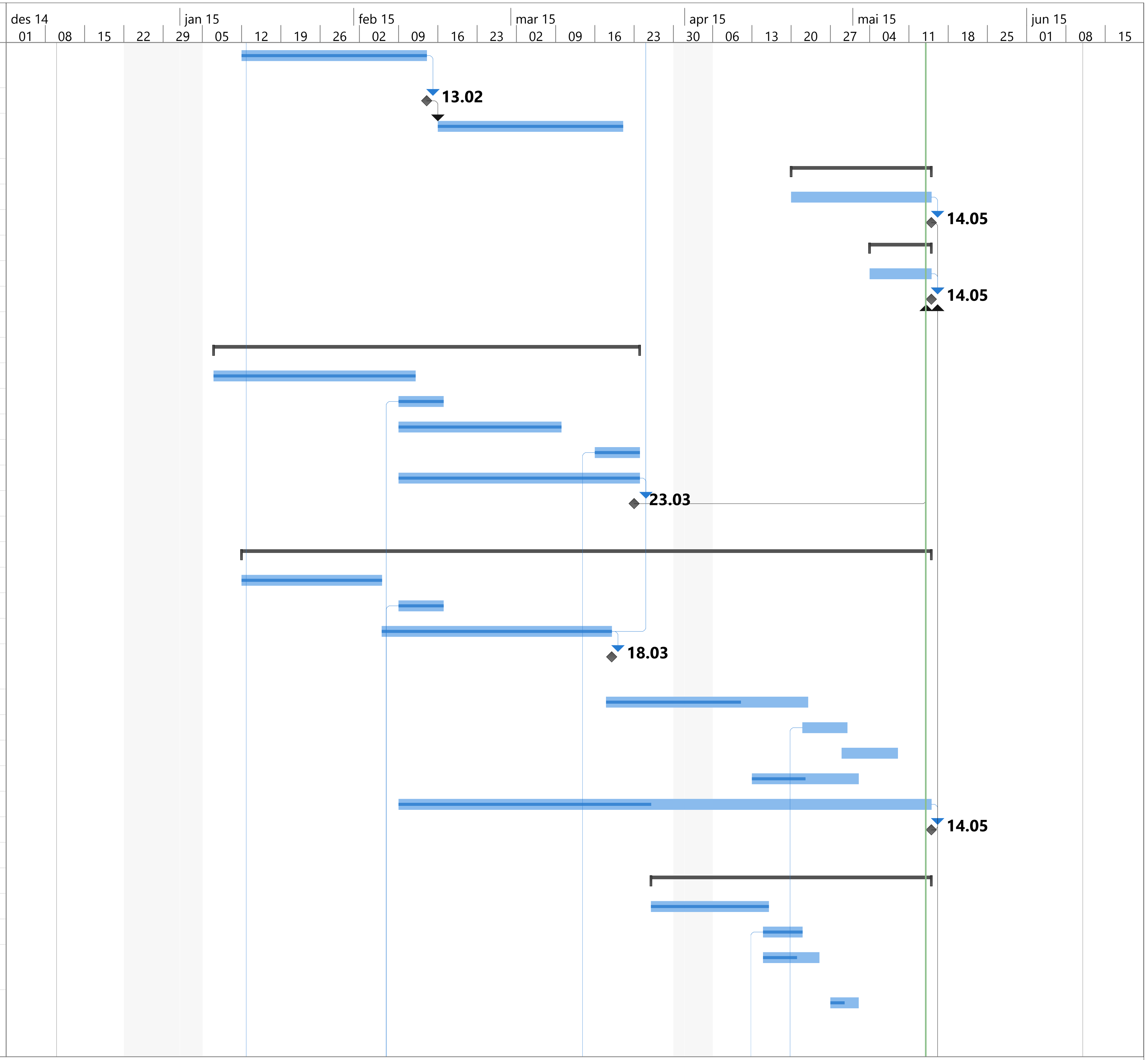
ID	i	Aktivitetsnavn	Varighet	Start	Slutt
1		**1XXX Project setup**	**35 dager**	**on 10.12.14**	**fr 20.02.15**
2	✓	**Project tools**	**25 dager**	**on 10.12.14**	**ma 02.02.15**
3	✓	Project plan	25 dager	on 10.12.14	ma 02.02.15
4	✓	Templates	12 dager	on 10.12.14	fr 09.01.15
5	✓	General project tools	12 dager	on 10.12.14	fr 09.01.15
6	✓	**Formal kick-off meeting**	0 dager	to 15.01.15	to 15.01.15
7		**Contract signoff**	0 dager	fr 20.02.15	fr 20.02.15
8					
9		**2XXX Presentation**	**73 dager**	**on 21.01.15**	**on 27.05.15**
10	✓	**1st Presentation**	**10 dager**	**on 21.01.15**	**to 05.02.15**
11	✓	Create presentation	10 dager	on 21.01.15	to 05.02.15
12	✓	1st Presentation day	0 dager	to 05.02.15	to 05.02.15
13		**2nd Presentation**	**11 dager**	**ma 09.03.15**	**to 26.03.15**
14		Create presentation	11 dager	ma 09.03.15	to 26.03.15
15	✓	2nd Presentation day	0 dager	to 26.03.15	to 26.03.15
16		**Final Presentation**	**8 dager**	**ma 18.05.15**	**on 27.05.15**
17		Create presentation	8 dager	ma 18.05.15	on 27.05.15
18		Final presentation day	0 dager	on 27.05.15	on 27.05.15
19					
20		**3XXX General documents**	**69 dager**	**ma 12.01.15**	**to 14.05.15**
21	✓	**Vision document**	**14 dager**	**to 15.01.15**	**fr 06.02.15**
22	✓	Create vision document	11 dager	to 15.01.15	ma 02.02.15
23	✓	Release revision 1	0 dager	ma 02.02.15	ma 02.02.15
24	✓	Update vision document	3 dager	on 04.02.15	fr 06.02.15
25		**Requierment specification**	**66 dager**	**to 15.01.15**	**on 13.05.15**
26	✓	Create requierment specification	11 dager	to 15.01.15	ma 02.02.15
27	✓	Release revision 1	0 dager	ma 02.02.15	ma 02.02.15
28		update requierment specification	55 dager	on 04.02.15	on 13.05.15
29		**Test specification**	**67 dager**	**on 14.01.15**	**on 13.05.15**
30	✓	Create test specification	12 dager	on 14.01.15	ma 02.02.15
31	✓	Release revision 1	0 dager	ma 02.02.15	ma 02.02.15
32		update test specification	55 dager	on 04.02.15	on 13.05.15
33		**Project plan doccument**	**53 dager**	**to 15.01.15**	**fr 24.04.15**
34	✓	Creat project plan docume	11 dager	to 15.01.15	ma 02.02.15
35	✓	Release revision 1	0 dager	ma 02.02.15	ma 02.02.15
36		Update project plan document	42 dager	on 04.02.15	fr 24.04.15
37	✓	**Project risk analysis documer**	**40 dager**	**ma 12.01.15**	**fr 20.03.15**



Prosjekt: Deep Water Riser Pipe
Dato: to 14.05.15

Aktivitet	Inaktiv aktivitet	Manuell sammendragsfremheving	Ekstern milepæl
Deling	Inaktiv milepæl	Manuelt sammendrag	Tidsfrist
Milepæl	Inaktivt sammendrag	Bare start	Fremdrift
Sammendrag	Manuell aktivitet	Bare slutt	Manuell fremdrift
Prosjektsammendrag	Bare varighet	Eksterne aktiviteter	

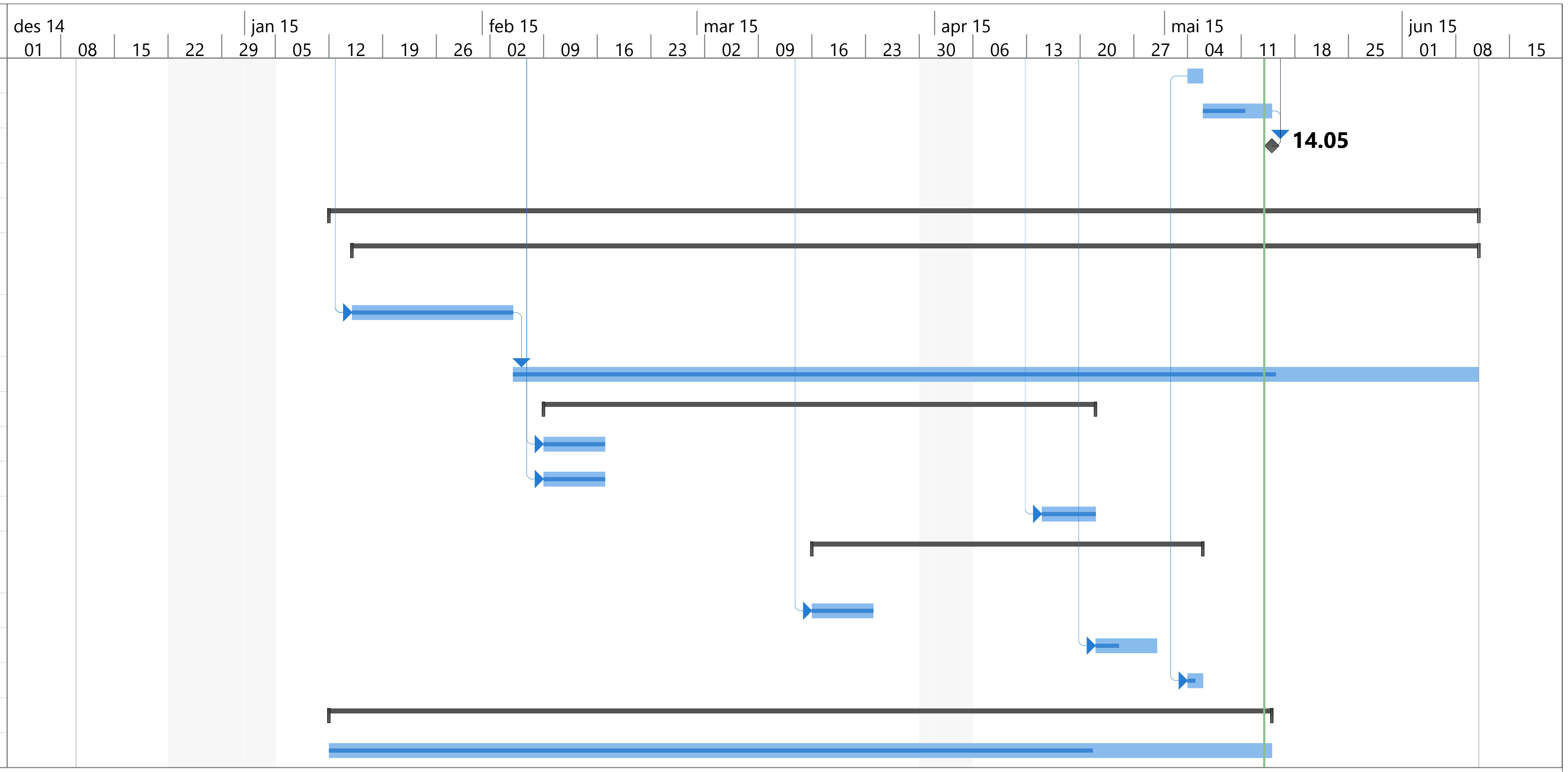
ID		Aktivitetsr	Aktivitetsnavn	Varighet	Start	Slutt
38	✓		Create project risk analysis document	20 dager	ma 12.01.15	fr 13.02.15
39	✓		Release revision 1	0 dager	fr 13.02.15	fr 13.02.15
40	✓		Update project risk analysis document	20 dager	ma 16.02.15	fr 20.03.15
41			**Final project report**	**19 dager**	**ma 20.04.15**	**to 14.05.15**
42			Reporting	19 dager	ma 20.04.15	to 14.05.15
43			Final report	0 dager	to 14.05.15	to 14.05.15
44			**Post project evaluation repo**	**9 dager**	**ma 04.05.15**	**to 14.05.15**
45			Reporting	9 dager	ma 04.05.15	to 14.05.15
46			Final report	0 dager	to 14.05.15	to 14.05.15
47						
48	✓		**4XXX Phase 1**	**44 dager**	**on 07.01.15**	**ma 23.03.15**
49	✓		General reaserch	21 dager	on 07.01.15	on 11.02.15
50	✓		Design basis document	5 dager	ma 09.02.15	ma 16.02.15
51	✓		Data collection	17 dager	ma 09.02.15	ma 09.03.15
52	✓		Test and verification	5 dager	ma 16.03.15	ma 23.03.15
53	✓		Reporting	25 dager	ma 09.02.15	ma 23.03.15
54	✓		Final report	0 dager	ma 23.03.15	ma 23.03.15
55						
56			**5XXX Phase 2**	**69 dager**	**ma 12.01.15**	**to 14.05.15**
57	✓		Training	15 dager	ma 12.01.15	to 05.02.15
58	✓		Design basis document	5 dager	ma 09.02.15	ma 16.02.15
59	✓		Methods and equations	23 dager	fr 06.02.15	on 18.03.15
60	✓		Methods and equations completed	0 dager	on 18.03.15	on 18.03.15
61			Create engineering tool	16 dager	on 18.03.15	on 22.04.15
62			Test engineerimg tool	6 dager	on 22.04.15	on 29.04.15
63			Refine engineering tool	8 dager	on 29.04.15	fr 08.05.15
64			Create user documentation	15 dager	ma 13.04.15	fr 01.05.15
65			Reporting	53 dager	ma 09.02.15	to 14.05.15
66			Final report	0 dager	to 14.05.15	to 14.05.15
67						
68			**6XXX Phase 3**	**27 dager**	**to 26.03.15**	**to 14.05.15**
69	✓		Training	6 dager	to 26.03.15	on 15.04.15
70	✓		Design basis document	5 dager	on 15.04.15	ti 21.04.15
71			Preliminary calculation and evaluation	8 dager	on 15.04.15	fr 24.04.15
72			Material selection or Optimizing design and calculation	5 dager	ma 27.04.15	fr 01.05.15



Prosjekt: Deep Water Riser Pipe
Dato: to 14.05.15

Aktivitet	Inaktiv aktivitet	Manuell sammendragsfremheving	Ekstern milepæl
Deling	Inaktiv milepæl	Manuelt sammendrag	Tidsfrist
Milepæl	Inaktivt sammendrag	Bare start	Fremdrift
Sammendrag	Manuell aktivitet	Bare slutt	Manuell fremdrift
Prosjektsammendrag	Bare varighet	Eksterne aktiviteter	

ID		Aktivitetsr	Aktivitetsnavn	Varighet	Start	Slutt
73	[calendar]		Test concept	2 dager	ma 04.05.15	ti 05.05.15
74	[calendar]		Reporting	7 dager	on 06.05.15	to 14.05.15
75			Final report	0 dager	to 14.05.15	to 14.05.15
76						
77			**Iterations**	**88 dager**	**ma 12.01.15**	**on 10.06.15**
78			**Evaluation of each project stage iteration**	**86 dager**	**to 15.01.15**	**on 10.06.15**
79	✓		Requirement and test specification---> Project	12 dager	to 15.01.15	on 04.02.15
80	[calendar]		Project phase 1-3	74 dager	to 05.02.15	on 10.06.15
81	✓		**Design basis iteration**	**36 dager**	**ma 09.02.15**	**ti 21.04.15**
82	✓		4XXX Phase 1	5 dager	ma 09.02.15	ma 16.02.15
83	✓		5XXX Phase 2	5 dager	ma 09.02.15	ma 16.02.15
84	✓		6XXX Phase 3	5 dager	on 15.04.15	ti 21.04.15
85			**Phase test and verification iteration**	**26 dager**	**ma 16.03.15**	**ti 05.05.15**
86	✓		4XXX Phase 1	5 dager	ma 16.03.15	ma 23.03.15
87			5XXX Phase 2	6 dager	on 22.04.15	on 29.04.15
88			6XXX Phase 3	2 dager	ma 04.05.15	ti 05.05.15
89			**Time planning iterations**	**69 dager**	**ma 12.01.15**	**to 14.05.15**
90	[calendar]		Weekly 3-20	69 dager	ma 12.01.15	to 14.05.15



Prosjekt: Deep Water Riser Pipe
Dato: to 14.05.15

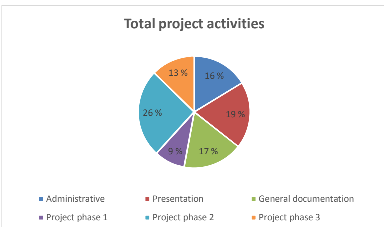
Aktivitet		Inaktiv aktivitet		Manuell sammendragsfremheving		Ekstern milepæl	
Deling		Inaktiv milepæl		Manuelt sammendrag		Tidsfrist	
Milepæl		Inaktivt sammendrag		Bare start		Fremdrift	
Sammendrag		Manuell aktivitet		Bare slutt		Manuell fremdrift	
Prosjektsammendrag		Bare varighet		Eksterne aktiviteter			

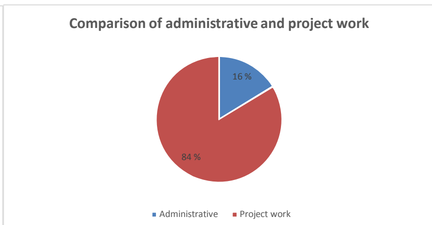
Appendix 2 project resource plan revision 4.0

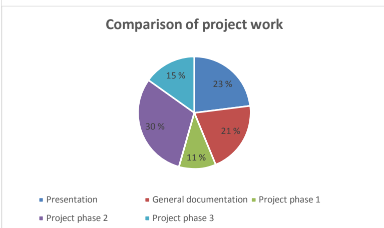
Project resource plan revision 4

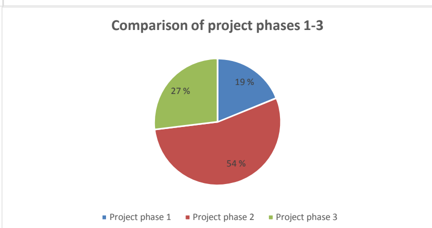
WBS	Description	Estimate	Actu	Re-estim	Actual w	Re-estimation week 15	Actual wee	Start d	End d	Re-Planed Start	Re-Plan End dat	Re-Planed Start	Re-Plan End date week 15
1XXX	**Administrative**												
1000	Weekly meeting	206	64	110	76	96	96	#####	####	07.01.2015	29.05.2015	07.01.2015	29.05.2015
1100	Other meetings	93,5	40	61	44	50	50	#####	####	07.01.2015	29.05.2015	07.01.2015	29.05.2015
1200	Admin Tasks (Project tools, Time sheet, Project plan, MOM etc.)	170	125	236	149	174	174	#####	####	07.01.2015	29.05.2015	07.01.2015	29.05.2015
					0	0	0						
1300	General research	13	14	14	14	14	14	#####	####	07.01.2015	29.05.2015	07.01.2015	29.05.2015
1400	HBV Friday lecture with Olaf	40	40	40	40	40	40	#####	####	07.01.2015	23.01.2015	07.01.2015	23.01.2015
TOTAL		**522,5**	**282**	**459,5**		**372**	**372**						
2XXX	**Presentation**												
2000	1st Presentation	75	125	125	125	125	125	#####	####	21.01.2015	05.02.2015	21.01.2015	05.02.2015
2100	2nd Presentation	75	0	100	117	117	117	#####	####	09.03.2015	25.03.2015	09.03.2015	26.03.2015
2200	Final presentation	200	0	200	0	200	200	#####	####	18.05.2015	01.06.2015	18.05.2015	27.05.2015
TOTAL		**350**	**125**	**425**		**442**	**442**						
3XXX	**General documentation**												
3000	Project vision document	30	19	25	19	19	19	#####	####	15.01.2015	15.04.2015	15.01.2015	06.02.2015
3100	Requirement specification	70	57	70	57	57	57	#####	####	15.01.2015	06.05.2015	15.01.2015	06.02.2015
3200	Test specification	80	63	80	66	80	80	#####	####	14.01.2015	13.05.2015	14.01.2015	13.05.2015
3300	Project plan document	50	43	50	43	50	50	#####	####	15.01.2015	11.03.2015	15.01.2015	24.04.2015
3400	Project risk analysis document	30	19	30	21	21	21	#####	####	12.01.2015	11.03.2015	12.01.2015	20.03.2015
3500	Final project report	100	0	100	0	100	100	#####	####	20.04.2015	14.05.2015	20.04.2015	14.05.2015
3600	Post project evaluation	70	0	70	0	70	70	#####	####	04.05.2015	14.05.2014	04.05.2015	14.05.2014
TOTAL		**430**	**201**	**424**		**396**	**396**						
4XXX	**Project phase 1**												
4000	Research phase 1	18	21	21	21	21	21	#####	####	07.01.2015	11.02.2015	07.01.2015	11.02.2015
4100	Data collection	50	40	50	50	50	50	#####	####	09.02.2015	06.03.2015	09.02.2015	09.03.2015
4200	Reporting	50	60	70	132	132	132	#####	####	09.02.2015	13.03.2015	09.02.2015	23.03.2015
TOTAL		**118**	**121**	**140,5**		**203**	**203**						
5XXX	**Project phase 2**												
5000	Training	20	10	10	10	10	10	#####	####	12.01.2015	05.02.2015	12.01.2015	05.02.2015
5100	Methods and equation	230	226	260	282	282	282	#####	####	06.02.2015	18.03.2015	06.02.2015	18.03.2015
5200	Create engineering tool	90	0	70	7	62	62	#####	####	13.03.2015	20.04.2015	18.03.2015	22.04.2015
5300	Test engineering tool	45	0	45	0	45	45	#####	####	20.04.2015	27.04.2015	22.04.2015	29.04.2015
5400	Refine engineering tool	45	0	45	0	45	45	#####	####	28.04.2015	05.05.2015	29.04.2015	08.05.2015
5500	User documentation	91	0	90	0	40	40	#####	####	13.03.2015	01.05.2015	13.04.2015	01.05.2015
5600	Reporting	76	6	76	23	100	100	#####	####	09.02.2015	14.05.2015	09.02.2015	14.05.2015
TOTAL		**597**	**241**	**596**		**584**	**584**						
6XXX	**Project phase 3**												
6000	Training	30	0	30	3	29	29	#####	####	13.03.2015	27.03.2015	26.03.2015	15.04.2015
6100	Preliminary calculation and evaluation	125	0	125	0	50	50	#####	####	25.03.2015	15.04.2015	15.04.2015	24.04.2015
6200	Material selection or Optimizing design and calculation	106	0	106	0	130	130	#####	####	16.04.2015	24.04.2015	27.04.2015	01.05.2015
6300	Test concept	30	0	30	0	30	30	#####	####	29.04.2015	05.05.2015	04.05.2015	05.05.2015
6400	Reporting	50	0	50	0	50	50	#####	####	29.04.2015	14.05.2015	06.05.2015	14.05.2015
TOTAL		**341**	**0**	**341**		**289**	**289**						
TOTAL	**Administrative**	**522,5**	**282**	**459,5**		**372**	**372**						
TOTAL	**Project work**	**1836**	**687**	**1926,5**		**1913**	**1913**						
Grand Total		**2359**	**969**	**2386**		**2285**	**2285**						

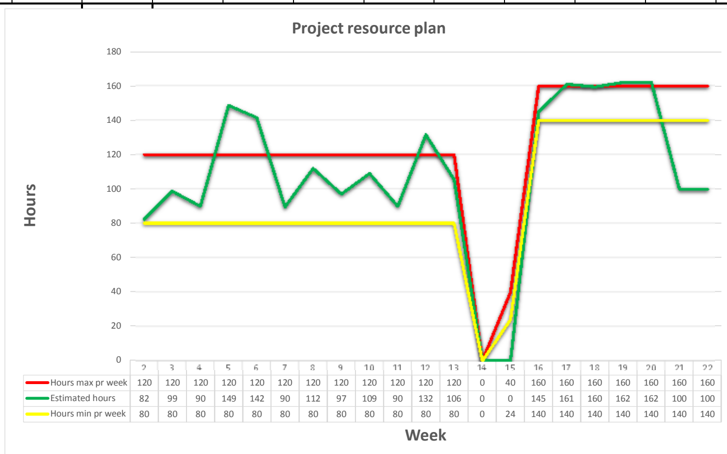
Hours per prs max	30	30	30	30	30	30	30	30	30	30	30	30		10	40	40	40	40	40	40	40	Total	Deviation
Hours per prs min	20	20	20	20	20	20	20	20	20	20	20	20		6	35	35	35	35	35	35	35		
Hours per prs avg	25	25	25	25	25	25	25	25	25	25	25	25	0	8	37,5	37,5	37,5	37,5	37,5	37,5	37,5	570	
Hours max pr week	120	120	120	120	120	120	120	120	120	120	120	120	0	40	160	160	160	160	160	160	160		
Hours min pr week	80	80	80	80	80	80	80	80	80	80	80	80	0	24	140	140	140	140	140	140	140		
Hours avg	100	100	100	100	100	100	100	100	100	100	100	100	0	30	150	150	150	150	150	150	150	2280	
Week	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**		
	18	18	6	2	6	4	4	4	2	4	6	2	0	0	4	4	4	4	4	0	0	96	-14
	11	11	4	4	0	1	0	6	3	0	4	0	0	0	0	2	0	2	2	0	0	50	-11
	25	25	20	7	2	7	18	22	1	4	5	15	0	0	5	5	5	5	5	0	0	174	-63
													0										0
	7	7	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	0
	16	12	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40	0
Administrative	**76**	**72**	**42**	**13**	**8**	**11**	**22**	**32**	**6**	**8**	**15**	**17**	**0**	**0**	**9**	**11**	**9**	**11**	**11**	**0**	**0**	**372**	**-88**
																							0
	0	0	3	25	98	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	125	0
	0	0	0	0	0	0	0	0	0	4	34	79	0	0	0	0	0	0	0	0	0	117	17
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	100	200	0
Presentation	**0**	**0**	**3**	**25**	**98**	**0**	**0**	**0**	**0**	**4**	**34**	**79**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**100**	**100**	**442**	**17**
																							0
	0	4	6	9	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19	-6
	0	5	14	36	2	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	57	-13
	0	7	14	43	0	0	0	0	1	0	3	0	0	0	3	4	3	2	2	0	0	80	1
	0	3	12	23	3	0	0	0	2	0	0	0	0	0	6	1	0	0	0	0	0	50	0
	0	1	1	0	0	6	11	1	0	0	2	0	0	0	0	0	0	0	0	0	0	21	-10
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	35	40	20	0	0	100	0
																		0	70			70	0
General documentati	**0**	**20**	**46**	**111**	**5**	**6**	**11**	**1**	**3**	**0**	**5**	**0**	**0**	**0**	**9**	**10**	**38**	**42**	**92**	**0**	**0**	**396**	**-28**
																							0
	6	7	0	0	6	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21	0
	0	0	0	0	0	4	25	10	2	11	0	0	0	0	0	0	0	0	0	0	0	50	1
	0	0	0	0	0	7	13	10	31	28	44	1	0	0	0	0	0	0	0	0	0	132	62
Project phase 1	**6**	**7**	**0**	**0**	**6**	**13**	**37**	**19**	**33**	**39**	**44**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**203**	**63**
																							0
	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0
	0	0	0	0	15	59	39	46	68	24	33	0	0	0	0	0	0	0	0	0	0	282	22
	0	0	0	0	0	0	0	0	0	0	2	5	0	0	35	20	0	0	0	0	0	62	-8
	0	0	0	0	0	0	0	0	0	0	0	0	0	0		27	18	0	0	0	0	45	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23	22	0	0	0	45	-1
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26	13	1	0	0	0	0	40	-50
	0	0	0	0	0	2	4	0	0	17	0	1	0	0	0	0	11	32	34	0	0	100	24
Project phase 2	**0**	**0**	**0**	**0**	**25**	**61**	**43**	**46**	**68**	**41**	**35**	**6**	**0**	**0**	**61**	**60**	**53**	**54**	**34**	**0**	**0**	**584**	**-13**
																							0
	0	0	0	0	0	0	0	0	0	0	0	3	0	0	26	0	0	0	0	0	0	29	-1
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40	10	0	0	0	0	0	50	-75
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	60	0	0	0	0	130	24
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	30	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25	25	0	0	50	0
Project phase 3	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**3**	**0**	**0**	**66**	**80**	**60**	**55**	**25**	**0**	**0**	**289**	**-52**
Estimated hours	**82**	**99**	**90**	**149**	**142**	**90**	**112**	**97**	**109**	**90**	**132**	**106**	**0**	**0**	**145**	**161**	**160**	**162**	**162**	**100**	**100**	**2285**	**-101**
Deviation from avg	18	1	10	-49	-42	11	-12	3	-9	10	-32	-6	0	30	5	-11	-10	-12	-12	50	50	-5	
Administrative	76	72	42	13	8	11	22	32	6	8	15	17	0	0	9	11	9	11	11	0	0	372	
Project work	6	27	49	136	134	79	90	66	103	83	117	89	0	0	136	150	151	151	151	100	100	1913	

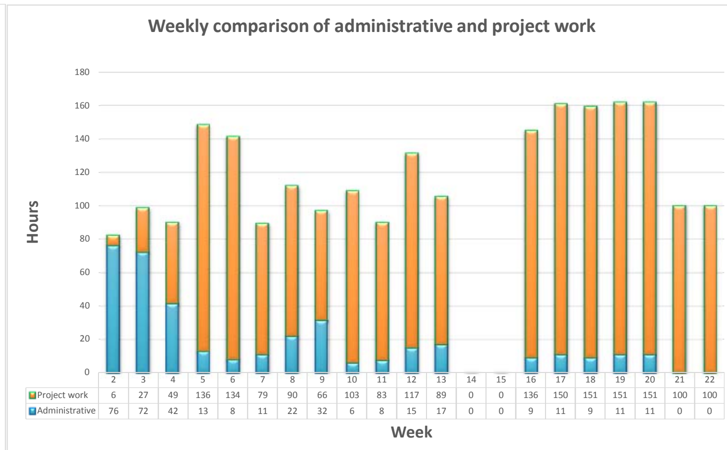












Apendix 3 contract revision 2.0

STANDARDAVTALE FOR STUDENTENES ARBEID MED BACHELOROPPGAVEN MED EKSTERNE OPPDRAGSGIVERE VED HØGSKOLEN I BUSKERUD OG VESTFOLD – FAKULTET FOR TEKNOLOGI OG MARITIME FAG – KONGSBERG INSTIUTT FOR INGENIØRFAG.

Høgskolen i Buskerud og Vestfold
Fakultet for Teknologi og Maritime fag
Kongsberg Institutt for Ingeniørfag

1. BAKGRUNN

Formålet med denne kontrakten er å formalisere forholdet mellom ekstern oppdragsgiver, Høgskolen i Buskerud og Vestfold og studentene i arbeidet med hovedprosjektet for avgangstudentene ved Avdeling for Teknologi og Maritime fag – Kongsberg Institutt for Ingeniørfag ved Høgskolen i Buskerud og Vestfold.

Denne avtale definerer plikter og rettigheter for partene i forbindelse med dette arbeidet.

Oppdragsgiver er kjent med og aksepterer fullt ut at dette arbeidet er utført som et ledd i en høgskoleingeniørutdanning og at Høgskolen i Buskerud og Vestfold ikke kan garantere for arbeidets kvalitet eller påta seg noe økonomisk eller juridisk ansvar for det produktet som arbeidet fører til, eller bruken av produktet i noen sammenheng. Høgskolen kan heller ikke påta seg vedlikeholdsansvar for det produktet som utvikles i forbindelse med hovedprosjektet.

Studentene har ikke anledning til å motta lønn for arbeidet som utføres.

2. PARTER

Avtalen har tre parter:

- Avgangsstudentene i prosjektgruppen, nedenfor kallt Studentene.

- Ekstern oppdragsgiver, Firma FMC Kongsberg Subsea AS
  nedenfor kalt oppdragsgiver.

- Høgskolen i Buskerud og Vestfold, nedenfor kalt Høgskolen.

3. OPPDRAGSGIVERS PLIKTER

Oppdragsgiver skal oppnevne en av sine ansatte som ekstern veileder for studentene. Det forutsettes at veilederen gir studentene den nødvendige hjelp med å definere oppgaven samt skaffe nødvendig underlag for arbeidet og at veilederen har myndighet til å opptre som ansvarlig representant for oppdragsgiver i spørsmål som omfattes av denne kontrakten.

Under arbeidet er det viktig at studentene får god anledning til regelmessige samtaler med veilederen i prosjektperioden.

Videre kreves det at oppdragsgiver stiller kvalifisert ekstern sensor(mastergrad / siv.ing eller tilsvarende innen fagområdet) til rådighet for prosjektet. Ekstern sensor skal medvirke ved vurdering av prosjektarbeidet, og må være tilstede på de tre presentasjonene. Ekstern sensor kan være den samme som veilederen.

Den eksterne veilederen skal godkjenne alle studentenes rapporter.

4. OPPDRAGSGIVERS RETTIGHETER

Oppdragsgiver har fulle rettigheter til å benytte resultatet av hovedprosjektet med mindre noe annet er angitt i vedlegget til denne kontrakten.

Ved bruk og eventuell publisering av resultatene av oppgaven skal det henvises til at arbeidet er et studentarbeid ved Høgskolen i Buskerud og Vestfold, Fakultet for Teknologi og Maritimefag samt studentenes og veiledernes navn.

5. HØGSKOLENS PLIKTER

Ved starten av avgangsåret skal studentene deles opp i prosjektgrupper på 4-6 personer som sammen skal gjennomføre en større oppgave, et hovedprosjekt. Omfanget er 20 studiepoeng. Dette tilsvarer ca. 600 timers arbeid pr. student.

Det er ønskelig at studentene innhentet en egnet prosjektoppgave fra oppdragsgiver og står for hoveddelen av kommunikasjonen med oppdragsgiver. Studentene skal i starten på prosjektet produsere en kravspesifikasjon og en prosjektplan i forbindelse med den foreslåtte prosjektoppgaven og rapportere disse skriftlig.

Hovedprosjektet skal evalueres med vanlige karakterer. Evalueringen vil bli gjort på grunnlag av det utførte arbeidet og av en rekke dokumenter og muntlige fremføringer/utspørringer samt regelmessige møter. Karakterene settes på individuelt grunnlag av intern veileder, intern sensor og ekstern sensor.

Høgskolen stiller intern veileder og intern sensor til rådighet i forbindelse med dette arbeidet.

6. UTGIFTER

Det vil påløpe en del utgifter i forbindelse med arbeidet. Disse dekkes på følgende måte:

Lønn	Studentene skal ikke motta lønn for arbeidet med hovedoppgaven. Den eksterne veilederens og sensors lønn og utgifter dekkes fullt ut av oppdragsgiver. Den interne veilederens og sensors lønn og utgifter dekkes fullt ut av høgskolen.
Innkjøp av utstyr	Innkjøp av utstyr og bøker skal ordnes via oppdragsgiver. Innkjøp utstyr og bøker er oppdragsgiver sin eiendom etter prosjektperioden.
Andre utgifter inkludert reiser	Oppdragsgiver dekker studentenes direkte utgifter. Alle utgifter skal avtales og godkjennes på forhånd av oppdragsgiver.

7. UTSTYR OG KOMPONENTER

Høgskolen stiller sitt utstyr vederlagsfritt til disposisjon for studentene i den grad utstyret er egnet og tilgjengelig.

Utstyr som lånes ut fra oppdragsgiver skal fortrinnsvis monteres i høgskolens lokaler. Utstyret skal holdes forsikret av oppdragsgiver. Utgifter til vedlikehold av utstyret dekkes av oppdragsgiver.

Komponenter til utstyr som konstrueres og bygges under arbeidet med hovedprosjektet betales av oppdragsgiver.

Utlånt utstyr og innkjøpte komponenter skal dokumenteres i eget vedlegg.

8. ENDRINGER

Alle endringer på denne standardavtalen skal dokumenteres i eget vedlegg.

9. OPPHAVSRETT

Studenten forbeholdes rettigheter etter Lov om arbeidstakeroppfinnelser, Lov om åndsverk og annen lovgivning der hvor dette er aktuelt. Høgskolen i Buskerud beholder imidlertid alle rettigheter til bruk av eventuelle resultater, rådata og lignende til forsking, undervisning og annet som faller inn under HiBus primæroppgave, så fremt dette ikke åpenbart ville stride mot studentens rettigheter og interesser.

10. VEDLEGGSLISTE

1. FMC Standardavtale-2015
2. FMC konfidensialitetsavtale-2015
3. Internal Student Cooperation Contract

KONGSBERG, DATO 18/2-2015

For Oppdragsgiver ....

For Høgskolen ....

Studentene:

Daniel Snorbun(?) Øystein Olsen(?)

Line Dyre-Hansen Kjersti S. Anthonsen(?)
....

Vedlegg 1: 1 Standardavtale FMC

STANDARDAVTALE

om utføring av masteroppgave/prosjektoppgave (oppgave) i samarbeid med bedrift/ekstern virksomhet (bedrift).

Avtalen er ufravikelig for studentoppgaver ved HBV som utføres i samarbeid med bedrift. Partene har ansvar for å klarere eventuelle rettigheter som tredjeperson (som ikke er part i avtalen) kan ha før bruk i forbindelse med utførelse av oppgaven.

Avtale mellom

Student: David Snarheim	født: 181182
Student: Kjersti Schrøder Anthonsen	født: 290588
Student: Line Dyre-Hansen	født: 190292
Student: Øystein Ulmo	født: 080286

Veileder ved HBV: Kjell Enger

Bedrift/ekstern virksomhet: FMC Kongsberg Subsea AS

og

Høyskolen i Buskerud og Vestfold avd Kongsberg

om bruk og utnyttelse av resultater fra masteroppgave/prosjektoppgave.

1. Utførelse av oppgave

Studenten skal utføre

Masteroppgave	
Prosjektoppgave	x

(sett kryss)

i samarbeid med

FMC Kongsberg Subsea AS

bedrift/ekstern virksomhet

01/01/2015 til 05/06/2015

startdato – sluttdato

Oppgavens tittel er:

Deep Water Riser Pipe Study

Ansvarlig veileder ved HBV har det overordnede faglige ansvaret for utforming og godkjenning av prosjektbeskrivelse og studentens læring.

Studenten har opphavsrett til oppgaven. Der oppgaven bygger på eller videreutvikler materiale og/eller metoder som eies av bedriften, eies dette fortsatt av bedriften og eventuell kommersiell utnyttelse av videreutviklingen må avtales spesielt mellom student (med bistand fra HBV) og bedrift.

2. Bedriftens plikter

Bedriften skal stille med en kontaktperson som har nødvendig veiledningskompetanse og gi studenten tilstrekkelig veiledning i samarbeid med veileder ved HBV. Bedriftens kontaktperson er:

Sondre R. Askim og Anders Wormsen

Formålet med oppgaven er studentarbeid. Oppgaven utføres som ledd i studiet, og studenten skal ikke motta lønn eller lignende godtgjørelse fra bedriften. Bedriften skal dekke følgende utgifter knyttet til utførelse av oppgaven:

Utskrift materialer
Eventuelt andre utgifter skal godkjennes av FMC Kongsberg Subsea

3. HBVs rettigheter

De innleverte eksemplarer/filer av oppgaven med vedlegg, som er nødvendig for sensur og arkivering ved HBV, tilhører HBV. HBV får en vederlagsfri bruksrett til oppgaven med vedlegg til denne og kan benytte denne til undervisnings- og forskningsformål med de eventuelle begrensninger som fremgår i punkt 5.

4. Publisering

Studenten har rett til å inngå avtale med HBV om publisering av sin oppgave i HBV's institusjonelle arkiv på internett. Studenten har også rett til å publisere oppgaven eller deler av den i andre sammenhenger dersom det ikke i denne avtalen er avtalt begrensninger i adgangen til å publisere, jf punkt 5.

5. Utsatt offentliggjøring

Hovedregelen er at studentoppgaver skal være offentlige. I særlige tilfeller kan partene bli enig om at hele eller deler av oppgaven skal være undergitt utsatt offentliggjøring i maksimalt 3 år, dvs. ikke tilgjengelig for andre enn student og bedrift i denne perioden.

Oppgaven skal være undergitt utsatt offentliggjøring i

ett år	
to år	
tre år	x

(sett kryss bak antall år hvis dette punktet er aktuelt)

Behovet for utsatt offentliggjøring er begrunnet ut fra følgende:

Arbeidet er tett knyttet opp mot bedriftenes virksomhet. Studentene vil få tilgang til informasjon av konfidensiell art. Studentene vil arbeide med nye løsninger som kan ha stor verdi for bedriften.

De delene av oppgaven som ikke er undergitt utsatt offentliggjøring, kan publiseres i HBV's institusjonelle arkiv.

Selv om oppgaven er undergitt utsatt offentliggjøring, skal bedriften legge til rette for at studenten kan benytte hele eller deler av oppgaven i forbindelse med jobbsøknader samt videreføring i et doktorgradsarbeid.

6. Bedriftens rettigheter til bruk av oppgaven

Bedriften skal ha en eksklusiv bruksrett til resultatene av oppgaven. Dette begrenser ikke HBV's adgang til å bruke oppgaven til undervisnings- og forskningsformål forutsatt at oppgaven ikke er undergitt utsatt offentliggjøring etter punkt 5.

Dersom det viser seg at resultatet av oppgaven kan være patenterbart, føre til designbeskyttelse, registrering av varemerke eller at resultatene kan kommersialiseres, skal det inngås egen avtale mellom partene som skal sikre studenten rimelig godtgjøring.

7. Generelt

Denne avtalen skal ha gyldighet foran andre avtaler som er eller blir opprettet mellom to av partene som er nevnt ovenfor. Dersom student og bedrift skal inngå avtale om konfidensialitet om det som studenten får kjennskap til i bedriften, skal HBV's standardmal for konfidensialitetsavtale benyttes. Eventuell avtale om dette skal vedlegges denne avtalen.

Eventuell uenighet som følge av denne avtalen skal søkes løst ved forhandlinger. Hvis dette ikke fører frem, er partene enige om at tvisten avgjøres ved voldgift i henhold til norsk lov. Tvisten avgjøres av sorenskriveren ved Sør-Trøndelag tingrett eller den han/hun oppnevner.

Denne avtale er underskrevet i 4 - fire - eksemplarer hvor partene skal ha hvert sitt eksemplar. Avtalen er gyldig når den er godkjent og underskrevet av HBV v/instituttleder.

18/2-2015 Kongsberg	Daniel Snolucas
18.02.2015 Kongsberg	Line Dyre-Hansen
18.02.2015 Kongsberg	Øystein Ulne
18.02.2015 Kongsberg	Kjersti Schroeder Anthonsen
sted, dato	student

Kongsberg 19/2-15	Kjell Enge	
sted, dato	veileder ved HBV	

19/2-15	Olaf [signature]	HIFI
sted, dato	instituttleder, HBV	institutt

KONGSBERG 19.02.2015	[signature]
sted, dato	for bedriften/institusjonen stempel og signatur

Vedlegg 2: 1 FMC konfidensialitetsavtale-2015

AVTALE
mellom

Student ved HBV: Kjersti Schrøder Anthonsen	født: 290588

Bedrift/ekstern virksomhet: FMC Kongsberg Subsea AS

om konfidensialitet.

1. Studenten skal utføre oppgave i samarbeid med bedrift/ekstern virksomhet som ledd i sitt studium ved HBV.

2. Studenten forplikter seg til å bevare taushet om det han/hun får vite om tekniske innretninger og fremgangsmåter samt drifts- og forretningsforhold som det vil være av konkurransemessig betydning å hemmeligholde for bedriften/den eksterne virksomheten. Det er bedriftens ansvar å sørge for å synliggjøre og tydeliggjøre hvilken informasjon dette omfatter.

3. Studenten er forpliktet til å bevare taushet om dette i 3 år regnet fra sluttdato, jf. standardavtale om utføring av oppgave i samarbeid med bedrift/ekstern virksomhet punkt 1.

4. Kravet om konfidensialitet gjelder ikke informasjon som:
a) var allment tilgjengelig da den ble mottatt
b) ble mottatt lovlig fra tredjeperson uten avtale om taushetsplikt
c) ble utviklet av studenten uavhengig av mottatt informasjon
d) partene er forpliktet til å gi opplysninger om i samsvar med lov eller forskrift eller etter pålegg fra offentlig myndighet

18.02.2015 .... Kjersti Schrøder Anthonsen ....
sted, dato — student

Kongsberg 19.02.2015 .... [signature] ....
sted, dato — for bedrift/ekstern virksomhet
stempel og signatur

Vedlegg 2: 1 FMC konfidensialitetsavtale-2015

AVTALE
mellom

Student ved HBV: David Snarheim	født: 181182

Bedrift/ekstern virksomhet: FMC Kongsberg Subsea AS

om konfidensialitet.

1. Studenten skal utføre oppgave i samarbeid med bedrift/ekstern virksomhet som ledd i sitt studium ved HBV.

2. Studenten forplikter seg til å bevare taushet om det han/hun får vite om tekniske innretninger og fremgangsmåter samt drifts- og forretningsforhold som det vil være av konkurransemessig betydning å hemmeligholde for bedriften/den eksterne virksomheten. Det er bedriftens ansvar å sørge for å synliggjøre og tydeliggjøre hvilken informasjon dette omfatter.

3. Studenten er forpliktet til å bevare taushet om dette i 3 år regnet fra sluttdato, jf. standardavtale om utføring av oppgave i samarbeid med bedrift/ekstern virksomhet punkt 1.

4. Kravet om konfidensialitet gjelder ikke informasjon som:

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c) ble utviklet av studenten uavhengig av mottatt informasjon
d) partene er forpliktet til å gi opplysninger om i samsvar med lov eller forskrift eller etter pålegg fra offentlig myndighet

18/2-2015 Kongsberg David Snarheim
....
sted, dato student

19/2-2015 KONGSBERG
....
sted, dato for bedrift/ekstern virksomhet
stempel og signatur

Vedlegg 2: 1 FMC konfidensialitetsavtale-2015

AVTALE
mellom

Student ved HBV: Line Dyre-Hansen	født: 190292

Bedrift/ekstern virksomhet: FMC Kongsberg Subsea AS

om konfidensialitet.

1. Studenten skal utføre oppgave i samarbeid med bedrift/ekstern virksomhet som ledd i sitt studium ved HBV.

2. Studenten forplikter seg til å bevare taushet om det han/hun får vite om tekniske innretninger og fremgangsmåter samt drifts- og forretningsforhold som det vil være av konkurransemessig betydning å hemmeligholde for bedriften/den eksterne virksomheten. Det er bedriftens ansvar å sørge for å synliggjøre og tydeliggjøre hvilken informasjon dette omfatter.

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4. Kravet om konfidensialitet gjelder ikke informasjon som:
a) var allment tilgjengelig da den ble mottatt
b) ble mottatt lovlig fra tredjeperson uten avtale om taushetsplikt
c) ble utviklet av studenten uavhengig av mottatt informasjon
d) partene er forpliktet til å gi opplysninger om i samsvar med lov eller forskrift eller etter pålegg fra offentlig myndighet

18.02. 2015 Kongsberg .... Line Dyre-Hansen ....
sted, dato — student

19-02-2015 KONGSBERG .... [signature] ....
sted, dato — for bedrift/ekstern virksomhet
stempel og signatur

Vedlegg 2: 1 FMC konfidensialitetsavtale-2015

AVTALE
mellom

Student ved HBV: Øystein Ulmo	født: 080286

Bedrift/ekstern virksomhet: FMC Kongsberg Subsea AS

om konfidensialitet.

1. Studenten skal utføre oppgave i samarbeid med bedrift/ekstern virksomhet som ledd i sitt studium ved HBV.

2. Studenten forplikter seg til å bevare taushet om det han/hun får vite om tekniske innretninger og fremgangsmåter samt drifts- og forretningsforhold som det vil være av konkurransemessig betydning å hemmeligholde for bedriften/den eksterne virksomheten. Det er bedriftens ansvar å sørge for å synliggjøre og tydeliggjøre hvilken informasjon dette omfatter.

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4. Kravet om konfidensialitet gjelder ikke informasjon som:
a) var allment tilgjengelig da den ble mottatt
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c) ble utviklet av studenten uavhengig av mottatt informasjon
d) partene er forpliktet til å gi opplysninger om i samsvar med lov eller forskrift eller etter pålegg fra offentlig myndighet

18.02.2015 Kongsberg .... Øystein Ulmo ....
sted, dato — student

19.02.2015 Kongsberg .... [signature] ....
sted, dato — for bedrift/ekstern virksomhet
stempel og signatur

Vedlegg 3: Internal Student cooperation contract

Cooperation Contract

We commit to follow this contract and the following guidelines

General

- Agree to the ground rules
- Treat the beliefs and opinions of the other group members with respect.
- Demonstrate excellent personal organizational skills and timekeeping.
- Communicate effectively with the rest of the group; this includes any problems with the allocated work or completion of tasks.

Meetings

- Attend all group meetings and study sessions.
  - If you can't attend, let everyone know as soon as possible
  - Failure to do so is a direct breach of contract
- Attend all group meetings on time
- Provide constructive feedback that avoids personal insults
- Attend all meetings with a positive frame of mind and the intention to contribute proactively to discussion.

Project work

- Complete all work by agreed deadlines
  - If you can't get your work finished on time, ask the other members for help, we all want to succeed whit the project
  - If you don't do the work you are suppose to do and this is an obstruction for the other team members work. That will be considered as a breach of contract.

- Contribute equally to project work and to the highest standard
- Use a variety of research sources
- Use formal academic style and references for written work and be aware of rules and regulations in relation to plagiarism

Breach of contract

- Raise any issues with regard to breach of contract during meetings and record in writing
- Agree that the disciplinary procedure following breach of contract is as follows:

  1st breach verbal warning

  2nd breach written warning, and an email to our supervisor

  3rd breach last warning and a meeting with our supervisor

- If the contract is breach one more time you will be excluded from the project and our supervisor will be notified

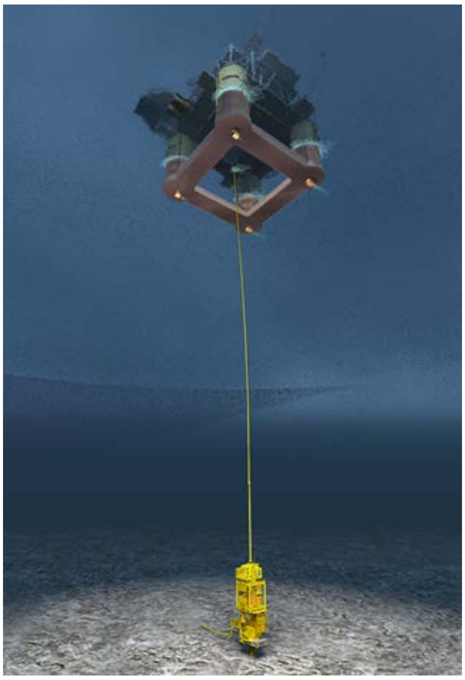
Declaration

I have read the contractual terms relating to the completion of this project and agree to be bound by its terms and conditions.

Role	Name	Signature	Date
Project Manager	David Snarheim	David Snarheim	18.02.2015
Technical Manager	Øystein Ulmo	Øystein Ulmo	18.02.2015
Documentation and Test	Line Dyre-Hansen	Line Dyre-Hansen	18.02.2015
Presentations and Visualization	Kjersti Schrøder Anthonsen	Kjersti S. Anthonsen	18.02.2015

Requirements Specification

Deep Water Riser Pipe Study



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Rev	Date	Prepared By	Reviewed By	Changes
3.0	14.05.2015	Øystein Ulmo	Line Dyre-Hansen	Requirement P2-ET-04 removed, P2-RR-04: changed

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List of Tables

Abbreviations

The following abbreviations are used throughout this document.

Abbreviation	Description
FMC	FMC Technologies Kongsberg Subsea
HBV	Høyskolen I Buskerud og Vestfold

1 Introduction

The purpose of this document is to define the requirements for the Deep Water Riser Study. The study consists of three phases and each of the phases have a separate set of requirements, all included in this document.

To ensure that the most critical requirements are met, the requirements are prioritized according to Table 1.

Table 1: Requirement priority

Priority	Description
A	The requirement has the highest priority
B	The requirement has medium priority and may be omitted if implementing the requirement leads to serious complications or major delays in the project plan.
C	The requirement will only be included if the overall project schedule allows it.

2 Requirement setup

The project consists of three phases and the requirements are grouped accordingly. Within each phase there are a set of general requirements, that defines the major components of the phase. In addition, there are sets of requirements that defines each component in detail.

2.1 Numbering

The requirements are numbered according to the following system:

- The first two digits defines which phase the requirement belongs to.
- Digits 3 and 4 defines witch subsection the requirement refers to
- The last two digits are the unique identification number for the requirement.

The letter/number codes used in the requirement numbers are described in Table 2

Table 2: Letter codes in requirement numbers

Code	Description
P1	Phase 1
P2	Phase 2
P3	Phase 3
GR	General Requirement
RR	Report Requirement
ET	Engineering Tool Requirement
01 – XX	Unique requirement Identification

3 Phase 1 requirements

3.1 Phase 1 general requirements

Table 3: Phase 1 general requirements

Requirement no	Requirement	reference	priority
P1-GR-01	A study identifying the future trends in the subsea market shall be performed	FMC	A
P1-GR-02	Trends for each subsea region shall be identified	FMC	A
P1-GR-03	The results from the study shall be presented in a report	FMC	A
P1-GR-04	A visual presentation in the form of a world map identifying the major oceans, subsea regions and operators	FMC	A

4 Phase 2 requirements

4.1 Phase 2 general requirements

Table 4: Phase 2 general requirements

Requirement no	Requirement	Reference	Priority
P2-GR-01	A new method for assessing applicability for different work-over riser types and dimensions, for use in tender processes shall be produced	FMC	A
P2-GR-02	All aspects that may affect the choice of work over-riser shall be assessed	FMC	A
P2-GR-03	The assessment method shall be described in detail in a report.	FMC	A
P2-GR-04	An engineering tool in the form of a Microsoft Excel workbook incorporating the method shall be created.	FMC	A
P2-GR-05	A user manual giving all intended users sufficient guidance in using the tool shall be produced	FMC	A

4.2 Phase 2 report requirements

Table 5: Phase 2 report requirement

Requirement no	Requirement	reference	priority
P2-RR-01	The report shall include a description of which variables are included in the calculations	FMC, P2-GR-03	A
P2-RR-02	The report shall include a description of which (if any) variables are excluded from the calculations and the reasons for excluding them	FMC, P2-GR-03	A
P2-RR-03	The effects of excluding parameters from the calculations shall be described	FMC, P2-GR-03	A
P2-RR-04	The report shall include a description of how the different variables are combined in equations.	FMC, P2-GR-03	A
P2-RR-05	The report shall describe the limitations in use of the method and associated tool. (only to be used for tender calculations, not for certification)	FMC, P2-GR-03	A
P2-RR-06	The report shall include directions and recommendations for further development of the method and associated tools	FMC, P2-GR-03	B

4.3 Phase 2 engineering tool requirements

The detailed requirements for the engineering tool will be defined in a separate document when all parameters have been identified and assessed. The requirements listed in Table 6 only give directions for general setup and limitations

Table 6: Phase 2 engineering tool requirements

Requirement no	Requirement	Reference	Priority
P2-ET-01	The engineering tool shall have an input interface, that allows the user to identify and enter all input data needed for the calculations	FMC, P2-GR-04	A
P2- ET-02	The tool shall make calculations based on input data and design standards to give outputs regarding choice of riser joints	FMC, P2-GR-04	A
P2- ET-03	The tool shall, based on applicable inputs, give limitations of water depth for the chosen riser dimension and material specifications	FMC, P2-GR-04	A
P2-ET-04	**Requirement removed**	FMC, P2-GR-04	A
P2-ET-05	The output in requirements P2-ET-03 and P2-ET-04 shall deviate no more than 3% from hand calculations	FMC, P2-GR-04	A
P2-ET-06	The tool shall present the output in req. P2-ET-03 as a visual presentation	FMC, P2-GR-04	A
P2-ET-07	All intended users provided with the tool and user manual shall be able to use the tool and get consistent and correct results	FMC, P2-GR-04	A
P2-ET-08	The tool shall be prepared for further development and incorporation of new capabilities	FMC, P2-GR-04	A

5 Phase 3 requirements

5.1 Phase 3 general requirements

Table 7: Phase 3 general requirements

Requirement no	Requirement	reference	priority
P3-GR-01	A specific case, where deep-water risers are required shall be defined in cooperation with FMC	FMC	A
P3-GR-02	One or more concept solutions for riser joint shall be developed	FMC	A
P3-GR-03	The concept or concepts shall if possible, be tested using the engineering tool created in phase 2 of the project	FMC	A
P3-GR-04	The project shall perform cost estimates for the concept/concepts	FMC	C
P3-GR-05	The project shall evaluate the concept/concepts and give recommendations on further development for one or more concepts	FMC	A
P3-GR-06	The findings from phase 3 shall be presented in a technology document	FMC	A

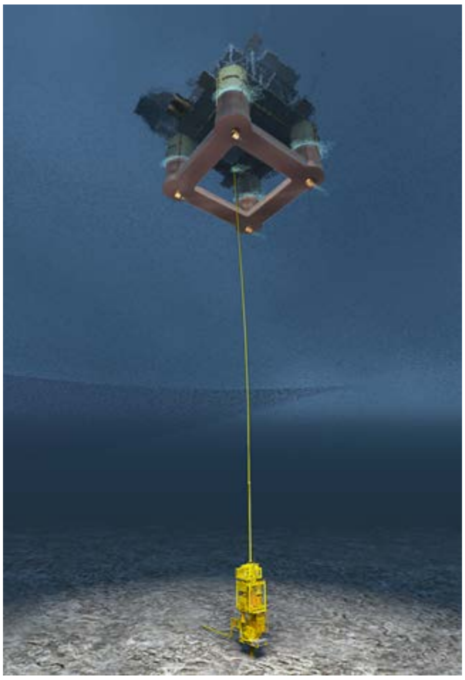
6 Document revision history

Table 8: Document revision history

Rev	Date	Prepared By	Reviewed By	Changes
3.0	14.05.2015	Øystein Ulmo	Line Dyre-Hansen	Requirement P2-ET-04 removed, P2-RR-04: changed
2.0	16.02.2015	Line Dyre-hansen	Øystein Ulmo	New document setup
1.0	29.01.2015	Øystein Ulmo	Line Dyre-Hansen	First revision

Test Specification

Deep Water Riser Pipe Study



FMC Technologies

HBV

Rev	Date	Prepared By	Reviewed By	Changes
3.0	14.05.2015	Line Dyre-Hansen	Øystein Ulmo	See section 5

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List of Tables

Abbreviations

The following abbreviations are used throughout this document.

Abbreviation	Description
ET	Engineering tool
FMC	FMC Technologies Kongsberg Subsea
GR	General requirement
ID	Identification
No	Number
P1	Phase 1
P2	Phase 2
P3	Phase 3
RR	Report requirement
T	Test
V	Verification

1 Introduction

This document contains a description for the various test and verification that shall be performed to ensure that requirements are met. The document also specifies the test and verification methods and lists, which test shall be conducted for each requirement.

2 Verification and test methods

This section defines the verification and test methods chosen for this project. The methods are divided into two main categories.

- Verification
- Testing

The details for the test methods are specified in section 2.1 and 2.2, and the chosen test method for each requirement are defined in section 3.

2.1 Verification methods

The verification method are divided into three sub categories, their definitions and acceptance criteria are as defined in Table 1.

Table 1: Verification categories

Verification code	**Description**	**Acceptance criteria**
V1	Internal verification of requirement	Correct content, quality and on time delivery
V2	External verification and approval from contracting authority	Correct content, quality and on time delivery
V3	User survey	Individual criteria to be specified for each survey created

The verification results shall be reported as shown in Table 2 and attached in final test report.

Table 2: Verification table

Verification ID		Date of verification	
Requirement ID			
Description			
Acceptance Criteria			
Verification code			
Result			
Conclusion			
Comments			
Verified by			

2.2 Test methods

The test method specified for testing of requirements follows the black box principals, and are defined to ensure that the acceptance criteria for each specified requirements are met.

The black box testing method defined is a test for examining the overall functionality of a product. The tester only knows the input and expected outputs from the product.

The test results shall be reported as shown in Table 3 and attached in final test report.

Table 3: Test report table

Test ID		Start date		Stop date	
Requirement ID					
Description					
Acceptance Criteria					
Procedure					
Result					
Conclusion					
Comments					
Tested by					

3 Verification and test plan

This section defines the test plan for the project and specifies which test or verification method shall be used for each requirement.

The test manager in cooperation with the project team and FMC shall manage the tests.

Test plan is divided into sections referring to each phase of the project.

Requirement that have the same verification method will follow the same verification or test procedure.

3.1 Verification and test plan phase 1

Table 4: Verification and test plan phase 1

Requirement number	Verification method	Verification ID / Test ID	Date (completion)
P1-GR-01	V1+V2	V-P1-01 + V-P1-02	13.03.2015
P1-GR-02	V1+V2	V-P1-01 + V-P1-02	13.03.2015
P1-GR-03	V1+V2	V-P1-01 + V-P1-02	13.03.2015
P1-GR-04	V1+V2	V-P1-01 + V-P1-02	13.03.2015

3.2 Verification and test plan phase 2

Table 5: Verification and test plan phase 2

Requirement number	Verification method	Verification ID / Test ID	Date (completion)
P2-GR-01	V1+V2	V-P2-01 + V-P2-04	08.05.2015
P2-GR-02	V1+V2	V-P2-01 + V-P2-04	08.05.2015
P2-GR-03	V1+V2	V-P2-03 + V-P2-06	08.05.2015
P2-GR-04	V1+V2+T	V-P2-02 + V-P2-05 + T-P2-01	08.05.2015
P2-GR-05	V1+V2+V3+T	V-P2-02 + V-P2-05 + V-P2-07 + T-P2-01	08.05.2015
P2-RR-01	V1 +V2	V-P2-03 + V-P2-06	08.05.2015
P2-RR-02	V1+V2	V-P2-03 + V-P2-06	08.05.2015
P2-RR-03	V1+V2	V-P2-03 + V-P2-06	08.05.2015
P2-RR-04	V1+V2	V-P2-03 + V-P2-06	08.05.2015
P2-RR-05	V1+V2	V-P2-03 + V-P2-06	08.05.2015
P2-RR-06	V1+V2	V-P2-03 + V-P2-06	08.05.2015
P2-ET-01	V1+V2+V3	V-P2-02 + V-P2-05 + V-P2-07	08.05.2015
P2-ET-02	V1+V2+V3+T	V-P2-02 + V-P2-05 + V-P2-07 + T-P2-01	08.05.2015
P2-ET-03	V1+V2+T	V-P2-02 + V-P2-05 + T-P2-01	08.05.2015
P2-ET-04	Requirement removed		
P2-ET-05	V1+V2+T	V-P2-02 + V-P2-05 + T-P2-01	08.05.2015
P2-ET-06	V1+V2+T	V-P2-02 + V-P2-05 + T-P2-01	08.05.2015
P2-ET-07	V1+V2+V3+T	V-P2-02 + V-P2-05 + V-P2-07 + T-P2-01	08.05.2015
P2-ET-08	V1+V2	V-P2-02 + V-P2-05	08.05.2015

3.3 Verification and test plan phase 3

Table 6: Verification and test plan phase 3

Requirement number	Verification method	Verification ID /Test ID	Date (completion)
P3-GR-01	V1+V2	V-P3-01 + V-P3-03	15.05.2015
P3-GR-02	V1+V2	V-P3-01 + V-P3-03	15.05.2015
P3-GR-03	V1+V2+T	V-P3-01 + V-P3-03 + T-P3-01	15.05.2015
P3-GR-04	V1+V2	V-P3-01, V-P3-02, V-P3-03, V-P3-04	15.05.2015
P3-GR-05	V1+V2	V-P3-01, V-P3-02, V-P3-03, V-P3-04	15.05.2015
P3-GR-06	V1+V2	V-P3-02 + V-P3-04	15.05.2015

4 Verification and test description and procedures

General description of verification and tests are listed in Table 7.

A document shall be created with detail description of procedure for verifications and tests.

Table 7: Verification and test description

Verification ID / Test ID	Description
V-P1-01	Internal verification of requirement in phase 1
V-P1-02	External verification and approval from contracting authority in phase 1
V-P2-01	Internal verification of methods created in phase 2
V-P2-02	Internal verification of engineering tool and user manual created in phase 2
V-P2-03	Internal verification of report created in phase 2
V-P2-04	External verification of methods created in phase 2
V-P2-05	External verification of engineering tool and user manual created in phase 2
V-P2-06	External verification of report created in phase 2
V-P2-07	User survey phase 2
V-P3-01	Internal verification of concept in phase 3
V-P3-02	Internal verification of report in phase 3
V-P3-03	External verification of concept in phase 3
V-P3-04	External verification of report in phase 3
T-P2-01	Functional testing of engineering tool and manual
T-P3-01	Testing of concept phase 3

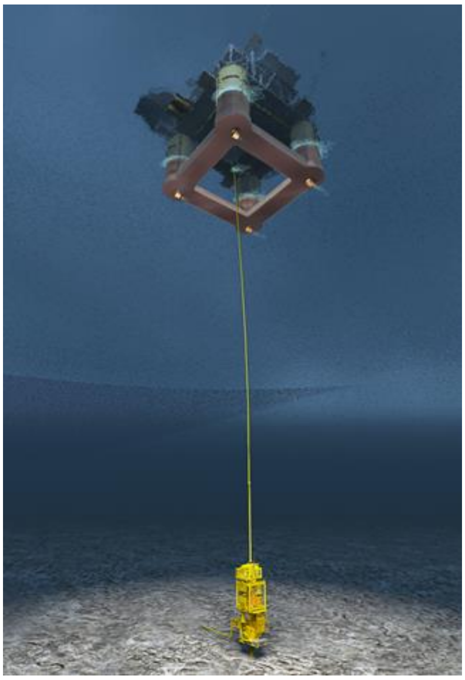
5 Document revision history

Table 8: Document revision history

Rev	Date	Prepared By	Reviewed By	Changes
1.0	31.01.2015	Line Dyre-Hansen	Øystein Ulmo	
2.0	22.03.2015	Line Dyre-Hansen	Øystein Ulmo	Added an extra row in the test and verification table. Updated dates for testing. New document setup. Spelling mistake.
3.0	14.05.2015	Line Dyre-Hansen	Øystein Ulmo	Requirement removed (P2-ET-04)

Risk Analysis

Deep Water Riser Pipe Study



FMC Technologies

HBV

Rev	Date	Prepared By	Reviewed By	Changes
2.0	12.05.2015	Kjersti Schrøder Anthonsen	David Snarheim	Spelling mistake

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Abbreviations

The following abbreviations are used throughout this document.

Abbreviation	Description
HBV	Høyskolen i Buskerud og Vestfold (Buskerud and Vestfold University College)
FMC	FMC Technologies

1 Introduction

This document describes the risks of the Deep Water Riser Pipe Study project. It includes all risks from the most likely to occur to the most unlikely.

Assessing the risks

- The risks has to be identified and listed
- They have to be ranked, to show how likely they are to occur and how severe the damage is if it occurs.
  - The probability is ranked from 1 to 5, were 1 is very low and 5 is very high.
  - The severity is ranked from 1 to 5, were 1 is very low and 5 is very high.
  - The probability and the severity are multiplied to assess the risk.

The risks will be ranked as low, medium or high, and will be displayed in Table 16. The reason for assessing the risks are to show how much effort that has to be used for preventing the risk. The higher the risk, the more effort should be used to prevent it. An example of the risk assessment is shown in Table 1: Example risk table

Table 1: Example risk table

Assessment	Probability: 3	Severity: 2	Assessed risk: 6
Risk	Risk explanation.		
Preventative measure	How to prevent or minimize the risk.		
Action if occurred	How to minimize the damage if the risk occurs, or what can be done as an alternative.		

2 Risks

2.1 Project risks

General project risks are the contract, the work scope for the project, and the quantity of work for specific tasks and the whole project.

Table 2: Contract

Assessment	Probability: 1	Severity: 5	Assessed risk: 5
Risk	One or multiple parties do not approve the contract between FMC, HBV and students.		
Preventative measure	Write the contract in cooperation with both FMC and HBV, and get their requirements for the contract early.		
Action if occurred	Write a new contract with the new requirements and try to get everyone satisfied.		

Table 3: Work scope

Assessment	Probability: 2	Severity: 3	Assessed risk: 6
Risk	The work scope/requirements for the project is not approved by some parties at FMC		
Preventative measure	Have multiple work scope meetings with the different parties, and define who the contractive parties is.		
Action if occurred	Redefine the work scope and have good communication with the contractive parties		

Table 4: Quantity task

Assessment	Probability: 4	Severity: 2	Assessed risk: 8
Risk	The quantity of work for one specific task is too high for the time calculated for that task		
Preventative measure	Have focus on good and precise planning of the tasks and get an idea early in the work on how much time that is needed and how much time that is available. In addition, always have focus on how much is done and how much is left in each task. If it is necessary to recalculate the time for the task it is important to do so early on.		
Action if occurred	If there are too little time for tasks they shall be recalculated and taken in to the project plan		

Table 5: Quantity project

Assessment	Probability: 3	Severity: 5	Assessed risk: 15
Risk	The quantity of work for the whole project is too high for the time we have available		
Preventative measure	Have focus on good and precise planning of the project and get an idea early in the project on how much time that is needed and how much time that is available. It is important to know as early as possible if some tasks has to be cut.		
Action if occurred	If there are too little time for finishing the project some tasks has to be cut or minimized it is now important to find the tasks that is least important for the outcome of the project and cut/minimize those.		

2.2 Technical risks

The technical risks for the project is mainly the technical difficulties in the 2nd phase of the project, and equipment failure.

Table 6: Technical challenges

Assessment	Probability: 3	Severity: 4	Assessed risk: 12
Risk	The technical aspect of the project is too difficult, especially in phase 2 of the project.		
Preventative measure	Start this phase early and start the technical part immediately, establish contact with personnel in FMC who can help with the technical aspects.		
Action if occurred	Use the resources from FMC and get all the help required, if the task still cannot be done, the requirements for the task has to be reconsidered.		

Table 7: Equipment failure

Assessment	Probability: 2	Severity: 2	Assessed risk: 4
Risk	One of the group members computers fail and all the work they have done is deleted		
Preventative measure	To prevent that all the work is deleted if one person has computer trouble it shall be made a Dropbox folder for the project. All the work done in the project is to be saved here, both the newest and the past editions of documents and drafts.		
Action if occurred	If all the work is deleted the document has to be started over again with an earlier edition and then implement all the changes that were made in the edition that were deleted.		

Table 8: Dropbox failure

Assessment	Probability: 1	Severity: 5	Assessed risk: 5
Risk	The Dropbox folder for the project is deleted or somehow faulted, which leads to, all the documents for the project are deleted.		
Preventative measure	To prevent that all the work is deleted if Dropbox fails, the documents shall also be saved in each of the project members personal computer, through Dropbox		
Action if occurred	If all the work is deleted the document has to be started over again with an earlier edition, found in one of the computers, and then implement all the changes that were made in the edition that were deleted.		

2.3 Group risks

The risks for the group is mainly illness or cooperation difficulties

Table 9: Regular illness

Assessment	Probability: 3	Severity: 2	Assessed risk: 6
Risk	A group member may be sick and in worst case not be able to do any work		
Preventative measure	There are defined workweeks for the project with 20-30 hours before Easter and 35-40 after, this will give each team member possibilities to plan their week, if someone is sick one week they can work extra the week after.		
Action if occurred	If someone is sick their important (time dependent) tasks shall be given to other group members.		

Table 10: Serious illness

Assessment	Probability: 1	Severity: 5	Assessed risk: 5
Risk	A group member may be sick and in worst case not be able to do any work for the rest of the project		
Preventative measure	There is defined a work weeks for the project on 20-30 hours before Easter and 35-40 after, this will give each team member possibilities to plan there week, if someone is tired and exhausted they have to take a break and do something different from the project work so they have more energy the next week.		
Action if occurred	If someone is sick their important (time dependent) tasks shall be given to other group members. If a member cannot do any work at all for the rest of the project the supervisors and sensors, both internal at HBV and external at FMC must be notified and the project plan must be recalculated.		

Table 11: Internal cooperation difficulties

Assessment	Probability: 2	Severity: 4	Assessed risk: 8
Risk	Cooperation difficulties in the group		
Preventative measure	Remember to have good communication in the group, no one shall be excluded from group discussions. Everyone shall have some main responsibilities, it is important that everyone have ownership to the project. An internal group contract is made, to prevent cooperation difficulties.		
Action if occurred	If there are cooperation difficulties the internal supervisor shall be included, it is important of solve all problems as early as possible to get a good outcome of this project.		

2.4 External risks

Cooperation and commitment given by HBV, FMC, and third party is important for the outcome of the project, and communication is a good way to ensure that the project team get the required help and support for this project

Table 12: Cooperation difficulties with supervisor at HBV

Assessment	**Probability: 1**	**Severity: 4**	**Assessed risk: 4**
Risk	Cooperation difficulties with our supervisor at HBV		
Preventative measure	Good communication and involving the supervisor in the tasks and the work that is done is important. There will be weekly meetings with the supervisor, were the work done that week and the work planned for next week is presented.		
Action if occurred	If there are cooperation difficulties the internal sensor at HBV and Olaf Graven has to be involved and there may be necessary to get a new supervisor.		

Table 13: Cooperation difficulties with FMC

Assessment	**Probability: 2**	**Severity: 5**	**Assessed risk: 10**
Risk	Cooperation with FMC is difficult or FMC do not give any commitment to the tasks of the project.		
Preventative measure	Good communication is important! If the project team require help from personnel in FMC it is important to tell them about the tasks so they can see the benefits of the project. It is also important to show excitement to the tasks so FMC can see that the project team is committed to the project.		
Action if occurred	If there are cooperation difficulties with FMC it is important to involve the supervisors and sensors both at FMC and HBV to gain the required support.		

Table 14: Cooperation difficulties with third party

Assessment	**Probability: 3**	**Severity: 4**	**Assessed risk: 12**
Risk	Cooperation with third party is difficult or third party do not give any commitment to the tasks of the project where the help from them is required.		
Preventative measure	Good communication is important! If we want help from a third party it is important to tell them about our task, and give them some benefits from our task.		
Action if occurred	If there are cooperation difficulties with third party it is important to involve the supervisor at FMC and maybe reevaluate if there is required help from third party or if there are any others that can supply the information needed.		

3 Risk matrix

To assess the risks, the probability of the risk is multiplied by the severity of the risk. In Table 15 the assessed risks are shown with green as low, yellow as medium and red as high.

Table 15: Risk matrix

	Severity:	**1**	**2**	**3**	**4**	**5**
Probability:						
1		1	2	3	4	5
2		2	4	6	8	10
3		3	6	9	12	15
4		4	8	12	16	20
5		5	10	15	20	25

The risks are ranked according to assessment number

- Risks assessed from 1 to 6 is ranked as low, and are shown in green on the table, however if a risk get either a severity or a probability number of 5 the risk shall be ranked as medium or higher.
- From 8 to 12 the risks are ranked as medium and are yellow on the table.
- From 15 to 25 the risks are ranked as high and are red on the table.

3.1 Assessing the risks

When assessing the risks all the factors is taken in to consideration, both how likely the risk are to occur and how sever it will be if it occurred. This is shown in Table 1, at the beginning of this document. In Table 16 the risks are shown with their assessed risks with the most severe on the top and the least severe on the bottom, there are also an explanation for why the risk are assessed to that number.

Table 16: Risk assessment

Risk	Table	Assessment	Reason
Quantity project	Table 5	15	This is the highest risk in this project. The project has a large workload and the time is limited.
Technical challenges	Table 6	12	The technical aspects of this project are large especially in phase 2
Cooperation difficulties with third party	Table 14	12	Cooperation difficulties with third party is likely to happen but the severity is not that big.
Cooperation difficulties with FMC	Table 13	10	Cooperation difficulties with FMC would be very severe for the project, but it is not likely to happen.
Quantity task	Table 4	8	The severity if one task has too much work is low but the possibilities for it to happen is high.
Internal cooperation difficulties	Table 11	8	A good project demands good communication and cooperation between the participants.
Contract	Table 2	5	If the contract is not accepted, the severity of this means that the project cannot be done.
Dropbox failure	Table 8	5	If Dropbox fails and all the work is deleted it will have a high severity for the project
Serious illness	Table 10	5	If one of the project participants gets ill and cannot work for the rest of the project, the project may not be finished satisfactorily.
Regular illness	Table 9	6	That someone get sick is not a serious problem
Work scope	Table 3	6	The work scope for the project is good defined before the project starts and with good communication this should not be a problem
Equipment failure	Table 7	4	There are created a Dropbox folder for the project and therefore will a computer problem be a minor risk for the project
Cooperation difficulties with supervisor at HBV	Table 12	4	Cooperation difficulties with the supervisor at HBV is not likely to happen and if it should happen there are other supervisors that can be assigned for this project

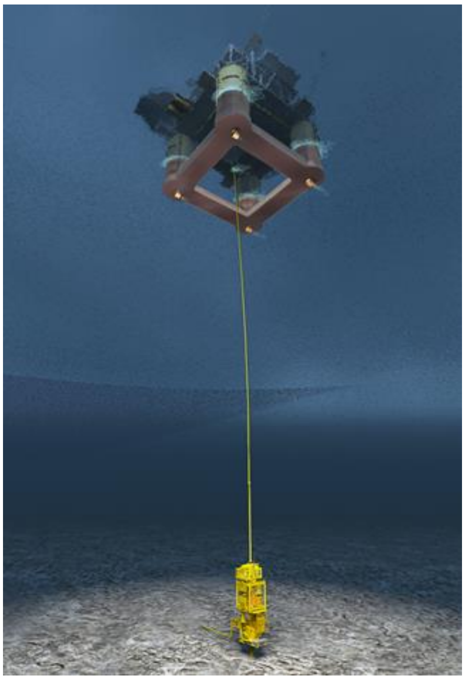
4 Document Revision History

Table 17: Revision history

Rev	Date	Prepared By	Reviewed By	Changes
1.0	19.03.2015	Kjersti Schrøder Anthonsen	David Snarheim	
2.0	12.05.2015	Kjersti Schrøder Anthonsen	David Snarheim	Spelling mistake

Design Basis Phase 1

Deep Water Riser Pipe Study



Rev	Date	Prepared By	Reviewed By	Changes
2.0	13.05.2015	Kjersti Schrøder Anthonsen	David Snarheim	See section 5

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List of Tables

Abbreviations

The following abbreviations are used throughout this document.

Abbreviation	Description
FMC	FMC Technology
GR	General requirements
HBV	Høyskolen i Buskerud og Vestfold (Buskerud and Vestfold University College)
HXT	Horizontal Christmas three
P1	Phase 1
VXT	Vertical Christmas three
XT	Christmas three (a valve block)

1 Introduction

This document describes the design basis for phase 1 of the Deep Water Riser Pipe Study project. In this phase, the project will conduct a marked study. This will show the trends in the offshore marked and specifically regarding work over systems.

2 Referenced documents and requirements

This document is based on the requirements found in the requirement document, shown in Table 1. This document continue to define the main requirements for phase 1. The requirements is shown in Table 2 and it identifies what chapter is built on which requirement.

Table 1: Document references

Document no	Document name
3100	Requirement specification
3200	Test specification

Table 2: Requirements phase 1

Requirement no	Requirement	Reference	Priority	Chapter in this document
P1-GR-01	A study identifying the future trends in the subsea market shall be performed	FMC	A	Entire Chapter 3
P1-GR-02	Trends for each subsea region shall be identified	FMC	A	Entire Chapter 3
P1-GR-03	The results from the study shall be presented in a report	FMC	A	Chapter 4.1 and 4.2
P1-GR-04	A visual presentation in the form of a world map identifying the major oceans, subsea regions and operators	FMC	A	Chapter 4.3

3 Market study

This phase is a marked study, it shall conclude with the trends for the future of oil and gas fields, and especially regarding the work over marked.

The study shall distinguish between different regions as listed below.

- Western region
- Eastern region
- Asia pacific

In each region, the study shall require info on the parameters listed in the chapters below. If necessary, the regions can be divided in to smaller areas.

3.1 Operators

The main operators shall be identified, in addition the project team should see if there are any local operators which do not operate any other places an explain why.

3.2 XT type VXT/HXT

XT type shall be identified and mapped. It shall also be a short introduction of the pros and cons for the different XT. With this there should be an explanation for the choices, and if is it location specific or operator specific.

3.3 Drift size

The tubing hanger drift sizes shall be identified, it should conclude with what the trends is for the future, and what has been common in the past.

3.4 Modes of operation

The operation modes shall be identified. There should also be made a short explanation of the different operation modes, and their pros and cons.

3.5 Field parameters

The other factors that has to be identified and mapped is as listed below:

- The water depth
- The well pressure
- The well temperature

4 Reporting

For this phase of the project there shall be made a final report as described below. It will present the outcome of the marked study, here it will be ideal to show past and future trends in a visual way with graphs and pictures. In addition, there shall be made a map to show the main operators in each region and a test report.

4.1 Final report

The final report for phase 1 shall contain the conclusions for the marked study, with explanations for each parameter. It is important to present the data in a visual way with graphs and pictures.

4.2 Visual map

The visual map shall be a world map, with the different regions marked and the main operators in each region should be presented with company logos. Some of the info gathered on the oil and gas field shall also be marked.

4.3 Test report

The testing for phase 1 will be performed according to the test specification see Table 1, then documented and reported in a test report.

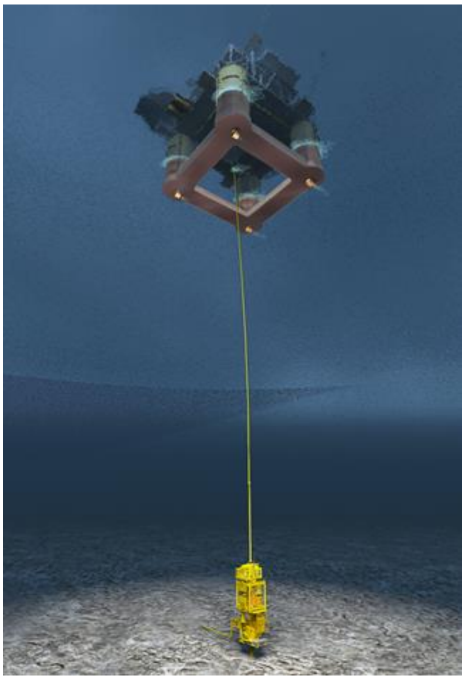
5 Document revision history

Table 3: Revisions

Rev	Date	Prepared By	Reviewed By	Changes
1.0	19.03.2015	Kjersti Schrøder Anthonsen	David Snarheim	First release
2.0	13.05.2015	Kjersti Schrøder Anthonsen	David Snarheim	Changed document name Updated table of contents

Final Report Phase 1

Deep Water Riser Pipe Study



Rev	Date	Prepared By	Reviewed By	Changes
2.0	13.05.15	Kjersti Schrøder Anthonsen	David Snarheim	See section 10

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Abbreviations

The following abbreviations are used throughout this document.

Abbreviation	Description
BOP	Blowout preventer
BP	British petroleum
EDP	Emergency disconnect package
FMC	FMC Technology
HXT	Horizontal Christmas three
LRP	Lower riser package
Ref	Reference
RLWI	Riser less well intervention
TH	Tubing hanger
TTRD	Trough tubing rotary drilling
VXT	Vertical Christmas three
XT	Christmas three (a valve block)

1 Introduction

This report consists of the findings from phase 1 of the bachelor project Deep Water Riser Pipe Study.

2 Project background

The background for the deep water riser pipe study project is, FMC well access system group wants to be able to propose and evaluate future development needs, have an easier way to take decisions early in a tender phase and to look at next generation riser pipes to meet future deep water projects.

This phase of the project will consist of gaining information and understanding the deep-water work over marked. It shall define a method for presenting trends across regions and propose basic requirements for future completion workover systems.

3 Basis for the report

For this report, multiple different resources have been utilized for analyzing the market trends for completion workover riser systems. The different resources are described in this section.

NOTE: Graphs presented in this document are mainly based on the quest subsea database for awarded project, graphs using data from quest forecast database and FMC internet home page are notated with “forecast” and “FMC”.

3.1 Internal resources

FMC internet home page

The FMC website (fmcti.com) has been used to identify all projects delivered by FMC global, the following information is derived.

- Location
- Operator
- Water depth
- XT classification (VXT or HXT)
- XT pressure rating
- Tubing hanger drift size
- Type of completion workover riser

Well access tender database

The FMC's tender database has been used to evaluate the operation modes as well as input to future well pressure / temperature and drift sizes for Eastern region.

Communication with system engineering group.

Mail and phone conversation with FMC personal from below mentioned locations have been used to evaluate the operation modes as well as input to future well pressure / temperature and drift sizes.

- Brazil
- Norway
- Houston
- Singapore

3.2 External resources

Quest subsea database

The quest subsea database provides historical and forecast information on global subsea project developments based on XT awards.

For this report the Historical global XT awards have been analyzed with the following restrictions

- Awarded project starting from 1990 to 2014
- Awarded project ending 2024 (2020 for water depth)
- Future forecasted projects, the database provides a five-year forecast of global XT awards.

The following data have been derived from quest subsea database.

- Region
- Operator
- Project
- Water depth
- XT type
- Amount of XT per project
- Award year
- Pressure and temperature rating
    - High pressure = 10 000 psi +
    - High temperature = 176 °C +

NOTE: The data from the quest subsea database is only indicative data with the purpose of identifying market trends.

4 Market study, descriptions

For this market study, the world has been divided into three regions, eastern region, western region and Asia pacific. The reason for this is that FMC divides their systems in the same way.

In this market study many different factors have been taken into consideration to get an accurate outcome for the future of completion workover riser systems. The reason for analyzing the different factors is that they all have an impact in choosing completion and workover riser system. These factors are further described in this section.

4.1 Operators

There are some major operators in each region and these are mostly international operators. In addition, most countries have their own oil and gas companies. In many countries, the national companies are just owners of the field or the platform, and they will hire other companies to operate the oil and gas production. In this study the focus will be on the operators, and not the owner of the field.

4.2 XT type

A Christmas tree (XT) is an assembly of valves installed on top of wellhead, it's primary function is to control well flow, both production and injection. A XT may also provide a numerous of other functionalities such as.

- Chemical injection point
- Monitoring points for
  - Pressure
  - Temperature
  - Corrosion
  - Erosion
  - Sand detection
  - Flow rate

There are two types of XT commonly used in the industry, vertical and horizontal XT (VXT and HXT), the difference between them and their advantages and disadvantages are described in this chapter.

4.2.1 VXT

Vertical Christmas tree (VXT), the production tubing and tubing hanger is installed in wellhead through marine riser and BOP prior to installing the VXT. This means that the XT can be replaced, without having to pull the whole tubing out of the well. The tubing hanger is where all the production tubing that goes down to the well is hanged off.

The tree is stacked vertically on top of wellhead and the main valves are in the vertical bore. In the past, the VXT had a max drift size on 5", however there are VXT with 7" drift size available today.

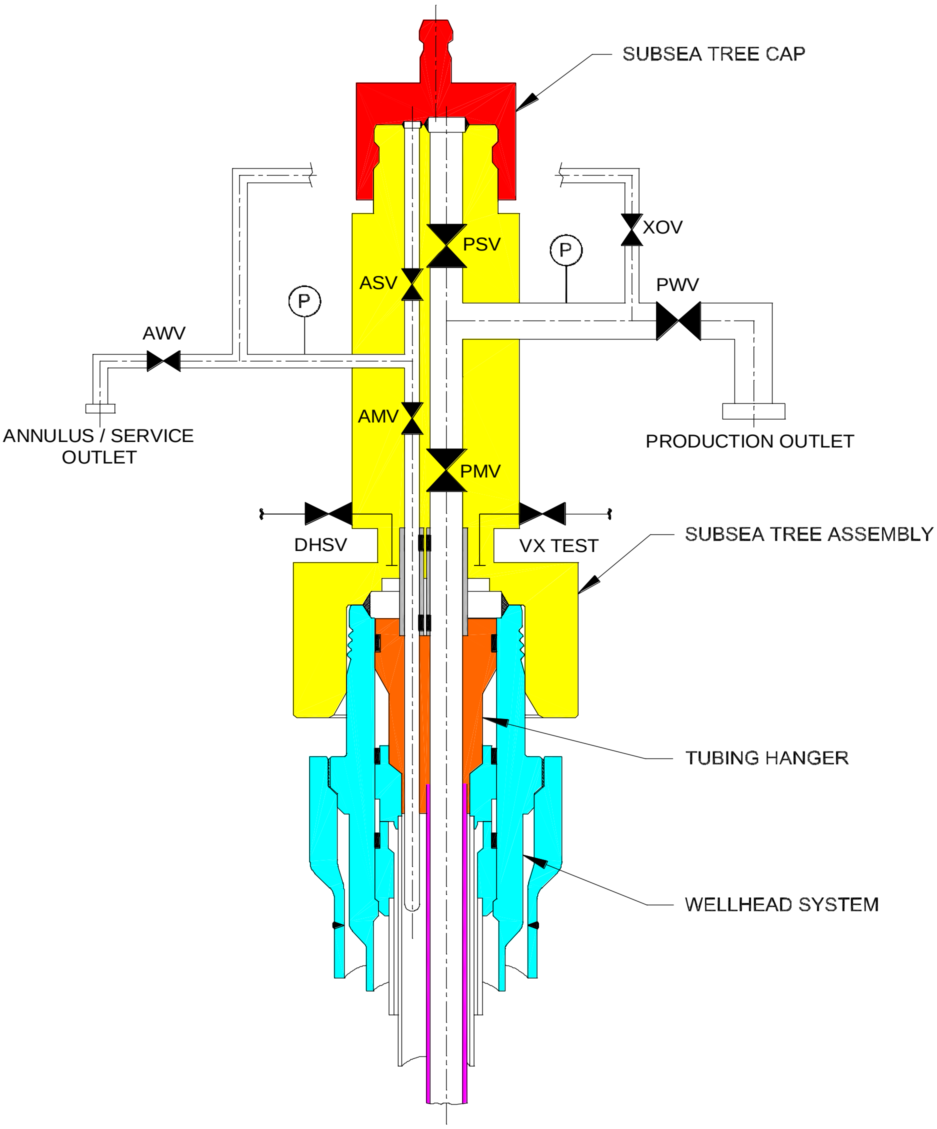


Figure 1: Vertical XT

4.2.2 HXT

Horizontal Christmas tree (HXT) is installed on top of wellhead prior to installation of production tubing and Tubing Hanger. This means that the tubing can be pulled and repaired without removing the XT. All valves are located outside the vertical bore in the horizontal plain. Production fluid flows from the reservoir and sideways out of the tubing hanger, through valves in the horizontal bore and out of the XT.

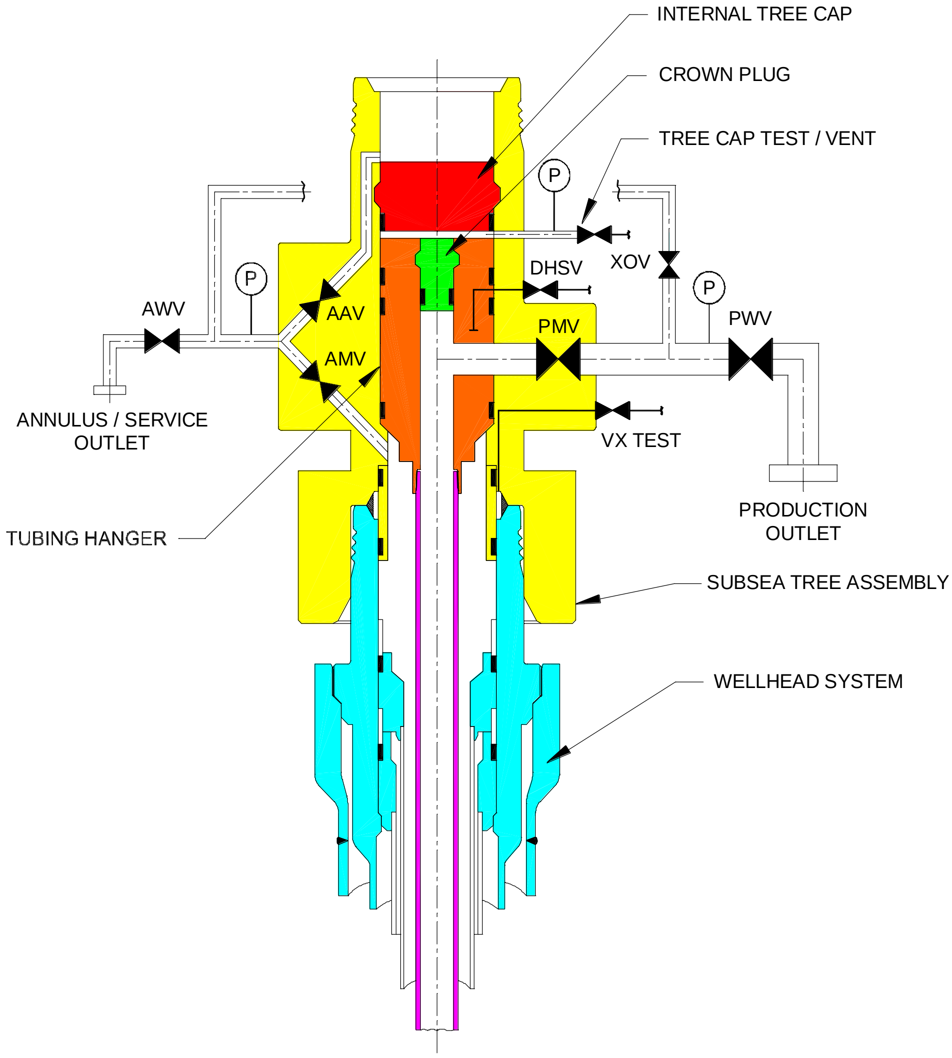


Figure 2: Horizontal XT

4.2.3 Comparison of VXT and HXT

Table 1 provides pro's and con's for comparisons of VXT and HXT.

Table 1: XT pros and cons

Tree type	Pro's	Con's
Horizontal(HXT)	TH can be retrieved without removing the XT Tubing can be easily accessed through the XT for work over operations	Two BOP trips required during installation TH and production tubing must be retrieved before retrieving XT
Vertical(VXT)	Only one BOP trip required during installation XT can be retrieved without removing the TH and production tubing	XT must be retrieved before retrieving TH

In general:

- In the past VXT required higher initial investment for the Oil Companies due to its production bore limitation of 5", i.e. more VXT required to meet the same flow rate as utilizing HXT with 7" production bore. However with today's new technology where 7" VXT is available the initial investment cost will be equal to HXT.
- HXT requires higher installation & operational cost for the Oil Company due to more BOP trips.
- Reservoir complexity and operator philosophy is typically a decision factor for what tree type that is optimal.
- From a safety perspective, a VXT system is considered safer than HXT system, this is because the tubing hanger with its attached production tubing is located in the wellhead not in the XT itself. A safety example is if the XT is incidentally ripped of the wellhead, the production tubing and tubing hanger will be intact for a VXT system and the down-hole safety valve will shut down the well stream. While for a HXT system, the production tubing and tubing hanger as well as the down-hole safety valve will be affected.

4.3 Drift size

By drift size it is meant the size of the production tubing that goes from tubing hanger and in to the well. There are mainly two drift sizes that are used in the oil and gas industry which are 7” and 5”. Some of the drivers for choosing small or large drift size are described in Table 2.

Table 2: Drift size drivers, small/large

Smaller sizes, 5”	Larger sizes, 7”
Oil wells	Gas wells
Deep water	High flow capacity
Gas lift	Well access
Low productivity reservoir	High productivity reservoirs
High reservoir pressure/temperature	
Higher equipment availability	
Limited rig capabilities	
Reservoir depth	
Deep wells	
Difficult drilling	
Complex casing program	

4.4 Operation mode

Operation mode refers to the method for completion of well, installation of XT and maintenance of well and XT during life of field. This section describes the different systems that utilizes a riser and are available in FMC portfolio today. Other methods for well maintenance such as RLWI and TTRD are not covered in this report.

The drivers for choosing one system over the other or a combination of systems is dependent on the parameters investigated in this report.

4.4.1 In marine riser work over riser systems

A marine riser is a large diameter, low pressure tube with external auxiliary lines that includes high pressure choke and kill lines for circulating fluids to the subsea blow out preventer.

Marine riser system consist of the following main components.

- Well control equipment BOP
- Standard joints
- Special joints

Figure 3: Marine riser and BOP

Typical operation performed trough a marine riser system.

- Drill well
    - Exploration
    - Production
    - Injection
- Install production tubing and tubing hanger with simplified landing string
- Start-up well with landing string
- Pull production tubing
- Cement and abandon well

There are mainly two types of completion workover systems run inside a marine riser and BOP setup as defined above.

4.4.1.1 Simplified landing string

The simplified landing string system does not contain any well control barrier and is used for running and installing production tubing and tubing hanger inside a marine riser system. It can be configured for HXT and VXT systems.

The simplified landing string system contains the following main components.

- Simplified landing string
- Standard riser joints (typically rig drill pipe)
- Special joints

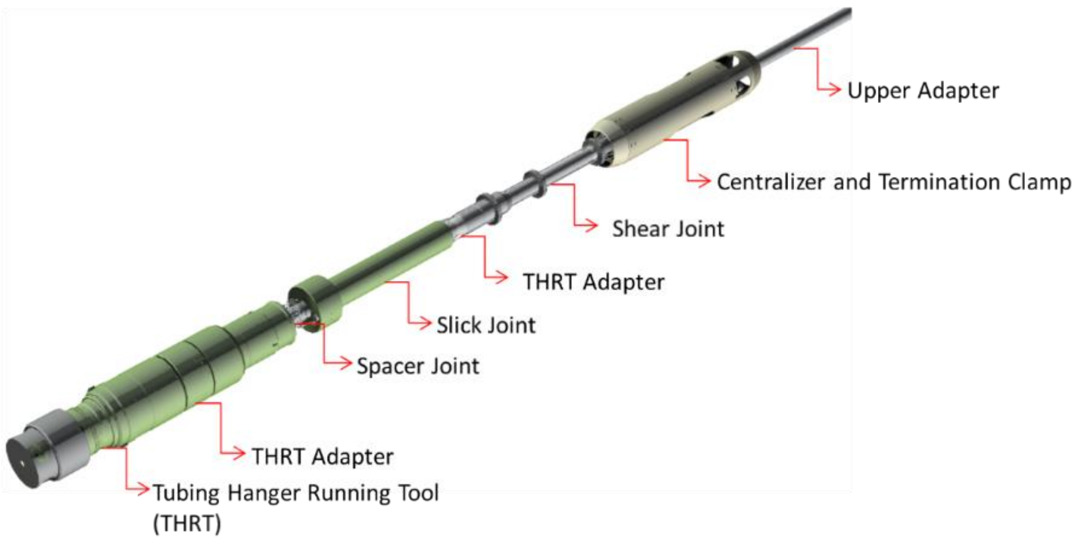


Figure 4: Simplified landing string

4.4.1.2 Landing string with well control

The Landing string system is the primary well control barrier during a range of subsea operations inside a marine riser system. The landing string can be used during a development well test, a well completion, or when conducting any subsequent well intervention operations on XT. It is configurable for HXT and VXT.

The landing string system contains the following main components.

- Well control package
- Standard riser joints
- Special joints

A landing string system can perform the following operations.

- Run production tubing and tubing hanger
- Well test and start-up
- Well maintenance such as
    - Coiled tubing operations
    - Wireline operations

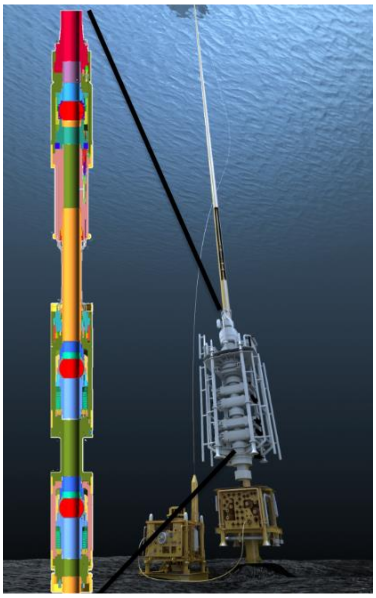


Figure 5: Landing string with well control

4.4.2 Well access completion workover riser system

The Well access completion workover riser system is used for installation, completion and intervention of XT in open water. It can be configured for HXT and VXT systems.

The well access completion workover riser system contains the following main components.

- Well control package (EDP/LRP)
- Standard riser joints
- Special joints

A well access completion workover riser system can perform the following operations.

- Well clean-up and testing
- Well maintenance such as
    - Coiled tubing operations
    - Wire line operations

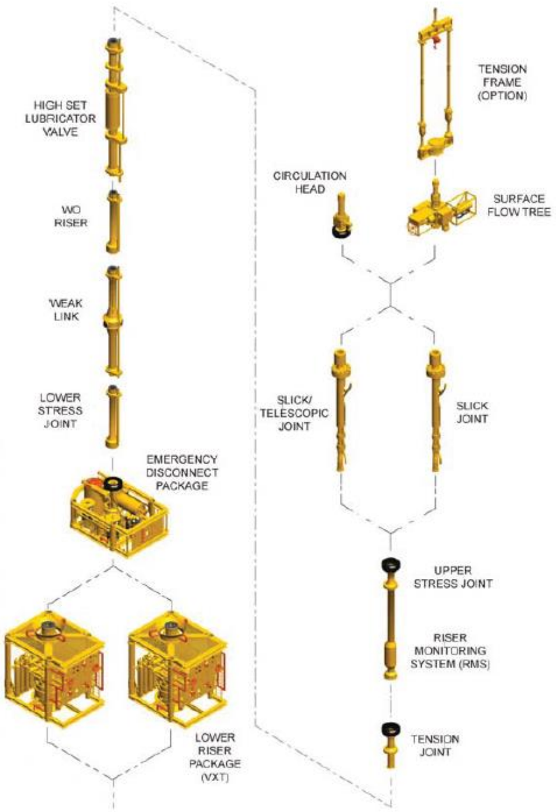


Figure 6: Well access completion workover riser system

4.5 Field parameters

Field parameters are decided by geography and geology (and cannot be changed by the operators). When choosing completion workover system these parameters have a large impact. The parameters are described below.

4.5.1 Water depth

For the water depth the fields that are developed by FMC, the fields that are listed as awarded in Quest, past and future, and the fields that are forecasted for the future have been investigated. Some places, as the North Sea the water depth will not change that much, this is because the North Sea is on a continental shelf, which means that the water depth will be almost the same everywhere. However, for some places there will be changes from the past developments.

4.5.2 Well pressure

For the well pressure the fields listed as awarded in Quest both past and future have been investigated. The well pressure is depended on where the oil and gas is located, how deep in the ground the reservoir is located and what kind of rock there is in and around the reservoir. The reason for investigating if there are changes in the well pressure is that the technology is under development and earlier it was challenging to recover oil and gas from wells with high pressure. The challenges is still there but the technology is more evolved, therefore there may be more developments with high pressure in the future. Some oil and gas reservoirs that have been found in the past, but not developed because of the challenges, will now be possible to recover oil and gas from.

4.5.3 Well temperature

For the well temperature the fields listed as awarded in Quest both past and future have been investigated. The well temperature is also depended on where the oil and gas is located, how deep in the ground the reservoir is located and what kind of rock there is around the reservoir. As with well pressure the reason for investigating if there have been any changes from the past in well temperature is the technology development, there are now easier to overcome the challenges in oil and gas recovery with high temperature in the reservoir.

5 Eastern region

The eastern region consists of Europe and Africa. In Europe the North Sea is a big part of the offshore marked. For this region the data collected has been divided into Europe and Africa for most of the graphs, the reason for this is that there are big differences between Europe and Africa's sea depth, and that leads to different working methods.

5.1 Operators

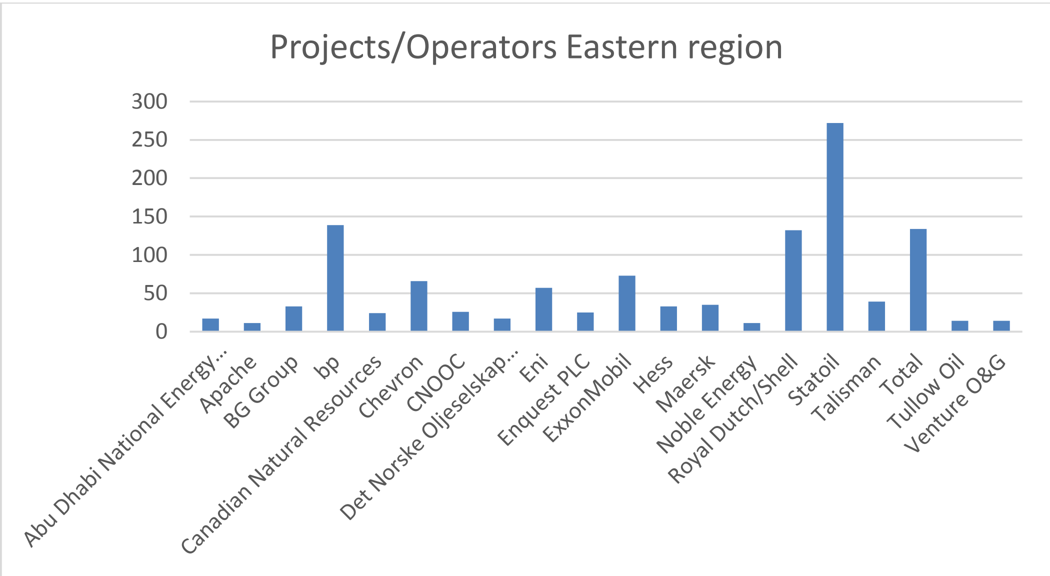


Figure 7: Operators Eastern region

As shown by Figure 7 the main operators in the Eastern region is BP, Shell, Statoil and Total. And divided between Europe and Africa as shown in Figure 8 and Figure 9 the main operators is Eni, ExxonMobil and Total for Africa and BP, Shell and Statoil for Europe.

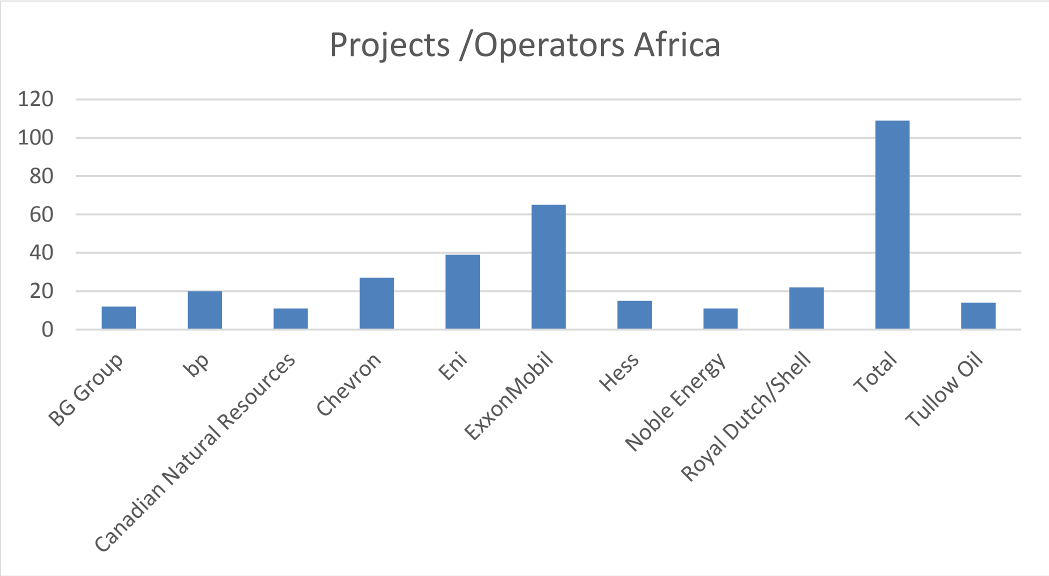


Figure 8: Operators Eastern region Africa

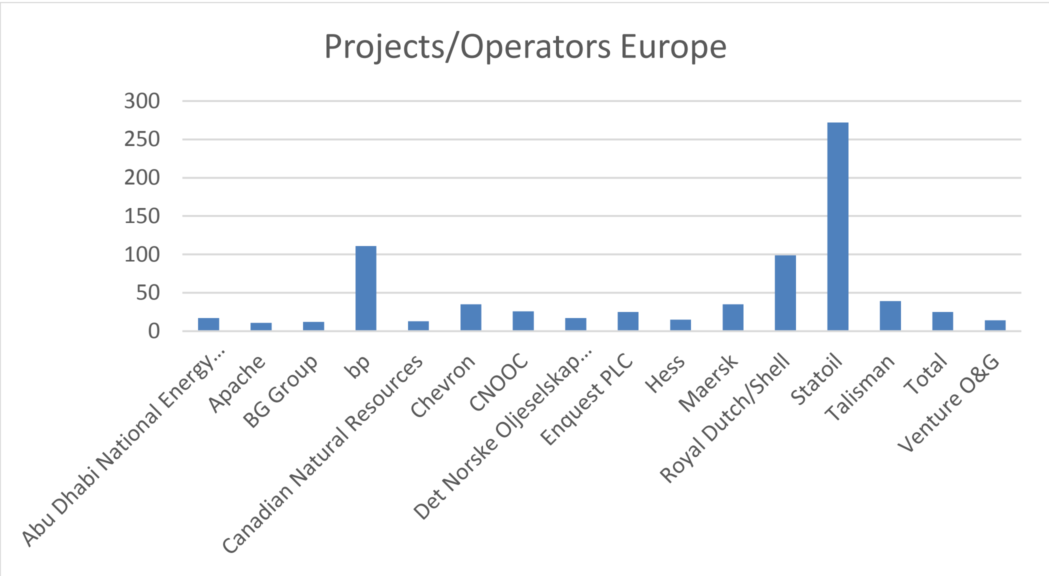


Figure 9: Operators Eastern region Europe

5.2 XT type

For XT-type Figure 10 shows the result for all of the Eastern region from the Quest awarded list, both past and future, from the graph it shows that there are slightly more vertical XT than horizontal XT in the region.

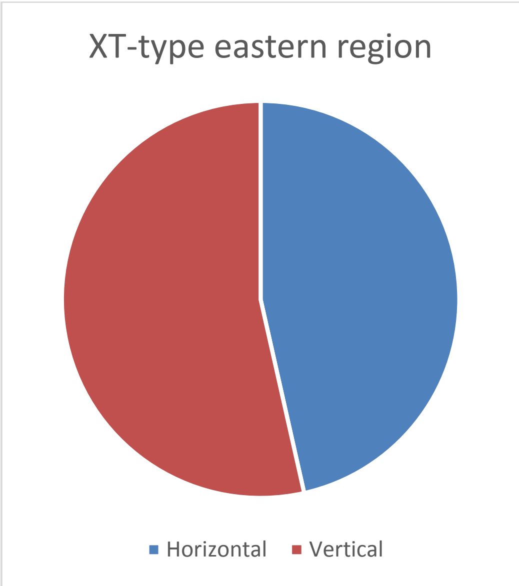


Figure 10: XT-type Eastern region

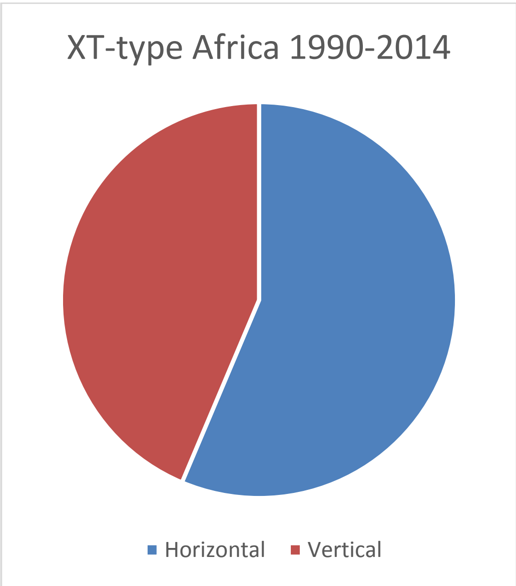


Figure 11: XT-type Africa, past

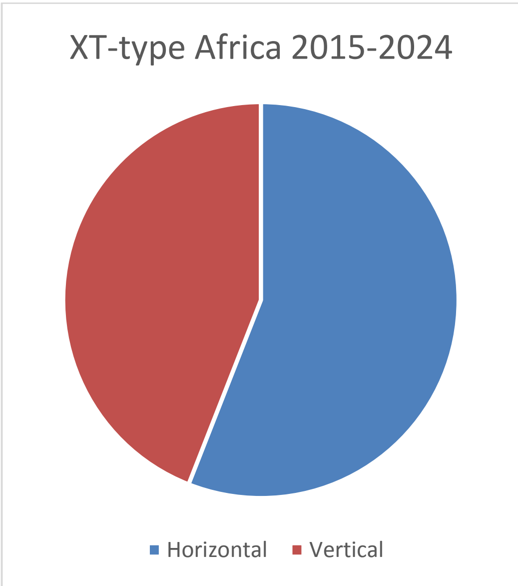


Figure 12: XT-type Africa, future

As shown by Figure 11 and Figure 12 there are more HXT in Africa, and as shown in Figure 14 the forecast for the future follow that same trend. However as shown in Figure 13 FMC has delivered slightly more vertical XT than horizontal XT to Africa, this can be explained by that FMC do not deliver to all the operators in Africa and the ones that FMC has delivered to have preferred VXT.

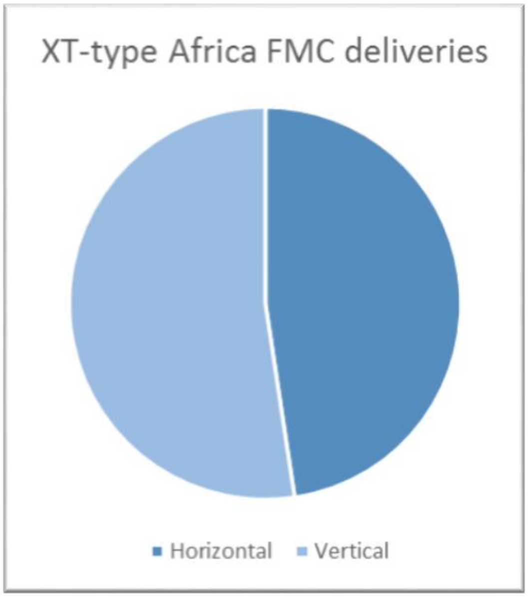


Figure 13: XT-type Africa, FMC

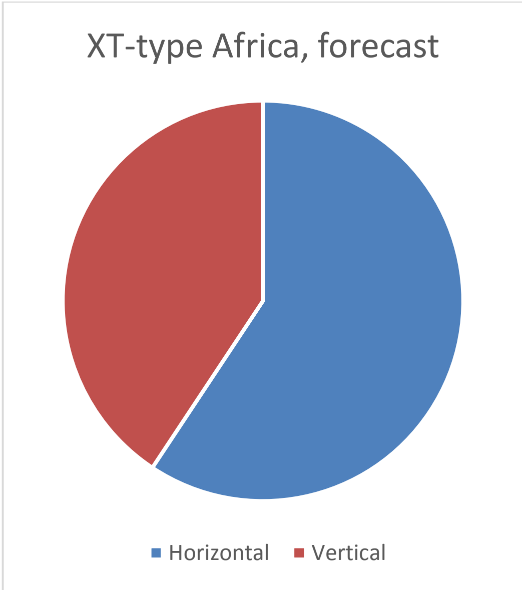


Figure 14: XT-type Africa, forecast

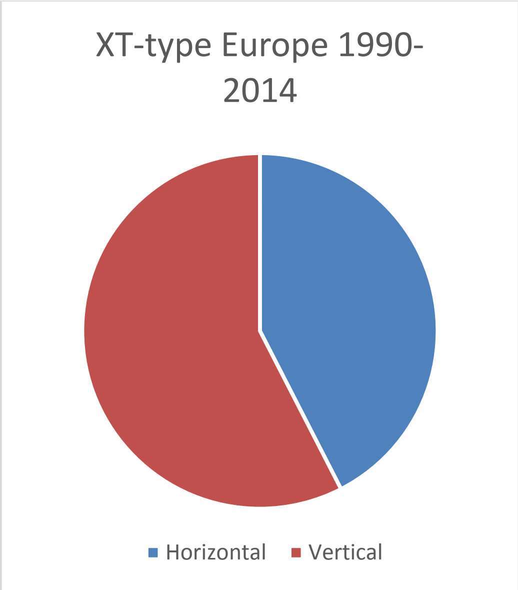


Figure 15: XT-type Europe, past

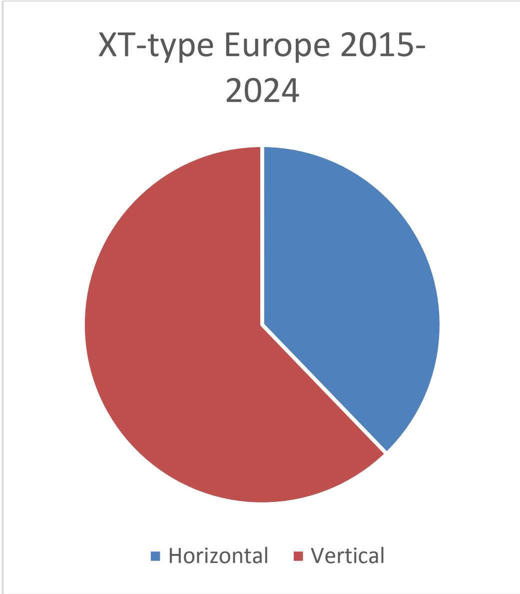


Figure 16: XT-type Europe, future

In Europe the Figure 15 and Figure 16 shows that there are more and more VXT being used. Also here, this trend is followed by the forecast for the future, shown in Figure 18. However here as well Figure 17 shows that the XT delivered by FMC shows the opposed trend in this case they have delivered more HXT. This can be explained by the necessity for larger drift sizes. In the past, as mentioned in chapter 4.2.1 the vertical XT could not be made with a drift size larger than 5”. Therefore, if the field required a drift size of 7” the operator had to choose a horizontal XT.

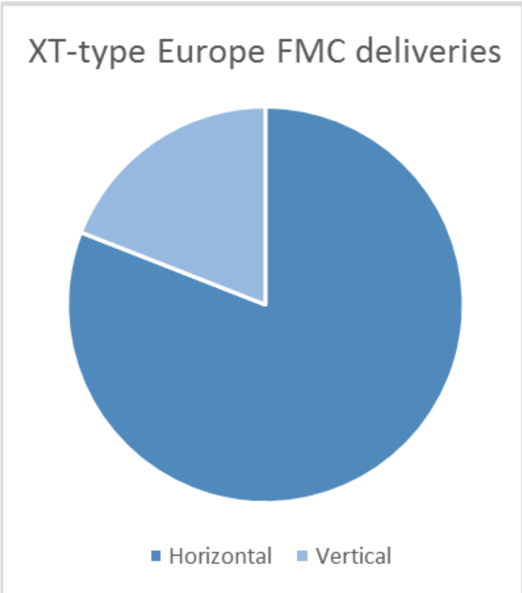


Figure 17: XT-type Europe, FMC

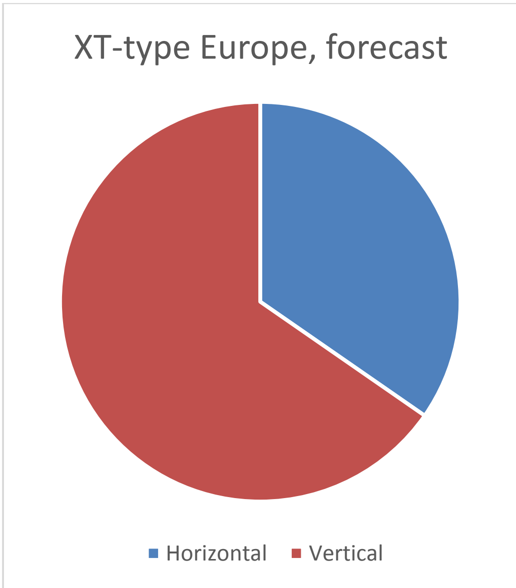


Figure 18: XT-type Europe, forecast

As shown in Figure 19 and Figure 20 the main operators for this region has different preferences for XT as shown Shell almost exclusively uses VXT but Statoil and ExxonMobil uses more HXT, and some uses both.

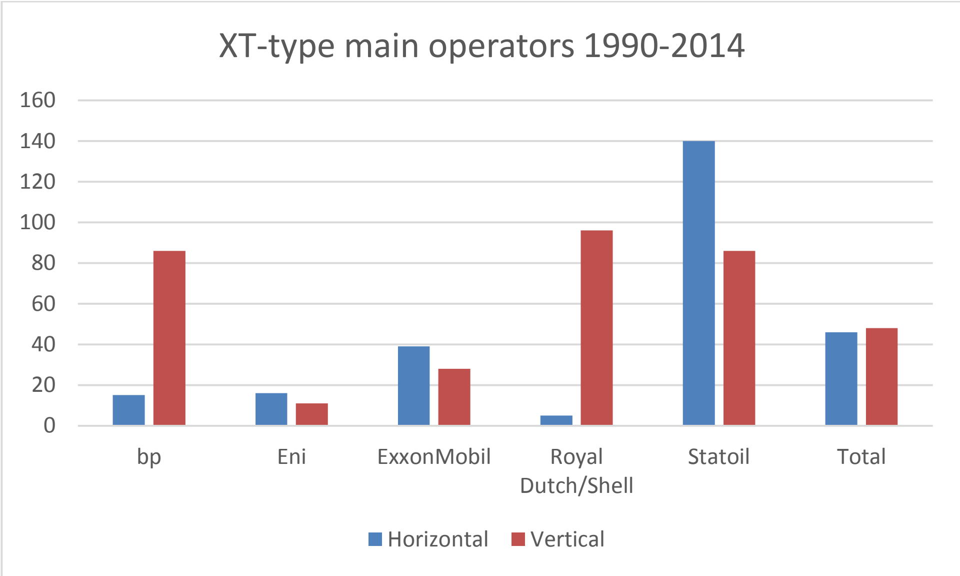


Figure 19: XT-type main operators, Eastern region, past

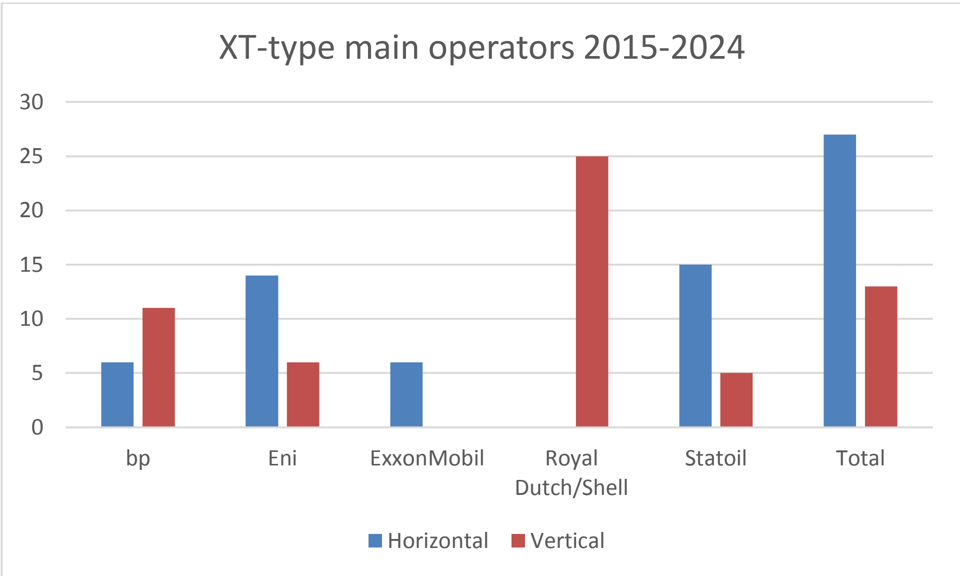


Figure 20: XT-type main operators, Eastern region, future

5.3 Drift size

For the tubing hanger drift sizes, the only information derived by the project team is from the projects where FMC has delivered equipment. The information presented is based on number of projects.

From Figure 21 it shows that the preferred drift size for Africa is 5”. This can be explained by the size and shape of the typical reservoirs in these projects. The reservoirs is narrow and over a large area, this lead to more XT but each XT do not need to produce at a high rate. In Europe however, the Figure 22 shows that the drift size goes towards 7”, this is because the reservoir is large and over a small area. The XT do not need to be placed over a large area and they have to produce at a high rate.

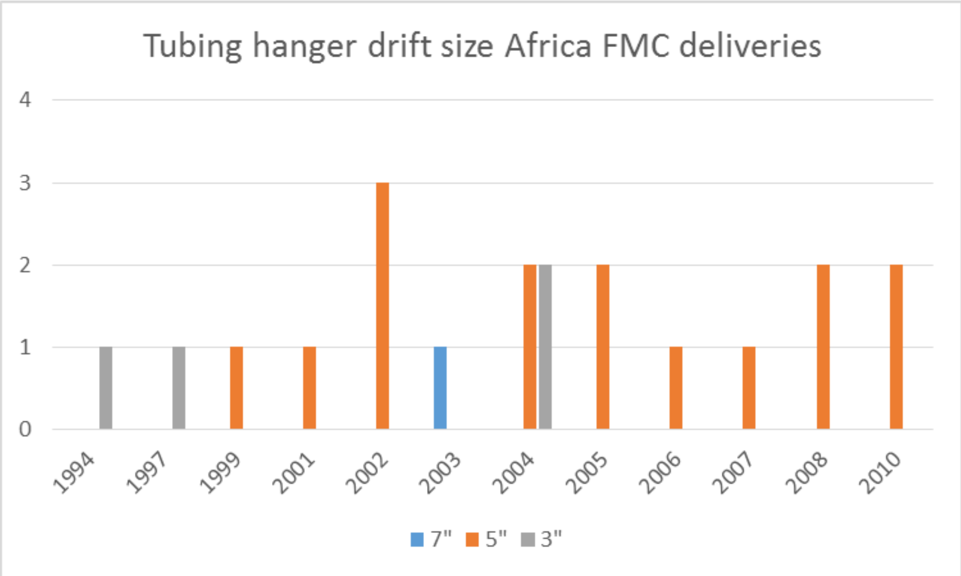


Figure 21: Drift size Eastern region Africa, FMC

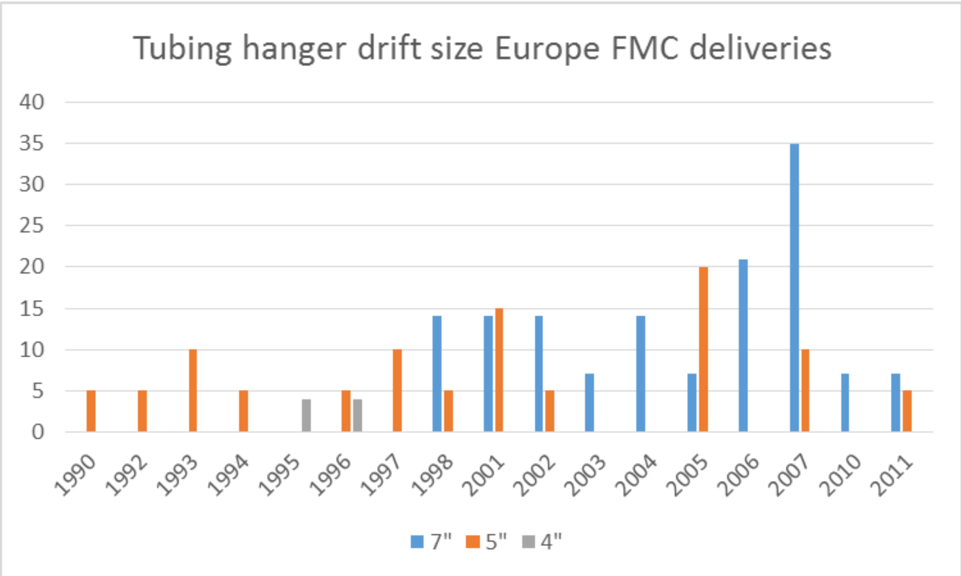


Figure 22: Drift size Eastern region Europe, FMC

5.4 Operation mode

The information derived in this section is based on meetings with FMC's system engineering group for well access in Kongsberg and a screening of delivered projects with completion and work over riser packages.

For oil and gas fields in Europe and Africa the operation modes are highly dependent on type of XT chosen as well as operator experience and other factors. However, a trend of the operation modes as defined below is identified.

VXT

1. Drill well with marine riser and BOP
2. Install production tubing and tubing hanger in marine riser and BOP with simplified landing string
3. Install VXT either on drill pipe from rig or on wire from boat.
4. Well test production from a well access completion workover riser system

HXT

1. Drill well with marine riser and BOP
2. Install HXT either on drill pipe from rig or on wire from boat.
3. Install production tubing and tubing hanger in marine riser and BOP with simplified landing string
4. Well test production from a well access completion workover riser system

5.5 Field parameters

5.5.1 Water depth

The water depth evaluation have been divided between Europe and Africa as shown in Figure 23 and Figure 24. As seen for the European projects the main bulk of project varies between 50 to 500 meters of water depth, which is the depth of North Sea continental shelf, on the other end of the water depth scale at approximately 1800 meters there are projects mainly located in the Barents Sea.

For the Africa region, there are a wide range in variations of water depths, ranging from 50 to 2500 meters, in addition to this there are ongoing studies in FMC for future projects with water depths down to 4000 meters.

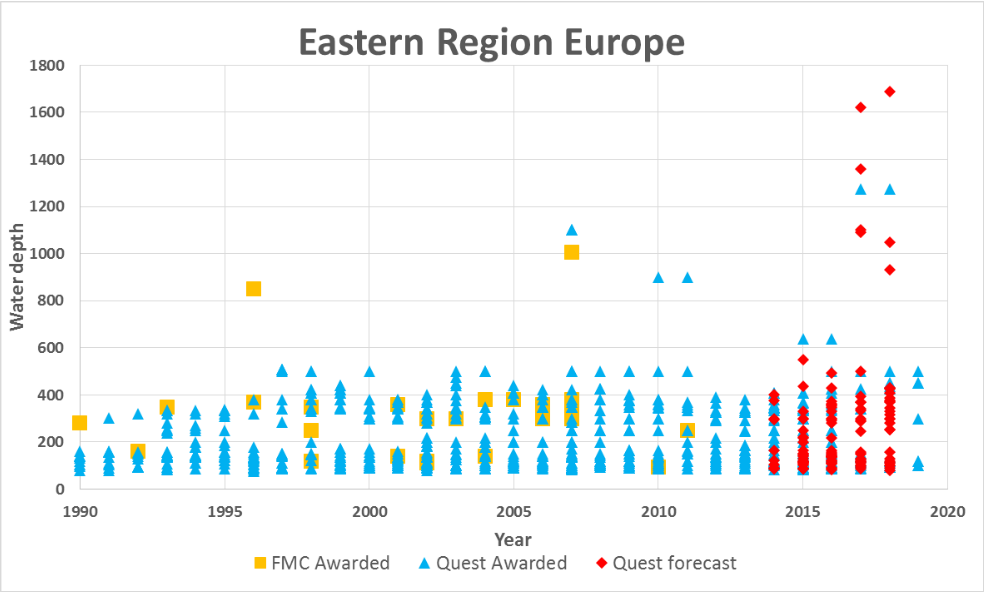


Figure 23: Water depth Eastern region Europe

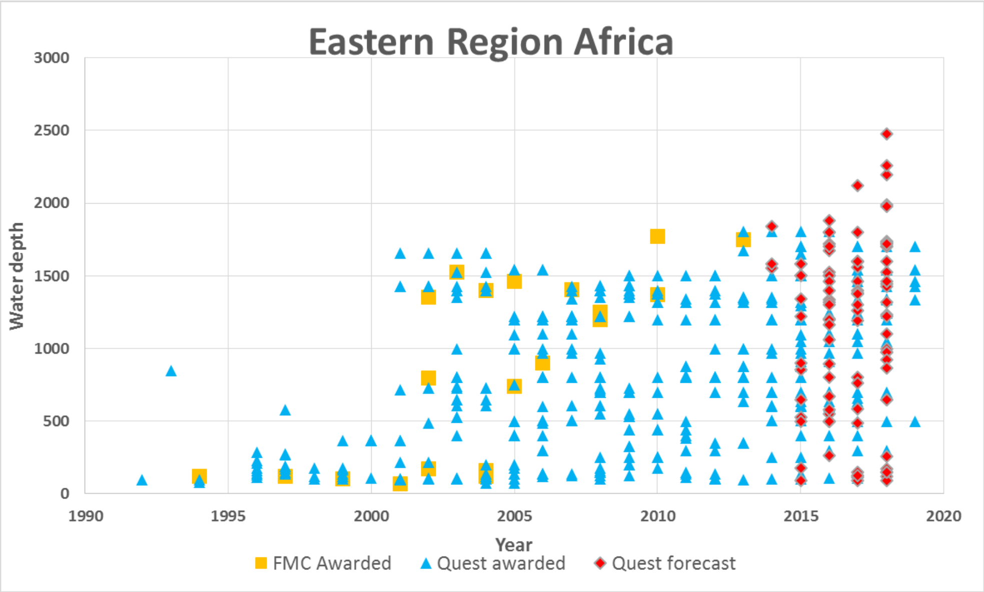


Figure 24: Water depth Eastern region Africa

5.5.2 Well pressure

For the well pressure the Figure 25 shows the pressure for all of the Eastern region, the well pressure is divided in to high and low pressure this is the info from the Quest database, were high pressure means pressure above 10 000 psi. Low pressure is pressures from 10 000 psi and lower.

Both for Europe and Africa there is mainly low pressure and in Europe, the percentage of high pressure fields has decreased as shown by Figure 31 and Figure 32

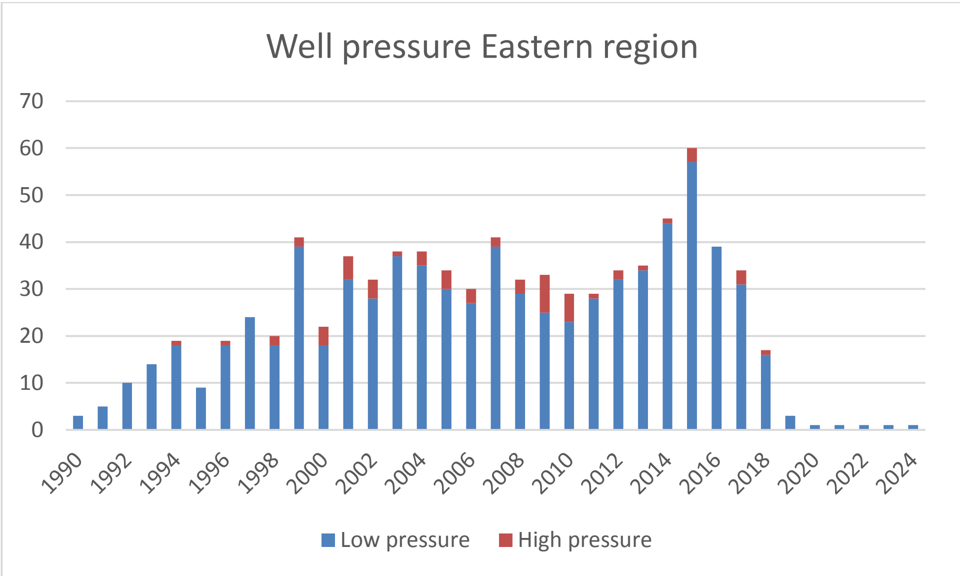


Figure 25: Well pressure Eastern region

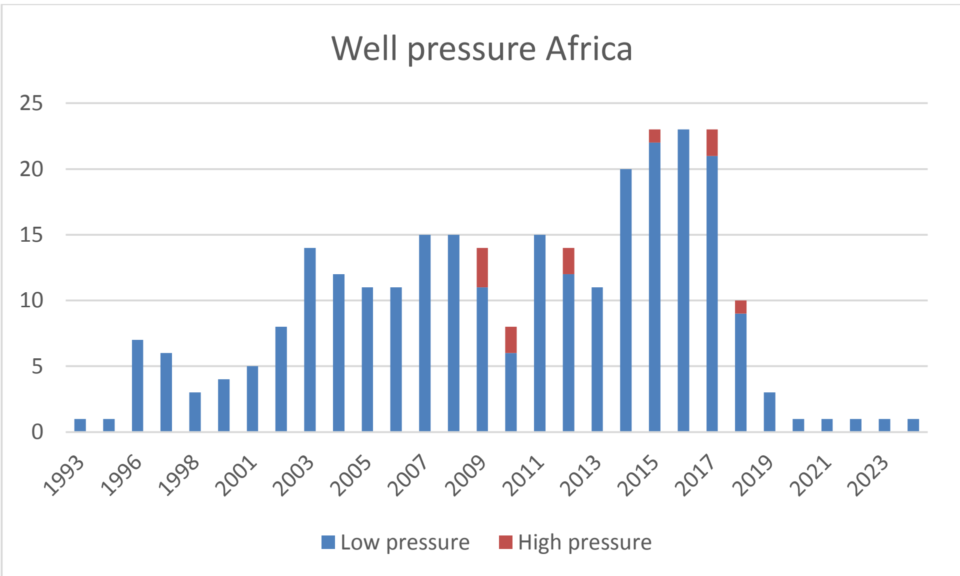


Figure 26: Well pressure Eastern region, Africa

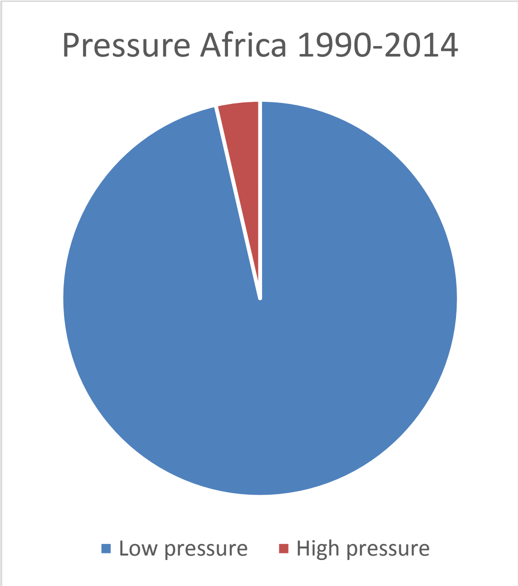


Figure 27: Pressure Africa, past

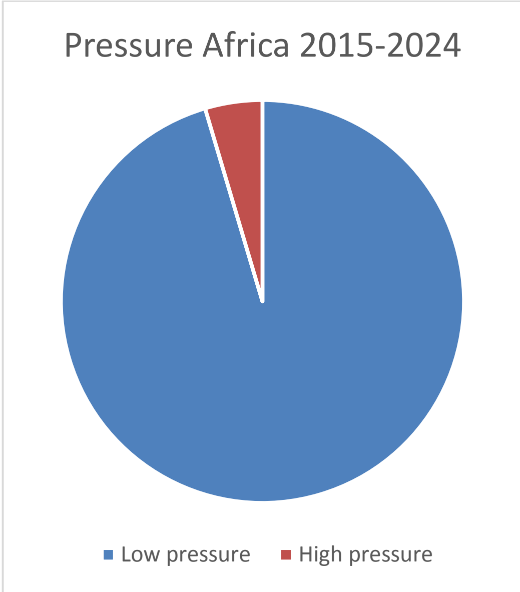


Figure 28: Pressure Africa, future

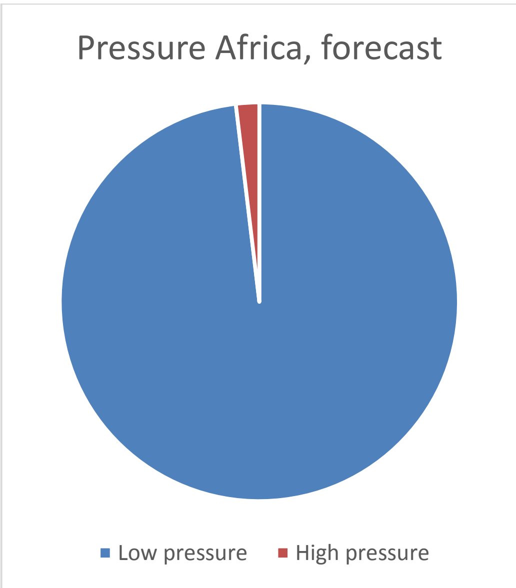


Figure 29: Pressure Africa, forecast

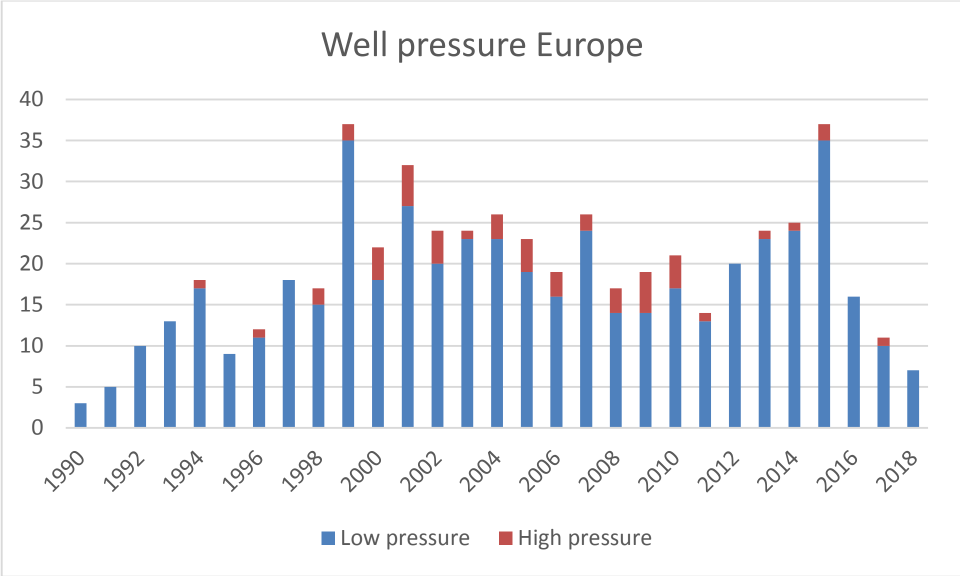


Figure 30: Well pressure Eastern region, Europe

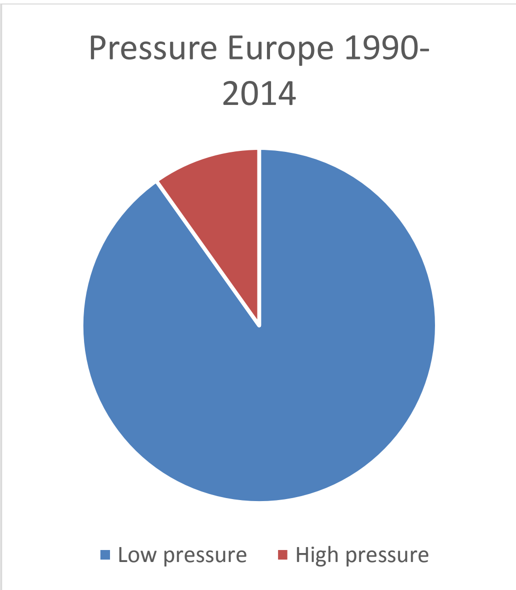


Figure 31: Pressure Europe, past

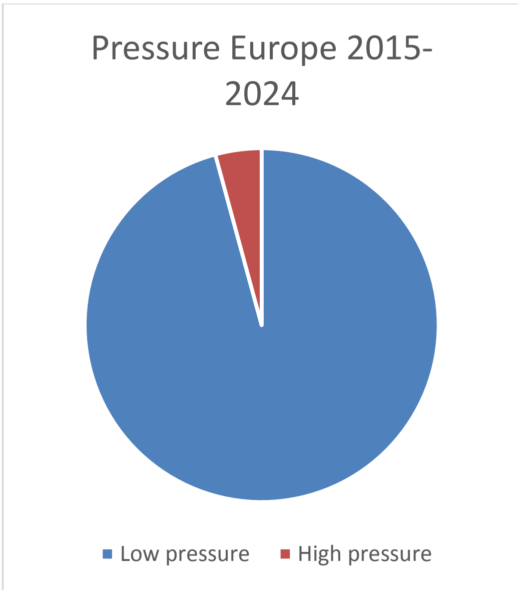


Figure 32: Pressure Europe, future

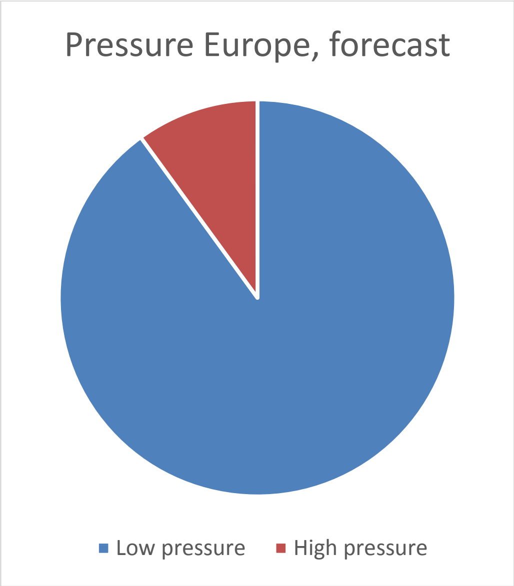


Figure 33: Pressure Europe, forecast

5.5.3 Well temperature

For the well temperature the Figure 34 shows the temperature for all of the Eastern region, the well temperature as well is divided in to high and low temperature this is the info from the Quest database, were high temperature means temperatures above 176°C (350F). Low temperature is the temperatures from 176°C and below.

The temperatures is mainly low both for Europe and Africa. As shown in Figure 36 and Figure 37 for Africa and Figure 40, Figure 41 for Europe, the percentage of high temperature is decreasing for the future. However the forecasted projects for Europe have a little more high temperature fields as shown in Figure 42

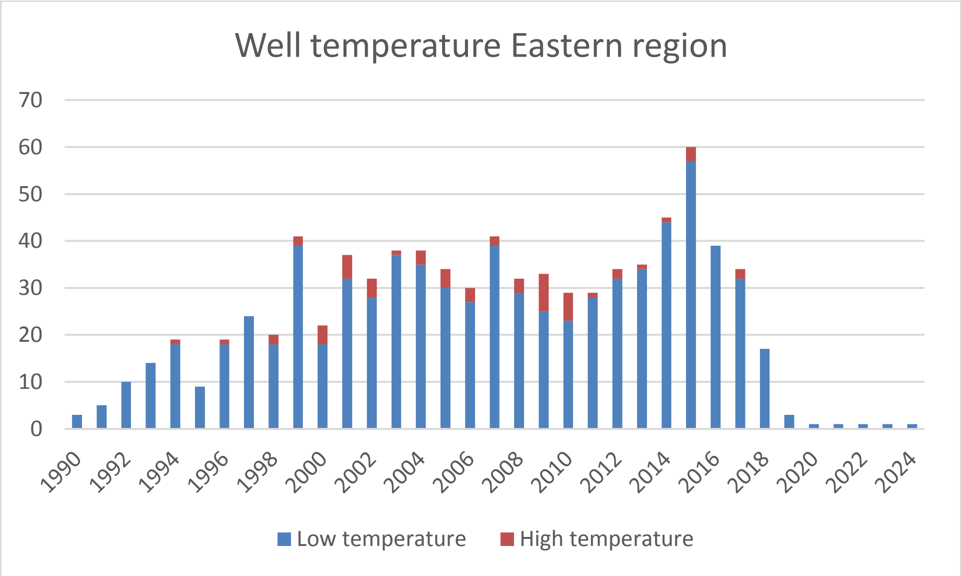


Figure 34: Well temperature Eastern region

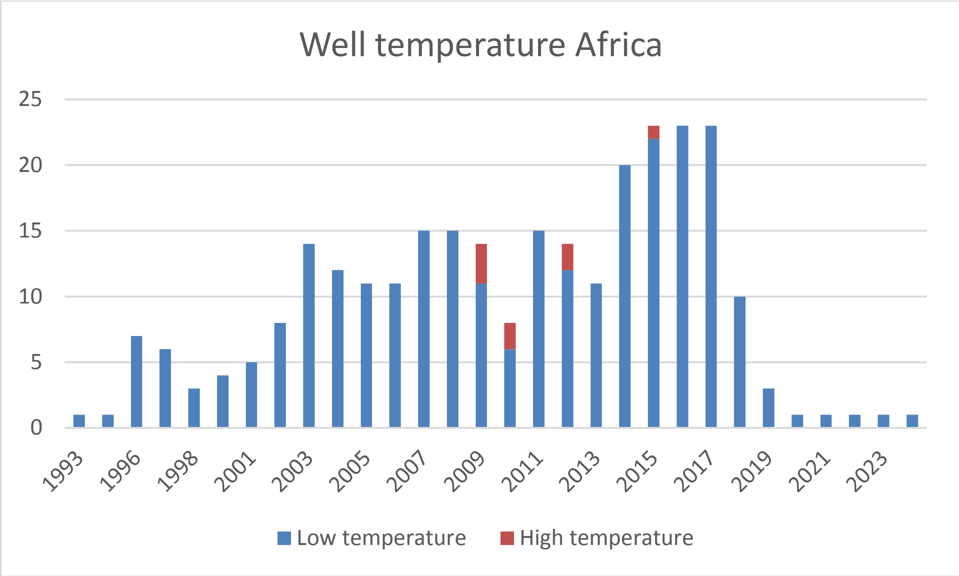


Figure 35: Well temperature Eastern region, Africa

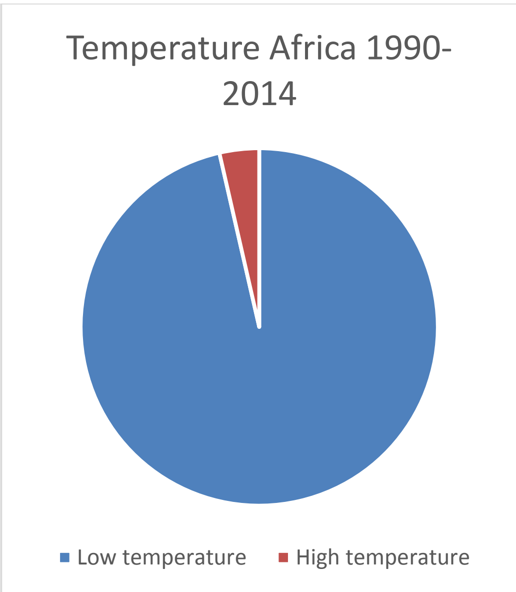


Figure 36: Temperature Africa, past

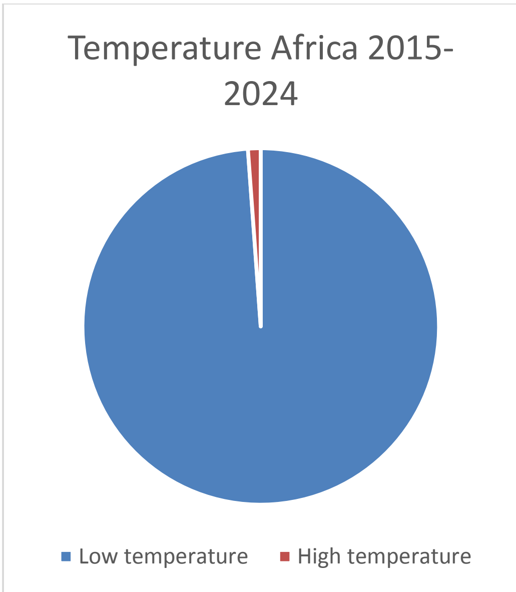


Figure 37: Temperature Africa, future

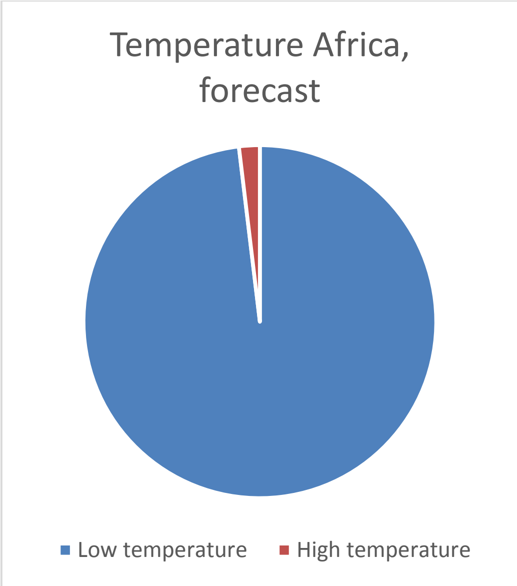


Figure 38: Temperature Africa, forecast

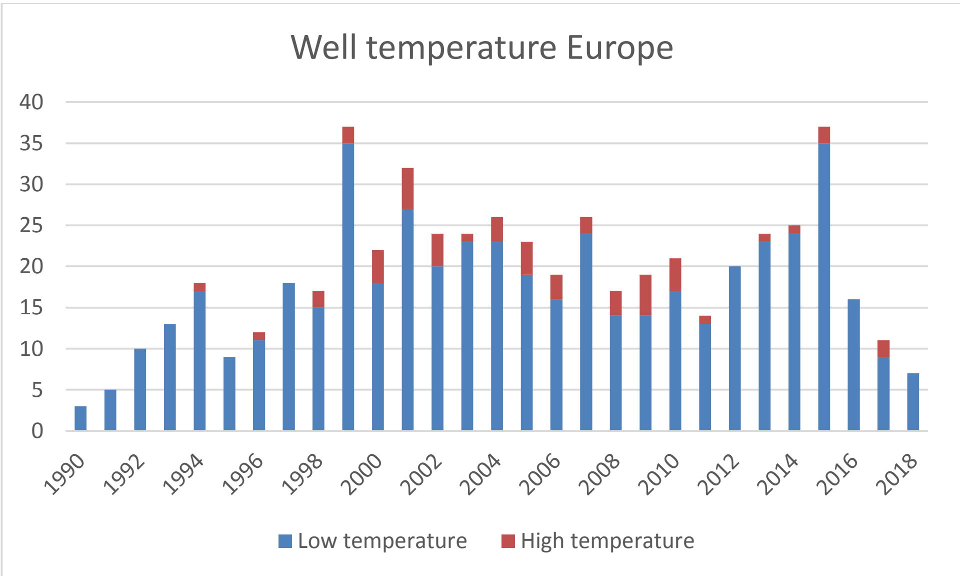


Figure 39: Well temperature Eastern region, Europe

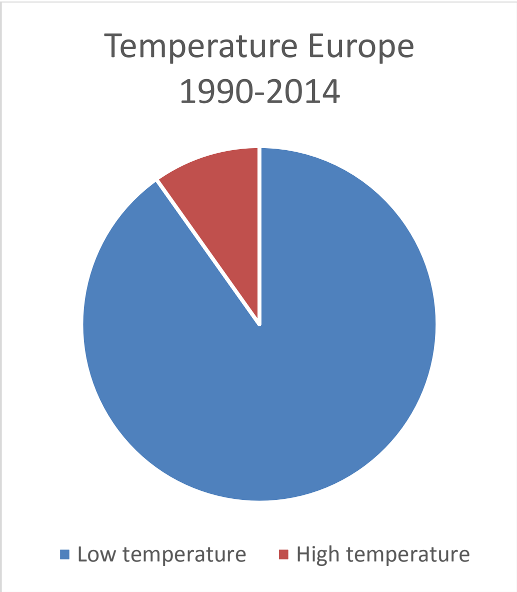


Figure 40: Temperature Europe, past

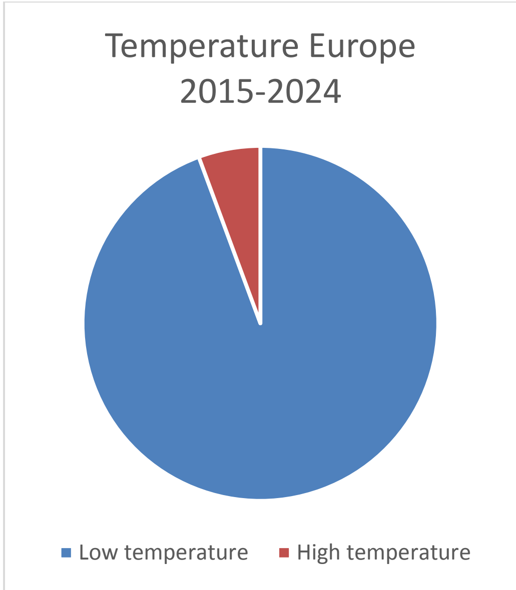


Figure 41: Temperature Europe, future

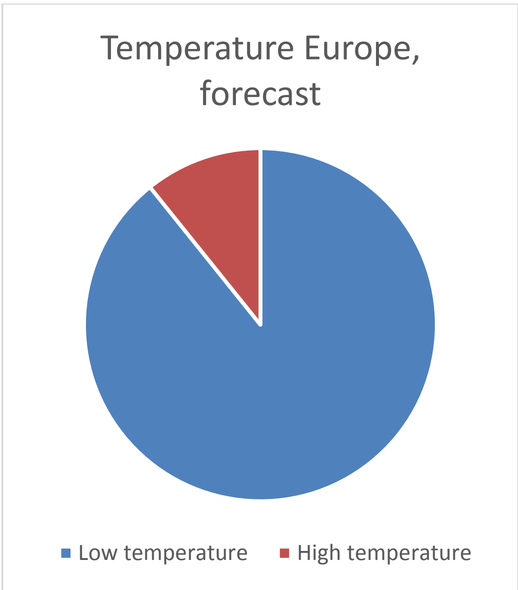


Figure 42: Temperature Europe, forecast

5.5.4 Pressure/temperature

Here in Figure 43 it is shown how the pressure and temperature of a field relate to each other, as shown there are mostly low pressure/low temperature fields. However, there is also a portion of high pressure/high temperature fields. It is read from Figure 44 that a mix of high and low is not common.

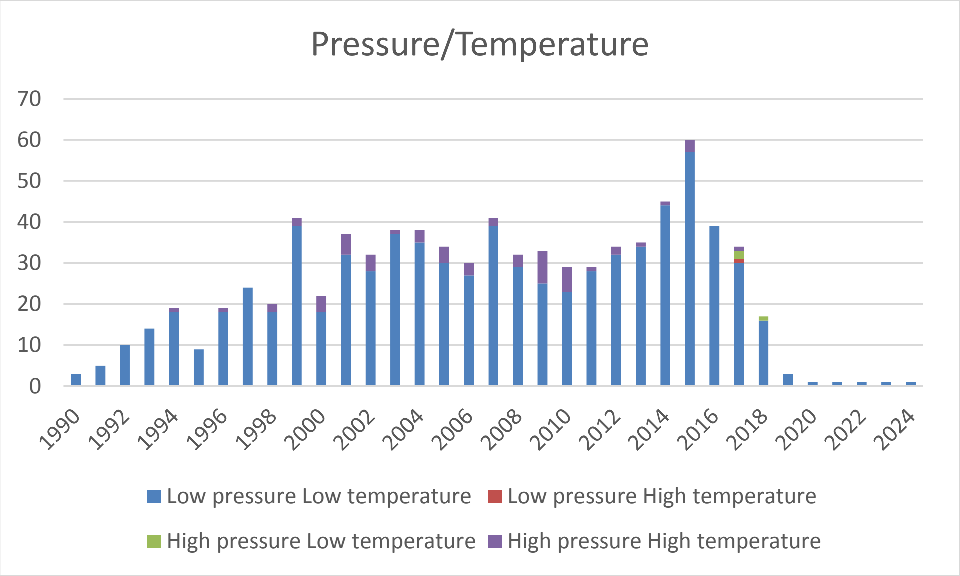


Figure 43: Pressure/temperature, Eastern region

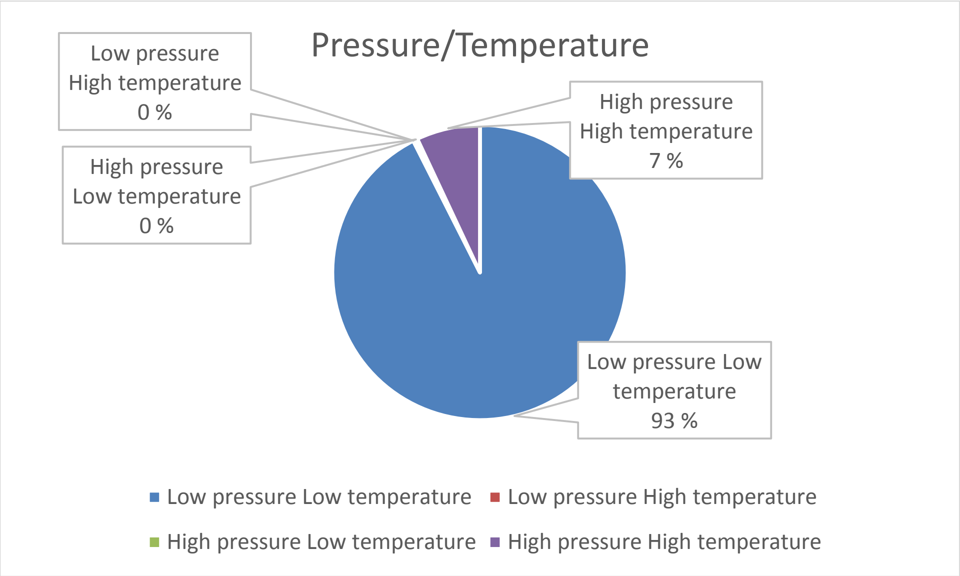


Figure 44: Pressure/temperature Eastern region, total

5.6 Conclusions

The main operators for eastern region have been identified and listed in Table 3.

Table 3: Main operator's Eastern region

Main operators Eastern region Europe		
Statoil	**Royal Dutch Shell**	**BP**
Main operators Eastern region Africa		
Total	**Eni**	**Exxon Mobile**

<u>Conclusion Eastern region Europe</u>

Based on the derived information, both from the data collection and the info from the FMC system engineering group it is assumed that the operators will standardize on VXT and with tubing hanger drift size of 7". The amount of projects with needs for HP/HT seems to be fairly low for the region, however if HP/HT is required on fields a 5" tubing hanger drift size most likely will be chosen due to XT limitations. Water depths for the north sea continental shelf range from 50 to 500 meters however future projects as deep as 1800 meters can be assumed for Barents sea projects.

<u>Conclusion Eastern region Africa</u>

Based on derived information it is assumed a mix between VXT and HXT and with tubing hanger drift size of 5" is common for Africa subsea fields, however it is assumed that Africa projects will in the future also utilize 7" bore due to high flow capacity wells. The amount of projects with needs for HP/HT seems to be fairly low for the region, however if HP/HT is required on fields a 5" tubing hanger drift size most likely will be chosen due to XT limitations. Water depths for the region seems to range from 50 to 3000 meters, however future projects as deep as 4000 meters can be assumed based on indications from system engineering group.

Conclusion Completion workover riser system

From a completion workover riser system perspective the following conclusion may be drawn.

It is assumed that operators will prefer multifunctional systems to cover several projects, not one system per project as the trend is today. This is because of the cost of the completion workover system.

The definitions of multifunctional is assumed to be, a system that:

Covers a wide range of:

- Water depths
- Well pressures
- Well temperature

Configurable for both VXT and HXT, marine riser system and well access completion workover riser system.

Based on data from Eastern region the parameters as specified in Table 4 are advised for a future completion workover riser system. Please note that sour service requirements have not been evaluated, however it is reasonable to assume a sour service compliant completion workover riser system for flexibility.

Table 4: Basic requirements for future developments, Eastern region

Specification	Requirement
Drift size	7”
Water depth	3000 meters (4000 meters may be required for extreme cases)
Well pressure	Up to 10 000 psi (690 bar)
Well Temperature	Up to 176°C (350°F)
Configurations	VXT and HXT marine riser system and well access completion work over riser systems

6 Western region

The western region consists of North and South Amerika.

6.1 Operators

The main operators for the Western region is divided in to two graphs, in Figure 45 the main operators for North America is shown, and they are Anadarko petroleum and Shell. The main operator for South America is shown in Figure 46 and is Petrobras.

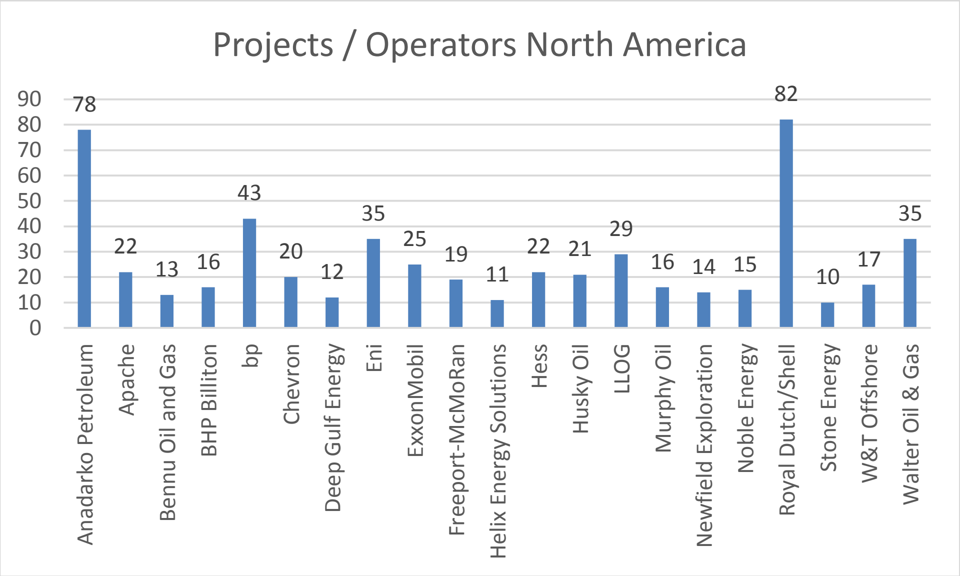


Figure 45: Operators Western region, North America

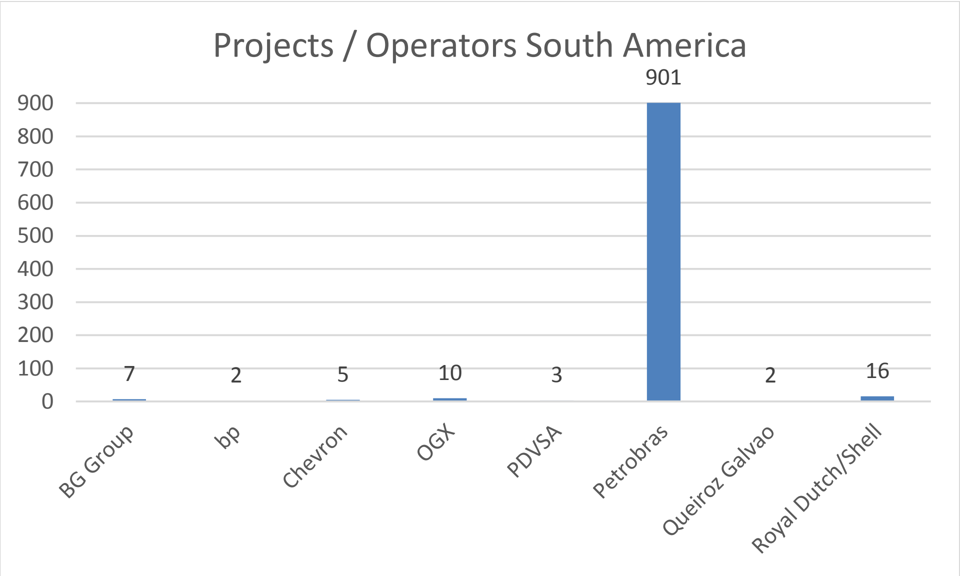


Figure 46: Operators Western region, South America

6.2 XT type

In the Western region it shows from Figure 47 and Figure 48 that there are more and more vertical XT used. Both the FMC deliveries shown in Figure 49 and the forecast for the future in Figure 50 also has more vertical XT. This can be explained by the fact that there has been used a 5” drift size as a standard in this area, this is shown by Figure 53 in chapter 6.3 and therefore there were not necessary with a horizontal XT, who earlier, as explained in chapter 4.2 was the only tree that could have a drift size of 7”.

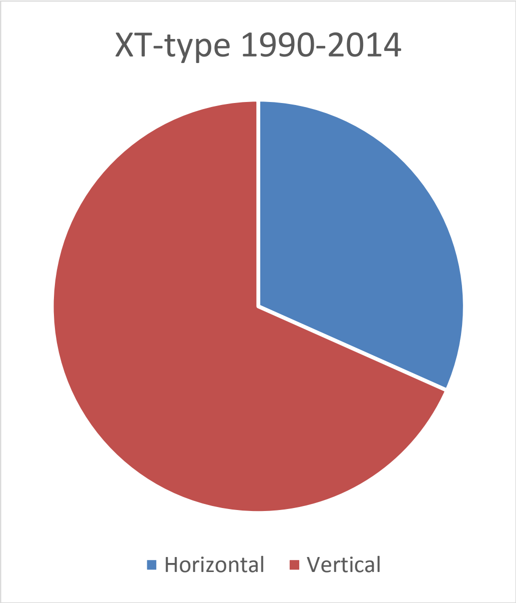


Figure 47: XT-type Western region, past

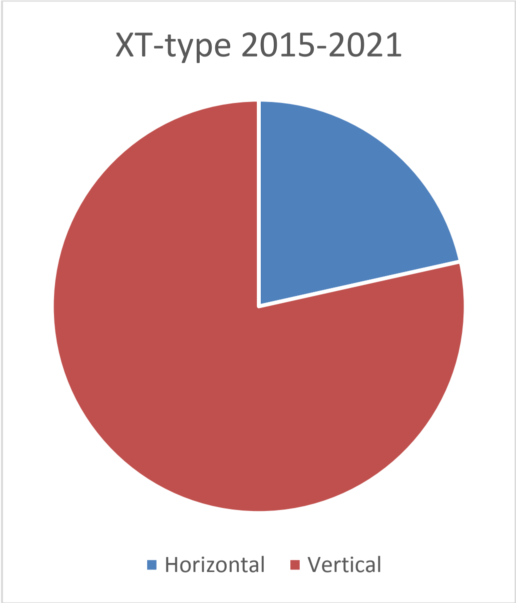


Figure 48: XT-type Western region, future

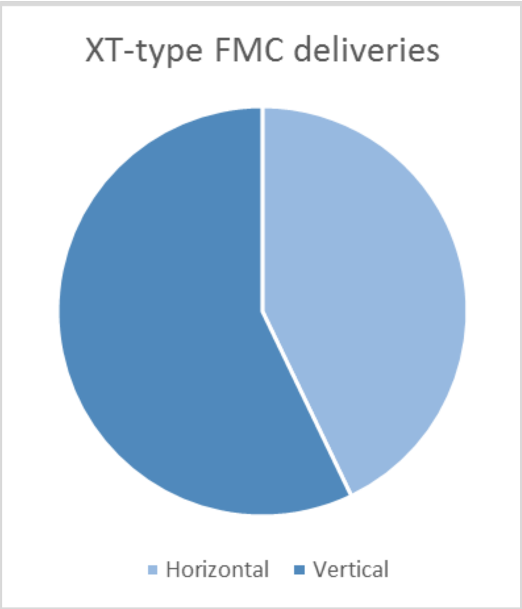


Figure 49: XT-type Western region, FMC

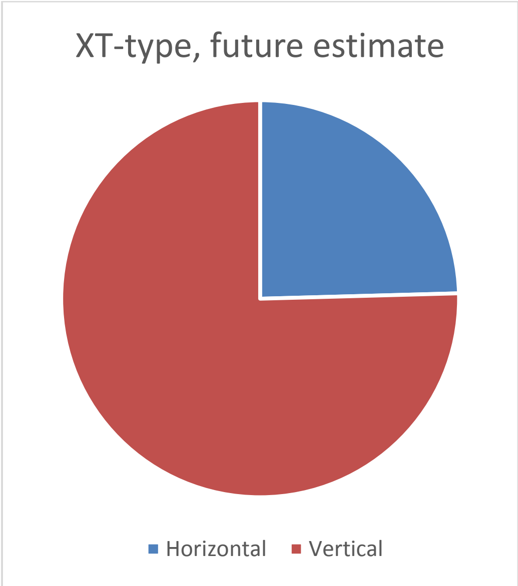


Figure 50: XT-type Western region, estimate

The main operator's choice of XT type is shown in Figure 51 and Figure 52 Petrobras and Shell uses mostly VXT for their projects in this area. However, Anadarko chooses more HXT.

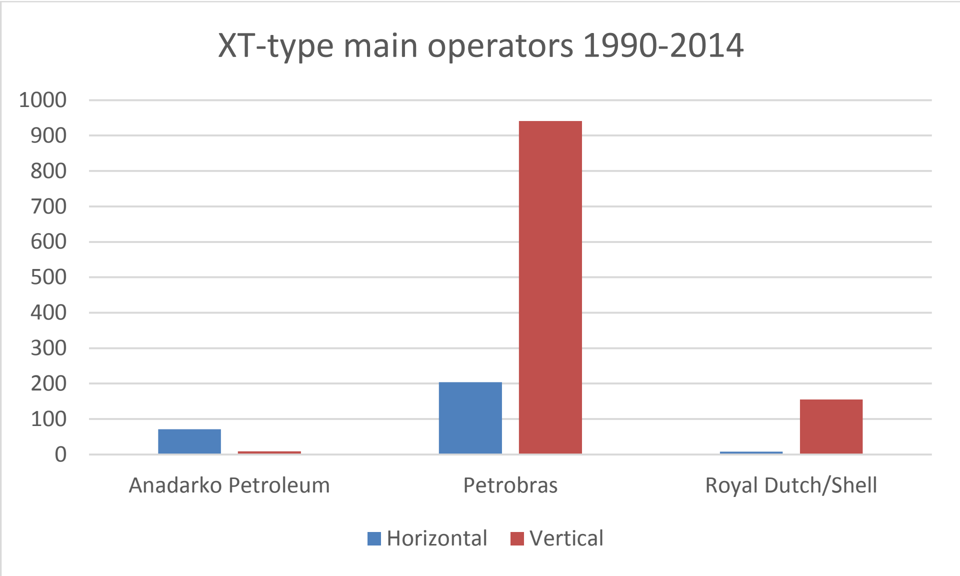


Figure 51: XT-type main operators, Western region, past

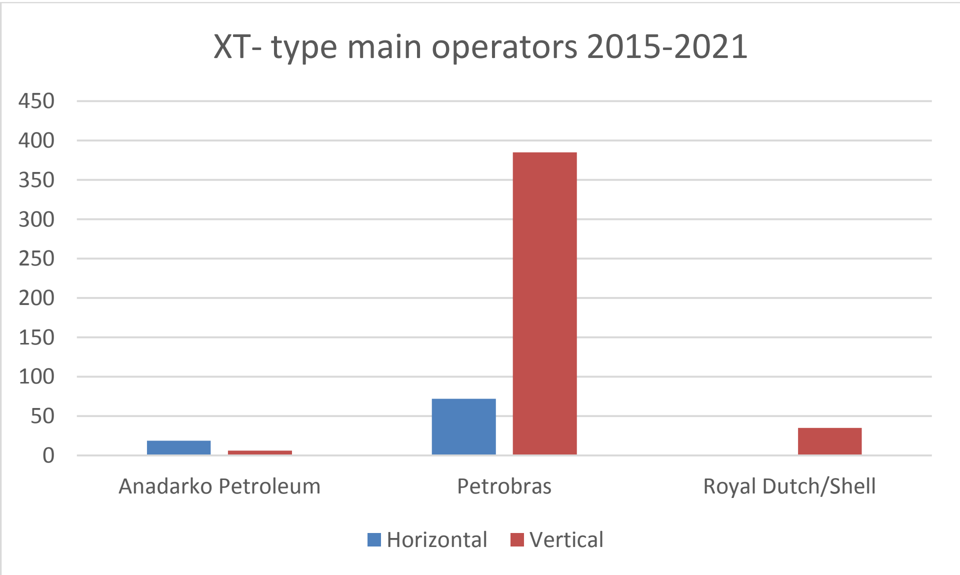


Figure 52: XT-type main operators, Western region, future

6.3 Drift size

The tubing hanger drift sizes as delivered by FMC is shown in Figure 53, the information presented is based on number of projects. There has been mostly small sizes for this region, mostly 4” and 5”, this can be explained by the size and shape of the reservoirs. If a reservoir is large in area but has a small height there is no use for large bore in the tubing, the amount of oil and gas will not increase that much with a larger bore, therefore the operator chooses a smaller drift size, which is cheaper than a larger one.

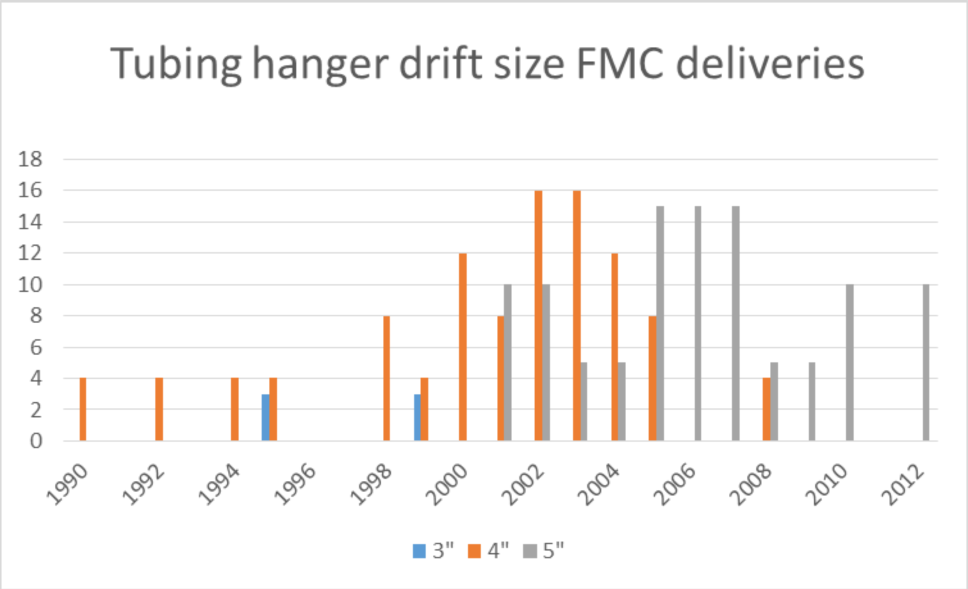


Figure 53: Drift size Western region, FMC

6.4 Operation mode

The information derived in this section is based on mail and phone conversation with FMC system engineering group for well access in Brazil and Houston.

For oil and gas fields in Western region the operation modes are highly dependent on type of XT chosen as well as operator experience and other factors. However, a trend of the operation modes as defined below is identified.

VXT

1. Drill well with marine riser and BOP
2. Install production tubing and tubing hanger in marine riser and BOP with simplified landing string
3. Install VXT either on drill pipe from rig or on wire from boat.
4. Well test production from a well access completion workover riser system

HXT

1. Drill well with marine riser and BOP
2. Install HXT either on drill pipe from rig or on wire from boat.
3. Install production tubing and tubing hanger in marine riser and BOP with simplified landing string
4. Well test production from a well access completion workover riser system

6.5 Field parameters

6.5.1 Water depth

The water depth evaluation has been divided between North and South America as shown in Figure 54 and Figure 55. As seen for the North America, project varies between 50 to 3000 meters of water depth. For South America projects, the water depth ranges from 50 to 2800 meters.

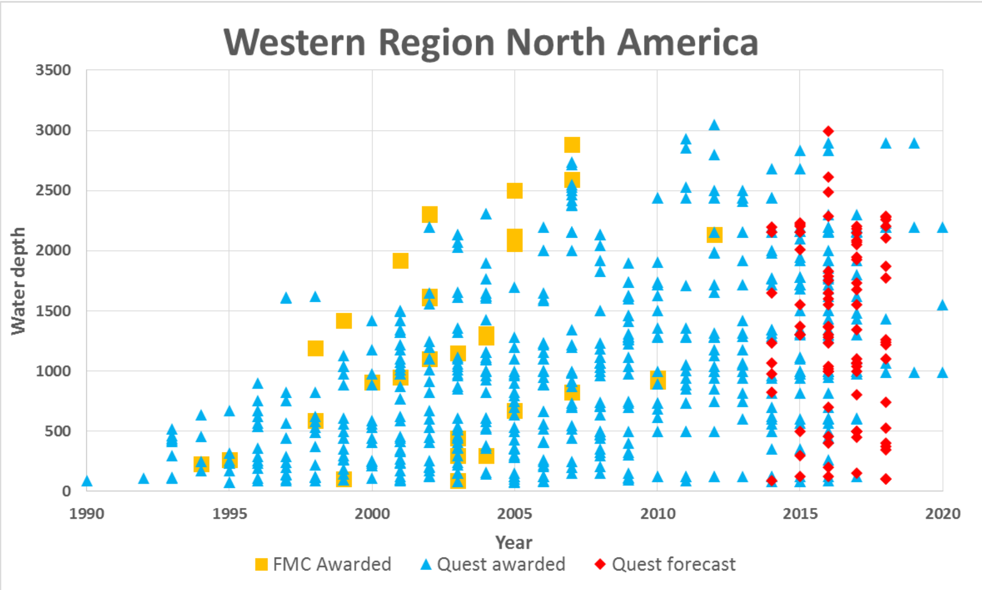


Figure 54: Water depth Western region North America

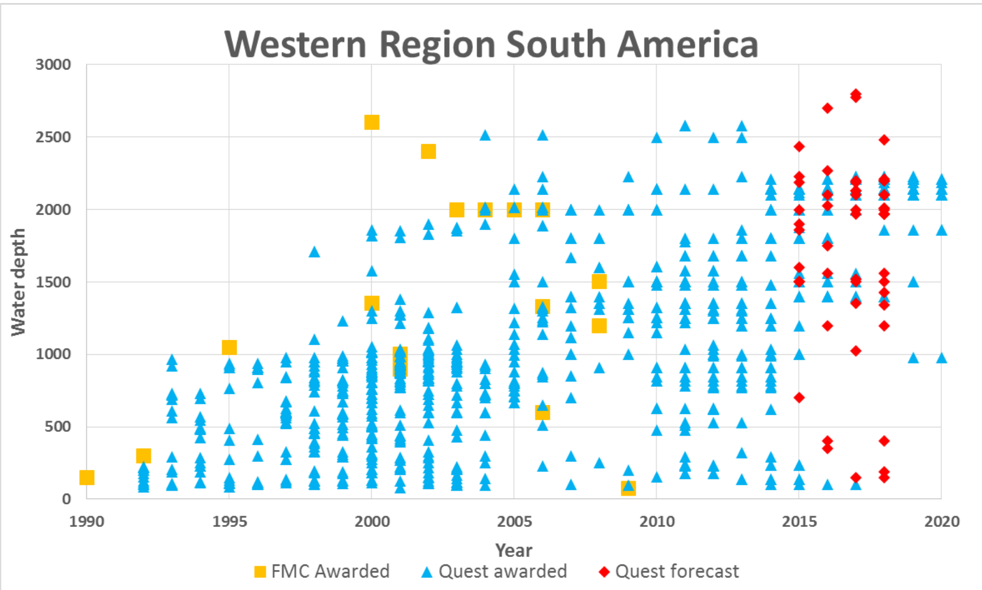


Figure 55: Water depth Western region South America

6.5.2 Well pressure

For the well pressure the Figure 56 shows the pressure for all of the Western region, the well pressure is divided in to high and low pressure this is the info from the Quest database, were high pressure means pressures above 10 000 psi. Low pressure is the pressure from 10 000 psi and below.

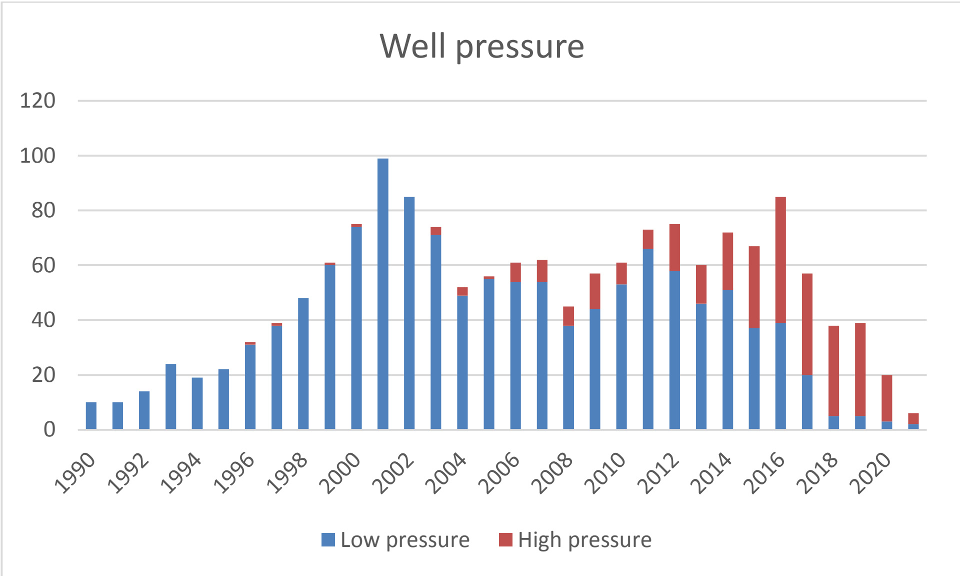


Figure 56: Well pressure Western region

As shown in Figure 57 and Figure 58 the amount of high-pressure fields have increased significantly from past to future. This can be explained by the increasing technology developments in the offshore industry. Also the forecasted projects in Figure 59 shows an increasing trend for high pressure.

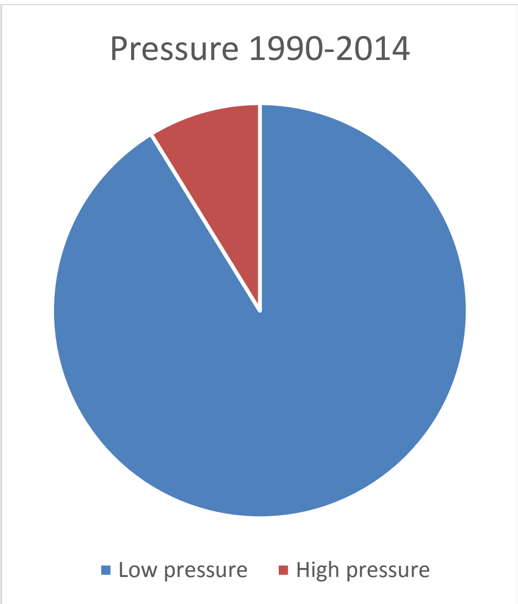


Figure 57: Pressure Western region, past

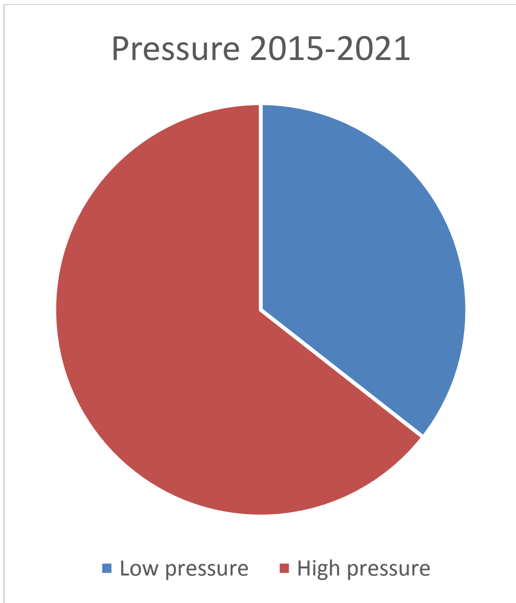


Figure 58: Pressure Western region, future

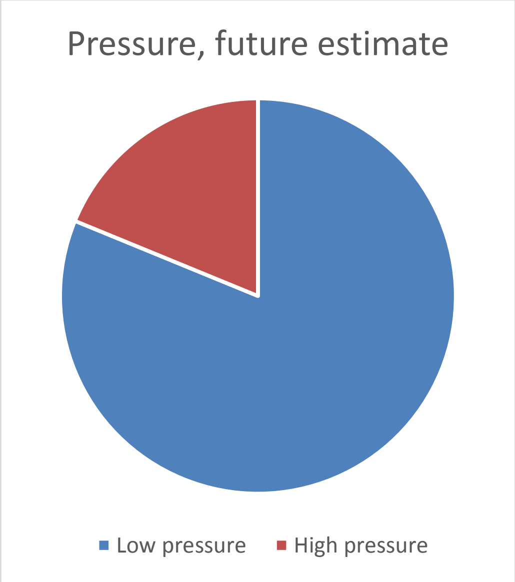


Figure 59: Pressure Western region, estimate

6.5.3 Well temperature

For the well temperature the Figure 60 shows the temperature for all of the Western region, the well temperature as well, is divided in to high and low temperature this is the info from the Quest database, were high temperature means temperatures above 176°C (350F). Low temperature is the temperatures from 176°C and below.

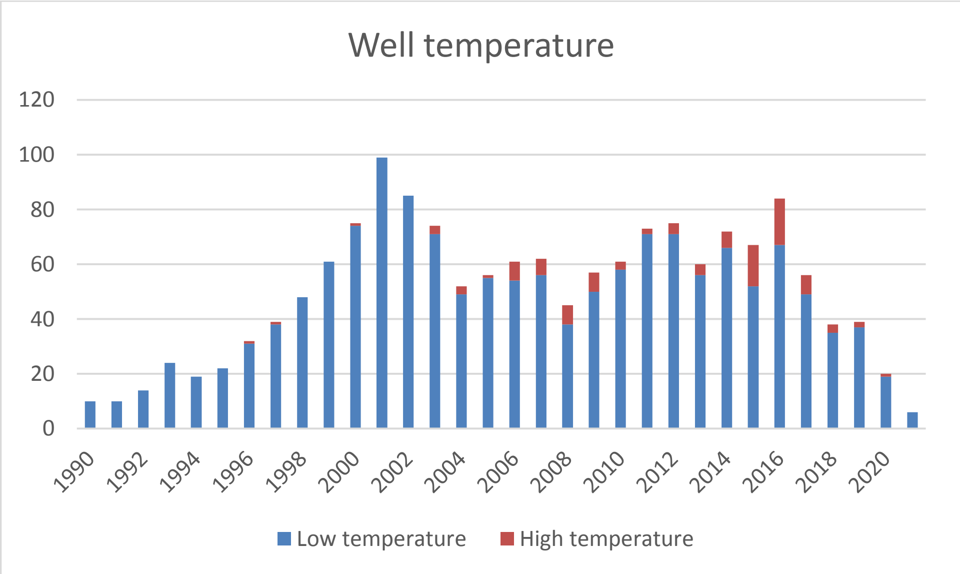


Figure 60: Well temperature Western region

As shown by Figure 61 and Figure 62 the temperature is also increasing from past to future also here the technology developments may have a part in this trend. The forecast for the future in Figure 63 shows the same trend.

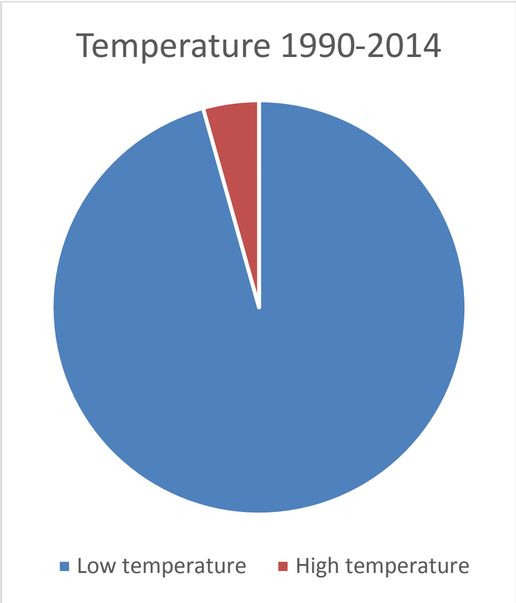


Figure 61: Temperature Western region, past

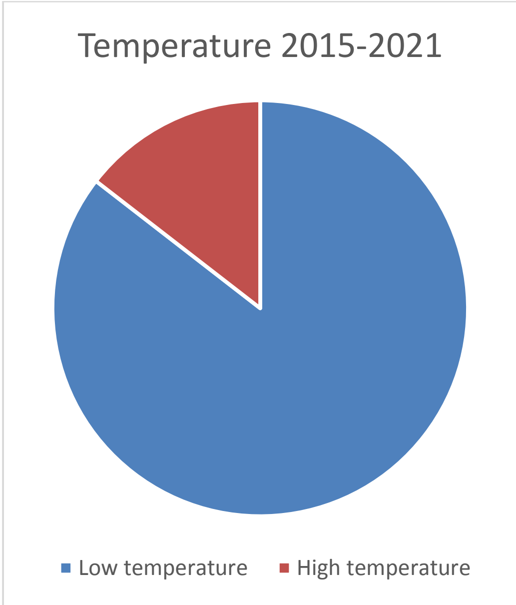


Figure 62: Temperature Western region, future

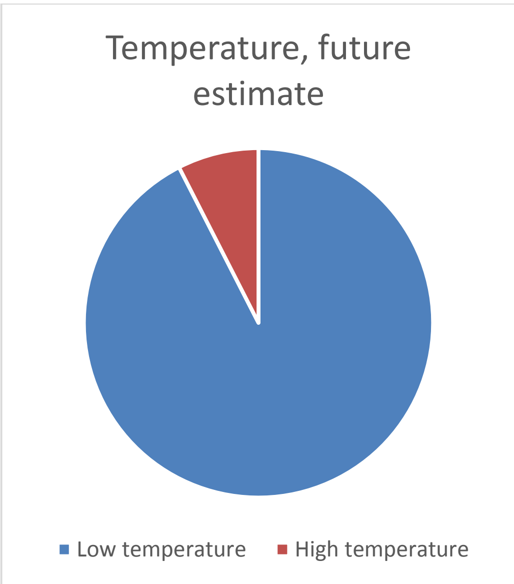


Figure 63: Temperature Western region, estimate

6.5.4 Pressure/temperature

Here in Figure 64 it is shown how the pressure and temperature of a field relate to each other, as shown there are mostly low pressure/low temperature fields, however there are also a portion of high pressure/high temperature, and high pressure/low temperature fields. It is read from Figure 65 that low pressure/high temperature fields is not common.

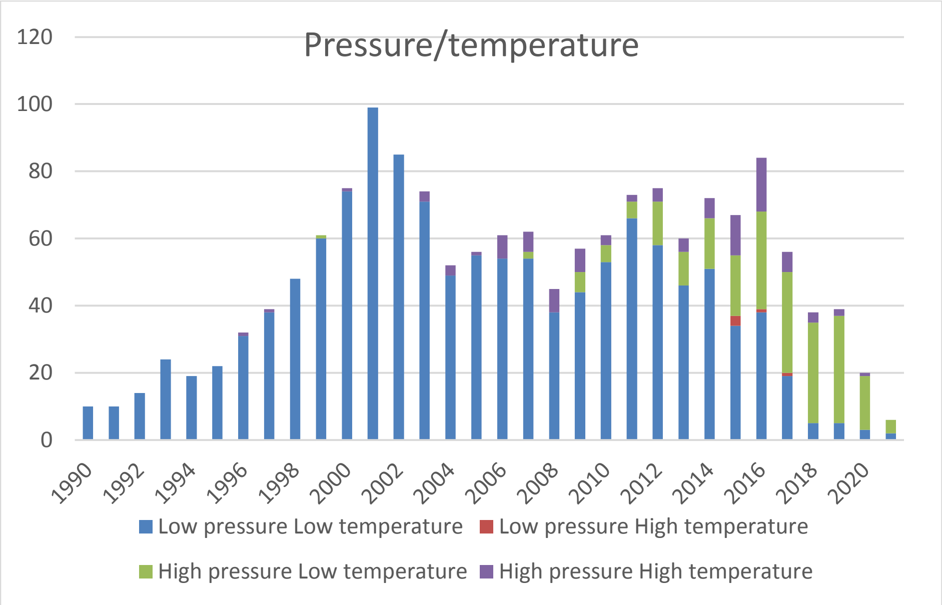


Figure 64: Pressure/temperature Western region

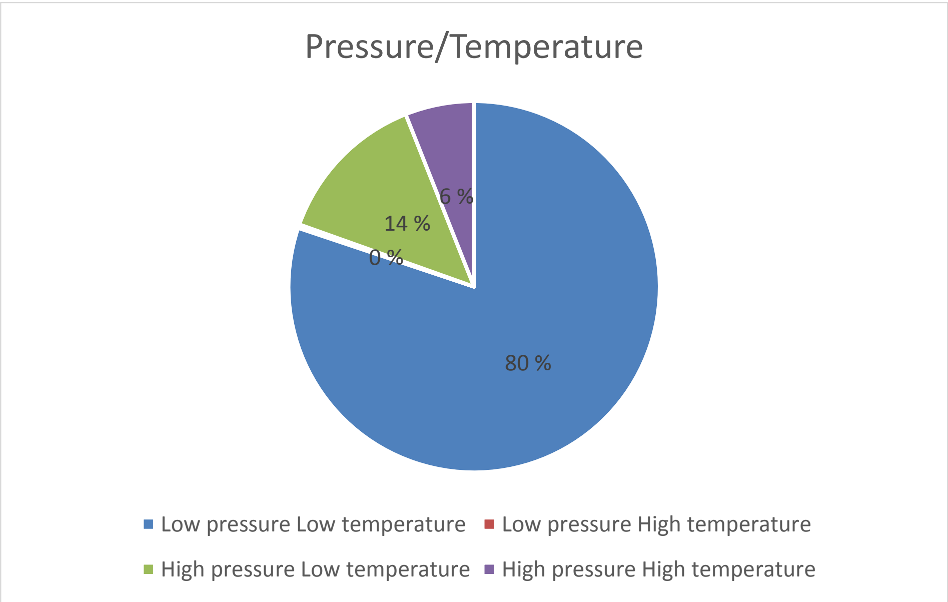


Figure 65: Pressure/temperature Western region, total

6.6 Conclusions

The main operators for Western region have been identified and listed in Table 5

Table 5: Main operator's Western region

Main operators Western region North America	
Royal Dutch Shell	**Anadarko**
Main operator Western region South America	
Petrobras	

Conclusion Western region North and South America

Based on the above derived information it is assumed that the operators will standardize on VXT and with tubing hanger drift size of 5", however some field may also require 7" tubing hanger drift size due to wells that require high flow rates. The amount of projects with needs for HP/HT seems to increase for the region, however for HP/HT wells on fields a 5" tubing hanger drift size most likely will be chosen due to XT limitations. Water depths for Western region ranges from 50 to 3000 meters.

Conclusion Completion workover riser system

From a completion workover riser system perspective the following conclusion may be drawn.

The operators in western region prefers multifunctional systems to cover several projects.

The definitions of multifunctional is assumed to be, a system that:

Covers a wide range of:

- Water depths
- Well pressures
- Well temperature

Configurable for both VXT and HXT, marine riser system and well access completion workover riser system.

Based on data from Western region the parameters as specified in Table 6 are advised for a future completion workover riser system. Please note that sour service requirements have not been evaluated, however it is reasonable to assume a sour service compliant completion workover riser system for flexibility.

Table 6: Basic requirements for future developments, Western region

Specification	Requirement
Drift size	5”
Water depth	3000 meters
Well pressure	15 000 psi (1034 bar) and above
Well Temperature	Up to 176°C (350°F) and above
Configurations	VXT marine riser system and well access completion work over riser systems

7 Asia pacific

Asia pacific region consists of Asia and Oceania.

7.1 Operators

As shown by Figure 66 the main operators in the Asia pacific region is BHP Billiton, ConocoPhillips and Woodside petroleum.

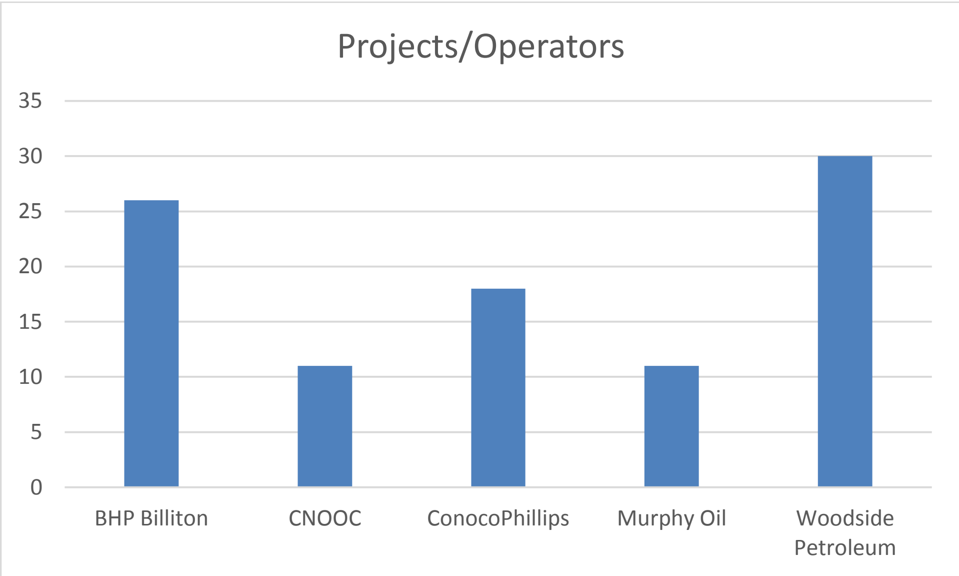


Figure 66: Operators Asia Pacific region

7.2 XT type

In the Asia Pacific region it shows from Figure 67 and Figure 68 that there is a increasing trend for delivering horizontal XT, based on quest awarded. However Figure 69 shows that FMC has delivered more vertical XT, this can be explained by the fact that FMCs deliveries depend on their customers, and their customers for this region have preferred VXT. The quest forecasted projects for the future shown in Figure 70 identifies a trend for VXT systems.

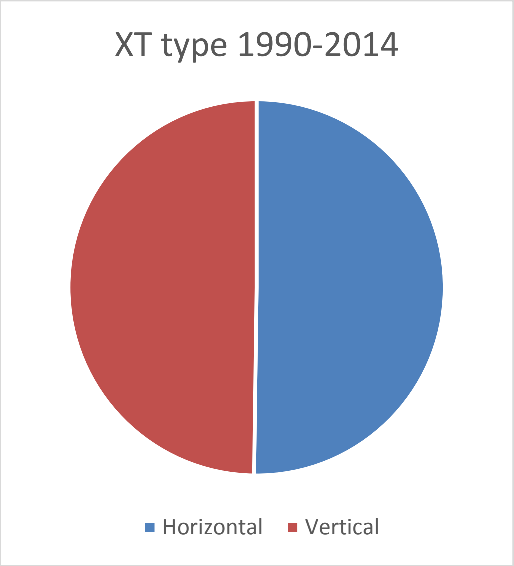


Figure 67: XT-type Asia Pacific, past

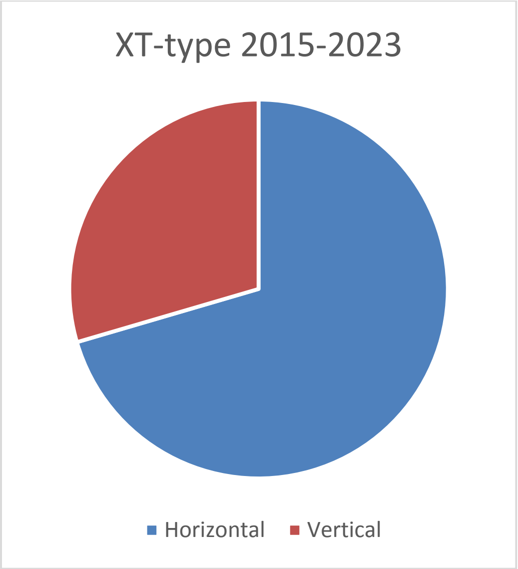


Figure 68: XT-type Asia Pacific, future

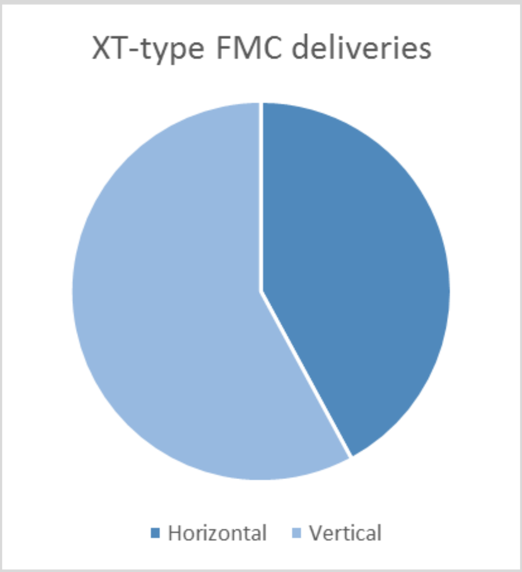


Figure 69: XT-type Asia Pacific, FMC

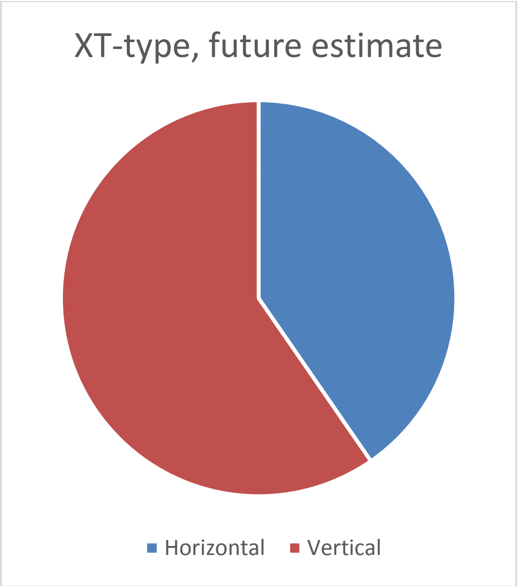


Figure 70: XT-type Asia Pacific, estimate

The main operator's choice of XT type is shown in Figure 71 and Figure 72, ConocoPhillips and Woodside Petroleum prefers VXT for their projects in this area. However, BHP Billiton uses both HXT and VXT.

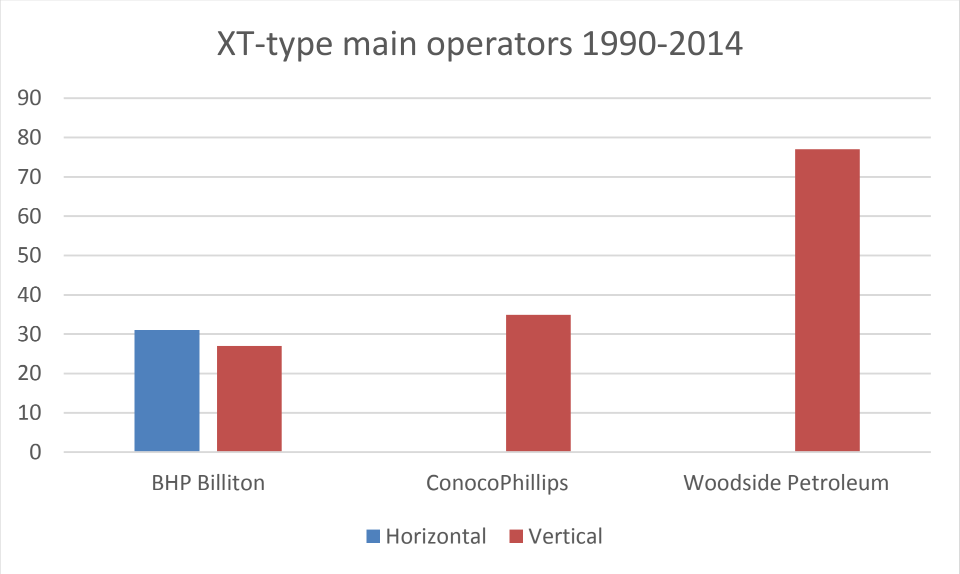


Figure 71: XT-type main operators Asia Pacific, past

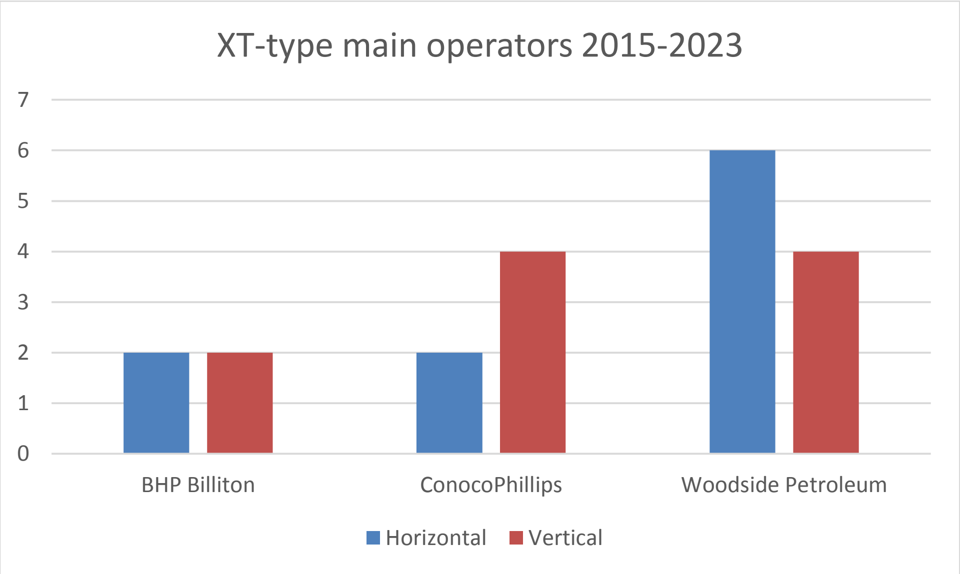


Figure 72: XT-type main operators Asia Pacific, future

As shown in Figure 68 there is chosen mostly HXT for this region in the future, this is not consistent with the preferences of the main operators shown in Figure 72 this can be explained that the previous main operators do not have that much projects planned for the future. As shown in Figure 73 there are some new operators that have taken over as the ones with more projects or more large projects (with more XT's/bigger fields). From the table there can be read that Chevron, INPEX and Husky Oil all are large operators for the future, and they all prefer HXT, this can be based on the companies experiences from other regions.

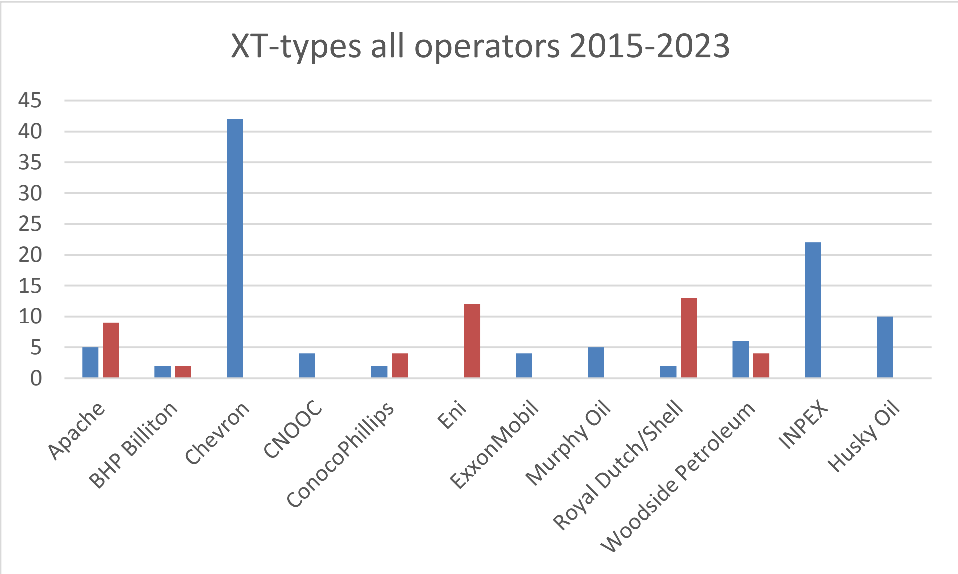


Figure 73: XT-type all operators, Asia Pacific, future

7.3 Drift size

The tubing hanger drift sizes as delivered by FMC is shown in Figure 74, there is tubing hangers in all sizes and the size is increasing, the latest years there has only been used 5" and 7".

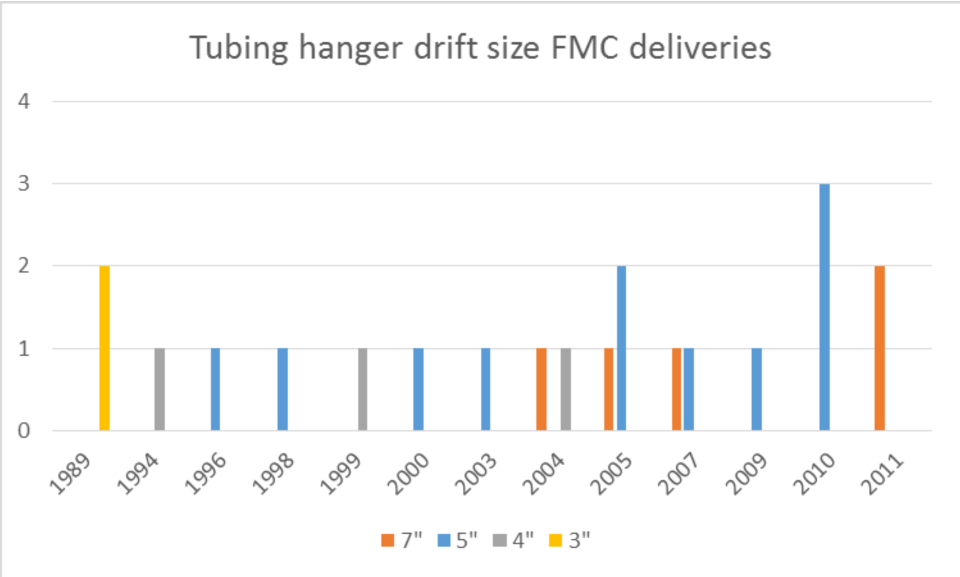


Figure 74: Drift size Asia Pacific region, FMC

7.4 Operation mode

The information derived in this section is based on mail and phone conversation with FMC system engineering group for well access in Singapore and a screening of delivered projects with completion and workover riser packages.

For oil and gas fields in Asia pacific the operation modes are highly dependent on type of XT chosen as well as operator experience and other factors. However, a trend of the operation modes as defined below is identified.

VXT

1. Drill well with marine riser and BOP
2. Install production tubing and tubing hanger in marine riser and BOP with simplified landing string
3. Install VXT either on drill pipe from rig or on wire from boat.
4. Well test production from a well access completion workover riser system

HXT

1. Drill well with marine riser and BOP
2. Install HXT either on drill pipe from rig or on wire from boat.
3. Install production tubing and tubing hanger in marine riser and BOP with simplified landing string
4. Well test production from a well access completion workover riser system

7.5 Field parameters

7.5.1 Water depth

As seen for the Asia pacific Figure 75 the main collection of projects are ranging from 50 to 1500 meters, however there are some deep water projects located outside of Indonesia with a water depth down to 2900 meters.

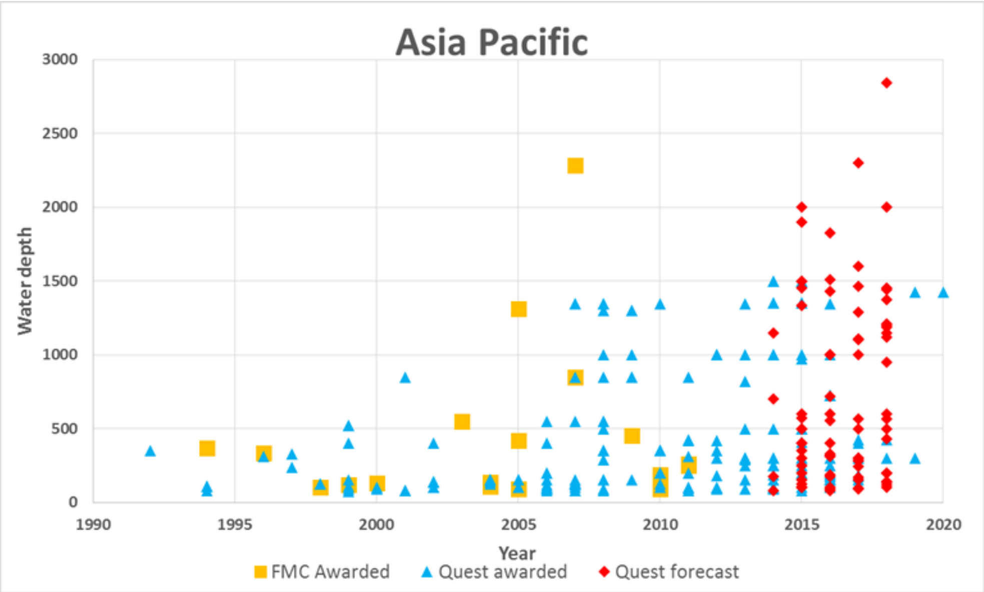


Figure 75: Water depth's Asia Pacific

7.5.2 Well pressure

For the well pressure the Figure 76 shows the pressure for the Asia Pacific region, the well pressure is divided in to high and low pressure this is the info from the Quest database, were high pressure means pressure from above 10 000 psi. Low pressure is the pressure from 10 000 psi and below.

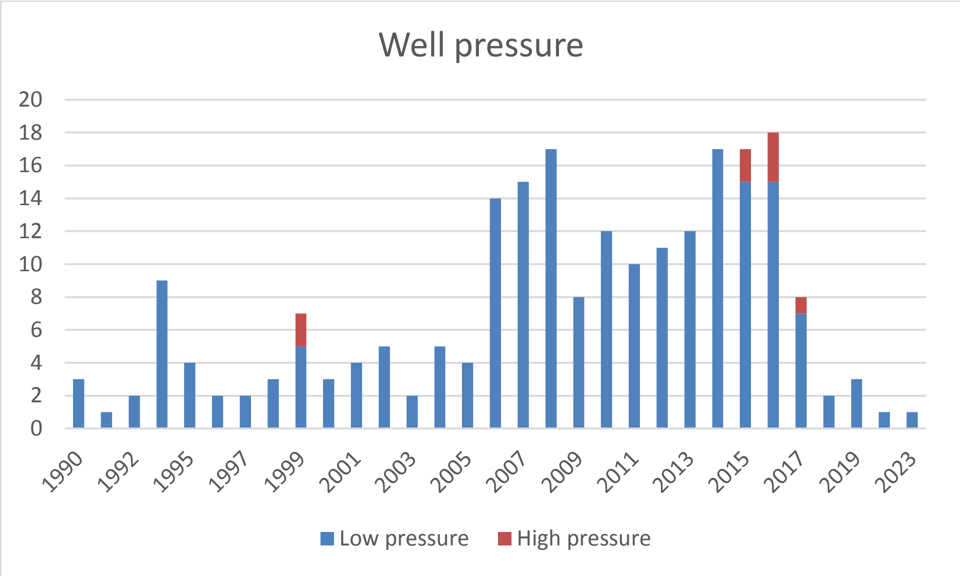


Figure 76: Well pressure Asia Pacific region

As shown in Figure 77 and Figure 78 the amount of high-pressure fields have increased significantly from past to future. This can be explained by the increasing technology developments in the offshore industry. However Figure 79, do not show so many high pressure fields.

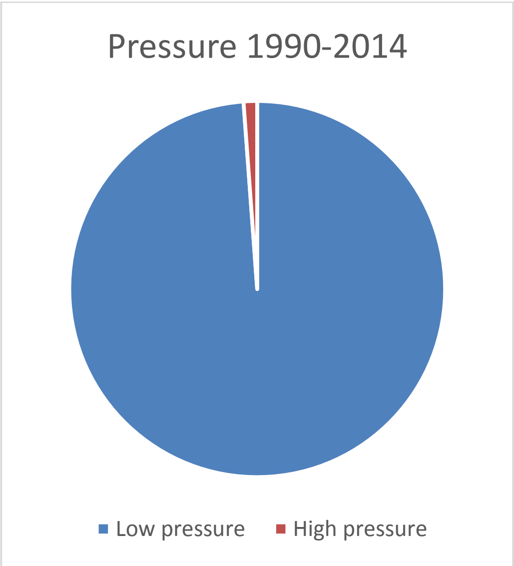


Figure 77: Pressure Asia Pacific, past

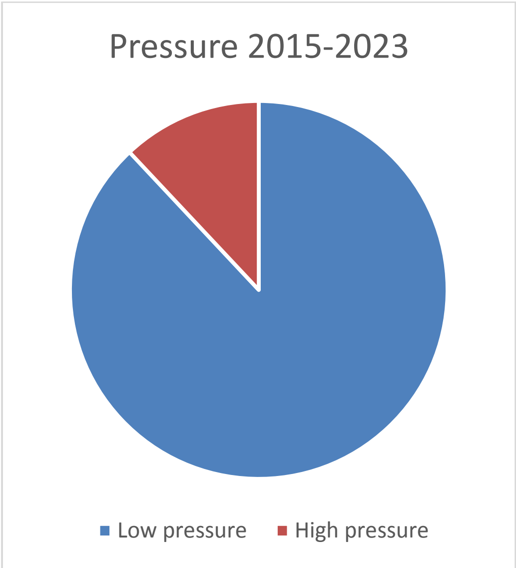


Figure 78: Pressure Asia Pacific, future

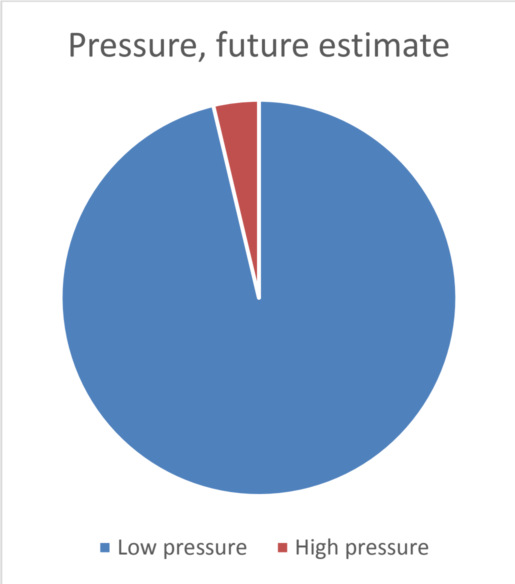


Figure 79: Pressure Asia Pacific, estimate

7.5.3 Well temperature

For the well temperature the Figure 80 shows the temperature for all of the region, the well temperature as well, is divided in to high and low temperature this is the info from the Quest database, were high temperature means temperatures from above 176°C (350F). Low temperature is the temperatures from 176°C and below.

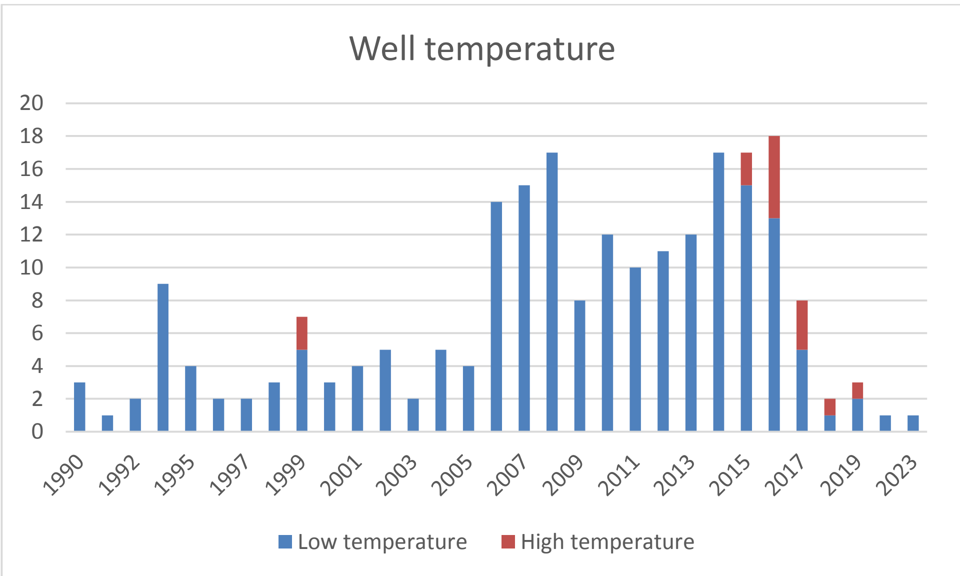


Figure 80: Well temperature Asia Pacific region

As shown by Figure 81 and Figure 82 the temperature is also increasing significantly from past to future also here the technology developments may have a part in this trend. In Figure 83 it shows that the temperature for the forecasted projects are not that high.

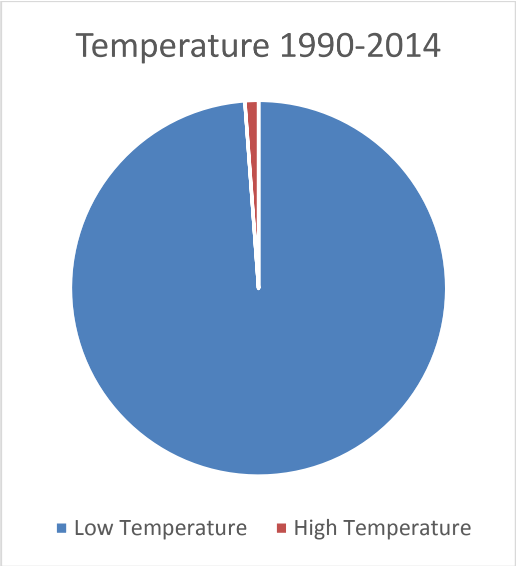


Figure 81: Temperature Asia Pacific, past

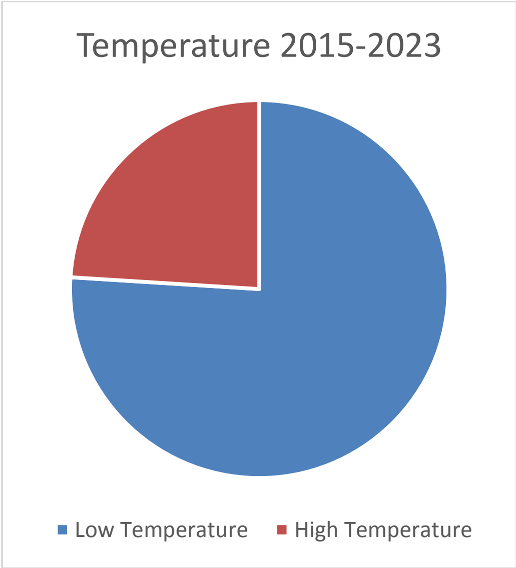


Figure 82: Temperature Asia Pacific, future

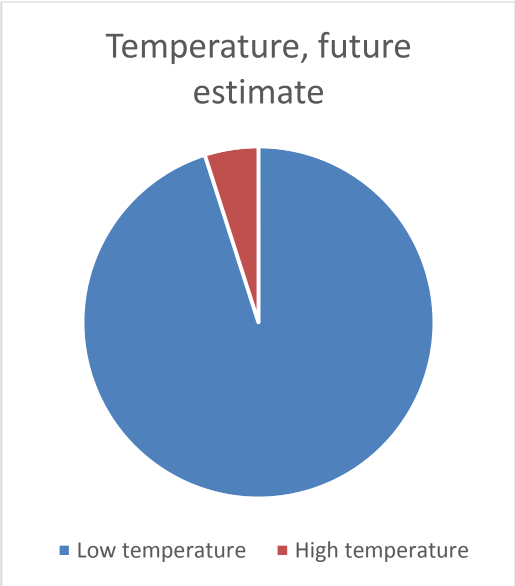


Figure 83: Temperature Asia Pacific, estimate

7.5.4 Pressure/temperature

Here in Figure 84 it is shown how the pressure and temperature of a field relate to each other, as shown there are mostly low pressure/low temperature fields, however, from Figure 85 it is shown that there also are a small portion of high pressure/high temperature and high pressure/low temperature fields. There are no low pressure/high temperature fields in this region.

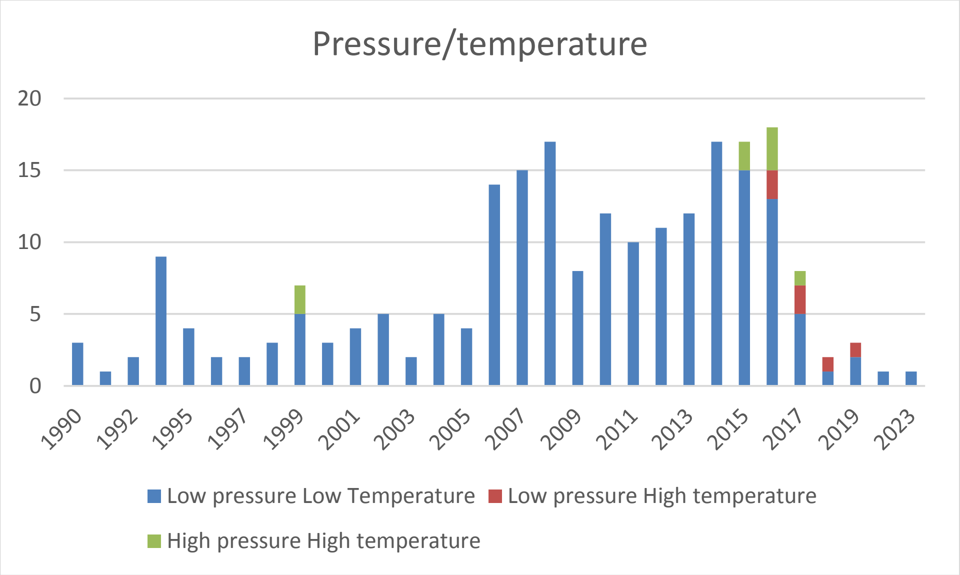


Figure 84: Pressure/temperature Asia Pacific region

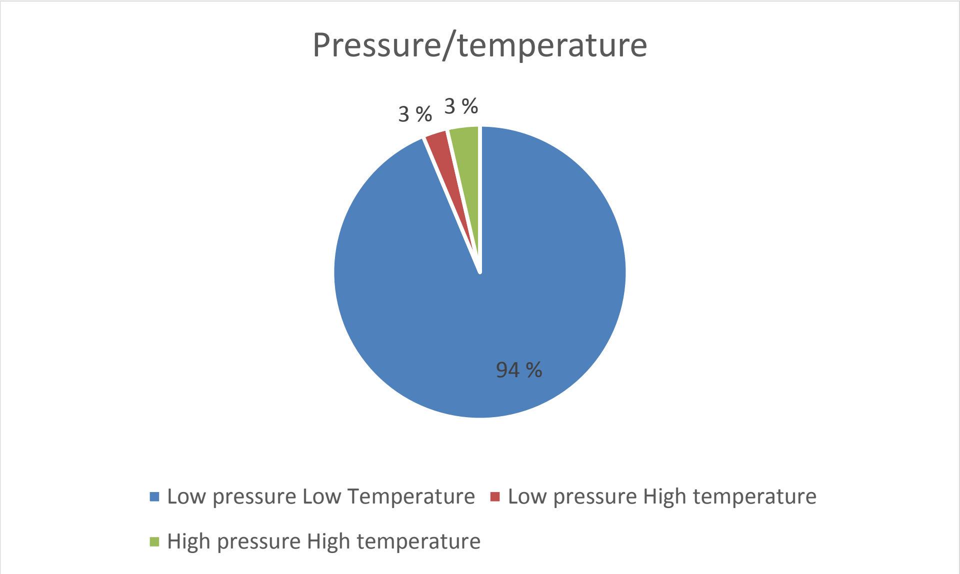


Figure 85: Pressure/temperature Asia Pacific region, total

7.6 Conclusions

The main operators for Asia pacific region have been identified and listed in Table 7

Table 7: Main operator's Asia Pacific.

Main operators Asia pacific region		
Bhp Billiton	**Conoco Phillips**	**Woodside**
Additional main operators for the future		
Inpex	**Husky Energy**	**Chevron**

Conclusion Asia pacific region

Based on the above derived information it is assumed a mix between VXT and HXT with tubing hanger drift size ranging from 5" to 7" is common for Asia pacific subsea fields. The amount of projects with needs for HP/HT seems to be fairly low for the region, however if HP/HT is required on fields a 5" tubing hanger drift size most likely will be chosen due to XT limitations. Water depths for the region seems to range from 50 to 2900 meters.

Conclusion Completion workover riser system

From a completion workover riser system perspective the following conclusion may be drawn.

It is assumed that operators will prefer multifunctional systems to cover several projects, not one system per project as the trend is today.

The definitions of multifunctional is assumed to be, a system that:

Covers a wide range of:

- Water depths
- Well pressures
- Well temperature

Configurable for both VXT and HXT, marine riser system and well access completion workover riser system.

Based on data from Asia Pacific region the parameters as specified in Table 8 are advised for a future completion workover riser system. Please note that sour service requirements have not been evaluated, however it is reasonable to assume a sour service compliant completion workover riser system for flexibility.

Table 8: Basic requirements for future developements, Asia Pacific region

Specification	**Requirement**
Drift size	7”
Water depth	2900 meters
Well pressure	Up to 10 000 psi (690 bar)
Well Temperature	Up to 176°C (350°F)
Configurations	VXT and HXT marine riser system and well access completion work over riser systems

8 Overall conclusions

The following overall conclusion can be drawn based on detailed conclusions from each of the defined regions:

- Eastern Region
- Western Region
- Asia Pacific

It is seen that the marked globally does not have a specific trend in standardizing on type of XT. Also the range of drift size, as well as pressure, temperature and water depth varies largely across regions.

However based on data derived it is advised to consider two types of completion workover riser configurations for future development. The proposed systems will combined cover most of the subsea marked in the future.

Workover riser system

- Configurable for VXT and HXT both in marine riser and well access completion workover riser system.
- Detail parameters are given in Table 9

Table 9: Basic requirements for future developments, global

Description	Drift size	Well pressure	Well temperature	Water depth	Sour service
5” 15K + Deep water HP/HT	5”	15 000 psi (1034 bar) +	176°C (350°F)+	3000 m	Yes
7” 10K Deep water	7”	10 000 psi (690 bar)	Up to 176°C (350°F)	4000 m	Yes

9 References

Table 10: Reference documents

No	Document no	Document name
1.	4110	Data collection FMC deliveries (excel)
2.	4120	Data collection FMC tender (excel)
3.	4130	Data collection water depth (excel)
4.	4140	Quest subsea database forecast (excel)
5.	4150	Quest subsea trees global awarded (excel)
6.	4210	Design basis Phase 1

Table 11: Data sources

Source	Description	File name
Quest subsea database (www.questoffshore.com/subsea-database)	Populated xls sheets from quest data base for awarded and forecasted projects	Data collection water depth, (Ref/3) Quest subsea database forecast, (Ref/4) Quest subsea trees global awarded, (Ref/5)
FMC internet home page (www.fmcti.com)	Populated xls sheets.	Data collection FMC deliveries, (Ref/1) Data collection water depth, (Ref/3)
FMC Tender database	Populated xls sheet based on database	Data collection FMC tender, (Ref/2)
FMC Kongsberg WAS system engineering group	Meeting: System engineering manager Meeting: Technical manager riser and rig interface product Conversations: Specialist system engineer	Not applicable
FMC Kongsberg field development group	Meeting: Manager field development Norway	Not applicable
FMC Brazil WAS system engineering group	Mail communication: System engineer	Not applicable
FMC Houston WAS system engineering group	Mail communication and phone conversation: WAS Technical manager	Not applicable
FMC Singapore WAS system engineering group	Mail communication and phone conversation: Chief engineer	Not applicable

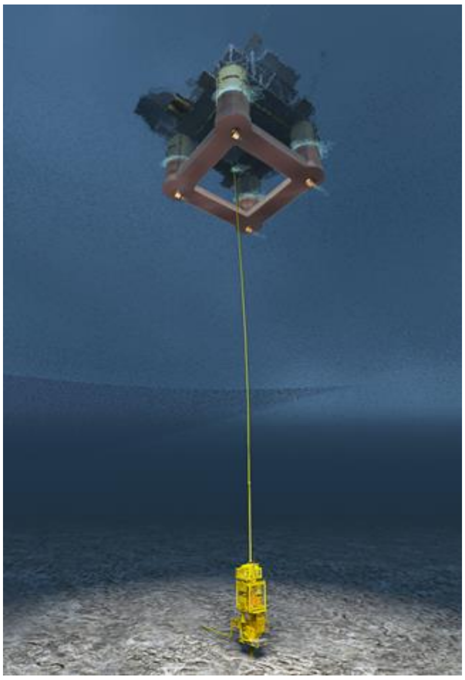
10 Document revision history

Table 12: Revision history

Rev	Date	Prepared By	Reviewed By	Changes
1.0	23.03.15	Kjersti Schrøder Anthonsen	David Snarheim	First releas
2.0	13.05.15	Kjersti Schrøder Anthonsen	David Snarheim	Inserted ref. documents Changed report description

Map Phase 1

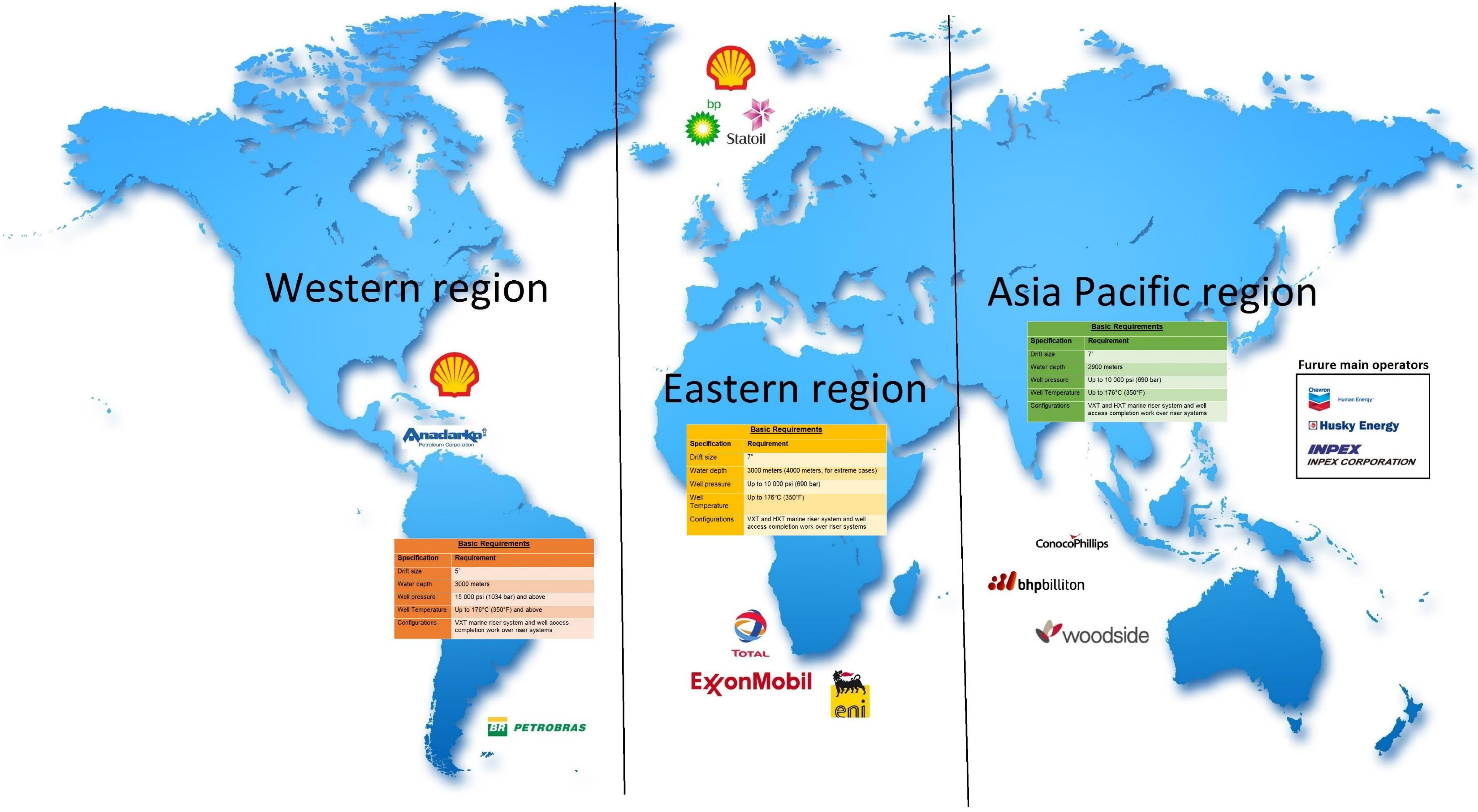
Deep Water Riser Pipe Study



Rev	Date	Prepared By	Reviewed By	Changes
1.0	23.03.2015	Kjersti Schrøder Anthonsen	David Snarheim	

DWRPS

Marked study



Western region

Basic Requirements	
Specification	**Requirement**
Drift size	5"
Water depth	3000 meters
Well pressure	15 000 psi (1034 bar) and above
Well Temperature	Up to 176°C (350°F) and above
Configurations	VXT marine riser system and well access completion work over riser systems

Eastern region

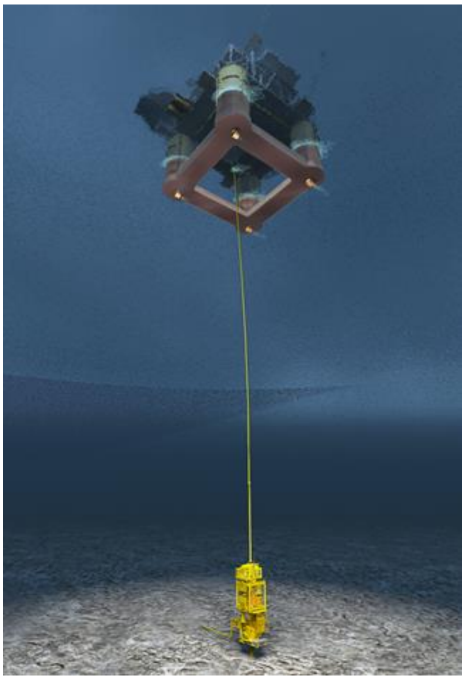
Basic Requirements	
Specification	**Requirement**
Drift size	7"
Water depth	3000 meters (4000 meters, for extreme cases)
Well pressure	Up to 10 000 psi (690 bar)
Well Temperature	Up to 176°C (350°F)
Configurations	VXT and HXT marine riser system and well access completion work over riser systems

Asia Pacific region

Basic Requirements	
Specification	**Requirement**
Drift size	7"
Water depth	2900 meters
Well pressure	Up to 10 000 psi (690 bar)
Well Temperature	Up to 176°C (350°F)
Configurations	VXT and HXT marine riser system and well access completion work over riser systems

Test Report Phase 1

Deep Water Riser Pipe Study



Rev	Date	Prepared By	Reviewed By	Changes
2.0	14.05.2015	Line Dyre-Hansen	Kjersti S. Anthonsen	See section 5

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List of Tables

Abbreviations

The following abbreviations are used throughout this document.

Abbreviation	Description
FMC	FMC Technologies Kongsberg Subsea
GR	General requirement
ID	Identification
No	Number
P1	Phase 1
V	Verification
Ref	Reference

1 Introduction

This document contains the verification results for market analysis (phase 1) of the Deep Water Riser Pipe Study. The verification is based on the requirement specifications (Ref/1) and the test specification (Ref/2) and this report documents the verification results of the final report for phase 1 (Ref/4), design basis for phase 1(Ref/3) and a market study map (Ref/5).

2 Internal verification results for phase 1

Table 1: Internal verification results for phase 1

Verification ID	V-P1-01	Date of verification	19.03.2015
Requirement ID	P1-GR-01, P1-GR-02, P1-GR-03, P1-GR-04		
Description	- Go through the documentation for phase 1 - Verify the requirements against the requirement specification - Verify the design basis phase 1 against requirement specification - Verify the report against the design basis document and the requirement specification		
Acceptance Criteria	Correct content Quality On time delivery		
Verification code	V1		
Result	Approved		
Conclusion	The design basis document and the report for phase 1 are following the requirements in the requirement specification. It’s a red line between the requirements specification, design basis phase 1 and the report phase 1. The map meet its requirement and the main ocean, subsea region and operators are identified.		
Comments			
Verified by	The bachelor group		

3 External verification results for phase 1

Table 2: External verification results for phase 1

Verification ID	V-P1-02	Date of verification	23.03.2015
Requirement ID	P1-GR-01, P1-GR-02, P1-GR-03, P1-GR-04		
Description	- Go through the documentation - Verify the requirements against the requirement specification - Verify the design basis phase 1 against requirement specification - Verify the report against the design basis document and the requirement specification		
Acceptance Criteria	Correct content Quality On time delivery		
Verification code	V2		
Result	Accepted with comments		
Conclusion	Accepted		
Comments			
Verified by	Sondre R. Askim, for FMC Technologies		

4 References

Table 3: Reference documents

No	Document no	Document name
1.	3100	Requirement specification
2.	3200	Test specification
3.	4210	Design basis Phase 1
4.	4230	Final report Phase 1
5.	4240	Visual presentation map

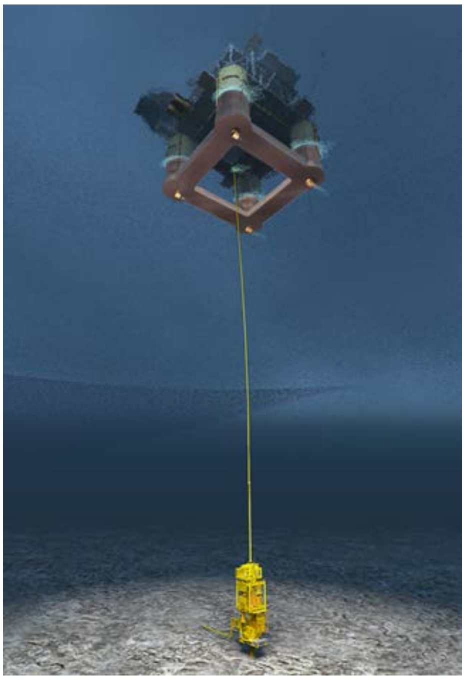
5 Document revision history

Table 4: Revision history

Rev	Date	Prepared By	Reviewed By	Changes
1.0	23.03.2015	Line Dyre-Hansen	David Snarheim	
2.0	14.05.2015	Line Dyre-Hansen	Kjersti S. Anthonsen	Changed setup and titles. Changed document titles for phase 1

Design Basis Phase 2

Deep Water Riser Pipe Study



FMC Technologies

HBV
HØGSKOLEN I BUSKERUD OG VESTFOLD · PROFESJONSHØGSKOLEN

Rev	Date	Prepared By	Reviewed By	Changes
2.0	23.04.2015	Line Dyre-Hansen	Øystein Ulmo	Changed title for chapter 4 Chapter 7 changed

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List of Tables

Abbreviations

The following abbreviations are used throughout this document.

Abbreviation	Description
DWRPS	Deep Water Riser Pipe Study
EDP	Emergency disconnect package
FMC	FMC Technology
LRP	Lower riser package
LS	Landing string
NACE	National Association of Corrosion Engineers
WSD	Working stress design

1 Introduction

This document describes the design basis for phase 2 of the Deep Water Riser Pipe Study project. In this phase of the study, the project will develop an engineering tool that utilizes a new methodology for evaluating which workover riser types and dimensions are suitable for specific projects. In addition, the tool will identify water depth limits for specified risers.

2 Referenced documents and requirements

This document is based on the requirements specification (doc. no. 3100), and gives further guidance on the implementation of each requirement. Table 2, Table 3 and Table 4, shows all the requirements defined for phase 2 of the project and which section of this document gives directions for implementation.

Table 1: Referenced documents

Document no	Document name
3100	Requirement specification
3200	Test specification

Table 2: Phase 2 general requirements

Requirement no	Requirement	Reference	Priority	Chapter in this document
P2-GR-01	A new method for assessing applicability for different work-over riser types and dimensions, for use in tender processes shall be produced	FMC	A	3 Methods and equations
P2-GR-02	All aspects that may affect the choice of work over-riser shall be assessed	FMC	A	3 Methods and equations
P2-GR-03	The assessment method shall be described in detail in a report.	FMC	A	7.1 Detailed report
P2-GR-04	An engineering tool in the form of a Microsoft Excel workbook incorporating the method shall be created.	FMC	A	Engineering tool
P2-GR-05	A user manual giving all intended users sufficient guidance in using the tool shall be produced	FMC	A	7.3 User manual

Table 3: Phase 2 report requirement

Requirement no	Requirement	Reference	priority	Chapter in this document
P2-RR-01	The report shall include a description of which variables are included in the calculations	FMC, P2-GR-03	A	3 Methods and equations 7.1 Detailed report
P2-RR-02	The report shall include a description of which (if any) variables are excluded from the calculations and the reasons for excluding them	FMC, P2-GR-03	A	3 Methods and equations 7.1 Detailed report
P2-RR-03	The effects of excluding parameters from the calculations shall be described	FMC, P2-GR-03	A	3 Methods and equations 7.1 Detailed report
P2-RR-04	The report shall include a description including schematics, of how the different variables are combined in equations and how the different outputs are affected	FMC, P2-GR-03	A	3 Methods and equations 7.1 Detailed report
P2-RR-05	The report shall describe the limitations in use of the method and associated tool. (only to be used for tender calculations, not for certification)	FMC, P2-GR-03	A	3 Methods and equations 7.1Detailed report
P2-RR-06	The report shall include directions and recommendations for further development of the method and associated tools	FMC, P2-GR-03	B	3 Methods and equations 4 Engineering tool

Table 4: Phase 2 engineering tool requirements

Requirement no	Requirement	Reference	Priority	Chapter in this document
P2-ET-01	The engineering tool shall have an input interface, that allows the user to identify and enter all input data needed for the calculations	FMC, P2-GR-04	A	4 Engineering tool
P2- ET-02	The tool shall make calculations based on input data and design standards to give outputs regarding choice of riser joints	FMC, P2-GR-04	A	Engineering tool
P2- ET-03	The tool shall, based on applicable inputs, give limitations of water depth for the chosen riser dimension and material specifications	FMC, P2-GR-04	A	4 Engineering tool
P2-ET-04	The tool shall, based on applicable inputs, give all standard pipe dimensions that meet load criteria for a specific case	FMC, P2-GR-04	A	4 Engineering tool
P2-ET-05	The output in requirements P2-ET-03 and P2-ET-04 shall deviate no more than 3% from hand calculations	FMC, P2-GR-04	A	4 Engineering tool
P2-ET-06	The tool shall present the output in req. P2-ET-03 as a visual presentation	FMC, P2-GR-04	A	4 Engineering tool
P2-ET-07	All intended users provided with the tool and user manual shall be able to use the tool and get consistent and correct results	FMC, P2-GR-04	A	4 Engineering tool
P2-ET-08	The tool shall be prepared for further development and incorporation of new capabilities	FMC, P2-GR-04	A	4 Engineering tool

3 Methods and equations

The methods and equations activity will consist of defining the method that shall be used for rating and selection of riser pipe size and material requirement. It shall consider and rate all relevant parameters that effects the design of a riser pipe. Parameters not critical or effecting the design notably should not be implemented such that the method and equations are kept as simple as possible without effecting the accuracy.

The parameters that shall be evaluated includes, but is not limited to:

- Riser dimensions
    - Outer diameter
    - Wall thickness
    - Drift size
- Tolerances
    - Ovality
    - Wall thickness
    - Corrosion allowance
- Riser loads
    - Internal pressure (burst)
    - External pressure (collapse)
    - Bending loads
    - Axial loads (Riser system weight)
- Thermal influences
    - Well temperature
    - Temperature gradient (wellhead to rig)
- Material requirements
    - Tensile strength
    - Yield strength
    - Yield/tensile strength ratio
    - NACE limitations
    - Temperature limitations

In addition the following international standards shall be included and/or considered:

- ISO 13628-7 (WSD, working stress design)
- ISO 13679
- ISO 11960
- ISO 11961
- API 5L
- API 6A

Based on the above parameters and evaluations, the project shall make a set of equations that will give recommendations on which riser types and dimensions are suited for a specific project and the depth limitations for a specified riser.

4 Engineering tool

The engineering tool is the main product of phase 2. The tool shall include the sets of equations defined in the methods and equations task and give two separate outputs.

4.1 Riser selection

In part 1 the tool shall give recommendations on pipe dimensions based on the inputs defined in Table 5.

Table 5: Engineering tool part 1 Inputs

Priority	Input
A	Water depth
A	Temperature in well
A	Well Pressure
A	Corrosion allowance ID
B	Corrosion allowance OD
A	Production tolerances
A	Weight EDP/ LRP/ LS, completion
A	Type of riser
A	Length of riser joint
A	Drift size
A	Applicable design code(s)
C	**Removed**
A	NACE / no NACE
A	Bending moment (M_b)

Based on the inputs the tool shall make calculations according to applicable standards, to identify the minimum pipe wall thickness for all applicable material grades.

The result will also be shown as a visual illustration.

Table 6 presents the output with priority.

Table 6: Engineering tool part 1 outputs

Priority	Output
A	Optimal pipe size and strength
B	Graphic view

4.2 Water depth

In part 2, the tool shall give water depth limitations for a predefined riser based on the inputs given in Table 7.

Table 7: Engineering tool part 2 Inputs

Priority	Input
A	Riser dimensions
A	Temperature in well
A	Pressure
A	Corrosion allowance Internal surface
A	Corrosion allowance external surface
A	Weight EDP/ LRP/ LS, completion
A	Type of riser
A	Length of riser joint
A	Applicable design code(s)
A	Bending moment

Based on the inputs the tool shall make calculations according to applicable standards, to identify the water depth limitation for the riser. In addition, an illustration of the riser limitations shall be made.

The outputs with priority is shown in Table 8.

Table 8: Engineering tool part 2 outputs

Priority	Output
A	Water depth
B	Graphic view

4.3 Temperature gradient calculation

In the third part of the tool, shall the temperature gradient be calculated. This part is separated from the other two parts, because of many various parameters that are included.

5 Testing

The testing of the engineering tool and associated documentation will be performed according to the test specification and be reported in a test report.

Table 9: Test specification

Document no	Document title
3200	Test specification

6 Refining

If the testing uncovers faults or failure to meet requirements or contracting authority`s expectations, the program and defining documents will be edited.

7 Reporting

7.1 Detailed report

The phase 2 main report describes in detail, the functionality of the engineering tool and the underlying evaluations and equations.

7.2 Test report

The test report gives a description of the tests and verifications performed in phase 2 including test results and conclusions.

7.3 User manual

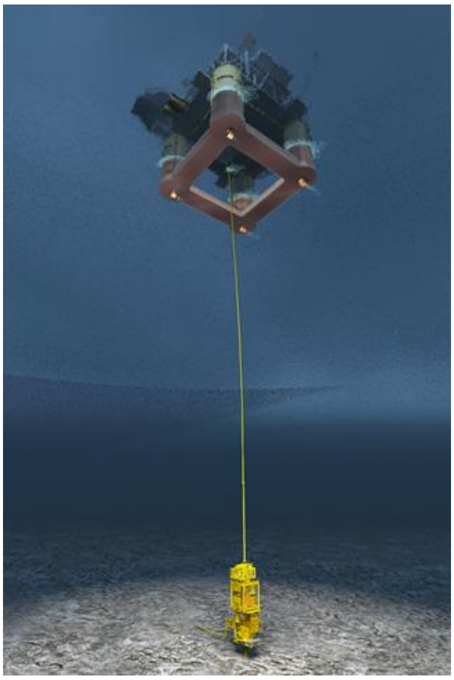
The user manual shall contain detailed instructions for correct use of the engineering tool that will be created in in phase 2.

8 Document revision history

Rev	Date	Prepared By	Reviewed By	Changes
2.0	23.04.2015	Line Dyre-Hansen	Øystein Ulmo	Changed title for chapter 4 Chapter 7 changed
1.0	16.03.2015	Øystein Ulmo	David Snarheim	First release

User Manual

Deep Water Riser Pipe Study



Rev	Date	Prepared By	Reviewed By	Changes
1.0	13.05.2015	Line Dyre-Hansen	Kjersti S. Anthonsen	

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List of Figures

Abbreviations

The following abbreviations are used throughout this document.

Abbreviation	Description
EDP	Emergency disconnect package
LRP	Lower riser package

1 Short description of the tool

The engineering tool is divided into three parts:

Riser dimension calculation

Gives recommended pipe dimensions as an output

Water depth limit calculation

Gives limited water depth

Temperature gradient calculation

Gives temperature drop along a pipeline

Each part include an input list and a visual presentation of the results in terms of a graph and a table.

2 Navigation guideline

The front page consists of three options, as shown in Figure 1:

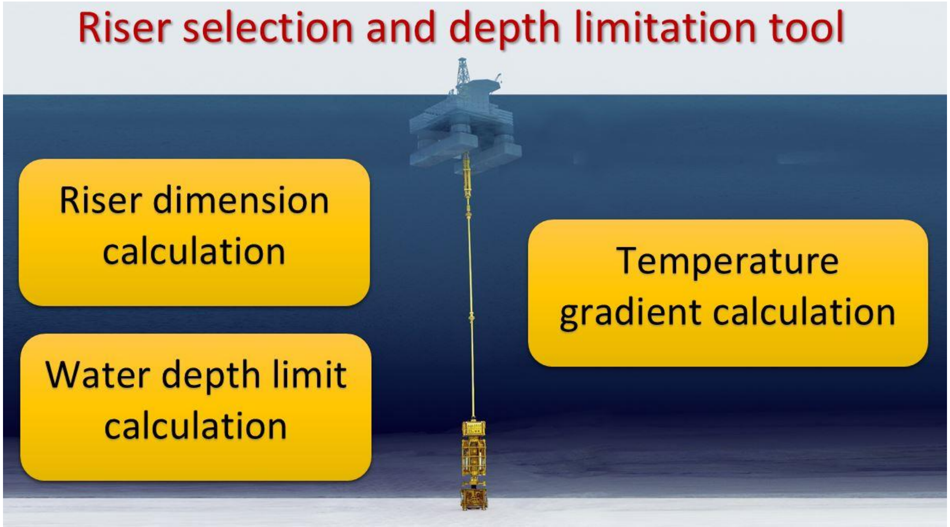
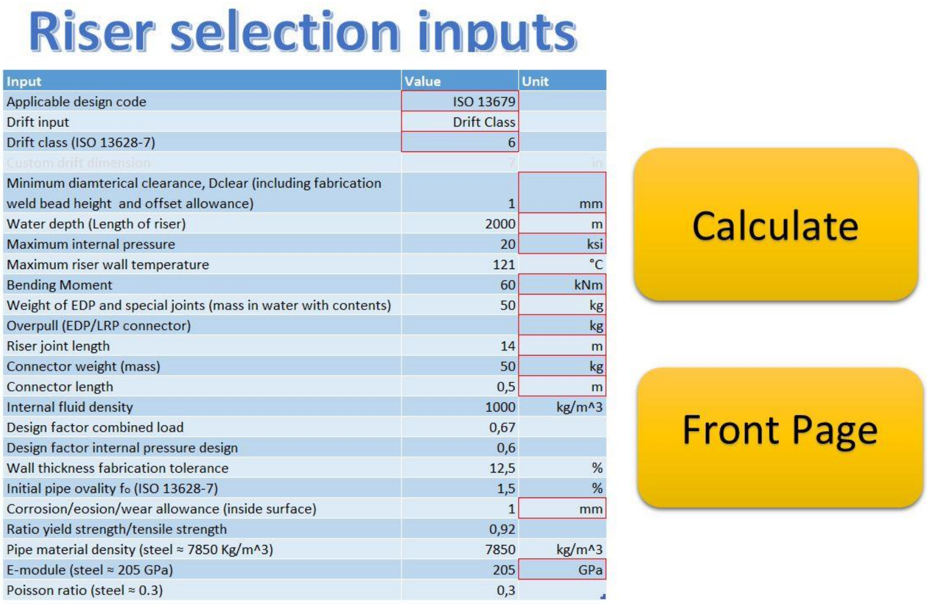


Figure 1: Front page for the engineering tool

2.1 Riser dimension calculation

The window that will appear if the chosen method is riser dimension calculation is shown in Figure 2.



Input	Value	Unit
Applicable design code	ISO 13679	
Drift input	Drift Class	
Drift class (ISO 13628-7)	6	
Custom drift dimension	7	in
Minimum diamterical clearance, Dclear (including fabrication weld bead height and offset allowance)	1	mm
Water depth (Length of riser)	2000	m
Maximum internal pressure	20	ksi
Maximum riser wall temperature	121	°C
Bending Moment	60	kNm
Weight of EDP and special joints (mass in water with contents)	50	kg
Overpull (EDP/LRP connector)		kg
Riser joint length	14	m
Connector weight (mass)	50	kg
Connector length	0,5	m
Internal fluid density	1000	kg/m^3
Design factor combined load	0,67	
Design factor internal pressure design	0,6	
Wall thickness fabrication tolerance	12,5	%
Initial pipe ovality f_0 (ISO 13628-7)	1,5	%
Corrosion/eosion/wear allowance (inside surface)	1	mm
Ratio yield strength/tensile strength	0,92	
Pipe material density (steel ≈ 7850 Kg/m^3)	7850	kg/m^3
E-module (steel ≈ 205 GPa)	205	GPa
Poisson ratio (steel ≈ 0.3)	0,3	

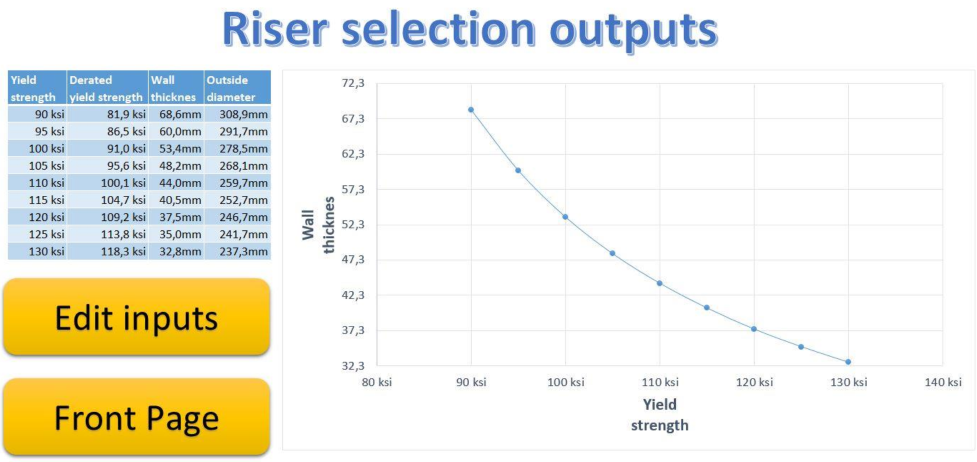
Figure 2: Riser selection input

Shown in the picture above the columns with red edges has a dropdown function. This makes it is possible to changes the units or applicable standards easily.

2.1.1 Calculation output

The calculation gives the ideal dimensions (wall thickness and outside diameter) for risers with material yield strength between 90 and 130 ksi. It also displays the de-rated yield strength (due to temperature and/or yield/tensile ratio) that is used for the calculations.

The graph shows the correlation between nominal yield strength and required wall thickness as shown in Figure 3.

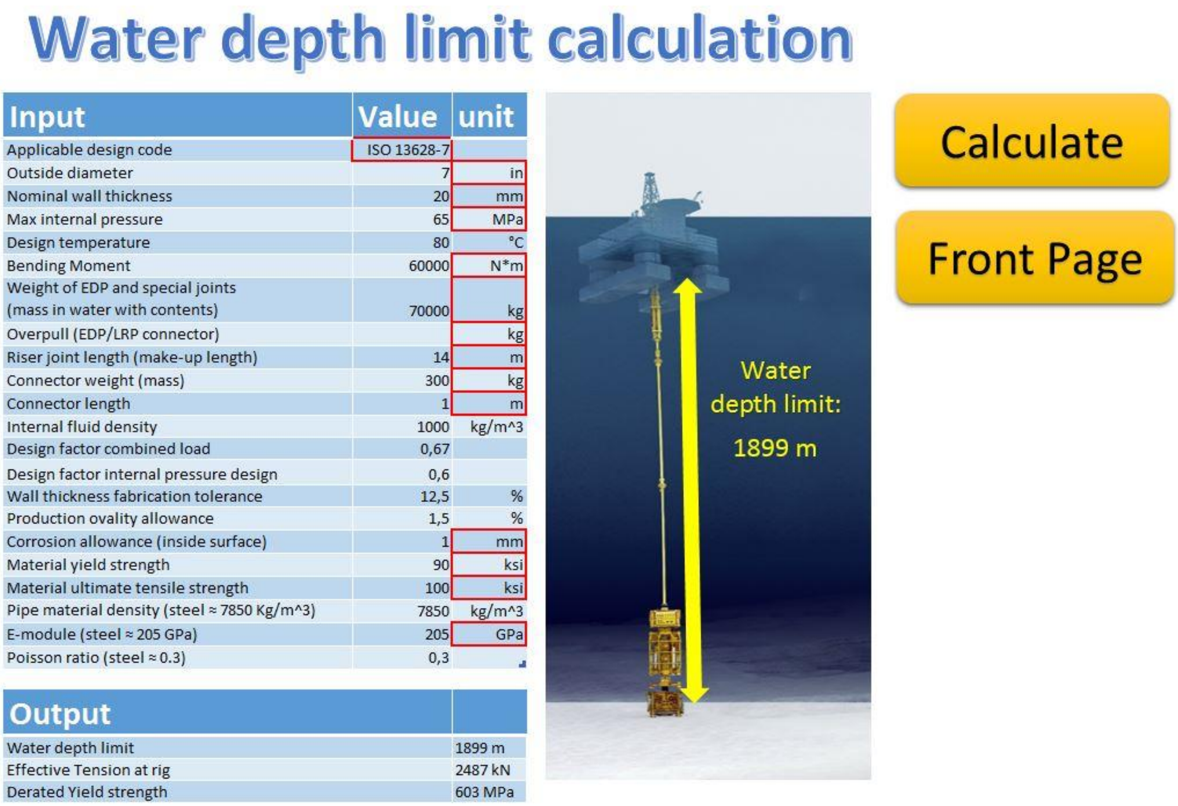


Yield strength	Derated yield strength	Wall thicknes	Outside diameter
90 ksi	81,9 ksi	68,6mm	308,9mm
95 ksi	86,5 ksi	60,0mm	291,7mm
100 ksi	91,0 ksi	53,4mm	278,5mm
105 ksi	95,6 ksi	48,2mm	268,1mm
110 ksi	100,1 ksi	44,0mm	259,7mm
115 ksi	104,7 ksi	40,5mm	252,7mm
120 ksi	109,2 ksi	37,5mm	246,7mm
125 ksi	113,8 ksi	35,0mm	241,7mm
130 ksi	118,3 ksi	32,8mm	237,3mm

Figure 3: Riser selection output

2.2 Water depth limit calculation

Figure 4 shows the window that will appear, if the chosen method is water depth limits. This window shows both the inputs and outputs of the calculations. The columns with red edges has a dropdown function which makes it is possible to change the units, or between standards easily.



Input	Value	unit
Applicable design code	ISO 13628-7	
Outside diameter	7	in
Nominal wall thickness	20	mm
Max internal pressure	65	MPa
Design temperature	80	°C
Bending Moment	60000	N*m
Weight of EDP and special joints (mass in water with contents)	70000	kg
Overpull (EDP/LRP connector)		kg
Riser joint length (make-up length)	14	m
Connector weight (mass)	300	kg
Connector length	1	m
Internal fluid density	1000	kg/m^3
Design factor combined load	0,67	
Design factor internal pressure design	0,6	
Wall thickness fabrication tolerance	12,5	%
Production ovality allowance	1,5	%
Corrosion allowance (inside surface)	1	mm
Material yield strength	90	ksi
Material ultimate tensile strength	100	ksi
Pipe material density (steel ≈ 7850 Kg/m^3)	7850	kg/m^3
E-module (steel ≈ 205 GPa)	205	GPa
Poisson ratio (steel ≈ 0.3)	0,3	

Output	
Water depth limit	1899 m
Effective Tension at rig	2487 kN
Derated Yield strength	603 MPa

Figure 4: Water depth input and output

2.2.1 Calculation output

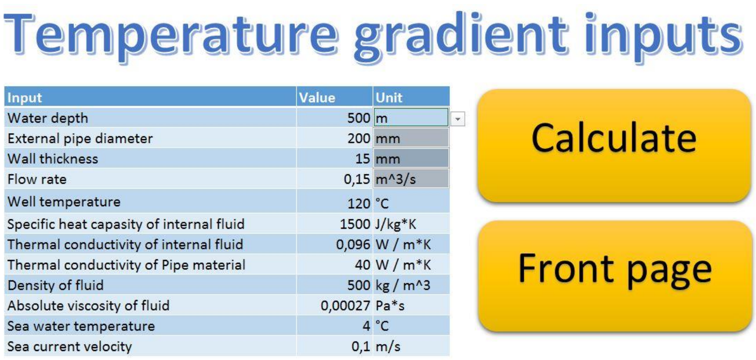
The output gives the maximum water depth the riser can reach with the parameters defined in the input page. In addition it shows the effective tension at the top of the riser, de-rated yield strength (value used for calculations) and the riser design pressure is shown.

Note: If “0 m” is shown as water depth limit, this means that the defined riser does not meet the design criteria for the defined conditions.

2.3 Temperature gradient calculation

This window will appear if the chosen method is the temperature gradient, see

Figure 5. The hatched columns’ has a dropdown function which makes it is possible to changes the units.



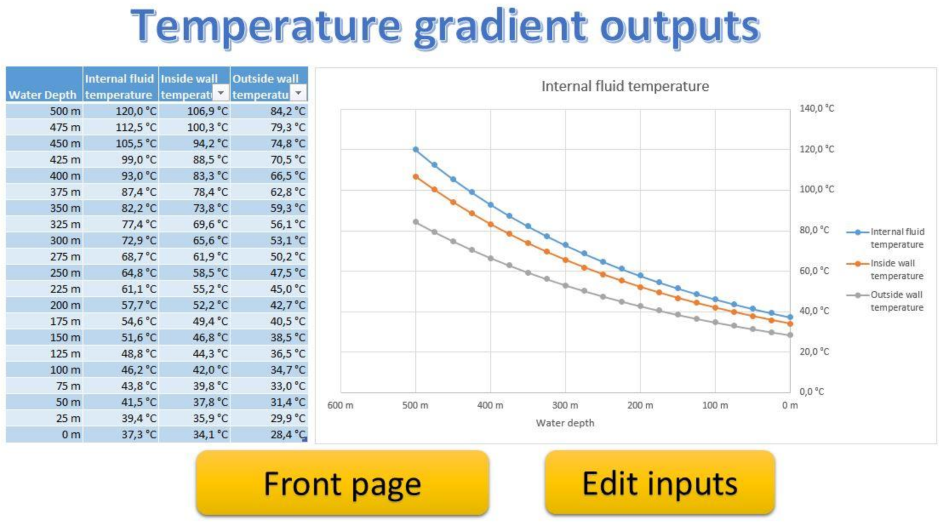
Input	Value	Unit
Water depth	500	m
External pipe diameter	200	mm
Wall thickness	15	mm
Flow rate	0,15	m^3/s
Well temperature	120	°C
Specific heat capasity of internal fluid	1500	J/kg*K
Thermal conductivity of internal fluid	0,096	W / m*K
Thermal conductivity of Pipe material	40	W / m*K
Density of fluid	500	kg / m^3
Absolute viscosity of fluid	0,00027	Pa*s
Sea water temperature	4	°C
Sea current velocity	0,1	m/s

Figure 5: Temperature gradient input

Note: the fluid properties differs significantly with each project and this has a large effect on the outcome of the calculations. If data is not available for your specific project, entering typical data may give a large deviation from actual conditions

2.3.1 Calculation output

After the calculation will this window appear, Figure 6.



Water Depth	Internal fluid temperature	Inside wall temperat	Outside wall temperatu
500 m	120,0 °C	106,9 °C	84,2 °C
475 m	112,5 °C	100,3 °C	79,3 °C
450 m	105,5 °C	94,2 °C	74,8 °C
425 m	99,0 °C	88,5 °C	70,5 °C
400 m	93,0 °C	83,3 °C	66,5 °C
375 m	87,4 °C	78,4 °C	62,8 °C
350 m	82,2 °C	73,8 °C	59,3 °C
325 m	77,4 °C	69,6 °C	56,1 °C
300 m	72,9 °C	65,6 °C	53,1 °C
275 m	68,7 °C	61,9 °C	50,2 °C
250 m	64,8 °C	58,5 °C	47,5 °C
225 m	61,1 °C	55,2 °C	45,0 °C
200 m	57,7 °C	52,2 °C	42,7 °C
175 m	54,6 °C	49,4 °C	40,5 °C
150 m	51,6 °C	46,8 °C	38,5 °C
125 m	48,8 °C	44,3 °C	36,5 °C
100 m	46,2 °C	42,0 °C	34,7 °C
75 m	43,8 °C	39,8 °C	33,0 °C
50 m	41,5 °C	37,8 °C	31,4 °C
25 m	39,4 °C	35,9 °C	29,9 °C
0 m	37,3 °C	34,1 °C	28,4 °C

Figure 6: Temperature gradient output

The table and graph, shows the internal fluid temperature at different water depths and can be used to decide temperature de-rating factor at different riser sections.

3 Description of input data

This section gives a short introduction to the different inputs for the engineering tool. Not all input is applicable for each part in the tool.

3.1 Design code

“Applicable design code” selects which design code the calculations are performed in accordance with. (ISO 13628-7 or ISO 13679).

Note: ISO 13679 does not specify temperature de-rating factors for the materials. However, the tool applies the de-rating factor from ISO 13628-7.

3.2 Site data

In the next rows, the site data is entered.

- “Water depth” is the water depth on the intended site.
- “Maximum internal pressure” is the highest internal pressure the riser may be subjected to.
- “Maximum riser wall temperature” is the highest temperature the riser may be subjected to in °C and is basis for material temperature de-rating.
- “Maximum bending moment” is the maximum bending moment the riser may be subjected to at any point of the riser.

Note: The first point does not apply for water depth limit calculation.

- “Nominal outside diameter” is the nominal outside diameter of the riser.
- “Nominal wall thickness” is the nominal wall thickness of the riser.
- “Minimum diametrical drift clearance” is diametrical clearance that is be required for sufficient drift clearance and allow for fabrication imperfections etc.

3.3 Riser details

- “Weight of EDP and special joints” is the total submerged weight (mass in water) of the EDP, including all special joints at the lower end of the riser.
- Overpull is the tension load in the connector between LRP and EDP.
- “Riser joint length” is the make-up length of one riser joint including connector.
- “Connector weight (mass)” is the total dry weight of one connector (pin and box). The weight of the pipe replaced by the connector is automatically subtracted by the tool.
- “Connector length” is the make-up length of one connector (pin + box).

3.4 Additional design data

- “Internal fluid density” is the maximum density that can be expected for the internal fluid.
- “Design factor combined load” is the design factor used for combined load and pipe collapse calculations. According to ISO 13628-7, a factor of 0.67 shall be used for normal operation.
- “Design factor internal pressure design” is the design factor used for internal pressure (burst) design and shall be set to 0.6 for design according to ISO 13628-7.
- “Negative wall thickness fabrication tolerance” is the negative wall thickness tolerance in %. For standard pipes, 12.5% is often used.
- “Initial pipe ovality f_o” is the maximum allowed ovality of the pipe.

  Note: the maximum ovality allowed according to ISO 13628-7 is 1.5 % and the minimum value that can be used for calculations is 0.25%

  Note: For deep water applications, initial ovality should in general not exceed 0.5%
- “Corrosion/erosion/wear allowance” is the corrosion, erosion and wear allowance on the inside surface of the riser.

3.5 Material data

- "Ratio, yield strength/tensile strength" is ratio between yield strength an ultimate tensile strength for the materials intended for the riser. ISO 13628-7 does not allow for a ration higher than 0.92 and the tool automatically de-rates the yield strength according to the standard.

  The ratio is only applicable for ISO 13628-7
- Pipe material density, E-module and Poisson ration describes basic properties of the riser material. Typical values for steel are shown in the description; however some deviation from these values may occur for high alloy steel.
- "Material yield strength" is the minimum yield strength for the riser material.
- "Material ultimate tensile strength" is the minimum ultimate tensile strength.

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3.6 Fluid properties

All fluid properties are entered in metric units and values for all parameters must be entered to get valid outputs.

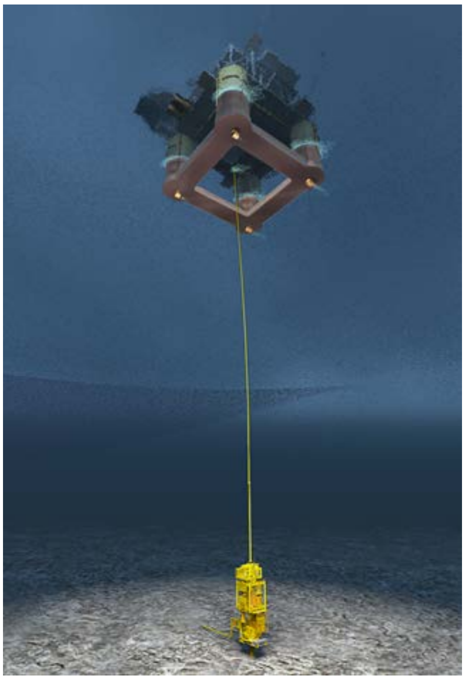
4 Document revision history

Table 1: Revision history

Rev	Date	Prepared By	Reviewed By	Changes
1.0	13.05.2015	Line Dyre-Hansen	Kjersti S. Anthonsen	

Final Report Phase 2

Deep Water Riser Pipe Study



FMC Technologies

HBV

Rev	Date	Prepared By	Reviewed By	Changes
1.0	12.05.2015	Øystein Ulmo Line Dyre-Hansen	Kjersti S. Anthonsen	

Table of Contents

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Abbreviations

The following abbreviations are used throughout this document.

Abbreviation	Description
EDP	Emergency Disconnect Package
FAT	Factory acceptance test
LRP	Lower Riser Package
NACE	National Association of Corrosion Engineers
XT	X-Mas tree (Subsea tree)

1 Introduction

This report documents the work that has been done in phase 2 of the Deep Water Riser Pipe Project. The report gives directions on selection and recommendations for riser pipe selection and limitation calculations. The calculations in this report is based on the ISO 13628-7 (Ref/A1/) and ISO 13679 (Ref/A2/) design standards but also includes equations from other references.

An important factor in riser design is the wall temperature at the point of interest due to de-rating of material properties. This report therefore includes a section describing a method for estimating the temperature drop along the riser (temperature gradient) so that local temperature can be calculated and included in the design.

The calculations are included in an engineering tool that simplifies the process and gives the user an indication on the dimensions required for a riser in a specific case, the maximum water depth for a specific riser and the temperature drop in a riser between the well and the rig.

2 Definitions

The definitions in this chapter will be used throughout this report and for the engineering tool, unless otherwise is specified. The definitions are mostly taken from ISO 13628-7(Ref/A1/), although some are altered or simplified for the purpose of the project.

2.1 Material properties

2.1.1 General properties

According to ISO 13628-7(Ref/A1/), the yield strength σ_y and the ultimate tensile strength σ_u shall be calculated as follows:

$$\sigma_y = \phi_{A5} * Y_y * R_{t0.5}$$ (1), Ref/A1/eq. 4

$$\sigma_u = \phi_{A5} * Y_u * R_m$$ (2), Ref/A1/eq. 5

Where

ϕ_{A5} is the ductility reduction factor; see equation 3

$R_{t0.5}$ is the specified minimum yield strength for 0,5 % total elongation at room temperature.

Y_y is the yield strength reduction factor at elevated temperature.

Y_u is the ultimate tensile strength reduction factor at elevated temperature.

R_m is the specified minimum ultimate tensile strength at room temperature.

A ductility factor (ϕ_{A5}) of 1 can be used when the minimum elongation after fracture ($A_{5,}$) is equal to or larger than 14%. For A_5 < 14%, the ductility reduction factor is calculated as given in equation 3

$$\phi_{A5} = \frac{1.5}{2-\sqrt{\frac{A_5}{56}}} \qquad (3), \text{Ref/A1/eq. 6}$$

2.1.2 Temperature de-rating

For carbon manganese steels and low alloy steels, the specified value a 20°C may be used for temperatures less than or equal to 50°C. For carbon manganese steels and low alloy steels with a temperature above 50°C, de-rated material properties shall be established as an input to the design. If no material properties at elevated temperatures are available, yield and tensile properties may be reduced in accordance with Table 1.

Table 1: Temperature reduction factors carbon manganese and low alloy steels. Ref/A1/Table 10

Temperature reduction factor	**Temperature °C**				
	Room temperature	**66**	**82**	**121**	**180**
Y_y	1.0	0.99	0.97	0.91	0.85
Y_u	1.0	1.0	1.0	1.0	1.0

ISO 13628-7(Ref/A1/) allows some yielding within the pipe capacities and therefore sets restrictions on the relations between σ_y and σ_u. The restrictions are as follows:

If $\sigma_y > 0.92 * \sigma_u$, σ_y shal be set as $0.92 * \sigma_u$

2.1.3 Sour service limitations (NACE)

ISO 15156-2 (Ref/A4) gives limitations for which materials can be used in sour service conditions. Materials approved for all sour service conditions ($p_{H_2S} \geq 0.3kPa$), are shown in Table 2. In addition, the standard gives direction for certification of materials for ranges of sour service.

Table 2: material grades approved for sour service. Ref/A4/Table A.1

For all temperatures	**For temperatures ≥ 65°C**	**For temperatures ≥ 80°C**	**For temperatures ≥ 107°C**
ISO 11960 grades: • H40 • J55 • K55 • M65 • L80 type 1 • C90 type 1 • T95 type 1	ISO 11960 grades: • N80 type Q • C95	ISO 11960 grades: • N80 • P110	ISO 11960 grade: • Q125b

Materials not listed in table 2 can be qualified according to ISO 15156-2 (Ref/A4), although in general, high grade steels does not meet the requirements.

A riser will be subjected to loads at temperatures varying between well temperature and sea temperature and material choices are therefore limited to column 1 in Table 2.

2.1.4 Simplifications

For the purpose of the calculation method and engineering tool, the ductility reduction factor will not be assessed. This is because the elongation, A_5 for the materials most commonly used for this purpose, is above 14%. Thereby giving a reduction factor of 1. However if materials with elongation of 14% or below is considered for the design, special considerations shall be taken.

2.2 Dimensions

The definitions regarding pipe dimensions, listed in Table 3 are used in ISO 13628-7, (Ref/A1)/ and will be used for all purposes in this project.

Table 3: Dimensional notations

Notation	Description	Correlation
D_o	Outside diameter of the pipe.	
D_i	Inside diameter of the pipe.	
t_n	Nominal wall thickness.	
t_1	Minimum wall thickness without fabrication and corrosion/erosion tolerances.(1)	$t_1=t_n-t_{fab}-t_{ca}$
t_2	Minimum wall thickness without corrosion/erosion tolerances.	$t_1=t_n- t_{ca}$
t_{fab}	Fabrication tolerances.(2)	
t_{ca}	Corrosion/erosion allowance.	

(1) For Mill/FAT pressure test, corrosion/erosion allowance is not included. However this is not applicable for the purposes of this project

(2) Given as percentage negative wall thickness

2.3 Design factors

ISO 13628-7 (Ref/A1) gives design factors to be used for calculations according to the standard. ISO 13679 (Ref/A2) does not specify any design factors, but the design factors given in 13628-7 is widely used in the industry and will be used for the purposes of this report.

Design factors as given in ISO 13628-7, is shown in Table 4.

Table 4: Design factors. Ref/A1/Table 11

Load condition	**F_d**
Assembly and disassembly	0.9
Mill & FAT hydrostatic pressure test	0.9
Normal operation	0.67
Extreme operation	0.8
System (in-service) pressure test	0.67
Temporary operation	0.8
Accidental (survival)	1.0

Burst pressure design factors, as given in ISO 13628-7 Ref/A1/ is shown in Table 5.

Table 5: Burst pressure design factor. Ref/A1/Table 13

Internal design pressure	**Hydrostatic test pressure**
0.60	0.90

The hydrostatic design pressure design factor is used to specify test pressures and is not applicable for design process. For the internal pressure design calculations in this project. The internal design factor of 0.60 will be used.

Hoop buckling (collapse) design pressures are given in Table 6.

Table 6: collapse pressure design factor. Ref/A1/Table 14

Pipe manufacturing process	**External design pressure**	**Hydrostatic test pressure**
Seamless	0.67	0.80

As for internal design, the hydrostatic test pressure is for establishing test pressures and external design pressure will be used for the purposes of this project.

2.4 Load conditions

As part of assessing a riser systems suitability for the intended use, the load cases as defined in Table 7 shall as a minimum be analyzed, the table is based on ISO 13628-7 (Ref/A1)

For preliminary calculations, using normal operation parameters will give a good indication on riser suitability. However, for some situations this may give unwanted limitations for other operation conditions.

The engineering tool allows the user to change the design factor and may therefore be used to perform calculations for all operation conditions.

The calculations described in this report and are performed by the engineering tool does not consider connector capacities, it assumes that the connector are equally or stronger than the riser pipe.

Table 7: Riser systems

Operational mode	Operational load	Operation condition	Design factor
In marine riser work over riser systems with landing string	Normal operation	Connected mode	Fd = 0,67
	Extreme operation	Running and retrieval	Fd = 0,8
		Over pull to verify tubing hanger lock	
		Over pull to retrieve stuck tubing	
	Accidental operation	Excessive top tensions (heave compensator lock-up)	Fd = 1,0
		Dynamic positioning failure (drift off)	
Well access completion workover riser system with EDP and LRP	Normal operation	Connected mode	Fd = 0,67
	Extreme operation	Running and retrieval	Fd = 0,8
		Over pull to verify EDP /LRP lock	
	Accidental operation	Excessive top tensions (heave compensator lock-up)	Fd = 1,0
		Dynamic positioning failure (drift off)	

3 Riser loads

3.1 Axial loads

For combined load calculations, Effective tension (T_e) is used as axial load input. Effective tension is calculated from equation 4

$$T_e = g * (m_e + m_a) + T_p \tag{4}$$

The true wall tension can be calculated from the following equation

$$T_w = g * (m_e + m_a) + T_p + \frac{\pi}{4} * \left(p_i * (D_o - 2 * t)^2 - p_o * {D_o}^2\right) \tag{5}$$

Where

p_i is the internal pressure.

D_o is the pipe external diameter.

t is the pipe wall thickness.

p_o is the external pressure.

g is the gravitation acceleration.

m_e is the apparent (submerged) weight (mass) of the riser below the point of interest.

m_a is the apparent (submerged) weight of the seafloor equipment (EDP/LRP, special joints etc.)

T_p is the EDP/XT connector load.

The apparent weight of the riser is calculated from equation 6.

$$m_e = m_p - \frac{m_p * \rho_o}{\rho_{pipe}} + A_{int} * (\rho_{int} - \rho_o) * L \tag{6}$$

Where

m_p is the dry weight (mass) of the riser.

A_{int} is the internal cross-section of the pipe.

ρ_{pipe} is the density of the pipe material.

ρ_{int} is the density of the internal fluid.

ρ_o is the density of the external fluid (seawater).

The riser dry weight is calculated from equation 7

$$m_p = \rho_{pipe} * (A_o - A_{int}) * (\mathrm{L} - \frac{L * L_{conn}}{L_j}) + \frac{L * m_{conn}}{L_j} \quad (7)$$

Where

A_{int} is the internal cross-section of the pipe.

A_o is the external cross-section of the pipe.

ρ_{pipe} is the density of the pipe material.

m_{conn} is the assed weight (mass) of each connector.

L_j is the length of each riser joint.

L_{conn} is the length of each connector (Pin + Box).

L is the length of the riser.

3.2 Bending loads

The riser bending loads are site and rig dependent and detailed analysis is needed to accurately predict the bending loads for each case. However, conservative estimations can be used for preliminary calculations, as is the purpose of this project.

3.3 Pressure loads

3.3.1 Internal pressure loads

For most situations, using the well design pressures will give conservative calculations.

3.3.2 External pressure loads

For external pressure load calculations, using hydrostatic load from sea water-column as external pressure and atmospheric pressure as internal pressure, gives conservative calculations.

4 Riser design according to ISO 13628-7

ISO 13628-7 Ref/A1/ is an international standard that dictates design guidelines for subsea completion and workover systems. The standard specifies different requirements that shall be met by the system and will be the basis for the calculations made by the engineering tool.

4.1 Pipe capacities

4.1.1 Pipe burst capacity

The pipe burst capacity can be calculated using equation 8. Note that for burst pressure capacity, t_1 shall be used and for combined load pressure capacity, t_2 is used.

$$p_b = 1.1 * (\sigma_y + \sigma_u) * \frac{t}{D_o - t}$$ (8) Ref/A1/eq.10

Where

σ_y is the design yield strength.

σ_u is the design ultimate tensile strength.

t is the wall thickness without tolerances. (for burst pressure capacity calculations, use t_1 and for combined load capacities use t_2 as defined in section 2.2.)

D_o is the specified nominal pipe outside diameter.

4.1.2 Hoop buckling (collapse) pressure

The minimum hoop buckling pressure can be calculated from equations 9 through 18. Note that for collapse pressure capacity, t_1 shall be used, and for combined load capacity, t_2 is used

$$p_c = y - \frac{1}{3} * b$$ (9) Ref/A1/eq. E.8

$$b = -p_{el}$$ (10), Ref/A1/eq. E.9

$$y = -2 * \sqrt{-u} * \cos\left(\frac{\phi}{3} + \frac{\pi}{3}\right)$$ (11), Ref/A1/eq. E.15

$$u = \frac{1}{3} * \left(-\frac{1}{3} * b^2 + c\right)$$ (12), Ref/A1/eq. E.12

$$\phi = arcos\left(\frac{-v}{\sqrt{(-u)^3}}\right)$$ (13), Ref/A1/eq. E.14

$$c = -\left({p_p}^2 + 2 * p_p * p_{el} * f_o * \frac{D_o}{t}\right)$$ (14), Ref/A1/eq. E.10

$$v = \frac{1}{2} * \left(\frac{2}{27} * b^3 - \frac{1}{3} * b * c + d\right)$$ (15), Ref/A1/eq. E.13

$$d = p_{el.min} * {p_{p,min}}^2$$ (16), Ref/A1/eq. E.11

Where

p_{el} is the elastic hoop buckling pressure.

p_p is the plastic hoop buckling pressure.

t is the wall thickness without tolerances. (for burst pressure capacity calculations, use t_1 and for combined load capacities use t_2 as defined in section 2.2.)

f_o is the initial ovality.

D_o is the specified nominal pipe outside diameter.

The initial ovality (f_o) shall not be set to less than 0 0025 (0.25%) Maximum initial ovality should not exceed 0.015 (1.5%).

The elastic hoop buckling pressure is calculated from equation 17.

$$p_{el} = \frac{2 * E\left(\frac{t}{D_O - t}\right)^3}{1 - v^2}$$ (17), Ref/A1/eq. 13

Where

E is the modulus of elasticity.

v is the Poisson’s ratio.

σ_y is the material yield strength.

The plastic hoop buckling pressure is calculated from equation 18.

$$p_p = 2 * \sigma_y * \frac{t}{D_o}$$ (18), Ref/A1/eq. 14

Where the variables are given as for equations 16 and 17.

4.1.3 Plastic bending moment capacity

The pipe plastic bending moment capacity is given in equation 19.

$$M_{pc} = \alpha_{bm} * \sigma_y * \frac{1}{6}\left({D_o}^3 - \left(D_o - 2 * t_2\right)^3\right) \quad \text{(19), Ref/A1/eq. 18}$$

Where

σ_y is the material yield strength.

α_{bm} is the pipe cross-section slenderness parameter.

D_o is the specified or nominal pipe outside diameter.

t_2 is the pipe wall thickness without allowances.

E is the modulus of elasticity.

The pipe cross-section slenderness parameter is given by equations 20 to 22.

$$\alpha_{bm} = 1.00 \;\; \text{for} \;\; \frac{\sigma_y * D_o}{E * t_2} \leq 0.0517 \quad \text{(20), Ref/A1/eq. 21}$$

$$\alpha_{bm} = 1.13 - 2.58 * \left(\frac{\sigma_y * D_o}{E * t_2}\right) \;\; \text{for} \;\; 0.0517 < \frac{\sigma_y * D_o}{E * t_2} \leq 0.1034 \quad \text{(21), Ref/A1/eq. 22}$$

$$\alpha_{bm} = 0.94 - 0.76 * \left(\frac{\sigma_y * D_o}{E * t_2}\right) \;\; \text{for} \;\; 0.1034 < \frac{\sigma_y * D_o}{E * t_2} \leq 0.170 \quad \text{(22), Ref/A1/eq. 23}$$

4.1.4 Plastic tension capacity

The riser plastic tension capacity is calculated from equation 23

$$T_{pc} = \sigma_y * \pi * \left(D_o - t_2\right) * t_2 \quad \text{(23), Ref/A1/eq. 19}$$

Where

σ_y is the design yield strength.

D_o is the specified or nominal pipe outside diameter.

t_2 is the minimum pipe wall thickness without allowances.

4.2 Initial pressure design

The following calculations are based on the internal pressure design and can be used to identify the minimum wall thickness required for the riser.

For a riser with known outside diameter equation 24 can be used for defining minimum wall thickness.

$$t_1 = \frac{D_o}{\frac{1.1*F_b*(\sigma_y+\sigma_u)}{p_{int}-p_o}+1}$$ (24), Ref/A1/eq. E.2

Where

D_o is the specified nominal pipe outside diameter.

F_b is the pipe burst design factor, given as 0.60 for internal pressure design.

σ_y is the design yield strength.

σ_u is the design ultimate tensile strength.

p_{int} is the internal design pressure.

p_o is the minimum external hydrostatic pressure.

t_1 is the minimum pipe wall thickness without allowances.

For risers with known inside diameter (defined by drift size and clearance, equation 25 can be used.

$$t_1 = \frac{D_i*\left(1-\frac{t_{fab}}{100}\right)+2*t_{ca}}{\frac{1.1*F_b*(\sigma_y+\sigma_u)}{p_{int}-p_o}*\left(1-\frac{t_{fab}}{100}\right)-\left(1+\frac{t_{fab}}{100}\right)}$$ (25), Ref/A1/eq. E.3

Where

D_i is the specified nominal pipe inside diameter.

t_{fab} is the pipe fabrication tolerance.

t_{ca} is the corrosion/erosion allowance.

Equations 24 and 25 will give sufficient capacity for tension and bending moment for most shallow water conditions.

4.3 Internal pressure (burst) design

The minimum burst pressure of the pipe shall exceed the internal pressure at all cross-sections of the riser string as given in equation 26.

$$\frac{p_{int,d}-p_{o,min}}{F_b * p_{b,min}} \leq 1$$ (26), Ref/A1/eq. 9

Where

$p_{int,d}$ is the internal design pressure.

$p_{o,min}$ is the minimum external hydrostatic pressure.

F_b is the pipe burst design factor, given as 0.60 for internal pressure design.

$p_{b,min}$ is the minimum pipe burst pressure given in section 4.1.1.

The standard states that the internal pressure design shall be met for all cross-sections of the riser. However, the maximum internal pressure that can be expected is equal to the well pressure and is the same for the entire riser. The external pressure is lowest at the top due to hydrostatic pressure in the surrounding waters. It is therefore sufficient to do the calculation for this section.

4.4 External pressure (hoop buckling) design

The hoop buckling pressure of the pipe shall exceed the net external pressure at all cross sections of the riser as follows:

$$\frac{p_o-p_{int}}{F_{hb} * p_c} \leq 1$$ (27), Ref/A1/eq. 11

Where

p_o is the external design pressure.

p_{int} is the minimum hydrostatic internal pressure.

F_{hb} is the pipe hoop buckling design factor defined as 0.67.

p_c is the minimum hoop buckling collapse pressure as given in section 4.1.2.

ISO 13628-7 states that the conditions shall be met at any cross section of the riser. However, the internal pressure must be expected to be zero at all cross sections of the riser and the maximum outside pressure I at the wellhead. It is therefore sufficient to do the calculations for this section.

4.5 Net internal overpressure

A riser subjected to combined internal pressure, effective tension and bending moment, shall be designed to satisfy the following conditions at any cross section.

$$\left(\frac{T_e}{F_d{*}T_{pc}}\right)^2 + \frac{|M_{bm}|}{F_d{*}M_{pc}} * \sqrt{1-\left(\frac{p_{int}-p_o}{F_d{*}p_b}\right)^2} + \left(\frac{p_{int}-p_o}{F_d{*}p_b}\right)^2 \leq 1 \qquad (28), \text{Ref/A1/eq. 17}$$

Where

T_e is the effective tension in the pipe.

T_{pc} is the plastic tension capacity of the pipe.

F_d is the design factor as given in section 2.3.

M_{bm} is the bending moment in the pipe.

M_{pc} is the plastic bending moment capacity of the pipe.

p_{int} is the internal pressure in the pipe.

p_o is the external pressure.

p_b is the burst pressure of the pipe.

Pipe capacities are given in section 4.1

The highest internal overpressure combined load is expected to appear at the rig. Due to temperature de-rating the most critical condition is expected to be during test production for high temperature wells. In this case, the density of the produced oil can be used to specify effective tension.

For conservative calculations, use values as given in Table 8

Table 8: Recommended values for internal overpressure calculations

Variable	Value
T_e	Effective tension at rig as given in section 3.1
T_{pc}	As given in section 4.1.4
F_d	As given in section 2.3
M_{bm}	Highest estimated bending moment at rig as given in section 3.2
M_{pc}	As given in section 4.1.3
p_{int}	Well pressure as given in section 3.3.1
p_o	Atmospheric pressure (0)
p_b	As given in section 4.1.1

Note: internal pressure will for some operational conditions be lower due to internal fluid column. If well pressure is not to be expected at the rig, actual values may be used

4.6 Net external overpressure

Risers subjectede to combined effective tension, bending moment and external overpressure, shall satisfy the following conditions at all cross-sections

$$\left(\left(\frac{T_e}{F_d * T_{pc}}\right)^2 + \left(\frac{M_b}{0.95 * F_d * M_{pc}}\right)\right)^2 + \left(\frac{p_o - p_{int}}{F_d * p_c}\right)^2 \leq 1 \qquad \text{(29), Ref/A1/eq. 25}$$

Where

T_e is the effective tension in the pipe.

T_{pc} is the plastic tension capacity of the pipe.

F_d is the design factor as given in section 2.3.

M_{bm} is the bending moment in the pipe.

M_{pc} is the plastic bending moment capacity of the pipe.

p_{int} is the internal pressure in the pipe.

p_o is the external pressure.

p_c is the pipe hoop buckling pressure.

Pipe capacities are given in section 4.1

The highest external overpressure combined load is expected to appear at the wellhead due to the highest external pressure. For conservative calculations, use values as given in Table 9.

Table 9: Recommended values for external overpressure calculations

Variable	**Value**
T_e	Effective tension at wellhead as given in section 3.1
T_{pc}	As given in section 4.1.4
F_d	As given in section 2.3
M_{bm}	Highest estimated bending moment at wellhead as given in section 3.2
M_{pc}	As given in section 4.1.3
p_{int}	Atmospheric pressure as given in section 3.3.2
p_o	External pressure at wellhead as given in section 3.3.2
P_c	Collapse pressure as given in section 4.1.2

5 Riser design according to ISO 13679

The calculations in this section is based on the von-Mises yield capacities with equations as described in ISO 13679 (Ref/47).

5.1 Pipe capacities

5.1.1 Pipe burst capacity

The pipe yield capacity can be calculated using equation 30

$$p_y = \frac{\sigma_y}{\sqrt{3}} * \frac{{D_o}^2 - (D_o - 2*t)^2}{{D_o}^2}$$ (30), Ref/B1/Table 2

Where

σ_y is the design yield strength.

t is the wall thickness without tolerances. (for burst pressure capacity calculations, use t_1 and for combined load capacities use t_2 as defined in section 2.2.)

D_o is the specified nominal pipe outside diameter.

5.1.2 Hoop buckling (collapse) capacity

The pipe hoop buckling capacity is dependent on several different factors, where the yield collapse capacity and plastic collapse capacities are deciding for pipes within the scope of workover risers. For relatively thin walled risers, the plastic collapse pressure is the deciding factor and for thick walled risers, the yield collapse pressure is deciding. The range for use of plastic collapse is given in Table 10, and for factor D/t below the range stated in Table 10, the yield collapse equation shall be used.

The pipe yield-collapse capacity is given by equation 31

$$p_{y,c} = -2 * \sigma_y * \frac{\left(\frac{D_o}{t_1} - 1\right)}{\left(\frac{D_o}{t_1}\right)^2}$$ (31), Ref/A2/eq. B.4

Where

σ_y is the design yield strength.

t_1 is the wall thickness without tolerances.

D_o is the specified nominal pipe outside diameter.

The plastic collapse pressure can be calculated using equation 32

Note: equation 32 is only valid for USC units (in/psi). Using SI units will not give valid results

$$p_{p,min} = \sigma_y \left(\frac{A_c * t_1}{D_o} - B_c\right) - C_c \qquad (32), \text{Ref A3/eq. 37}$$

Where

A_c is the empirical constant in historical API collapse equation.

B_c is the empirical constant in historical API collapse equation.

C_c is the empirical constant in historical API collapse equation.

The empirical constants are dependent on material grades and is found in Table 10: Equation factors for plastic collapse equation. Ref/A3/Table 12

Table 10: Equation factors for plastic collapse equation. Ref/A3/Table 12

Material grade[(a)]	A_c	B_c	C_c (psi)	*D/t* range
H40	2.950	0.0465	754	16.40 to 27.01
-50	2.976	0.0515	1056	15.24 to 25.63
J55, K55	2.991	0.0541	1206	14.81 to 25.01
-60	3.005	0.0566	1356	14.44 to 24.42
-70	3.037	0.0617	1656	13.85 to 23.38
C75, E75	3.054	0.0642	1806	13.60 to 22.91
L-N-80	3.071	0.0667	1955	13.38 to 22.47
C90	3.106	0.0718	2254	13.01 to 21.69
C95, T95, X95	3.124	0.0743	2404	12.85 to 21.33
-100	3.143	0.0768	2553	12.70 to 21.00
P105, G105	3.162	0.0794	2702	12.57 to 20.70
P110	3.181	0.0819	2852	12.44 to 20.41
-120	3.219	0.0870	3151	12.21 to 19.88
Q125	3.239	0.0895	3301	12.11 to 19.63
-130	3.258	0.0920	3451	12.02 to 19.40
S135	3.278	0.0946	3601	11.92 to 19.18
-140	3.297	0.0971	3751	11.84 to 18.97
-150	3.336	0.1021	4053	11.67 to 18.57
-155	3.356	0.1047	4204	11.59 to 18.37
-160	3.375	0.1072	4356	11.52 to 18.19
-170	3.412	0.1123	4660	11.37 to 17.82
-180	3.449	0.1173	4966	11.21 to 17.47
a: Grades indicated without letter designation are not API grades but are grades in use or grades being considered for use and are shown for information purposes.				

5.1.3 Bending moment capacity

The pipe elastic bending moment capacity is given in equation 33

$$M_y = \sigma_y * W = \sigma_y * \frac{\pi * \left(D_o{}^4 - \left(D_o - 2 * t_2\right)^4\right)}{32 * D_o} \qquad (33), \text{Ref/B1/Table 4}$$

Where

W is the elastic section modulus.

σ_y is the design yield strength.

t_2 is the minimum pipe wall thickness without allowances.

D_o is the specified nominal pipe outside diameter.

5.1.4 Tension capacity

The pipe elastic tension capacity is given by equation 34.

$$T_y = \sigma_y * \frac{\pi}{4} * (D_o{}^2 - \left(D_o - 2 * t_2\right)^2) \qquad (34), \text{Ref /B1/Table 3}$$

Where

σ_y is the design yield strength.

t_2 is the minimum pipe wall thickness without allowances.

D_o is the specified nominal pipe outside diameter.

5.2 Initial pressure design

The following equation is based on internal pressure yield design and gives an initial minimum wall thickness that will meet most shallow water applications.

$$t_{1,min} = \frac{1}{2} * \left(D_o - \sqrt{D_o{}^2 * \left(1 - \frac{\sqrt{3} * (p_{int,d} - p_o)}{\sigma_y * F_b}\right)}\right) \qquad (35)$$

Where

$p_{int,d}$ is the internal design pressure.

$p_{o,min}$ is the minimum external pressure.

F_b is the pipe burst design factor, given as 0.60 for internal pressure design.

p_y is the minimum pipe yield pressure, given in section 3.2.1.

5.3 Internal pressure (yield) design

The differential pressure for a riser shall not exceed the internal design pressure for risers according to ISO 13679. The internal design pressure (including design factor) is given by equation 32

$$p_{int,d} = F_b * p_y \tag{36}$$

Where

$p_{int,d}$ is the internal design pressure.

F_b is the pipe burst design factor, given as 0.60 for internal pressure design.

p_y is the minimum pipe yield pressure, given in section 3.2.1.

For conservative calculations, use well pressure as internal pressure and atmospheric pressure as outside pressure.

5.4 External pressure (collapse design)

The external design pressure is given by equation 37.

$$p_{o,d} = F_c * p_c \tag{37}$$

Where

$p_{o,d}$ is the external design pressure.

F_c is the pipe collapse design factor, given as 0.67 for external pressure design.

p_c is the minimum pipe collapse pressure. Depending on the outer diameter (D_o), wall thickness (t) and material grade, either the yield collapse pressure ($p_{y,c}$) or the plastic collapse pressure shall be used. The valid ranges for the equations are shown in Table 10.

5.5 Combined load, internal overpressure

In a combined load condition, the highest stress can occur either at the inside or at the outside surface, depending on the relationship between the loads. Therefore, calculations for both surfaces must be performed.

The following conditions shall be satisfied for all cross sections of the riser:

Inside surface:

$$\left(\frac{p_{int}-p_o}{p_y}\right)^2 + \left(\left|\frac{T_e}{T_y}\right| + \left|\frac{M_{bm}}{M_y}\left(\frac{D_o-2*t_2}{D_o}\right)\right|\right)^2 \leq {F_d}^2$$

(38), Ref/B2 Table 8

Outside surface:

$$\left(\frac{p_{int}-p_o}{p_y}\left(\frac{D_o-2*t_2}{D_o}\right)^2\right)^2+\left(\left|\frac{T_e}{T_y}\right|+\left|\frac{M_{bm}}{M_y}\right|\right)^2\leq {F_d}^2 \qquad (39), \text{Ref/B2 Table 8}$$

Where

p_{int} is the internal pressure in the pipe.

p_o is the external pressure.

p_y is the pipe yield pressure.

T_e is the effective tension in the pipe.

T_y is the elastic tension capacity of the pipe.

M_{bm} is the bending moment in the pipe.

M_y is the elastic bending moment capacity of the pipe.

F_d is the design factor as given in section 2.3.

D_o is the specified or nominal pipe outside diameter.

t_1 is the minimum pipe wall thickness without allowances and fabrication tolerances as appropriate.

Pipe capacities are given in section 5.1, and recommended values are given in Table 11

Table 11: Recommended values internal overpressure calculations

Variable	Value
T_e	Effective tension at rig as given in section 3.1
T_y	As given in section 5.1.4
F_d	As given in section 2.3
M_{bm}	Highest estimated bending moment as given in section 3.2
M_y	As given in section 5.1.3
p_{int}	Well pressure as given in section 3.3.1
p_o	Atmospheric pressure
p_y	As given in section 5.1.1

5.6 Combined load, external overpressure

For combined load, external overpressure, equation 38 and 39 have been modified to account for external overpressure.

As for internal overpressure the combined load must be calculated for both inside and outside surface

The following conditions shall be satisfied for all cross sections of the riser:

Inside surface:

$$\left(\frac{p_o - p_{int}}{p_{y,c}}\right)^2 + \left(\left|\frac{T_e}{T_y}\right| + \left|\frac{M_{bm}}{M_y}\left(\frac{D_o - 2*t_2}{D_o}\right)\right|\right)^2 \le F_d^{\,2} \quad \text{(40), Ref/B2 Table 8 (modified)}$$

Outside surface:

$$\left(\frac{p_o - p_{int}}{p_{y,c}}\left(\frac{D_o - 2*t_2}{D_o}\right)^2\right)^2 + \left(\left|\frac{T_e}{T_y}\right| + \left|\frac{M_{bm}}{M_y}\right|\right)^2 \le F_d^{\,2} \quad \text{(41), Ref/B2 Table 8 (modified)}$$

Where

p_{int} is the internal pressure in the pipe.

p_o is the external pressure.

$p_{y,c}$ is the pipe external pressure yield capacity.

T_e is the effective tension in the pipe.

T_y is the elastic tension capacity of the pipe.

M_{bm} is the bending moment in the pipe.

M_y is the elastic bending moment capacity of the pipe.

F_d is the design factor as given in section 2.3.

D_o is the specified or nominal pipe outside diameter.

t_1 is the minimum pipe wall thickness without allowances and fabrication tolerances.

Pipe capacities are given in section 5.1, and recommended values are given in Table 12

Table 12: Recommended values for external overpressure calculations

Variable	Value
T_e	Effective tension at wellhead as given in section 3.1
T_y	As given in section 5.1.4
F_d	As given in section 2.3
M_{bm}	Highest estimated bending moment as given in section 3.2
M_y	As given in section 5.1.3
p_{int}	Well pressure as given in section 3.3.1
p_o	Hydrostatic pressure due to external water column (0)
$p_{y,o}$	As given in section 5.1.2

6 Temperature Gradient

Temperature gradient is temperature changing along the pipeline.

The temperature of the fluid inside a pipe will affect the temperature in the pipe wall. At elevated temperature, the mechanical properties of the pipe material are lower and the pipe dimensions required will increase.

As the fluid flows through a riser, heat transferred from the fluid through the pipe wall, to the surrounding water and the internal fluid is cooled. As a result, the temperature at the rig will be lower than at the wellhead and the design of the riser system can be adjusted for the lower temperature.

6.1 Overall heat transfer

Overall heat transfer is a term used to describe the amount of heat transferred from one fluid, through a solid wall and to a second fluid. The overall heat transfer in the case of a riser is dependent of three factors:

- Heat transfer from the internal fluid to the pipe wall
- Heat conduction through the wall
- Heat transfer from the pipe wall to the surrounding water

The measure for overall heat transfer is the overall heat transfer coefficient U with the unit W/m^2*k.

6.2 Convective heat transfer

Convection is the transfer of energy between a fluid and a solid.

The convection in pipes depends on the following factors:

- Fluid properties
- Velocity
- Pipe diameter

The measure for convective heat transfer is the convection coefficient h with the unit W/m^2*k

6.2.1 Internal Convection

When the fluid flows through the pipe inlet, it comes in contact with the pipe inner wall which is cold. The cold wall then absorbs heat from the fluid, which is cooled down.

The flow inside the pipe can be categorized in three groups:

- Laminar flow
- Transition flow
- Turbulent flow

6.2.1.1 Fluid properties

Internal convection depends on various fluid properties like:

- Density
- Viscosity
- Ratio between gas and oil (GOR)
- Temperature
- Pressure

These properties are a factor that can decide the velocity of the fluid.

6.2.1.2 Flow conditions

Flow conditions inside the pipeline can be categorized in three groups decided by the Reynolds number.

Laminar flow, Re < 2100

In laminar flow the convective heat transfer is relatively low, because the fluid close to the wall moves slowly and is not mixed with the faster moving fluid in the center of the pipe, see Figure 2, and the flow layer are parallel with each other (Figure 1).

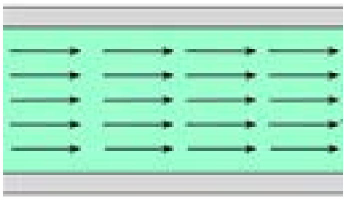


Figure 1: Laminar flow direction

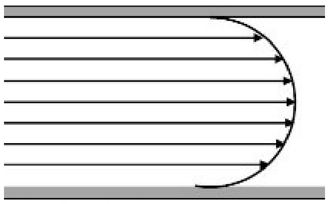


Figure 2: Laminar flow velocity

Transient flow, 2100 < Re < 10^4

Transient flow is a mixture of turbulent and laminar flow. This occur when there is turbulent flow in the centre of the pipe and laminar flow near the pipe wall,

For transient flow, we can calculate the Reynolds number and determine the degree turbulence in the flow.

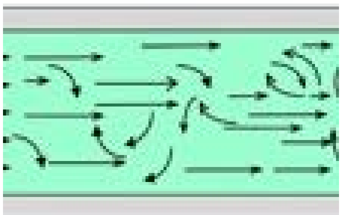


Figure 3: Transient flow direction

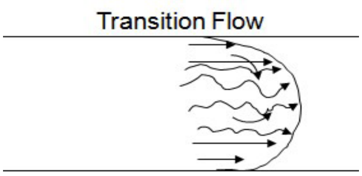


Figure 4: Transient flow velocity

Turbulent flow, Re > 10^4

Occur in fluid with high velocity and the flow layers are unstable because of the fast changes in flow direction and velocity. Due to the unstable flow, the conductive heat transfer is significantly higher, because the fluid close to the wall flows faster than the laminar flow.

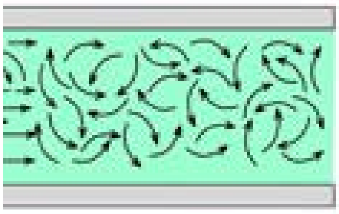


Figure 5: Turbulent flow direction

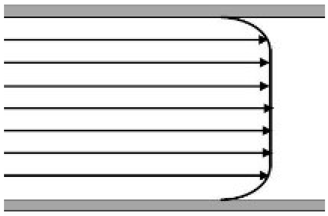


Figure 6: Turbulent flow velocity

6.2.2 External convection

The external heat transfer is the transfer of heat from the external pipe surface to the surrounding water. The amount of heat transfer depends on water temperature, salt content and pressure. As seen in Figure 7, the temperature changes along the riser and this have to be considered in the calculations.

External convection is divided in two categories:

- Natural (free) convection
- Forced convection

In most cases, the actual convection will be a combination of the two.

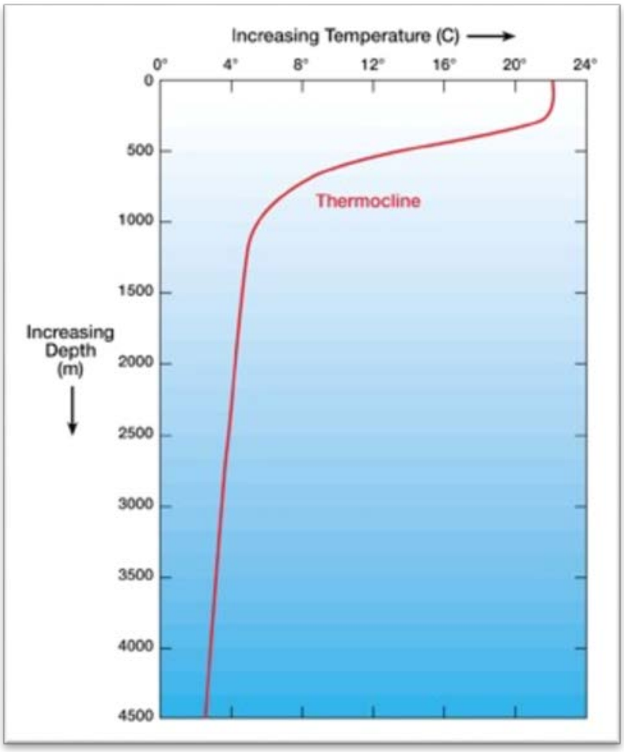


Figure 7: Temperature vs. water depth

6.2.2.1 Natural convection

If the water surrounding the riser is completely still, the amount of heat transfer to the water would be only due to the conductivity of the water. However, as the water close to the pipe is heated, the density decreases and it starts to rise towards the surface. This leads to an induced circulation of water and adds to the cooling effect of the pipe. This is called natural convection.

6.2.2.2 Forced convection

Since there are constant currents in the seawater, the water around the riser is constantly moving. Therefore, the water heated by the riser is constantly being changed and this adds to the cooling effect. Instead of circulating as natural convection, the warmer water is being transported away from the riser giving a significantly higher heat transfer.

6.3 Heat conduction in pipe wall

Heat conduction through a pipe wall is governed by conductive heat transfer. Conductive heat transfer is dependent on three factors;

- The thermal conductivity of the material (k)
- The distance or wall thickness (Δx or t)
- The difference in temperature (ΔT)

7 Temperature gradient calculation

Calculating the heat transfer and temperature gradient in a riser is complicated due to the many factors affecting the outcome. There are also several different approaches (correlations) to calculating the heat transfer. This chapter contains equations that based on factors usually available for a project, gives estimates of the temperature drop in a riser.

7.1 Temperature drop in pipeline equation

The following equations 42 and 43 are different variations of an equation giving the temperature either at a cross section x along a pipe (equation 42) or the temperature of the fluid flowing out through the end (equation 43).

$$T_{(x)} = T_o + (T_{in} - T_o)\exp(\frac{-U*\pi*D*x}{\dot{m}*C_p})$$ (42), Ref/C1/Eq. 14-36/ p. 419

$$T_2 = T_w + (T_1 - T_w)\exp(\frac{-U*\pi*D_i*L}{\dot{m}*C_p})$$ (43)

Where

T_2 Topside temperature ($T_{(x)}$ *the temperature of fluid at distance x from inlet*), °C.

T_1 Well temperature (T_{in}), °C.

T_W Seawater temperature (T_o), °C.

U Heat transfer coefficient total, W / m^2*K .

D_i Inner diameter (D = D_i), m.

ṁ Mass flow rate of internal fluid, kg / s.

L Pipe length (same as x in equation 42).

C_p Specific heat capacity of internal fluid, J / kg*K.

7.2 Overall heat transfer calculation

The overall heat transfer is defined by the following equation.

$$\frac{1}{U*A} = \frac{1}{h_1*A_1} + \frac{dx_w}{k*A_m} + \frac{1}{h_2*A_2} \quad (44), \text{Ref/D1}$$

The overall heat transfer coefficient U can be calculated either for the inside or for the outside pipe surface. To calculate overall heat transfer coefficient, equation 44 is used but the parameter for wall thickness is changed from dx_w to *t* (wall thickness), the index 1 will be replaced as i (inside surface) and 2 will be o (outside surface).

$$\frac{1}{U_i*A_i} = \frac{1}{h_i*A_i} + \frac{t}{k*A_m} + \frac{1}{h_o*A_o} \quad (45)$$

The area in calculation for overall heat transfer is the surface area of the pipeline.

$$\frac{1}{U*\pi*D_i*L} = \frac{1}{h_i*\pi*D_i*L} + \frac{t}{k*\pi*D_m*L} + \frac{1}{h_o*\pi*D_o*L} \quad (46)$$

This equation for surface area, π*D*L, will be cancelled out to be just the diameter.

$$\frac{1}{U*D_i} = \frac{1}{h_i*D_i} + \frac{t}{k*D_m} + \frac{1}{h_o*D_o} \quad (47)$$

Solved for U, the equation becomes:

$$U_i = \frac{h_i * D_m * k * h_o * D_o}{k * D_m * ((h_i * D_i) + (h_o * D_o)) + t * (h_i * D_i * h_o * D_o)} \quad (48)$$

Where

U_i Heat transfer coefficient total, inside surface W / m^{2}K.

h_i Internal convection heat transfer coefficient, W / m^2*K.

h_o External convection heat transfer coefficient, W / m^2*K .

k Thermal conductivity of the material, W / m*K.

t Wall thickness (use t instead of dx), m.

D_i Internal pipe diameter, m.

D_o External pipe diameter, m.

D_m Midle pipe diameter, m.

7.3 Internal convection calculation

There are different equation for calculating the internal convection depending on the type of flow (laminar, transition or turbulent flow).

The same equation are used for calculating the Reynolds number (Re) and Prandtl number (Pr), but the equation for the Nusselt number (Nu), changes between the types of flow.

Nusselt number:

The Nusselt number can be defined as a relationship between the fluids heat transfer and the thermal conductivity of the material. The Nusselt number is defined by equation 49, and this can be used to find the heat transfer coefficient h_i.

$$Nu_i = \frac{h_i * D_i}{k_f}$$ (49), Ref/C1/p. 405

Solved for hi, this becomes:

$$h_i = \frac{Nu_i * k_f}{D_i} \quad (50)$$

Where:

Nu_i Internal Nusselt number.

D_i Internal pipe diameter, m.

k_f Thermal conductivity of the inner fluid, W / m*K.

h_i Internal convection heat transfer coefficient, W / m^2*K.

Laminar flow

The Nusselt number for laminar flow is calculated from equation 51.

$$Nu_{i1} = 3.66 + \frac{0.0668*\left(\frac{D_i}{L}\right)*Re_i*Pr_i}{1+0.4*[\left(\frac{D_i}{L}\right)*Re_i*Pr_i]^{\frac{2}{3}}}$$

(51), Ref/C1/Eq. 14-8/ p. 406

Valid for Re $\leq$ 2000

Where

Re	Reynolds number
Pr	Prandtl number
Di	Internal pipe diameter, m
Nui1	Internal Nusselt number, laminar flow
L	Distance from pipe inlet, m

The Nusselt number for laminar flow is dependent on the inside diameter (D_i) and the distance from the pipe inlet (L). As L increases, the Nusselt number converges towards 3.66.

Transitional and turbulent flow

For transitional and turbulent flow. The equation proposed by Gnielinski is considered most accurate.

$$Nu_{i2} = \frac{\left(\frac{f}{8}\right)*(Re_i-1000)*Pr_i}{1+12.7*\left(\frac{f}{8}\right)^{\frac{1}{2}}*\left(Pr_i^{\frac{2}{3}}-1\right)}$$

(52), Ref/C1/Eq. 14-10/ p. 406

Where

f	friction factor
Re_i	Reynolds number
Pr	Prandtl number
Nu_{i2}	Internal Nusselt number, either laminar or turbulent flow

The friction factor calculated from equations 53 to 55

$$f = 8 * \left(\left(\frac{8}{Re_i}\right)^{12} + (\Theta_1 + \Theta_2)^{1.5}\right)^{\frac{1}{12}}$$ (53), Ref/B5

$$\Theta_1 = \left(-2.457 * \ln\left(\left(\frac{7}{Re_i}\right)^{0.9} + 0.27 * \frac{\varepsilon}{D}\right)\right)^{16}$$ (54), Ref/B5

$$\Theta_2 = \left(\frac{37530}{Re_i}\right)^{16}$$ (55), Ref/B5

Where

Re_i	is the internal Reynolds number
ε	is the surface roughness factor. (0.5 µm for steel tubes)

Reynolds number:

The Reynolds number is used to define flow types inside a pipe;

- Laminar flow
- Turbulent flow
- Transitional flow

Can be defined as the relationship between the fluids kinetic energy and the viscosity of the fluid.

$$Re_i = \frac{D_i * V_f * \rho_f}{\mu_f}$$ (56), Ref/C1/p. 405

Prandtl number:

Used to calculate the heat transfer in fluid and is a relationship between kinematic viscosity and the thermal conductivity of a material or flowing fluid.

$$Pr_i = \frac{C_{pf} * \mu_f}{k_f}$$ (57), Ref/C1/p. 406

Where

Re_i	Internal Reynolds number
Pr_i	Internal Prandtl number
V_f	Velocity of fluid, m / s
ρ_f	Density of fluid, kg / m^3
μ_f	Viscosity of fluid, Pa*s
Cp_f	Specific heat capacity factor of fluid, J / kg*K
k_f	Thermal conductivity of the inner fluid, W / m*K

7.4 External convection calculation

7.4.1 Combined natural and forced convection

Natural convection is negligible when Gr/Re2 < 0,1

Forced convection is negligible when Gr/Re2 > 10

Neither is negligible when 0,1< Gr/Re2 < 10

$$h_{combined} = \left(h_{forced}^{n} +/- h_{natural}^{n}\right)^{\frac{1}{n}}$$ (58), Ref/C2/eq. 9-66

Where

$h_{combined}$	is the combined heat transfer coefficient
h_{forced}	is the forced heat transfer coefficient
$h_{natural}$	is the natural heat transfer coefficient
n	is a coefficient varying between 3 and 4 where 3 is chosen for vertical surfaces and 4 is used for horizontal surfaces.

The +/- indicates that for opposing flows, - is used and for assisting or transverse flows + is used.

Grashof number:

$$Gr = \frac{g * \beta (Ts - Tw) * L^3}{v^2} \quad (59)$$

Where

Gr	Grashof number.
g	Gravity, m / s^2 .
β	Volumetric thermal expansion coefficient, m^3/m^{3}K.
Ts	Surface temperature, ^{o}C.
Tw	Water temperature, ^{o}C.

7.4.2 Natural convection

$$Nu_{natural} = \left\{ 0.825 + \frac{0.387 * Ra^{\frac{1}{6}}}{\left(1 + \left(\frac{0.492}{Pr}\right)^{\frac{9}{16}}\right)^{\frac{8}{27}}} \right\}^2 \quad (60), \text{Ref/B4}$$

Where

Ra	Rayleigh number.
Pr	Prandtl number.

The equation for natural convection is the same as for vertical plates and is valid for $\frac{D}{L} > \frac{35}{Gr^{\frac{1}{4}}}$. This mean that for long vertical pipes such as risers, the equation is not by definition valid. However, there is no equation describing natural convection for long vertical tubes and this equation gives the closest estimation.

Since equation 60 is taken from calculations for vertical pipes, the corresponding equation for heat transfer coefficient is used as in equation 61

$$h_{natural} = \frac{Nu_{natural} * k_o}{L} \quad (61)$$

Where

L	is the length of the pipe.
$Nu_{natural}$	External Nusselt number due to natural convection.
k_o	Thermal conductivity for seawater

Rayleigh number:

Rayleigh number is a combination between Prandtl number and Grashof number.

$$Ra = Gr * Pr$$

Where

Ra	Rayleigh number.
Pr	Prandtl number.
Gr	Grashof number.

For free convection, the properties of the fluid at T_{film} temperature shall be used, where t_{film} is calculated from the following equation

$$T_{film} = \frac{T_{\infty} + T_{wall}}{2}$$

Where

T_{film}	is the film temperature
T_{∞}	is the fluid temperature at a sufficient distance from the object
T_{wall}	is the object wall temperature

The riser wall temperature can be calculated from the following equations

$$T_{outer\ wall} = T_w + \frac{(T_i - T_w) * U_i * D_i}{D_o * h_o}$$ (62), Ref/C1/p. 412-416

$$T_{inner\ wall} = T_i - \frac{(T_i - T_w) * U_i * D_i}{D_i * h_i}$$ (63), Ref/C1/p. 412-416

Where

Tw	Water temperature, ^oC.
T_i	internal fluid temperature, ^oC.
U_i	overall heat transfer coefficient, W / m^2*K
h_i	Internal convection heat transfer coefficient, W / m^2*K
h_i	External convection heat transfer coefficient, W / m^2*K
D_i	Internal pipe diameter, m.
D_o	External pipe diameter, m.

7.4.3 Forced convection

The external forced convection equation is similar to the one used for the internal convection.

$$h_{forced} = \frac{Nu_{forced} * k_o}{D_o}$$ (64), Ref/C1/p. 408

Where

h_{forced}	External convection coefficient
Nu_{forced}	Nusselt number for seawater
k_o	Thermal conductivity for seawater
D_o	External pipe diameter

Use the Churchill and Bernstein equation for calculating the Nusselt number outside the pipe.

$$Nu_{forced} = 0.3 + \frac{0{,}63 * Re_o^{\frac{1}{2}} * Pr_o^{\frac{1}{3}}}{\left[1+\left(\frac{0{,}4}{Pr_o}\right)^{\frac{2}{3}}\right]^{\frac{1}{4}}} + \left[1 + \left(\frac{Re_o}{282000}\right)^{\frac{5}{8}}\right]^{\frac{4}{5}}$$ (65), Ref/B3

The equation for forced convection can only be used if $Re_o * Pr_o > 0.2$.

$$Re_o = \frac{D_o * V_o * \rho_o}{\mu_o}$$ (66), Ref/C1/p.408

$$Pr_o = \frac{C_{po} * \mu_o}{k_o}$$ (67), Ref/C1/p.408

Where

Nu_{forced}	Forced convection Nusselt number.
Re_o	External Reynolds number.
Pr_o	External Prandtl number (equals to 7.2 for seawater).
D_o	External pipe diameter, m
V_o	Velocity of the surrounding fluid, m / s.
ρ_o	Density of the surrounding fluid, Kg / m^3.
μ_o	Viscosity of the surrounding fluid, Pa*s.
k_o	Thermal conductivity of the surrounding fluid, W / m*K.
Cp_o	Specific heat capacity factor of the surrounding fluid, J / kg*K.

8 Engineering tool

8.1 General description

The engineering tool created by this project is to be used as a support tool by the Well Access Systems department at FMC technologies. The tool has three main capabilities:

- Calculating ideal riser dimensions for specific situations
- Calculating maximum water depth for risers under different conditions
- Calculating the temperature of the internal fluid along the riser.

The tool is developed in Microsoft Excel and uses Visual Basic macros to perform the calculations in addition to several Excel functions.

8.2 Tool simplifications and limitations

8.2.1 Riser dimensioning and depth limit

As described in section 3, the largest differential pressure loads and combined loads are to be expected either at the upper or lower end of the riser. The tool therefore only performs calculations for the sections where the highest load is expected.

The pressure drop inside the riser caused by fluid column and flow friction is not included in the calculations. As a function, the actual internal pressure at the rig, for some modes of operation will be lower than what is used for the calculations and this leads to calculations that are more conservative.

8.2.2 Temperature gradient

For the temperature gradient, the difference in water temperature is not included in the calculations. The change in properties of the internal fluid as a function of pressure drop and change in temperature through the riser is not assessed.

These factors are excluded because of technical challenges and complicated calculations needed. This also increases the amount of inputs needed. this would complicate the use of the tools and contribute to confusion and is therefore a potential source of error.

As a function of this, some deviation is to be expected from the calculations. However, the outputs still gives a good indication that is sufficient for the intended use of the tool

The following factors are excluded from the calculations and have minimal effect on the results:

- Change in the properties of seawater as function of change in temperature, salt content and pressure.
- Change in heat transfer due to different riser geometry at connections

8.3 Tool navigation and function

For navigating the tool, buttons with functional description is used. The inputs are entered in input tables and outputs are shown in tables and as visual presentation.

Tool navigation and functionality is described in detail in the user manual ref 1.

8.4 Technical description

8.4.1 General

The tool uses buttons assigned to Visual Basic macros to navigate between Excel worksheets and performing logic calculations. The macros are located in four separate VBA modules: Riser_selection, Depth_limit, Temp_gradient and Varius_subs.

The tool also uses excel functions such as data validation for unit selection and worksheet protection to prevent unwanted alteration of the tool.

8.4.2 Riser selection module

The riser selection module is used to calculate the minimum wall thickness for risers with different material qualities.

The module consist of the following subroutines:

- Riser_selection_main: Calls subroutine based on which design standard has been chosen for the calculations.
- Riser_selection_13679: Calculates minimum wall thickness according to ISO 13679.
- Riser_selection_14628_7: Calculates minimum wall thickness according to ISO 13628-7.

The riser selection routines have the following setup:

- The worksheet where the outputs are written is unprotected.
- Constants and variables are defined.
- Input values are assigned based on input value and unit selected in the input worksheet.
- The contents in the intended output worksheet area is cleared.
- An if function defines drift diameter based on a table in the worksheet “input selection tables” if “Drift class” is selected as input.
- Internal diameter is calculated.
- The routine enters a loop that calculates and prints the minimum wall thickness, outside diameter and de-rated properties of risers with yield strength between 90 and 130 ksi with 5ksi increments.
    - The yield strength of the material is de-rated to meet brittleness criteria. (Only for ISO 13628.7).
    - The yield strength of the material is de-rated through interpolation between the values defined in section 2.1.2 in this document.
    - The routine enters a new loop that calculates the minimum wall thickness for the current material qualities. The wall thickness is increased by 0.1 mm until the riser meets all design criteria according to the selected standard, as described in sections 4 and 5 in this report.
        - The riser capacities for the current riser is calculated.
        - The loads for the current riser is calculated.
        - The load factor for all design criteria is calculated.
        - If all load factors are below 1 (the design criteria is met), the loop is exited.
        - If the wall thickness is increased to 100 mm without all design criteria being met, the loop is ended reporting a wall thickness of 100.

    - If the design criteria has been met, the results of the calculations (de-rated yield strength, nominal wall thickness and outside diameter) is written in the outputs worksheet. If the design criteria is not met, an error message Is written instead.
- The outputs sheet is selected and the graph axes are adjusted to display the results.
- The output worksheet is protected to prevent unwanted alterations by the user.

8.4.3 Water depth limit module

The water depth limit module is used to calculate the maximum water depth of a specific riser

The module consist of the following subroutines:

- Depth_limit_main: Calls subroutine based on which design standard has been chosen for the calculations.
- Depth_limit _13679: Calculates depth limit according to ISO 13679.
- Depth_limit _14628_7: Calculates depth limit according to ISO 13628-7.

The Depth limit routines have the following setup:

- The worksheet is unprotected to allow for writing outputs
- Constants and variables are defined.
- Input values are assigned based on input value and unit selected in the input worksheet.
- Effective wall thickness of the riser is calculated
- The yield strength of the material is de-rated to meet brittleness criteria. (only for ISO 13628.7)
- The yield strength of the material is de-rated through interpolation between the values defined in section 2.1.2 in this document
- The routine enters a loop that calculates the maximum water depth for the specified riser
    - An initial water depth of 20 000m is defined and reduced with 1m for each time the loop is repeated
    - The riser capacities for the current riser is calculated according to chosen standard
    - The loads for the current riser is calculated
    - The load factor for all design criteria is calculated
    - If all load factors are below 1(the design criteria is met), the loop is exited

  - o If the loop is repeated until the water depth reaches 0 without all design criteria being met, the maximum water depth reported is 0
- The maximum water depth is written to the output sheet and the worksheet is protected to prevent unwanted alterations by the user.

8.4.4 Temp gradient module

The temperature gradient module calculates the temperature of the fluid in the riser at different sections.

The module contains a single subroutine, temp_gradient, with the following setup.

- The output worksheet is unprotected to allow for writing outputs
- Constants and variables are defined.
- Input values are assigned based on values and units entered in the inputs sheet.
- An initial wall temperature is defined
- The riser is divided into 20 sections and temperature change in each section is calculated in a loop.
  - o The routines enters another loop that is repeated 20 times, using the outside wall temperature from the last cycle as input to the next
    - ▪ The temperature drop and mid section riser wall temperatures is calculated according to the equations in section 7 of this report.
  - o The calculated exit temperature, corresponding water depth and mid-section wall temperatures are written to outputs sheet
  - o Exit temperature of current section is set as entry temperature for the next section.
  - o The process is repeated for the remaining sections.
- Well temperature and riser water depth of the wellhead is written
- Output sheet is selected

8.4.5 Various subs module

The various subs section contains small sub-routines used for navigation between worksheets.

8.5 Password protection

The structure of the tool, visual basic modules and worksheet cells that should not be altered by the user is protected with password.

The password that can be used to unlock all functions is “**dwrps1234**”.

Note: The calculation subroutines contains a function that automatically protects the output worksheets.

8.6 Calculation accuracy and quality

All calculations made by the tool have been tested against manual calculations using the equations and procedures described in this report. All significant deviations have been assessed and rectified.

The temperature gradient calculations have also been tested against tools currently in use by FMC and only minor deviations were found. The deviations were identified to be due to slightly different approach to the calculations and a difference in which simplifications are made.

To make the temperature gradient calculations more user friendly, some of the parameters have been set to typical values. Calculations performed by the project shows that varying these parameters have relatively small impact on the result.

The tool gives the user an indication on the required dimensions and water limit for risers. The tool is however not a substitute for a full global analysis, nor was it ever intended to be. For this purpose, a more extensive analysis is required.

8.7 Future development

The tool has a potential for future development to add functionality. The capabilities in this section have been considered by the project group and omitted due to limited time for development and testing.

8.7.1 Combining tool functions

Combining the temperature gradient with the riser selection and water depth limit calculations will allow calculations where the local temperature is used instead of the well temperature thus giving a higher capacity.

Note: The temperature may vary significantly with sea current, water temperature and internal fluid properties. This function must therefore be used with great caution to prevent exceeding the design criteria.

8.7.2 Reporting function

By adding a function that automatically creates a report with the calculation results and input values, the user can easily visualize the results and compare different cases.

8.7.3 Sectioned riser calculation

The capability to calculate dimensions and depth limit for risers with different dimensions at different sections of the riser would be helpful when designing risers for deep-water applications.

8.7.4 Internal pressure drop

By including the pressure drop inside the riser between the wellhead and the rig, the calculated pressure load at the top will decrease and further capacity is added to the riser.

8.7.5 Additional data outputs

By adding further calculation capabilities the tool can give additional outputs such as bending moment capacities at different water depths, bending moment vs effective tension graphs, connector capacity requirements etc.

8.7.6 Further visualisation of output data

Additional output capabilities increases the possibilities for adding graphs and figures illustrating riser capacities and limitations as shown in Figure 8.

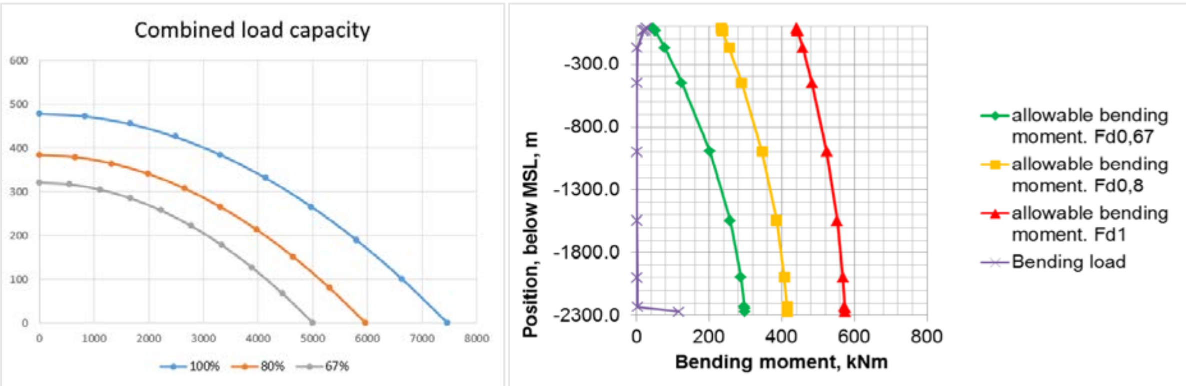


Figure 8: examples of output visualization

8.7.7 Varying sea water current and temperature

The program currently uses the same value for water temperature and current for the entire riser. By adding a function for entering varying data for different sections of the riser, a more accurate result can be calculated.

9 User manual

A user manual for the engineering tool have been created and this document describes in detailed how the engineering tool works. The user manual is intended as a guideline for the user and if problems or conflicts are encountered, the user manual will guide the user back on track, (Ref / 1).

The input parameters are described in a separate section and these parameters are divided into various categories.

A description of the output parameters are also presented in the user manual, so the user can see the most relevant choice. The output is illustrated by a table and in a graph.

10 Conclusions

For phase 2 of the Deep Water Riser Pipe study project, the work scope and requirements defined in the project assignment, requirement specification (Ref / 2) and design basis (Ref / 3) have been met. The engineering tool and the user manual have been evaluated by FMC through a user survey and the feedback were in general positive. Although, there were some comments and suggestions for changes. All the comments have been evaluated and addressed through changes made to the tool and user manual.

10.1 Riser design

For design according to ISO 13628-7 (Ref / A1), the standard itself gives relatively good and simple directions for calculating riser capacities and limitations. The procedure described in this report is more or less taken directly from the standard, although some recommendations and suggestions for simplifications have been added to reduce the workload for the user performing preliminary calculations.

For design according to ISO 13679 (Ref / A2), there is no defined procedure or full set of equations to use for preliminary calculations. The equations and procedure in this report is therefore based on several different sources and the project groups own evaluation of the standard to give a relatively simple and accurate procedure for performing preliminary calculations of riser capacities and loads.

10.2 Temperature gradient

The equations for calculating temperature gradient defined in this report is considered relatively accurate and have been confirmed by the FMC flow assurance department. However the outcome of the calculations are dependent on factors that may not be known in early phases of riser design for a project and using typical or estimated values for these factors will give significant deviations in the results. However, the calculations still gives an indication that can be used as input in early stage evaluations

10.3 Engineering tool and user manual

The engineering tool gives accurate and quick calculation results to otherwise time consuming manual calculations. The results have been tested against manual calculations using the equations in this report and all deviations have been evaluated and proper rectification applied where necessary.

Feedback from the intended users in the form of a user survey indicates that the tool and the user manual meets or exceeds their expectations and will be helpful in their work.

11 References

Table 13: Referenced project documentation

No	Document no	Description
1.	5510	User manual
2.	3100	Requirements Specification
3.	5610	Phase 2 design basis

Table 14: referenced standards

No	Title	Description
A1.	ISO 13628-7	Petroleum and gas industries – design and operation of subsea production system. Part-7:Completion/workover riser systems
A2.	ISO 13679	Petroleum and gas industries – Procedures for testing casing and tubing connections
A3.	ISO 10400	Petroleum and natural gas industries – Equations and calculations for the properties of casing, tubing, drill pipe and line pipe used as casing or tubing
A4.	ISO 15156-2	Petroleum and natural gas industries – Materials for use in H2S-containing environments in oil and gas production. Part 2: Cracking-resistant carbon and low-alloy steels, and the use of cast irons

Table 15: Referenced papers

No	Author(s)	Description
B1.	Finn Kirkemo	Burst and gross plastic deformation limit state equation for pipes: part 1 – theory
B2.	Finn Kirkemo Harald Holden	Burst and gross plastic deformation limit state equation for pipes: part 2 application
B3.	Churchill SW Bernstein M	(1977), "A Correlating Equation for Forced Convection From Gases and Liquids to a Circular Cylinder in Crossflow", J. Heat Transfer, Trans. ASME 99: 300–306
B4.	Churchill SW Chu HHS	(1975) Correlating equations for laminar and turbulent free convection from a vertical plate. Int J Heat Mass Transfer 18(11):1323–1329
B5.	Churchill, S.W.	(1977). Friction-factor equation spans all fluid-flow regimes.

Table 16: Referenced books

No	Author(s)	Description
C1.	Yong Bai and Qiang Bai	Subsea Engineering Handbook
C2.	Yunus Cengel, and Afshin Ghajar	Heat and Mass Transfer: Fundamentals and Applications

Table 17: Referenced Web pages

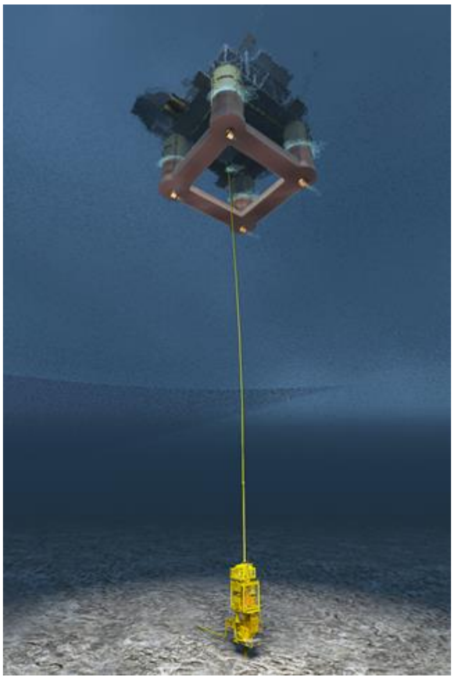
No	Web site	Date of download
D1.	http://www.engineeringtoolbox.com/overall-heat-transfer-coefficient-d_434.html	20.02.2015

12 Document revision history

Rev	Date	Prepared By	Reviewed By	Changes
1.0	12.05.2015	Øystein Ulmo Line Dyre-Hansen	Kjersti S. Anthonsen	

Test Report Phase 2

Deep Water Riser Pipe Study



Rev	Date	Prepared By	Reviewed By	Changes
1.0	14.05.2015	Line Dyre-Hansen	Øystein Ulmo	

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Abbreviations

The following abbreviations are used throughout this document.

Abbreviation	Description
V	Verification
T	Test
GR	General requirement
P2	Phase 2
ET	Engineering tool requirement
RR	Report requirement
ID	Identification
FMC	FMC Technologies Kongsberg Subsea
No	Number
Ref	Reference

1 Introduction

This document contains the test and verification results for phase 2 of Deep Water Riser Pipe Study. In this phase, a new method for selection completion and workover risers and implementing this in an engineering tool.

2 Internal verification results for phase 2

Table 1: Internal verification of general requirement in phase 2

Verification ID	V-P2-01	Date of verification	08.05.2015
Requirement ID	P2-GR-01, P2-GR-02, P2-GR-03, P2-GR-04, P2-GR-05		
Description	• Go through the documentation • Verify requirements against requirement specification • Creating an engineering tool workbook in excel • Verify the description for methods and equations		
Acceptance Criteria	Correct content Quality On time delivery		
Verification code	V1		
Result	Approved		
Conclusion	The design basis document for phase 2 and the report for method and tool development are following the requirements in the requirement specification. It’s a red line between the requirement specification, design basic and the report for phase 2. There have been produced an engineering tool workbook in excel and has been approved from FMC personnel. There have also been produced a user manual for this tool according to the design basis. The verification for the description for methods and equation have been according to ISO 13628 – 7, ISO 13679 and for the temperature gradient, FMC analysis department have approved the methods and equations.		
Comments			
Verified by	The bachelor group		

Table 2: Internal verification of engineering tool and user manual created in phase 2

Verification ID	V-P2-02	Date of verification	08.05.2015
Requirement ID	P2-GR-05, P2-ET-01, P2-ET-02, P2-ET-03, P2-ET-05, P2-ET-06, P2-ET-07, P2-ET-08		
Description	• Verify the engineering tool against requirement specification • Verify the engineering tool against the user manual • Verify the output from the tool • Verify the tool against hand calculations		
Acceptance Criteria	Correct content Quality On time delivery		
Verification code	V1		
Result	Approved		
Conclusion	The engineering tool is created according to the requirement specification. There have been done tests and a user survey to verify the engineering tool and the results is presented in section 5 and 8		
Comments			
Verified by	The bachelor group		

Table 3: Internal verification of report created in phase 2

Verification ID	V-P2-03	Date of verification	08.05.2015
Requirement ID	P2-RR-01, P2-RR-02, P2-RR-03, P2-RR-04, P2-RR-05, P2-RR-06		
Description	• Verify the report against the requirement specification • Verify the parameters description and explanation. • Verify the calculation against the engineering tool		
Acceptance Criteria	Correct content Quality On time delivery		
Verification code	V1		
Result	Approved		
Conclusion	The report contains the requirements in the requirement specification and the parameters are described and explained in the report. There have been done hand calculation and calculating result from an analysis tool have been compared against the engineering tool. More described in section 7.		
Comments			
Verified by	The bachelor group		

3 External verification results

Table 4: External verification of methods created in phase 2

Verification ID	V-P2-04	Date of verification	13.05.2015
Requirement ID	P2-GR-01, P2-GR-02, P2-GR-03, P2-GR-04, P2-GR-05		
Description	• Go through the documentation • Verify requirement against requirement specification • Creating an engineering tool workbook in excel • Verify the description for methods and equations		
Acceptance Criteria	Correct content Quality On time delivery		
Verification code	V2		
Result	Accepted		
Conclusion	All defined requirements are fulfilled		
Comments			
Verified by	Sondre R. Askim		

Table 5: External verification of engineering tool and user manual created in phase 2

Verification ID	V-P2-05	Date of verification	13.05.2015
Requirement ID	P2-GR-05, P2-ET-01, P2-ET-02, P2-ET-03, P2-ET-05, P2-ET-06, P2-ET-07, P2-ET-08		
Description	• Verify the report against the requirement specification • Verify the variables description and explanation. • Verify the calculation against the engineering tool • Verify the tool against hand calculations		
Acceptance Criteria	Correct content Quality On time delivery		
Verification code	V2		
Result	Accepted with comments		
Conclusion	The tool and corresponding user manual is valuable for FMC riser product engineering. Using the tool as intended in early phase engineering will increase efficiency and consistency to the work executed and support decision making in tender phase.		
Comments	The tool is easy to use with the following user manual and generates good visual illustrations of results and input data. This allows us to generate and compare multiple cases in an efficient and consistent manner. The team has shown willingness to incorporate comments and suggested changes to the tool in accordance with FMC interests even for suggested changes assumed to be time consuming and slightly outside the initial defined requirements.		
Verified by	Sondre R. Askim		

Table 6: External verification of report created in phase 2

Verification ID	V-P2-06	Date of verification	15.05.2015
Requirement ID	P2-RR-01, P2-RR-02, P2-RR-03, P2-RR-04, P2-RR-05, P2-RR-06		
Description	• Verify the report against the requirement specification • Verify the parameters description and explanation. • Verify the calculation against the engineering tool		
Acceptance Criteria	Correct content Quality On time delivery		
Verification code	V2		
Result	Accepted		
Conclusion	A well written detailed report has been established. References to selected equations and description of variables are clearly defined which makes the document easily readable for qualified engineers.		
Comments	The combination of equations established and used in the tool is verified by Well Access Systems SWI department. The output of a specific case used to verify the tool indicated high accuracy when using the tool.		
Verified by	Sondre R. Askim & Anders Wormsen		

4 User survey

Table 8 describes the user survey and the answer will be conducted in form of a checkbox. Table 7 describes the verification ID, which requirement, verification code and date of verification.

Table 7: User survey reference

Verification ID	V-P2-07	Date of verification	01.05.2015
Requirement ID	P2-GR-05, P2-ET-01, P2-ET-02, P2-ET-06		
Verification code	V3		

The user survey below, Table 8, is filled out in section 5.

Table 8: The user survey

Question	Excellent	Good	Fair	Poor
User manual				
How is the navigation in the manual?				
Is the manual straight forward to follow?				
Input pages				
How is the navigation method in the tool?				
Is it easy to enter new input parameters?				
How is the methods for choose standards?				
Is it easy to see what to enter for each input?				
Calculation in tool				
Did you get all the information you needed from the tool?				
How is the result demonstrated?				
How is the visualization of the result?				
Tool and user manual				
How is the guideline in the user manual?				
Is the manual helpful for the tool?				
General				
Suggestion for changes				
Other comments				

The results from the user survey, is written in Table 12

5 User survey results

Table 9 and Table 10 describes the results for the user survey. The number shown in each box represents the number of test subjects selected this answer.

Table 9: User survey reference

Verification ID	V-P2-07	Date of verification	01.05.2015
Requirement ID	P2-GR-05, P2-ET-01, P2-ET-02, P2-ET-06		
Verification code	V3		

Table 10: The user survey results

Question	Excellent	Good	Fair	Poor
User manual				
How is the navigation in the manual?	2		1	
Is the manual straight forward to follow?	3			
Input pages				
How is the navigation method in the tool?	2	1		
Is it easy to enter new input parameters?		2	1	
How is the methods for choose standards?	3			
Is it easy to see what to enter for each input?		2	1	
Calculation in tool				
Did you get all the information you needed from the tool?	1	2		
How is the result demonstrated?	1	2		
How is the visualization of the result?	1	1	1	
Tool and user manual				
How is the guideline in the user manual?	2	1		
Is the manual helpful for the tool?	2	1		
General				
Suggestion for changes				
Other comments				

In Figure 1 is the user survey results are presented and each question have four answer opportunities, see different color. Since the answer category named pore, was not ticket off, is this section not shown in Figure 1.

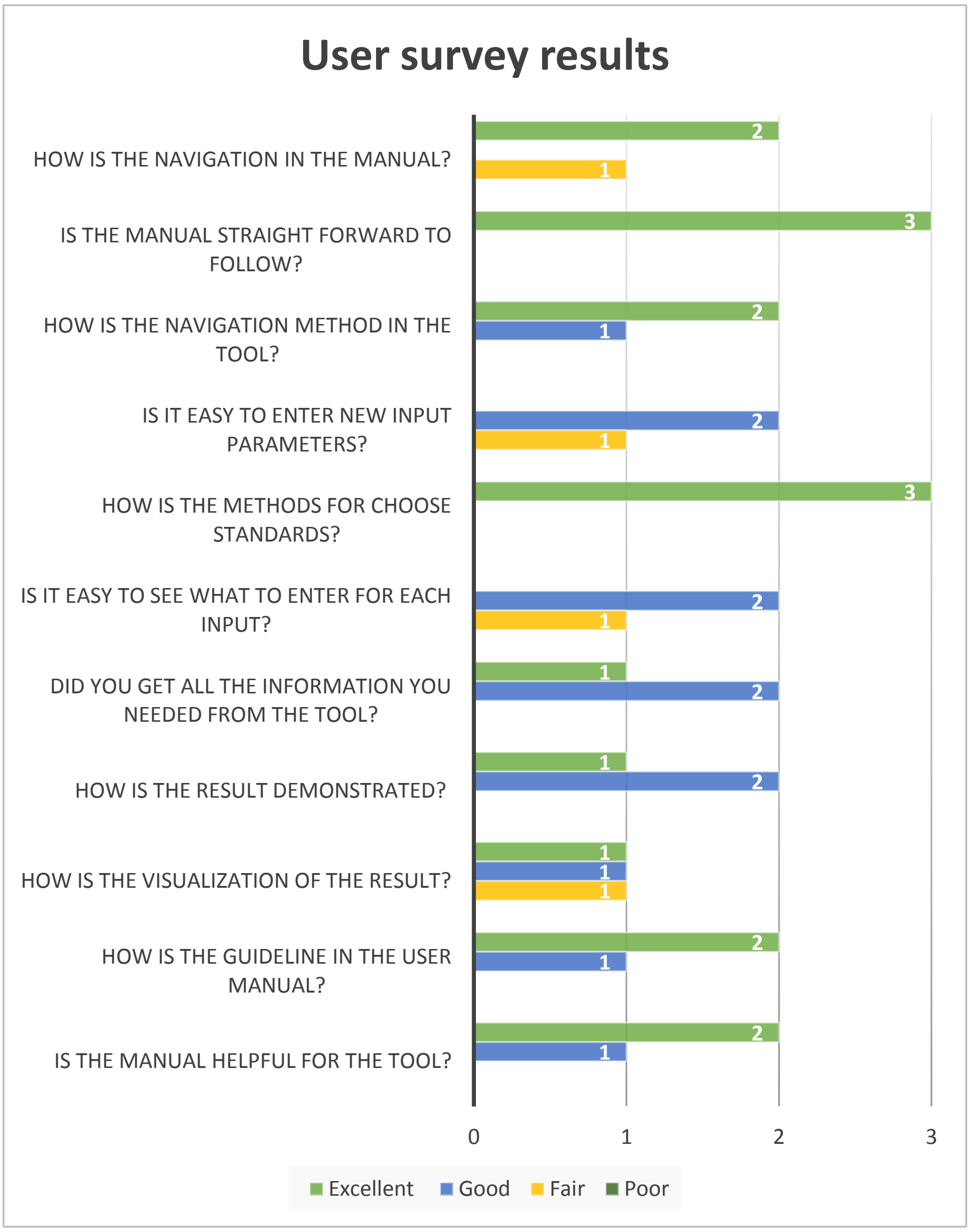


Figure 1: Results from user survey

In the table below, Table 11, the comments from the survey is presented. The comments are not edited so some comments are in Norwegian and other in English.

Table 11: Comments from users

No.	Name	Comment	Responded
1	Kjell Enger	**Engineering tool:**	
		Har satt "fair" her også siden man er tvunget til å bruke de enhetene som er oppgitt, og ikke har mulighet til å endre disse. Tungvint om man må regne om størrelser for å få de til å passe med enhetene i toolet	Implemented
		Is it easy to see what to enter for each input: Nei, det er jo ikke det når det for water depth limit ikke står enheter for yield og ultimate strength. Vet ikke helt hva slags info jeg trenger, så jeg burde vel satt NA for Not applicable på det spørsmålet	Implemented
		How is the result demonstrated og How is the visualization of the result er vel to spørsmål som går litt over i hverandre. Jeg er misfornøyd med at det ikke står enheter på aksene i diagrammene for riser dimensjon og temperatur gradient. Litt uklart for meg hva som menes med de to siste spørsmålene, som ikke dekkes av de to første spørsmålene.	Implemented
		User Manual:	
		Trekker ned at dere ikke varierer font, eller innrykk i innholdsfortegnelsen. Alt fra 2.1 til 2.3.2 har samme font. 2.1, 2.2 og 2.3 bør skilles klart ut slik at man ser at dette er hovedpunkter, og at input data descriptions og Calculation Outputs er underpunkter, som gjentas for 2.2 og 2.3 Når det gjelder navigering i dokumentet så har innholdsfortegnelsen mye å si. Når man har beveget seg vekk fra innholdsfortegnelsen så er manualen lett å følge.	Implemented
2	Sondre R. Askim	**Engineering tool:**	
		The tool is of great value for FMC riser product group.	
		Add title above the calculation sheets	Implemented
		Include the results generated to the calculation sheet rather than separate sheet if possible.	Implemented for deep water limit calculation
		Add feature to save and/or print a calculated case with input parameters and results presented in a practical formate (typ. one page A4).	Not implemented because of the time limit
		Add option to change unit from drop down menu for each input parameter independently (typ. relevant alternatives are both metric and imperial values).	Implemented
		Add comments for typical value or default values for material density. Assume this parameter will have minimal impact to overall result assuming material is steel.	Implemented
		Same as above for E-module	Implemented

		Poisson ratio; this parameter does not seem to affect the calculated result. Please verify and consider to remove parameter. Alternatively, ref. above comment (E-module and density).	Only affects collapse calculation, normally not deciding factor.
		Submerged weight; what is XMT abbreviation for? Replace with XT if no reason for 'M'.	Implemented
		Potential bug in the WD calculation module (ref. separate email). Increase in material yield & tensile reduces the WD limit for selected case. Please investigate.	Implemented
		Add some more key performance date for selected riser pipe when calculating WF limits if possible (typ. Max. design pressure, combined load capacity plots, etc.?)	Partially implemented
		For WD limit calculations it seems that WD=0 is a min. criteria is exceeded (Ex. if Well pressure input parameter exceeds the pipe capacity for burst pressure design, WD limit is reported as 0m).	Implemented
		Is it possible to highlight the exceeded criteria to give the tool operator an idea of which input data / criterias to be re-evaluated?	Implemented
		General:	
		Is it possible to highlight the exceeded criteria to give the tool operator an idea of which input data / criterias to be re-evaluated?	Implemented
		Part 1:	
		Mulighet for å endre unit? (eks. legge inn riser length 45' istedenfor m)	Implemented
		Corrosion allowance, inside and outside? Husker ikke dette helt, men spiller det ingen rolle om det er utvendig eller innvendig?	Implemented: changed to inside
		Mulighet til å navngi en utregnet case samt lagre denne. Generere nytt sheet slik at man kan jobbe med flere samtidig?	Not implemented cause of time limit
		Lage en liten modul for å kunne regne ut pipe material density? Er det noe særlig forskjell her? Hvis ikke, trenger dette være et valg?	Not implemented cause of time limit
		Part 2:	
		Hva er XMT?	Imlemented
		Det ser ut til at man får 0m vanndyp hvis man f.eks. ikke tilfredstiller kriteriet for design trykk. Er det mulig å få frem hvilke kriterier som fører til at en konfigurasjon ikke går? (eks. design pressure for selected pipe limited to X PSI for selected kriteria…eller noe..) • Kan man eventuelt få frem nøkkeltall som f.eks design pressure på valgt pipe i tillegg til vanndyp?	Partially implemented
3	David Anthony Muff	**Engineering tool:**	
		Recommend that the name of all input terminology is identical to ISO 13628-7 and that the symbol used in ISO 13628-7 is also give. Otherwise there will be confusion	Partially implemented

		Use ISO 13628-7 terminology Units	Partially implemented
		It is recommended to use either SI or imperial units, but not to use a mixture .	Implemented
		Is the radial or diametrical. Use "Minimum diametrical clearance, D_{clear}"	Implemented
		What is well pressure? MWHSIP ? maximum down hole pressure? I think this design pressure not MWHSIP	Partially implemented, maybe new updates
		What is well temperature? Shut-in temperature, flowing temperature? or is this design temperature?	Partially implemented, maybe new updates
		Needs to be specific. Mass in air without contents, or mass in water without contents, or mass in water with contents	Implemented
		Pipe wall thickness tolerance can +ve and -ve. But only -ve shall be used. Stated "Negative pipe wall thickness tolerance"	Partially implemented, will be updated
		Use ISO 1362-7 terminology, "Corrosion/wear/erosion tolerance , t_{ca}"	Implemented
		Note that ISO 13628-7 definition of pipe ovality is different to other codes. Use "Initial pipe ovality, f_o"	Implemented
		specify units in this figure	Implemented
		specify units for parameter in this table	Implemented
		Use ISO 13628-7 terminology and symbols, "Nominal out side diameter, D_o	Implemented
		Is the "Design maximum metal temperature" or "design maximum fluid temperature"?	Partially implemented, maybe new updates
		Use ISO 13628-7 terminology and symbols, "Internal design pressure, pint,d"	Partially implemented, maybe new updates
		User manual:	
		Is the diametrical clearance, D_{clear} in accordance with ISO 13628-7 Figure E.1	Will be changed
		This is not correct. Design pressure does not equal maximum working pressure of the well. Recommend that only design pressure is used. Or is required for thermal analysis, maximum well head shut-in pressure, maximum well head flowing pressure. Only use terminology given in Annex F of ISO 13628-7.	Will be changed
		Where is this bending moment located? in the riser pipe ? Along the whole length? at the top or at the bottom?	Will be changed
		Initial pipe ovality, f_0 in accordance with Equation (15) of ISO 13628-7	Will be changed
		According to equation in ISO 13628-7, corrosion/erosion/wear allowing in on the inside. OD of the pipe is not reduced. This means external corrosion shall be controlled by corrosion protection.	implemented

4	Roar Kongsjorden	**Engineering tool:**	
		Better visualization of where it's allowed to enter values (in the value column)	Not implemented cause of time limit
		Drop-down for units where relevant (ex psi/ksi//bar/MPa, inch/mm)	Implemented
		For the water depth calculation, it could be good to visualize the combined load limits within 67%, 80% and 100% in a graph (with y: water depth, x: bending moment))	Not implemented cause of time limit. Added as suggestion for future development
		It is possible to enter drift size even if you have chosen the drift class (not custom). Perhaps it is possible to prohibit entering a value when the drift class is chosen?	Not implemented due to technical challenges and that customer drift value does not affect the result when drift class is chosen.
		Could it be good to have default values, where these represents typical values (E-module, y/t ratio etc), or perhaps a "reset values" button to reset the values to typical...?	Typical values added in description

There were some grammatical errors in the user manual, they have been corrected.

6 User survey verification results

Table 12: User survey results

Verification ID	V-P2-07	Date of verification	01.05.2015
Requirement ID	P2-GR-05, P2-ET-01, P2-ET-02, P2-ET-06		
Description	Results from user survey See Figure 1		
Acceptance Criteria	Quality The safety of the program On time delivery		
Verification code	V3		
Result	Approved		
Conclusion	In generally, FMC is pleased with this tool, however some new suggestion are described in section 5		
Comments	The results indicates that he tool is of great value for FMC riser product group.		
Verified by	Line Dyre-Hansen		

7 Tests

In this section, the tests for verifying the tool is described and performed in four various terms as follow:

- Hand calculation results for riser dimension
- Hand calculation results for water depth limit
- Hand calculation results for temperature gradient
- Comparative test

.

7.1 Hand calculation results for riser dimension

There were found some deviation between hand calculation and the engineering tool. This deviation are described under section 7.1.2, results.

7.1.1 Description

This test verifies the calculations made by the tool to calculate optimal riser dimensions.

The test is performed as follows

- Input parameters are entered into the tool and optimal dimensions are calculated.
- Manual calculations using the dimensions calculated by the tool are made and compared to the tool output

Several different cases were tested, where all parameters were altered to identify all calculation deviations.

7.1.2 Results

The deviations and errors found, together with the cause of the deviations are listed in Table 13.

Table 13: Deviations and errors from hand calculation for calculating riser dimension

No.	Deviation	Cause
1	The load design factors calculated manually were all significantly below 1, causing higher than necessary wall thickness	The logic calculating the pipe body slenderness factor was faulty, causing a lower bending moment capacity.
2	A slight deviation in all pipe capacities were detected	The tool uses a value for π of 3.14 while the manual calculations use the exact value
3	The collapse pressure load factor for ISO 13679 deviated from the manual calculation	Wrong wall thickness is used to calculate yield collapse pressure.

7.1.3 Conclusions

The test uncovered some deviation in the tool calculations. That will require rectification prior to release of the tool.

7.2 Hand calculation results for water depth limit

There were found some deviation between hand calculation and the engineering tool. This deviation are described under section 7.2.27.1.2, results

7.2.1 Description

This test verifies the calculations made by the tool to calculate maximum water depth for risers

The test is performed as follows

- Input parameters are entered into the tool and maximum water depth is calculated
- Manual calculations using the water depth calculated by the tool are made and compared to the tool output

Several different cases will be tested, where all parameters are altered to identify all calculation deviations.

7.2.2 Results

The deviations and errors found, together with the cause of the deviations are listed in Table 14

Table 14: Deviations and errors from calculating maximum water depth

No.	Deviation	Cause
1	When value for yield stress above 0.92 * ultimate tensile strength was entered, water depth limit of 0 m was calculated	Ultimate tensile strength of the material is not defined when derating due to high Yield/UTS ratio is performed
2	Load factor for burst design deviates from manual calculations	Wrong burst pressure variable is used to calculate load factor

7.2.3 Conclusion

The test uncovered some deviation in the tool calculations. That will require rectification prior to release of the tool.

7.3 Hand calculation results for temperature gradient

There were found some deviation between hand calculation and the engineering tool. This deviation are described under section 7.3.2, results.

7.3.1 Descriptions

This test verifies the calculation made by the engineering tool to calculate the temperature gradient.

The test is performed as follow:

- Input parameters are defined and implemented in the tool, and the temperature drop from the well to the riser opening are calculated.
- Hand calculation with the same inputs parameters and compared the result against each other.

7.3.2 Results

The results from the hand calculation, is approximately the same as the results from the tool, there was just a little deviation with some few degrees. The cause of this can be rounding failure with the decimals, or the calculation in the program can be a little different from the hand calculations.

Test deviation and errors found before the rectification, together with the cause of deviation are presented in Table 15.

Table 15: Deviations and errors for hand calculation for temperature gradient

No.	Deviation	Cause
1	When value for the well temperature is below the sea temperature will it be some deviation.	If the temperature of the well is below the sea temperature, the Rayleigh number will be negative and there will be problematic to calculate the nusselt number.

7.3.3 Conclusion

In the first tests, there were found one deviation, see Table 15, but after the rectification, this deviation was removed. So now is there no limitation for calculating the temperature gradient.

The test will uncover some deviation in the calculating of the temperature gradient, and this deviation will be refining in the tool.

7.4 Comparative test

There have been done a comparative test between engineering tool and an analysis tool from analysis department of FMC in Asker. The results from this test was very optimizing because the results were approximately the same, just some few deviations in the decimals.

The test is performed as follow:

- The same parameters were put into the different programs, engineering tool and FMC analysis program, Table 16. There were also used same parameters for oil.

Table 16: Inputs for comparative test

Model	Value
Inner diameter	180 mm
Outer diameter	219,075 mm
Length	2000 m
Sea water parameters	
Density	1025 kg/m^3
Absolute viscosity	$1,08 * 10^{-3}$
Kinematic viscosity	$1,05 * 10^{-6}$
Specific heat capacity	3993 J/kg
Thermal conductivity	0,596 K*m/W
Thermal expansion coefficient	$2,07 * 10^{-4}$ m^3/m^3*K

- Compared the outputs for the two programs and there was approximately the same.

8 Test results

This section describes the results from testing the engineering tool three parts. Riser selection, water depth and temperature gradient will be tested separately. The result will be written in the same general report (Ref/Table 17).

Table 17: Functional testing of engineering tool and manual

Test ID	T-P2-01	Start date	27.04.2015	Stop date	01.05.2015
Requirement ID	P2-GR-04, P2-GR-05, P2-ET-02, P2-ET-03, P2-ET-05, P2-ET-06, P2-ET-07,				
Description	The tool is divided into three parts, but two of these three parts (part 1 and 2), will be testes in a case from FMC. <u>Riser dimension calculation</u> • Various cases from FMC • Results from various drift classes (7") • Hand calculation result against results from engineering tool • Test the two standards against each other, (ISO – 13679 and ISO – 13628-7) <u>Water depth limit calculation</u> • Hand calculation result against result from engineering tool • Test the two standards against each other, (ISO – 13679 and ISO – 13628-7) <u>Temperature gradient calculation</u> • Results from the engineering tool against results from FMC analysis department • Results against each other, if deviation in the results, find the reason. • Result of calculation with invalid parameters • One case with different values inside the pipe • Hand calculation result against results from engineering tool				
Acceptance Criteria	Correct content Quality Precise results				
Procedure					
Result	Approved, see section 7				
Conclusion	It has been performed successful tests in terms of hand calculations and comparisons between analysis tool from FMC and the engineering tool. There was found a few deviations, but these have been corrected.				
Comments					
Tested by	Line Dyre-Hansen and Øystein Ulmo				

9 Rectification and retesting

There have been done some fault rectification and retesting of the tool with background from the user survey and testing.

Rectifications and changes of the tool:

- Drop- down function for the units and standards
- For water depth limit are the inputs and the results at the same page
- Title on every sheet
- Units in the table and along the axis have been done
- Gnielinski equation for all Reynolds number
- Churchill equation for friction factor.
- Use ISO 13628-7 terminology
- The logic calculating the pipe body slenderness factor was changed so that correct factor is used
- The constant defining π has been changed to 3.1416. this is sufficiently accurate for the calculations
- Wall thickness used to calculate yield collapse pressure was changed
- Logic defining ultimate tensile strength of the material was changed
- The burst pressure variable used to calculate load factor was changed

Applicable tests were repeated with no significant deviations.

10 Reference

The documents referenced in this report is listed in Table 18.

Table 18: Document references

No.	Document No	Document title
1.	3100	Requirement Specification
2.	3200	Test Specification
3.	5510	User Manual
4.	5610	Design Basis Phase 2
5.	5630	Final Report Phase 2

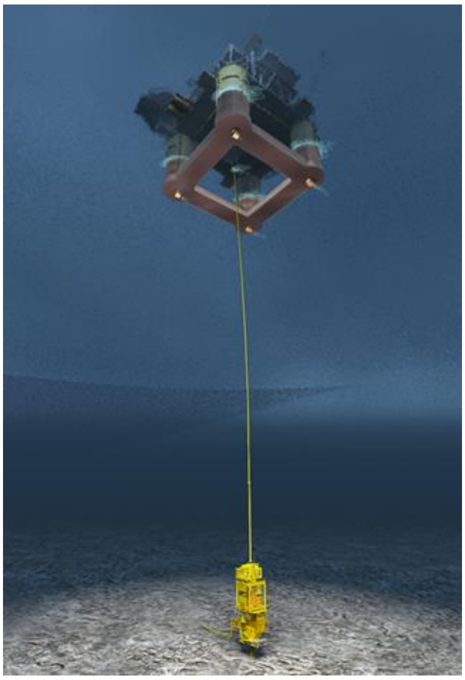
11 Document revision history

Table 19: Document revision history

Rev	Date	Prepared By	Reviewed By	Changes
1.0	14.05.2015	Line Dyre-Hansen	Øystein Ulmo	

Design Basis Phase 3

Deep Water Riser Pipe Study



FMC Technologies

HBV

Rev	Date	Prepared By	Reviewed By	Changes
1.0	20.04.2015	David Snarheim	Kjersti S. Anthonsen	

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Abbreviations

The following abbreviations are used throughout this document.

Abbreviation	Description
10K	10 000 psi
17,5K	17 500 psi
EDP	Emergency disconnect package
FMC	FMC Technology
GR	General requirements
HBV	Høyskolen i Buskerud og Vestfold (Buskerud and Vestfold University College)
HP	High pressure
HSLV	High set lubricator valve
HT	High temperature
LRP	Lower riser package
P3	Phase 3

1 Introduction

This document describes the design basis for phase 3 of the Deep Water Riser Pipe Study project. In this phase, the project will conduct a conceptual study and present a proposal for new riser pipe design to meet deeper water.

2 Referenced documents and requirements

This section references the documents and requirements used as input for creating the detailed requirements for phase 3. It also reference which section of this document is based on which requirement as shown in Table 2.

Table 1: Document references

Document no	Document name
3100	Requirement specification
3200	Test specification

Table 2: Requirements phase 3

Requirement no	Requirement	Reference	Priority	Chapter in this document
P3-GR-01	A specific case, where deep-water risers are required shall be defined in cooperation with FMC	FMC	A	Section 3
P3-GR-02	One or more concept solutions for riser joint shall be developed	FMC	A	Section 3
P3-GR-03	The concept or concepts shall if possible, be tested using the engineering tool created in phase 2 of the project	FMC	A	Section 3.2.2
P3-GR-04	The project shall perform cost estimates for the concept/concepts	FMC	C	Section 3
P3-GR-05	The project shall evaluate the concept/concepts and give recommendations on further development for one or more concepts	FMC	A	Section 3
P3-GR-06	The findings from phase 3 shall be presented in a technology document	FMC	A	Section 0

3 Concept

This section describes the boundaries for conducting the conceptual study phase 3.

3.1 Preliminary calculations

The preliminary calculations shall be conducted to estimate the suitability for a steel riser in deep water conditions, the preliminary check shall be performed for.

- 7” 10K Deep water
- 5” 17,5K Deep water HP/HT

Parameters as defined in Table 3 and Table 4 shall be used as basis for preliminary calculations.

The preliminary calculation may utilize a sectioned riser with variation in pipe dimensions across the riser system length, as shown in Figure 1 and Figure 2 or a combination of both.

Table 3: 7” 10K Deep water case parameters

Parameter	Requirement
Design standard	ISO 13628-7
Water depth	4000 m
Drift size	7 according to ISO 13628-7 (Ø178,56 mm)
Design pressure	690 bar / 10 000 psi
Design Temperature	Temperature class U according to ISO 13628-7 -18 to 121 °C
Bending moment	50 kNm
Weight EDP/LRP	50 ton
Weight Connector	0,5 ton
Weight HSLV	5 ton
Over pull at wellhead connector	20 ton
Internal fluid weight	1000 kg/m^3
Sour service	Yes

Table 4: 5” 17,5K Deep water HP/HT case parameters

Parameter	Requirement
Design standard	ISO 13628-7
Water depth	1900 m*
Drift size	4a according to ISO 13628-7 (Ø129,9 mm)
Design pressure	1206 bar / 17 500 psi *
Design Temperature	Temperature -18 to 149 °C*
Bending moment	50 kNm
Weight EDP/LRP	50 ton
Weight Connector	0,5 ton
Weight HSLV	5 ton
Over pull at wellhead connector	20 ton
Internal fluid weight	1000 kg/m^3
Sour Service	Yes
*parameters from FMC JDA 20K project	

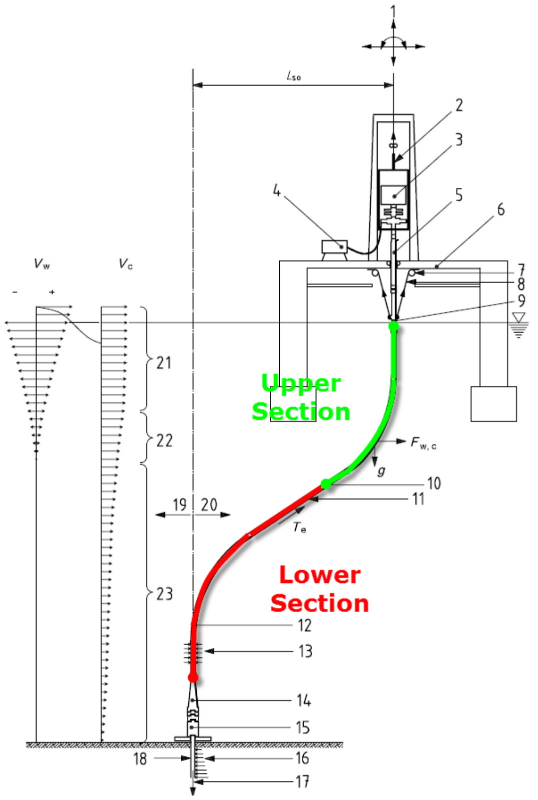


Figure 1: Two sectioned riser

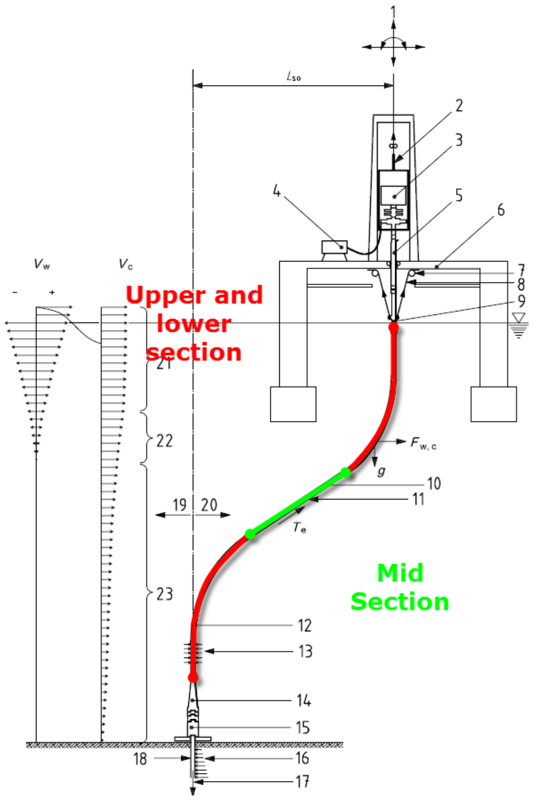


Figure 2: Three sectioned riser

3.2 Preliminary calculation evaluation

The outcome from preliminary calculations shall be evaluated, and a decision shall be taken whether a steel riser is suitable for the specified deep water cases or not. The outcome of this will dictate the further scope of work as specified below.

1. **If not suitable** the scope of work presented in section 3.2.1 shall be performed
2. **if suitable** the scope of work presented in section 3.2.2 shall be performed

In a situation where steel riser is suitable for only one of the cases with parameters as defined in Table 3 and Table 4. The project team will in conjunction with FMC determine which scope that shall be performed.

3.2.1 Material selection

Other materials than steel that may be suitable for riser pipe.

- Material selection (i.e. composite, titanium etc.)
- Cost estimate

3.2.2 Optimizing design and calculation

The concepts shall be optimized based on the following parameters.

- Dimensions and material grade
- Weight
- Temperature gradient
- Configuration
- Cost estimate
- Establish effect of increasing / decreasing pressure and temperature
- Test with phase 2 engineering tool.

4 Reporting

For phase 3 there shall be a final report as described below.

4.1 Final report

The conceptual phase main report shall describes in detail, all data such as method /equations /cost estimate as well as detailed evaluation of the conceptual phase.

4.2 Test report

The test report gives a description of the tests and verifications performed in phase 3 including test results and conclusions as specified in test specification see Table 1.

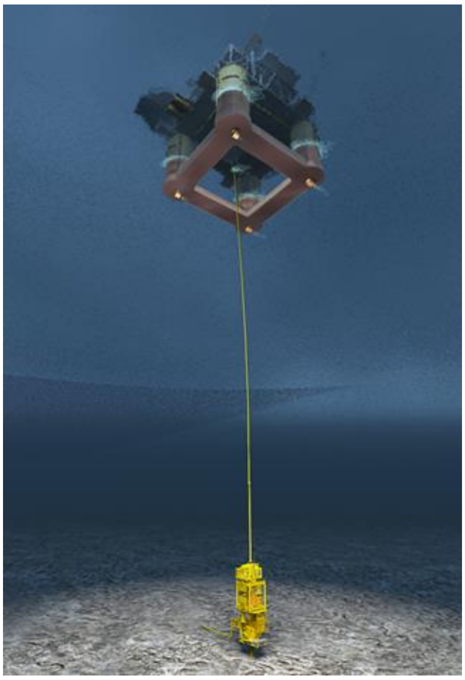
5 Document revision history

Table 5: Revisions

Rev	Date	Prepared By	Reviewed By	Changes
1.0	20.04.2015	David Snarheim	Kjersti S. Anthonsen	

Final Report Phase 3

Deep Water Riser Pipe Study



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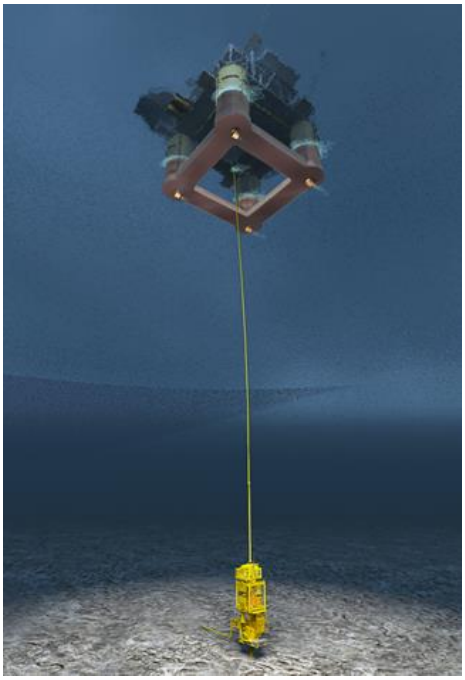
Test Report Phase 3

Deep Water Riser Pipe Study



Rev	Date	Prepared By	Reviewed By	Changes
1.0	15.05.2015	Kjersti Schrøder Anthonsen	Line Dyre-Hansen	

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Abbreviations

The following abbreviations are used throughout this document.

Abbreviation	Description
EDP	Emergency disconnect package
ERC	Enhanced riser connector
FMC	FMC Technologies Kongsberg Subsea
GR	General requirement
HP	High pressure
HSLV	High set lubricator valve
HT	High temperature
Id	Identification
ID	Internal diameter
LRP	Lower riser package
No	Number
OD	Outer diameter
P3	Phase 3
Ref	Reference
UN	Union nut
V	Verification

1 Introduction

This document contains the test and verification results for conceptual proposal for new riser pipe design to meet deeper water (phase 3) of the Deep Water Riser Pipe Study.

The test and verification is based on the requirement specification (Ref/1) and test specification (Ref/2), this report documents the test and verification results of the final report phase 3 (Ref/5), and the design basis phase 3 (Ref/4).

2 Internal verification results for phase 3

The internal verification is divided into two parts, one for the concept (Table 1) and one for the report (Table 2).

Table 1: Internal verification of concept in phase 3

Verification Id	V-P3-01	Date of verification	11.05.15
Requirement Id	P3-GR-01, P3-GR-02, P3-GR-03, P3-GR-04, P3-GR-05		
Description	- Defining a specific case in phase 3 - Several concept solution for riser joint shall be developed - Concept shall be tested against the engineering tool - Shall perform cost estimate for the concept - Shall give a recommendation for further projects		
Acceptance Criteria	Correct content Quality On time delivery		
Verification code	V1		
Result	Approved		
Conclusion	- There has been made two specific cases, one 7" riser to meet the depth of 4000 meters. And one 5" HP/HT riser to meet a depth of 2000 meters. - For each case there has been made two solutions - The riser concepts are sectioned, and there are no possibility to test the riser concepts in to engineering tool. - A cost analysis has been preformed for the 7" case, for both solutions. - Recommendations are described in the report.		
Comments			
Verified by	The project group		

Table 2: Internal verification of report in phase 3

Verification Id	V-P3-02	Date of verification	11.05.15
Requirement Id	P3-GR-04, P3-GR-05, P3-GR-06		
Description	- Go through the documentation for phase 3 - Verify requirement against requirement specification - Verify design basis document for phase 3 against requirement specification		
Acceptance Criteria	Correct content Quality On time delivery		
Verification code	V1		
Result	Approved		
Conclusion	The design basis document and the report for phase 3 are following the requirements in the requirement specification. It’s a red line between the requirements specification, design basis phase 3 and the report for phase 3.		
Comments			
Verified by	The project group		

3 External verification results for phase 3

The External verification is divided into two verifications, one for the concept (Table 3) and one for the report (Table 4).

Table 3: External verification of concept in phase 3

Verification Id	V-P3-03	Date of verification	15.05.15
Requirement Id	P3-GR-01, P3-GR-02, P3-GR-03, P3-GR-04, P3-GR-05		
Description	- Defining a specific case in phase 3 - Several concept solution for riser joint shall be developed - Concept shall be tested against engineering tool - Shall perform cost estimate for the concept - Shall give a recommendation for further projects		
Acceptance Criteria	Correct content Quality On time delivery		
Verification code	V2		
Result	Accepted		
Conclusion	The established cases are relevant and all defined requirements are clearly fulfilled.		
Comments			
Verified by	Sondre R. Askim		

Table 4: External verification of report in phase 3

Verification Id	V-P3-04	Date of verification	15.05.15
Requirement Id	P3-GR-04, P3-GR-05, P3-GR-06		
Description	- Go through the documentation for phase 3 - Verify requirement against requirement specification - Verify design document for phase 3 against requirement specification - Verify the report against design document and requirement specification		
Acceptance Criteria	Correct content Quality On time delivery		
Verification code	V2		
Result	Accepted with comments		
Conclusion	A well written detailed report has been established. The established cases well documented. All defined requirements are clearly fulfilled and includes additional configurations exceeding the initial defined requirements.		
Comments	Markup and comments provided in separate document and meeting.		
Verified by	Sondre R. Askim		

4 Test of the calculations in phase 3

To test the calculations and therefore the results of phase 3 two tests have been performed. The tests are described in the sections below.

4.1 Testing in the engineering tool

One of the requirements from requirement specification (Ref/1) are that the concepts made in phase 3 shall be tested in the engineering tool created in phase 2 (Ref/3) of the project. However all the concepts investigated are on sectioned risers. These are not possible to test in the tool at the current moment. Nevertheless, the case used as an input for the parameter optimizing, see the final report (Ref/5/section 6.5.3), are a one-section riser, which goes down to 3000 meter. This can be tested in the tool, the results will then be applicable for the other cases as well because the same equations are used in all cases.

4.1.1 Input for the test

The inputs used for the testing of the calculations in phase 3 are described in Table 5 and Table 6.

Table 5: 5" HP/HT riser, 3000 m

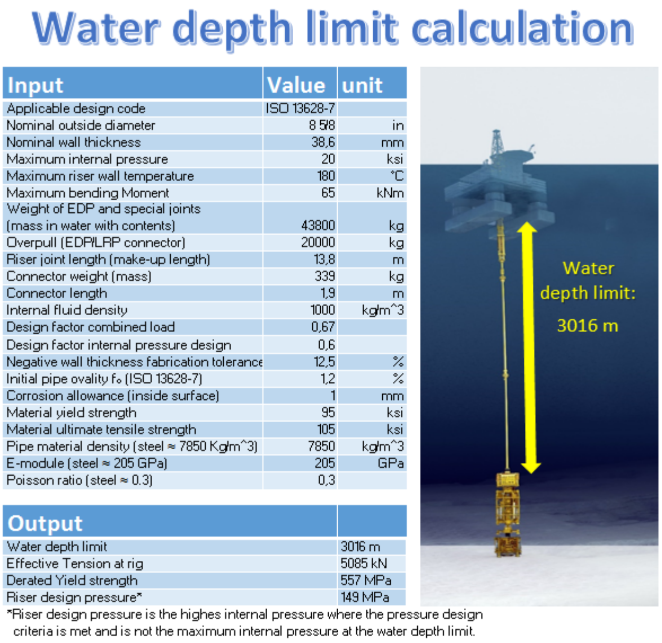
Parameter	Requirement
Design standard	ISO 13628-7
Water depth	3000 m
Drift size	4a according to ISO 13628-7 (Ø129,9 mm)
Design pressure	1379 bar / 20 000 psi
Design Temperature	Temperature class X according to ISO 13628-7 -18 to 180 °C
Bending moment	65 kNm
Weight EDP/LRP	40 ton (wet weight)
Weight Connector	ERC connectors (339 kg)
Weight HSLV	3,8 ton (wet weight)
Over pull at wellhead connector	20 ton
Internal fluid weight	1000 kg/m^3
Fabrication tolerances	12,5%
Corrosion allowance	1 mm
Pipe ovality factor	1,2%
Sour service	Yes

Table 6: Results, 5" HP/HT riser, 3000 m

Parameter	Result
Depth	0m – 3000m
Length	3000m
Connector type	ERC
Pipe OD	8 5/8", (219,075 mm)
Pipe ID	141,875 mm
Pipe drift ID	132 mm
Pipe wall thickness (T_n)	38,6 mm
Effective tension (T_e)	5064,7 kN
Code check	**Result**
Internal pressure design (Burst)	OK (0,93)
Net internal overpressure	OK (0,997)
Net external overpressure	OK
External pressure design (hoop buckling)	OK

4.1.2 Outputs from the test

The input and the results from the calculations in the engineering tool is visualized in Figure 1, and shown in Table 7 and Table 8.



Input	Value	unit
Applicable design code	ISO 13628-7	
Nominal outside diameter	8 5/8	in
Nominal wall thickness	38,6	mm
Maximum internal pressure	20	ksi
Maximum riser wall temperature	180	°C
Maximum bending Moment	65	kNm
Weight of EDP and special joints (mass in water with contents)	43800	kg
Overpull (EDP/LRP connector)	20000	kg
Riser joint length (make-up length)	13,8	m
Connector weight (mass)	339	kg
Connector length	1,9	m
Internal fluid density	1000	kg/m^3
Design factor combined load	0,67	
Design factor internal pressure design	0,6	
Negative wall thickness fabrication tolerance	12,5	%
Initial pipe ovality fo (ISO 13628-7)	1,2	%
Corrosion allowance (inside surface)	1	mm
Material yield strength	95	ksi
Material ultimate tensile strength	105	ksi
Pipe material density (steel ≈ 7850 Kg/m^3)	7850	kg/m^3
E-module (steel ≈ 205 GPa)	205	GPa
Poisson ratio (steel ≈ 0.3)	0,3	

Output	
Water depth limit	3016 m
Effective Tension at rig	5085 kN
Derated Yield strength	557 MPa
Riser design pressure*	149 MPa

*Riser design pressure is the highes internal pressure where the pressure design criteria is met and is not the maximum internal pressure at the water depth limit.

Figure 1: Results from engineering tool.

Table 7: Input engineering tool

Input	Value	Unit
Applicable design code	ISO 13628-7	
Nominal outside diameter	8 5/8	in
Nominal wall thickness	38,6	mm
Maximum internal pressure	20	ksi
Maximum riser wall temperature	180	°C
Maximum bending Moment	65	kNm
Weight of EDP and special joints (mass in water with contents)	43800	kg
Overpull (EDP/LRP connector)	20000	kg
Riser joint length (make-up length)	13,8	m
Connector weight (mass)	339	kg
Connector length	1,9	m
Internal fluid density	1000	kg/m^3
Design factor combined load	0,67	
Design factor internal pressure design	0,6	
Negative wall thickness fabrication tolerance	12,5	%
Initial pipe ovality fo (ISO 13628-7)	1,2	%
Corrosion allowance (inside surface)	1	mm
Material yield strength	95	ksi
Material ultimate tensile strength	105	ksi
Pipe material density (steel ≈ 7850 Kg/m^3)	7850	kg/m^3
E-module (steel ≈ 205 GPa)	205	GPa
Poisson ratio (steel ≈ 0.3)	0,3	

Table 8: Results engineering tool

Output	Value	Unit
Water depth limit	3016	m
Effective Tension at rig	5085	kN
De-rated Yield strength	557	MPa
Riser design pressure*	149	MPa

4.1.3 Conclusions

There are some differences in the equation used for buoyancy, in the calculations done in phase 3 the extra effect of the buoyancy from the connectors has not been calculated, but in the tool this effect is included. This means that the calculations made in phase 3 is more conservative, and may get shorter depths than the engineering tool. However as seen in the tables above, the water depth limit for this case is 3016 meters when tested in the tool, and originally it was 3000 meter, this is approximately the same. In addition, the effective tension is 5065 kN for the calculations and 5085 kN from the tool. From this, it concludes that the calculations are correct and the test is accepted.

4.2 Calculation test

To evaluate the calculations conducted in phase 3 a tested was performed by Anders Wormsen, from the analysis group at FMC. The case described in Table 9 and the results described in Table 10 were sent to the analysis group and tested with their calculation tool. The results received from the test showed that the calculations in phase 3 where correct, and the test was accepted.

Table 9: UN standard riser

Parameter	Requirement
Design standard	ISO 13628-7
Water depth	4000 m
Drift size	4a according to ISO 13628-7 (Ø129,9 mm)
Design pressure	690 bar / 10 000 psi
Design Temperature	Temperature class U according to ISO 13628-7 -18 to 121 °C
Bending moment	65 kNm
Weight EDP/LRP	40 ton (wet weight)
Weight Connector	UN connectors (780 kg)
Weight riser pipe	1569 kg (UN-standard riser)
Weight HSLV	3,8 ton (wet weight)
Over pull at wellhead connector	20 ton
Internal fluid weight	1000 kg/m^3
Fabrication tolerances	10 %
Corrosion allowance	1 mm
Pipe ovality factor	1,2%
Sour service	Yes

Table 10: UN standard riser, 2340m

Parameter	Result
Depth	0m – 2340m
Length	2340m
Connector type	UN
Pipe OD	241,554 mm
Pipe ID	193,802 mm
Pipe drift ID	181,27 mm
Pipe wall thickness (T_n)	23,876 mm
Effective tension (T_e)	4121,2 kN
Code check	**Result**
Internal pressure design (Burst)	OK (0,85)
Net internal overpressure	OK (0, 9986)

5 Test results for phase 3

The concept will be tested with the criteria described in Table 11 and the concept will be tested against the engineering tool if possible.

Table 11: Testing of concept phase 3

<table>
<tr><td>Test Id</td><td>T-P3-01</td><td>Start date</td><td>04.05.15</td><td>Stop date</td><td>14.05.15</td></tr>
<tr><td>Requirement Id</td><td colspan="5">P3-GR-03</td></tr>
<tr><td>Description</td><td colspan="5">- The concept shall be tested with the engineering tool
- The calculations shall be tested by FMC</td></tr>
<tr><td>Acceptance Criteria</td><td colspan="5">- Get approximately the same depth as the depth used for the case investigated.</td></tr>
<tr><td>Procedure</td><td colspan="5">- Use the same input data as defined in the case.
- Use the wall thickness from the calculation results</td></tr>
<tr><td>Result</td><td colspan="5">Approved</td></tr>
<tr><td>Conclusion</td><td colspan="5">See section 4 for more information about the performance of the tests.

Comparisons with engineering tool
- Water depth, calculations: 3000m
- Water depth, tool: 3016m

Calculation comparisons by FMC
- The calculations have approximately the same result.</td></tr>
<tr><td>Comments</td><td colspan="5">The concepts made for the specified cases are all sectioned risers and cannot be tested using the engineering tool. However, the concept used for parameter optimisations, have been tested in the engineering tool.</td></tr>
<tr><td>Tested by</td><td colspan="5">The project team, FMC (Anders Wormsen)</td></tr>
</table>

6 References

Table 12: Reference documents

No	Document no	Document title
1.	3100	Requirement specification
2.	3200	Test specification
3.	5210	DWRPS Engineering tool
4.	6410	Design basis phase 3
5.	6420	Final report

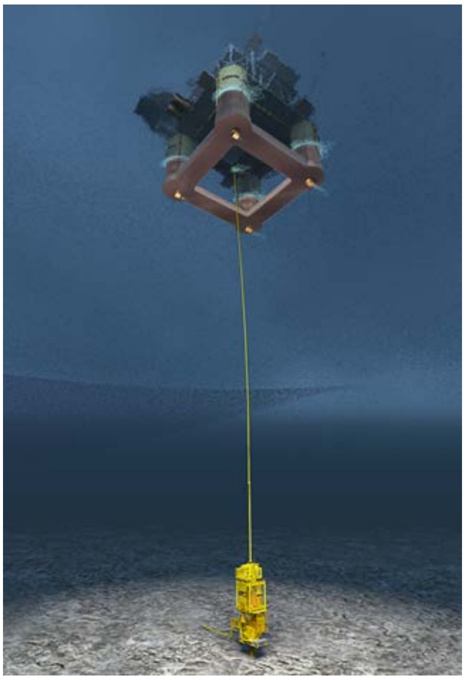
7 Document revision history

Table 13: Document revision history

Rev	Date	Prepared By	Reviewed By	Changes
1.0	15.05.2015	Kjersti Schrøder Anthonsen	Line Dyre-Hansen	

Post Project Evaluation

Deep Water Riser Pipe Study



Rev	Date	Prepared By	Reviewed By	Changes
1.0	14.05.2015	David Snarheim	Kjersti S. Anthonsen	

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Abbreviations

The following abbreviations are used throughout this document.

Abbreviation	Description
CAPEX	Capital expenditure
FMC	FMC Technologies Kongsberg Subsea
HBV	Høyskolen i Buskerud og Vestfold (Buskerud and Vestfold university college)
HP	High pressure
HT	High temperature
JDA	Joint development agreement
OPEX	Operational expenditure

1 Introduction

This document describes the Deep Water Riser Pipe project team's post project analysis of the project. The post project analysis is divided into two main sections, project analysis and individual analysis.

2 Project analysis

2.1 Project management

This section describes the post project analysis related to project management execution.

2.1.1 Project control tool

The project control tool developed for this bachelor thesis has been actively used throughout the whole project, the control tool has provided detailed and accurate information related to posting of hours, input for weekly follow-up and have provided excellent control of the project.

2.1.2 Project model

This project has an unconventional form with three different phases, each with separate requirements, timeframe and deliverable products. Finding a project model that would ensure good quality and precise planning proved to be challenging. A specially adapted project model was therefore created for the project.

Iterations

The guidelines set by the project model have been utilized though the project. The output from each stage has been evaluated by the project group and alterations and corrections have been implemented, where this was necessary.

The quality and time planning iterations were performed as specified in the project model description. All documents have been revised and corrective actions have been made as specified.

The output from each phase have been tested and or verified as specified in the project plan and test specification. For all phases the tests and verifications uncovered some deviation and corrective actions was performed for all phases.

Re-planning of estimated work hours have been performed on 2 occasions. The re-planning was necessary due to certain tasks requiring more time than anticipated.

As specified in the project plan a design document was created for each phase. The documents were written based on work scope meetings with FMC. This ensured that the work performed was in compliance with the contractors expectations.

2.1.3 Project timeline

As specified in section 2.1.2 the project timeline has been revised twice during the project, input used for revising the timeline where based on the project control tool and current project status.

A major timeline change to phase 1 and 3 where performed in week 10, Figure 1 visualizes the change in timeline where "old base line" represents the initial plan for phase 1 and 3. The timeline revision is related to the challenges as specified in section 2.2.2.

In week 15 small adjustments where performed to sub tasks in the time line, however this had no effect on the planed end dates for the project phases.

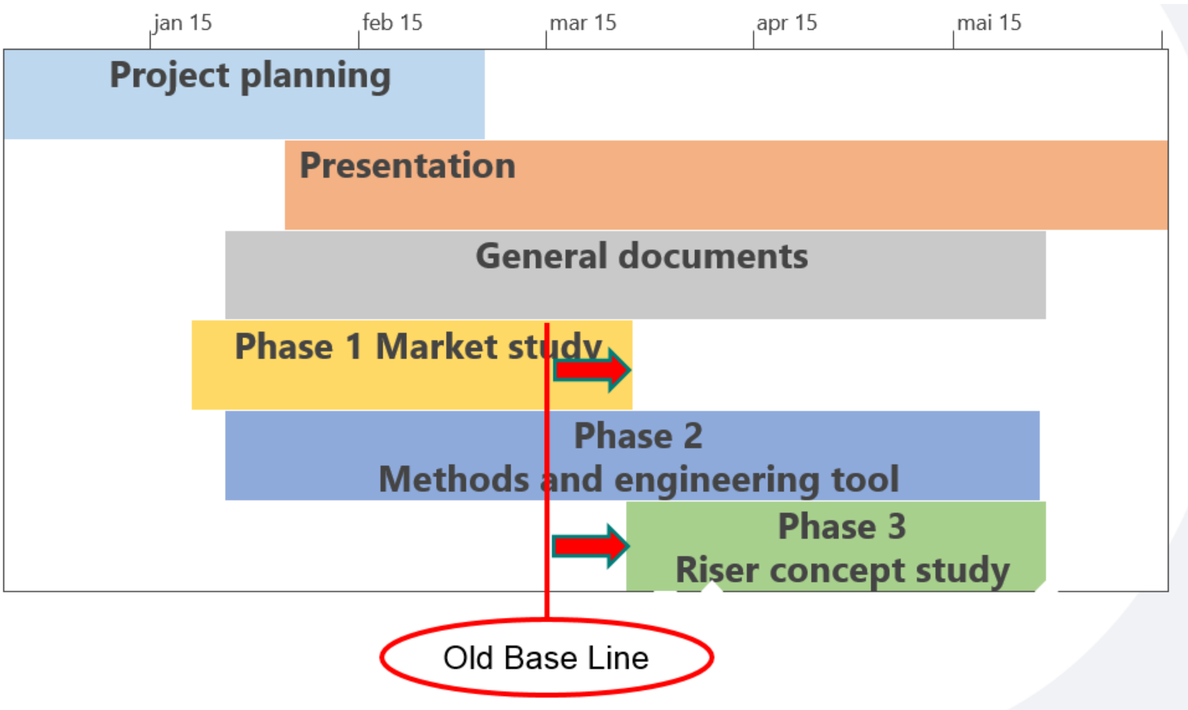

Figure 1: Project timeline

2.1.4 Project hours

The project hours has been derived from the project control tool and are based on actual reported hours including week 19. A summary of the most important graphs are shown in this section, more details related posting of hours and graphs are found in the project control tool.

The graph presented on the left side in Figure 2 to Figure 4 shows a percentage division between resources and workload, the graph presented on the right side shows the reported hours compared to estimated hours. For phase 2 and 3 a estimation of work hours for week 20 is also included.

As seen in Figure 2, phase 1 required more work hours than initially anticipated. The additional hours are related to the challenges as specified in section 2.2.2.

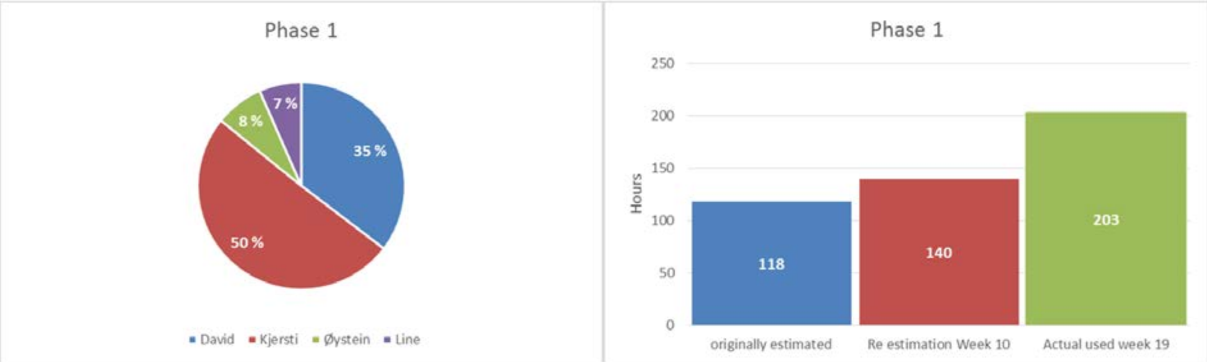

Figure 2: Phase 1 workload

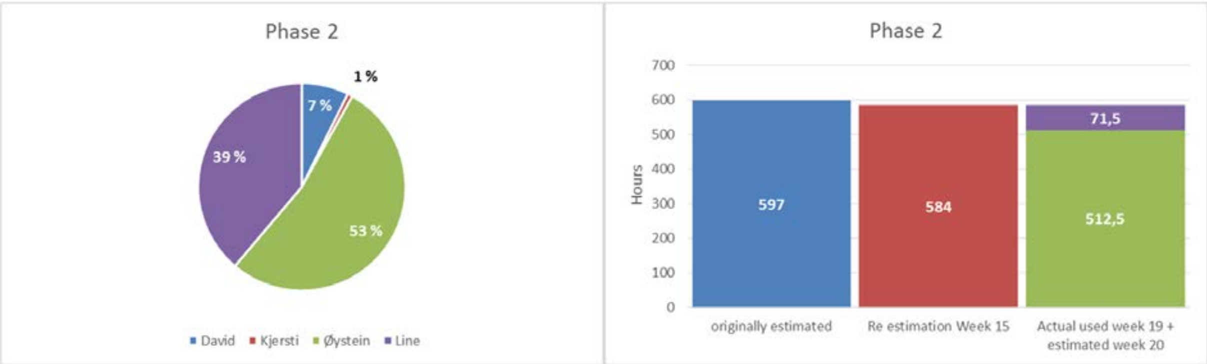

Figure 3: Phase 2 workload

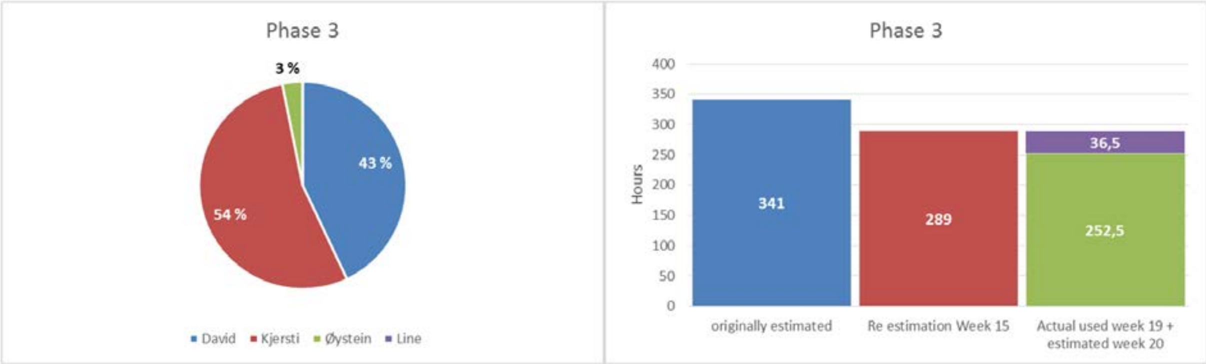

Figure 4: Phase 3 workload

Figure 5 represents the estimated and actual used hours for the general project documents.

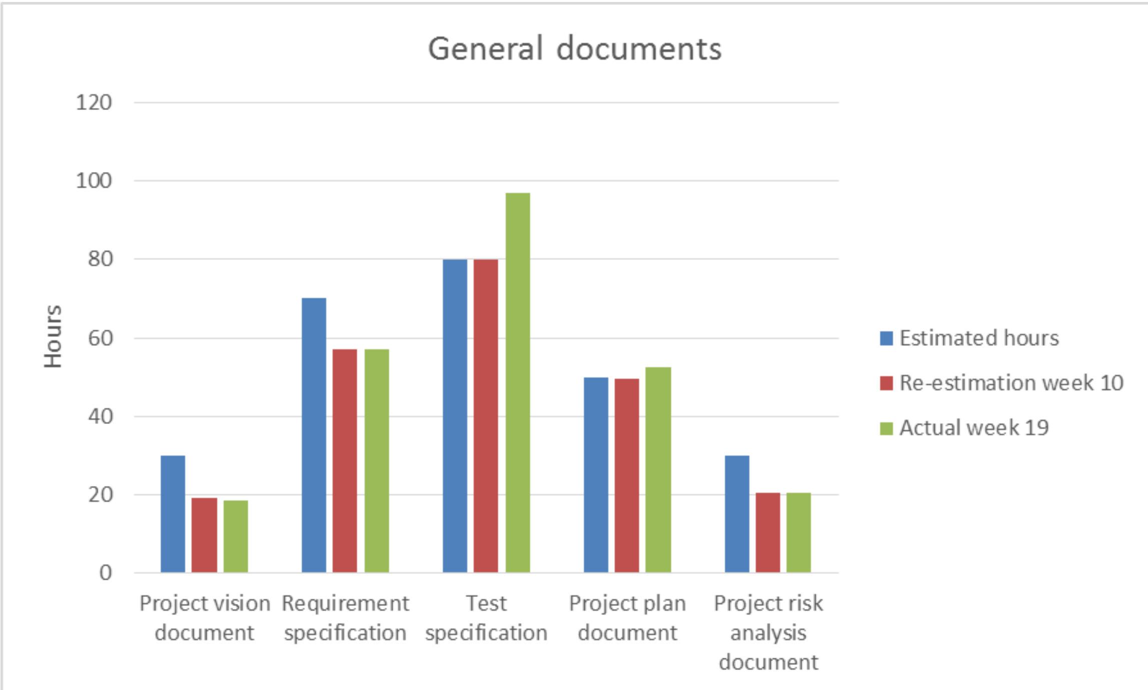

Figure 5: General documentation workload

2.1.5 Risk analysis

Based on the risk analysis conducted by the project team, a few of the pre-identified risk where encountered during the project phases. Table 1 represents these risks and the preventive actions performed.

Table 1: Project risk assessment and preventive action

Risk	Risk assement	Project phase and task	Preventive actions
Technical challenge	Medium	Project phase 2 (Temperature gradient)	Relocation of resources for supporting work on temperature gradient
Quantity task	Medium	Project phase 1	A re calculation of hours and timeline where conducted and resulted in postponing completion date for phase 1, and delayed start date for phase 3
Contract	Medium	Project management	Addition focus required formulate a contract that met all stakeholders requirements
Regular illness	Low	All project phases	Lost time due to regular illness where incorporated the week after illness period

2.1.6 Project responsibilities

Each different phases and sub phases has been managed by different resources and supporting resources, this is shown in Table 2 to Table 5.

Table 2: Project phase responsibility

Project Phases	Sub Phases	Main responsible resource	Supportingg resource
Phase 1	General research	David	Kjersti
	Design basis document	Kjersti	David
	Data collection	Kjersti	David
	Test and verification + report	Line	Kjersti
	Report	Kjersti	David
Phase 2	Training	David	Øystein Line Kjersti
	Design basis	Øystein	Line
	Methods and equation	Øystein	Line David
	Temperature gradient	Line	Øystein David
	Engineering tool	Øystein	Line
	Test and verification + report	Line	Øystein Kjersti
	Refine engineering tool	Øystein	Line
	User document	Line	Øystein
	Report	Øystein	Line
Phase 3	Training	David	Kjersti
	Design basis	David	Kjersti
	Preliminary calculations	Kjersti	David
	Optimizing design and calculation	Kjersti	David
	Cost analysis	David	Kjersti
	Test and verification + report	Kjersti	Line
	Report	David	Kjersti

Table 3: General documentations responsibility

General documents	Responsible
Vision document	Kjersti
Requirements specification	Øystein
Test specification	Line
Project plan document	David
Project risk analysis	Kjersti
Post project analysis document	David

Table 4: Presentations and visualisation responsibility

Presentation and visualization	Responsible
Presentation 1	Kjersti
Presentation 2	Kjersti
Presentation 3	Kjersti
Web page	Kjersti
Project poster	Kjersti

Table 5: Project management and documentations responsibility

Project management and documentation	Responsible
General project follow-up (timeline, hours)	David
Weekly project follow-up document	David
Documentation follow-up	Line
Meeting leaders	All
Minutes of meeting	All

2.1.7 Cross reference to engineering classes

Table 6 describes the cross reference between project phases and engineering classes at HBV.

Table 6: Cross reference to engineering classes at HBV

Subjects	Project phase
Engineer role and project management	Project management
System design and engineering	Project management
Mathematic 1 and 2	Project phase 1,2 and 3
Statistics	Project phase 1
Physics	Project phase 2 and 3
Material technology 1 and 2	Project phase 2 and 3
Statics and mechanics / construction techniques	Project phase 2 and 3
Thermodynamic and fluid mechanics	Project phase 2
Programing micro controllers	Project phase 2 and web page
Subsea	Project phase 1, 2 and 3

2.1.8 Conclusion

Overall, the project management has performed well. The project model in combination with project tools has functioned optimal during the project phases. In addition it provided the project team with accurate and reliable information, such that encountered challenges where easily solved and led the project back on track.

2.2 Project phases

The following definitions are used throughout this section.

Accomplishment**:** Describes the achievements that the project team has accomplished during the project phases.

Challenges**:** Describes the challenges that the project team has encountered and solved during the project phases.

2.2.1 Project requirements, test and verification

Accomplishment

The project team have managed to create clear and concise requirements and a method for test and verification of these.

Challenges

The bachelor thesis has an outline as a study, a result of this was the challenge to specify clear and concise requirements. The challenge were solved by thinking outside the box and having good communication with the contractor.

2.2.2 Phase 1 market analysis

Accomplishment

The project team has gained a good understanding of the current workover riser marked and future trends, further the final report provides FMC Well Access Systems with valuable information as input to future strategy development. In addition to this the project team has gained valuable experience within organizational skills. Phase 1 also provided basic data as input for phase 3 of the bachelor thesis.

Challenges

One of the key challenges with phase 1 where due to the wide range of resources approached, it required good organizational skills to organize for data collection from different databases and resources across the FMC global network.

As encountered early in the data collection phase it became clear that all critical data were not available for completing the project phase. The challenge where solved by performing an approximations based on experience and comparing delivered projects. In addition, the data collection where more time consuming that initially estimated.

As a result of the above mentioned challenges the project phase timeline and hours had to be extended, resulting in postponing the start-up of phase 3.

2.2.3 Phase 2 methods and engineering tool

Accomplishment

The project team have gained a good system understanding of the parameters affecting a riser design. As well as comprehensive understanding of the complex calculations required and their respective ISO standards.

The methods for calculation and their advanced equations has given the project team valuable additional learnings in a wide range of engineering disciplines, such as fluid mechanics and static mechanical engineering.

A fully functional and accurate engineering tool has been developed, that has met and exceeded the contractor expectations. The tool includes extensive visual basic programing which was not an initial requirement, however it gives the tool added functionality, user friendliness and possibilities for future development.

A complete set of equations for calculating temperature gradient, required an in-depth knowledge of advanced fluid mechanics and thermodynamics, which is beyond the curriculum in engineering classes at HBV. This has required the project to perform research at serval different external resources such engineering discipline textbooks and research papers.

The set of equations derived from these sources has been verified by FMC flow assurance department and positive feedback has been received. The temperature gradient calculations performed by the tool, has been tested against tools used by the flow assurance department and found to be accurate.

In addition, a set of equations for calculating the inner and outer wall temperature has been included in the tool. This was not initially specified by the requirements, however the function gives additional information that is useful for assessing the temperature effect on the riser.

The work performed has been highly recognized within Well Access System group, and the project team has been approached by WAS P25 project for incorporating the engineering tool into their toolbox. The goal of the P25 project is to reduce overall riser cost where riser dimension optimization is a key area.

Challenges

The initial plan with the temperature gradient was to include the calculations into the riser optimization. However, the calculations proved to be complicated. Varying many different parameters gave significant changes in results. This was evaluated by the project team and it was concluded that this gave a significant source of error affecting the optimizing calculations. It was therefore decided that a separate function for calculating the temperature were to be created.

The equations for calculating temperature gradient were more complex than initially anticipated. It was also challenging to find complete and consistent sources for the equations. This meant that the project team had to use extra project resources on the subject and the timeline for methods and equations had to be adjusted. The result of this was less time for testing and refining of the engineering tool.

Early calculations using regular equations in Excel showed that using this method for the tool would result in the tool being less transparent and user friendly. This was solved by incorporating Visual Basic programming for the calculations.

Due to the complex sets of equations both for riser dimension and temperature gradient, finding an accurate and effective method for testing was challenging. This was solved by close cooperation with flow assurance and Well Access Analysis group. The calculation results were compared with results from other analysis tools and manual calculations. In addition, the results were compared with the calculations performed in phase 3.

Requirement P2-ET-04 states that the tool shall recommend standard dimensions that meet the design criteria. This proved to be challenging due to several factors. It was also indicated by FMC that this was not a critical requirement. To allow more focus on other requirements and tasks this was therefore removed.

2.2.4 Phase 3 concept proposal

Accomplishment

The project team proposed two concepts for each of two specified cases. In addition a parameter optimization where conducted. This was to investigate the effect of internal pressure, differential pressure and temperature. Further, a comprehensive cost analysis including CAPEX and OPEX costs where performed for two of the concepts.

The work performed has been highly recognized within Well Access System group and the project team has been approached by WAS P25 project, which is a project with the main goal to reduce overall riser cost. The project team were also approached by FMC management through the 20K JDA project. Input from the JDA project where used for the 5"HP/HT case.

A short summary from the mail sent to several global managers (JDA) in FMC system reflecting the recognition of the project is shown below.

> *"ISO 13628-7 (API 17G) for riser pipe allows for differential pressure design, which would allow for thinner wall thickness with increasing depth provided that external collapse capacity is not exceeded. A HBV student project is looking at this."*

Challenges

One of the key challenges for the project team was that phase 3 initially had two main concept options. They were sectioned steel riser or selecting other riser materials. When proposing this for FMC they preferred a steel riser solution. This challenge was solved by conducting preliminary calculations for steel riser, to assess the suitability for the specified cases. The assessment concluded that a steel riser was suitable. Another challenge in phase 3 where to find the optimal number of section for each concept, and where to divide them. This challenge where solved by using an approximation technique.

The project team had anticipated to get support from material department and pipe producers (Tenaris and Vallourec). However, the team gained sufficient information from pipe producer web page and experience trough reading ISO standards.

The cost analysis where initially conducted with specific prices. Due to confidentiality it was not accepted to present this in any report by FMC. This challenge was solved by using a fraction estimate, which was accepted by FMC.

3 Individual analysis

3.1 David Snarheim

Based on many years as employee at FMC Kongsberg well access group, I identified a business case based on needs that I have had challenges with in my daily work routines, especially during tender phases. This idea where further evolved together with Sondre R. Askim and resulted in a thesis description.

The thesis's description may have been slightly vague for my co-students when first presenting them for the project. I therefore used some time at the project startup for training them such that they were well prepared for the challenges to come.

The thesis formed as a study made it challenging to specify clear and concise requirements as well as finding a suitable project model. This required thinking outside of the box, which we managed to accomplish in an effective and professional way. We managed to specify clear and concise requirement and a method to either test or verify them. We also developed our own project model for the thesis, the model where followed and functioned optimal during the project.

My role as project manager for this project has consisted of performing detailed planning, follow-up and leading the project team towards success, as well as providing technical support, ideas and a broad global contact network to the project team.

Some of the project management achievements I have encountered during the project are, getting experience in developing detailed plans, follow up and early identifying the consequences of postponing a task. Further, the role has given me great insight and understanding of managing a group of team members.

From a technical standpoint, the following achievements has been accomplished. I gained a lot of experience in market study phase 1, which gave me great understanding of the market both past and future. This will make me capable of bringing valuable information into strategically future development discussion.

Supporting the temperature gradient in phase 2 has given me in-depth experience in advanced fluid mechanics.

Concept development phase 3 of the project has given me a great insight into the variables that effects the design of a riser system, both technical and commercial aspects.

To sum this up I would say that my learning throughout the project has been multifunctional covering a wide range of professions.

Overall the project team has functioned perfectly well. We have delivered a project, which have met my initial expectations by fare, this is also the indication I have got from FMC well access group. The fact that our group have been recognized and approached by serval internal development project, support this statement.

At the end, I will point out that I am proud of the work accomplished in this thesis, and working with the groups highly technical and professional team members.

3.2 Kjersti Schrøder Anthonsen

I feel that the work we have performed in this bachelor project has been of high quality and has by fare exceeded my expectation. The fact that our contractor FMC has been so pleased with the work we have done, and that we have been participants at meetings concerning internal projects to explain what we have done highlights this.

The group has worked well together we have had good communication and cooperation throughout the projects. We have not had any major disagreements only discussions about the tasks ahead. In addition, I feel that we all have learned a lot from working with each other.

My role in the project as presentation and visualization manager meant that I had the main responsibility for the group image towards our contractor and others. This also meant that I had the responsibility for the presentations, the web page and the poster. In addition, I had the main responsibility for phase 1 and partly responsible for phase 3 of the project.

We have met some challenges along the way, in the beginning the project scope were a bit unclear for me, but we had some meetings and discussions the first week and after this the scope was more clear. Since the project is divided into three phases there were some difficulties to define requirements and test specification. In addition, it was difficult to choose a project model, we had to do more work than initially expected to get a good plan for the project. However I feel that the work we put in at the beginning has paid of later on, the plan has been easy to follow and the requirements and test has been clear.

I have mainly worked with phase 1 and phase 3 of the project. In phase 1 we used more time to gather information than we had planned. In addition, there were very little information about some of the main parameters, which meant that we had to make some assumptions for the conclusion. However, I am very pleased by the result from that phase, especially since FMC was so pleased with the report and the map we created. In phase 3 the work scope was a bit unclear to me, however after some meetings with FMC and discussions in the group the scope became clear. In this phase the biggest challenge for me was learning the equations we would use for the calculations, I have learned a lot from that experience. Another thing that was a big challenge for me was the web page, I have never created a web page before and it was much more difficult than I expected. However because I had the subject, programming and microcontrollers before Christmas it was manageable, and I am very proud of the result.

Working with the project has given me a lot of experience with cooperating with others and the importance of good communication. I have learned how to make a web page and learned a lot about risers and workover systems. In addition, I have gained experience with writhing documents, creating presentations and using excel for both statistics and for equations. Something I definitively will use in the future is the experience I gained in writing technical English and the experience in how to work well in a group.

3.3 Line Dyre-Hansen

My opinion of the group is that we have had a good cooperation between each other, which has led to a result of high quality and the level of knowledge are much higher now that it was at the beginning of the project. We have not had any major discussion within the group, only some small discussion about what the task should contain. Each member has made sure to constantly do their best for the group, and the group itself has contributed to highlight the strengths of each member and enhanced the weaknesses. If there was some problems, the group supported each other to find a solution.

The result from the bachelor project is of high quality and our contractor are very pleased with the result of this project, and the tool that have been created, has been recognized by various development projects in FMC. I am proud of what we have created in this project and that FMC may can use the information we got, has given us extra power to achieve our goals.

My main responsibility in this project was testing and documentation. I was also a partly responsible for phase 2 (one of the three phases) in terms of calculating the temperature gradient. At first, I thought that this was an easy match, but realized quickly that it was more complicated. The most challenging part was the temperature gradient, because there are no defined equation for vertical pipes, so we had to use approximately equations. This part of phase 2 took some more time than originally anticipated because of the dependence between the various equations and parameters. There have also been a challenge to test this part of the tool, since there are no methods today for this. Therefore, we had to do some hand calculations and a comparing to an analysis tool from FMC. The results from the hand calculation and the analysis tool from FMC have been compared with our engineering tool and the result were approximately the same.

At the beginning of the bachelor project, did I not really understand what the task was, since I though there was a mechanical tool and not a calculating tool for engineers. After some discussions and meetings with the group (in a positive way), was my understanding of the project better and the main project was to create a calculation tool for engineers.

At the beginning, I thought this project exciting and would give me more knowledge of the problems that are with work over riser systems today. Now, when I think back, I know that this project have given me experience with work in a team, what challenges an engineer daily have to deal with in a project, and learned to find new solution to problems that can appear.

I have learned enormously from this assignment and teamwork between group members in this bachelor assignment that I can take with me later in life. At the same time, I have used curriculum from thermodynamics and fluid dynamic that I have learned in the engineering classes at HBV.

3.4 Øystein Ulmo

In my opinion, the work performed in this project is of high quality and is has been indicated by FMC, that our product and documentation is of great use for them in their work. The fact that development projects in the company have requested inputs form the project empathizes this.

The cooperation in the project group has worked well. We have had no major disagreements and all members have shown great commitment and performed all tasks to the best of their abilities.

Even though we are pleased with the results of the project, there has been some challenges along the way. The form of the assignment made it difficult to define specific requirement and test specifications to assure the requirements was met. The fact that the project is divided into three separate phases and thereby differs from a traditional product development project, also made it difficult to find a predefined project model that fit the project. We therefore had to develop our own model, based on several different existing models.

My role as Technical Manager meant that I had the main responsibility for the technical outputs of the project. As a function of this had the task of leading the work on the development of the engineering tool. Early in the process it became clear that using only basic excel functions would not give a result fulfilling the potential of the engineering tool. We therefore decided to include Visual Basic programming as part of the setup. This gave us freedom to extend the functionality and the user interface of the tool, resulting in a better overall result.

In phase 2 of the project, the biggest challenges were in connection with the temperature gradient. At first, this was meant as a relatively small part of the tool. However, the calculations required for accurate estimations of the temperature drop proved to be complicated. We found no literature source that gave a clear method for the calculations required and there are several different approaches and correlations used for the calculations. To ensure the quality of the calculations, the main responsibility for the temperature calculations were given to Line, with some support from David. The result of this was a set of equations and a method for calculating the temperature that proved accurate when tested against analysis tools in use at FMC. In addition, it gave me the freedom to focus on other tasks, such as the riser design method and the engineering tool.

For me, this project has been a great learning experience. I have been able to use much of what I have learned through my studies in addition to acquiring a lot of new knowledge and experience. I have also gained experience in project management and the interactions needed when working in an engineering environment.

4 Document revision history

Table 7: Revisions

Rev	Date	Prepared By	Reviewed By	Changes
1.0	14.05.2015	David Snarheim	Kjersti S. Anthonsen	