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IGI Poseidon

IGI Poseidon - Offshore Section Update

Pipeline Mechanical Design Report

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INTECSEA B.V.
Poortweg 6, 2612 PA Delft
P.O. Box 3178, 2601 DD Delft
The Netherlands
Tel.: +31 (0)15 256 56 75
Fax: +31 (0)15 256 01 94
www.intecsea.com

PROJECT 406010-00159 - PIPELINE MECHANICAL DESIGN REPORT

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1 INTRODUCTION

1.1 Background

The Poseidon Pipeline Project, developed by IGI Poseidon S.A., will be designed for the supply of gas from Turkey and the Eastern Mediterranean region to the European market through the interconnection of the Greek and Italian gas networks.

The Poseidon Pipeline consists of two sections:

- An onshore section, stretching from Kipi (north-east of Greece, next to the Greek Turkish border) to the north western coast of Greece (Thesprotia area);
- An offshore section, from the north-western coast of Greece to Italy (Figure 1-1).

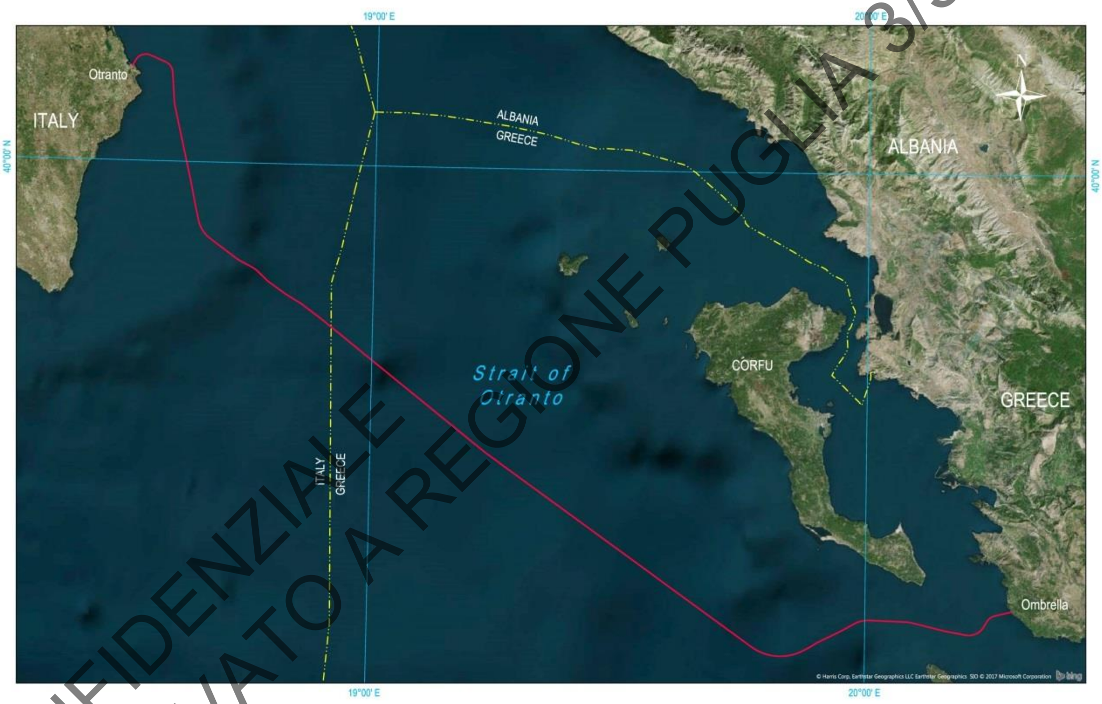


Figure 1-1 Poseidon Pipeline Project – Offshore Section

The offshore section of the Poseidon pipeline comprises:

- A compressor and fiscal metering station next to the Greek landfall (Thesprotia area);
- A deep water offshore pipeline from the Greek landfall to Italy (Otranto, Apulia region). The offshore section (about 200 km, ca. 1,370 m water depth) will cross the Greek shelf, descend the slope into the north Ionian Basin and then ascend the Italian slope, to make landfall east of Otranto;
- A receiving fiscal metering and pressure reduction station in Italy (Otranto, Apulia region);
- Two short buried onshore pipeline sections connecting compressor station in Greece and metering station in Italy to the respective landfalls, including associated scraper launching and receiving facilities.

The FEED phase of the offshore section of the Poseidon Pipeline Project was completed in 2013 and designed for a maximum flow rate of 12 BNCMA of gas (12.66 BSCMA).

ENGINEER’s scope of work is named the Poseidon Pipeline Project - Offshore Section Update (the PROJECT). It concerns the Design Update to accommodate a maximum flow rate of 20 BSCMA of gas (which represents a potential development of the gas pipeline, not yet authorized, but evaluated for the maximum design capacity and related technical aspects) for the deep water offshore pipeline from the Greek landfall to Italy (Otranto) and the short onshore buried pipelines connecting compressor station in Greece and fiscal metering and pressure reduction station in Italy to the respective landfalls. Updating of FEED specific aspects for the Greek onshore section, such as the geological, geotechnical, route selection and civil design aspects is not included in the scope.

The document numbers for the FEED Revision have a new CTR number (1000 series).

1.2 Document Scope

This document presents the mechanical design for the Italian offshore pipeline section of the Poseidon Project. The offshore mechanical design comprises the determination of the minimum required wall thicknesses per section of the Italian offshore pipeline route and the associated buckle arrestor dimensions, if required.

The Italian onshore wall thickness design is separately reported in the Onshore Pipeline Mechanical Design Report – Italy (Ref. [3]).

1.3 System of Units

All dimensional data and results presented shall be expressed in the International System of Units (SI Units). In addition, other units may be used where they are universally accepted standards, such as for standard flow rates, temperature (°C), pressures (bar), or pipeline diameters (inch).

2 DEFINITIONS AND ABBREVIATIONS

2.1 Definitions

Definitions applicable to the Project are provided in Table 2-1.

Table 2-1 Project Definitions

WORK	Scope of Services per CONTRACT for "Poseidon Pipeline Project – Offshore Section Update"
CONTRACT	The CONTRACT between IGI Poseidon and ENGINEER for WORK as detailed in the CONTRACT documents
CLIENT	IGI Poseidon (50% EDISON S.p.A. and 50% DEPA)
INTECSEA	INTECSEA B.V, the engineering company appointed by CLIENT to carry out the WORK
ENGINEER	INTECSEA
Project	The official title of the Project is "Poseidon Pipeline Project – Offshore Section Update"
INTECSEA Project No.	406010-00159

2.2 Abbreviations

Abbreviations applicable to the Project are provided below.

ASME	American Society of Mechanical Engineers
BA	Buckle Arrestor
BNCMA	Billion Normal Cubic Meters per Annum
BSCMA	Billion Standard Cubic Meters per Annum
DNV	Det Norske Veritas
DNVGL	Det Norske Veritas Germanischer Lloyd
EN	European Standard
FEED	Front End Engineering Design
HAZ	Heat Affected Zone
ID	Internal Diameter
IGI	Interconnector Greece – Italy
ISO	International Organization for Standardization
JCOE	J-ing, C-ing, O-ing and Expanding (pipe manufacturing method)
KP	Kilometre Post

MAOP	Maximum Allowable Operating Pressure
MPQT	Manufacturing Procedure Qualification Test
MOP	Maximum Operating Pressure
MTO	Material Take-Off
OD	Outside Diameter
OS	Offshore Standard
RP	Recommended Practice
SAWL	Submerged Arc-Welding Longitudinal
SI	International System of Units
TRB	Three Roll Bending
UOE	U-ing, O-ing and Expanding (pipe manufacturing method)
WT	Wall Thickness

3 SUMMARY AND CONCLUSIONS

This document presents the offshore section update of the mechanical design for the Italian offshore pipeline section of the Poseidon Project.

The offshore mechanical design comprises the determination of the minimum required wall thicknesses per section of the 32-inch offshore pipeline route (KP140.0 – KP204.8) and the associated buckle arrestor dimensions. This design is performed in accordance with the European Standards (Ref. [11]), supplemented with the Italian Ministerial Decree of 17/04/2008 (Ref. [12]) for the pipeline sections on Italian territory and the international design code DNVGL-ST-F101 (Ref. [9]).

The wall thickness requirement for the offshore pipeline has been analysed for DNV SAWL 485 steel grade, using a constant outside diameter (OD) of 32-inch.

The governing wall thickness is found in the deep water section, where the concrete weight coating is absent. The minimum required wall thickness for this section is driven by the minimum specific gravity requirement of the pipeline.

The analyses further revealed that buckle arrestors are required for a considerable part of the offshore route.

For the Italian offshore pipeline section a wall thickness phasing comprising two (2) wall thickness values has been selected. The selected pipeline and associated buckle arrestor wall thickness phasing is presented in Table 3-1 and shown in Figure 3-1.

Note that selected transition locations between the wall thicknesses values, as presented in Table 3-1, are used as starting point for further offshore pipeline design activities. The final selected transition points (KP's) of the wall thicknesses will be shown on the Pipeline Alignment Sheets (Ref. [6]) and included in the final Material Take-Off (Ref. [7]).

Table 3-1 Selected Sectionalized Pipeline and Buckle Arrestor Wall Thicknesses

Section (km)	Section Length (km)	Maximum WD (m)	Pipeline[1] WT (mm)	Pipeline[1] OD (mm)	Buckle Arrestor WT [2, 3] (mm)
KP 140.0 – KP 158.0	18.0	810	30.7	812.8	48.6
KP 158.0 – KP 160.2	2.2	320			-
KP 160.2 – KP 180.0	19.8	294	20.0	812.8	30.7
KP 180.0 – KP 203.7	23.7	107			-
KP 203.7 – KP 204.8	1.1	52	30.7	812.8	

Notes: 1. A constant OD of 812.8mm is applied from KP140.0 to KP204.8.

2. The buckle arrestor assemblies will have a length of 12.2m with a thick wall section equal to 4m.

3. Buckle arrestors with a WT of 30.7mm are regular line pipe joints with lengths of 12.2m.

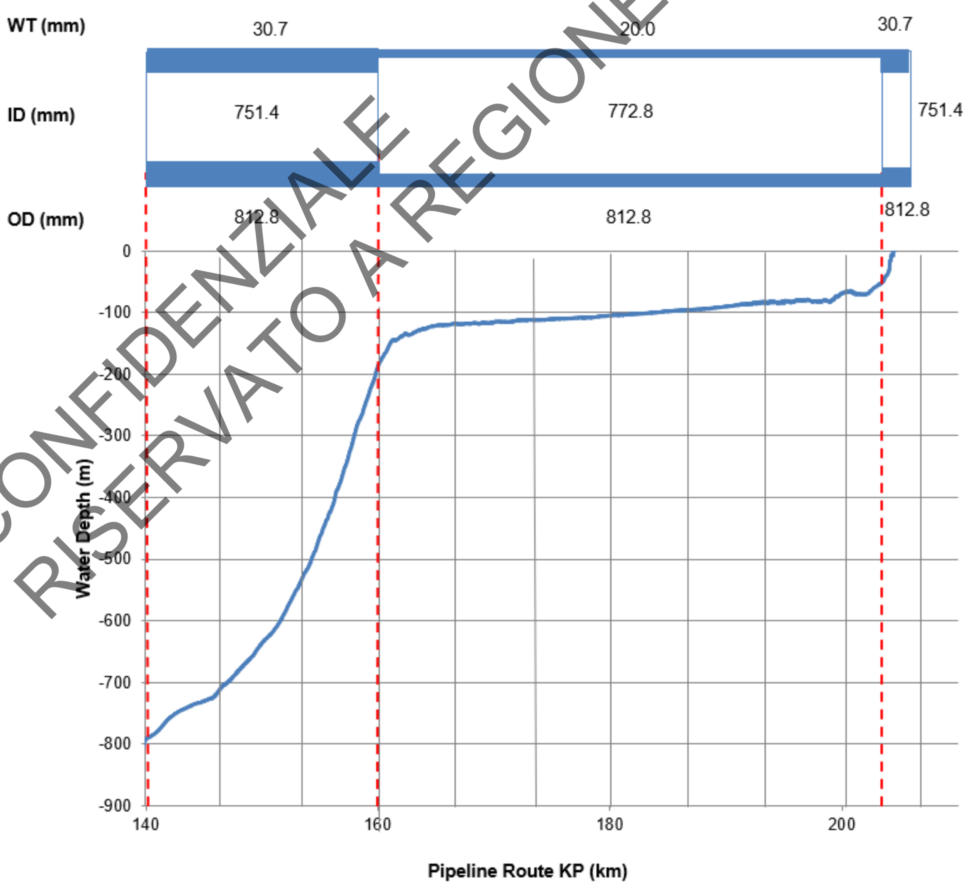


Figure 3-1 Wall Thickness along Italian Offshore Pipeline Route

4 SELECTION OF STEEL GRADE

For the Poseidon offshore pipeline section, the selection of line pipe steel grade is based on technical and commercial considerations. Considering the project specific conditions, including the design pressure, design temperature, water depth and pipeline content, DNV SAWL 485 with supplementary requirements F, D and U is considered to be the most suitable line pipe grade. For more details regarding steel grade selection, reference is made to the Material Selection Report (Ref. [4]).

As such, the offshore pipeline mechanical design as reported in this document has been performed for steel grade DNV SAWL 485, or equivalently API 5L X70.

5 BASIS OF OFFSHORE WALL THICKNESS DESIGN

5.1 Design Data

This section summarizes the data and requirements on which the wall thickness design is based. For further details reference is made to the Design Basis Memorandum (Ref. [1]).

5.1.1 Design Code Framework

DNVGL-ST-F101 (Ref. [9]) is used as primary guiding principle for the offshore pipeline design.

DNVGL-ST-F101 states specifically that it is intended to comply with the requirements of ISO 13623, which has been taken over as European Standard EN 14161 (Ref. [11]). As per Code Selection Report (Ref. [2]), deviations from the EN code will be accounted for during the design, where applicable. For the offshore wall thickness design, this implies that the pressure containment design condition will be calculated in accordance with both DNVGL-ST-F101 and EN 14161 as the following is stated in the DNVGL code:

"The following deviations to ISO 13623 are intentional:

…Applying the supplementary requirements U, for increased utilisation, this standard allows 4% higher pressure containment utilisation than ISO 13623…"

From the above, it can be concluded that the EN 14161 might be more conservative than DNVGL-ST-F101 for the pressure containment design condition, when the supplementary requirement U is applied. As per Ref. [4], supplementary requirement U is applied for the Poseidon pipeline, and therefore EN 14161 has been considered for this design aspect.

For the Italian territory, including territorial waters, additional requirements of the Ministerial Decree of 17/04/2008 (Ref. [12]) apply. This document provides further detail to the requirements as per European Standards. For the offshore wall thickness design, the ministerial decree is applied to the Italian 12 nautical mile zone.

As detailed in Ref. [2], the ministerial decree provides insufficient guidance for the design of a complex deep water system; however it presents a solution for the pressure containment design condition. Therefore, the wall thickness requirement to meet the pressure containment condition for the offshore pipeline section in the Italian 12 nautical mile zone is determined for three codes, i.e. DNVGL-ST-F101, EN 14161 and the Ministerial Decree of 17/04/2008.

Note that the presented solutions for pressure containment in both EN 14161 and the Italian ministerial decree are common for onshore and shallow water pipelines. For the largest part of the offshore crossing, the water depth is such that other design criteria than pressure containment are governing for the wall thickness design. Guidance for the design of the pipeline wall thickness in line with these criteria, such as local buckling and buckle propagation are given only in the DNVGL code. Therefore, for the largest part of the offshore pipeline, DNVGL guidance is decisive for wall thickness selection.

5.1.2 Limit State Definitions

The limit states relevant to the offshore pipeline wall thickness calculations are those caused by the net internal pressure, net external pressure at maximum water depth, and bending during pipeline installation or at spanning pipeline sections. These combine in the following limit states to be considered for the wall thickness design:

- Ultimate limit state of bursting,
- Ultimate limit state of local buckling.

Bursting limit state

The bursting limit state (pressure containment) is the condition at which the pipe wall material flow stress is exceeded by the hoop stress caused by internal pressure. Bursting may be avoided by limiting the hoop stress to a fraction of the pipe specified minimum yield strength or specified ultimate tensile strength. Both of these conditions are calculated along the offshore pipeline route during pipeline operation and hydrotesting, the more conservative value has been selected.

As detailed in Subsection 5.1.1, the bursting limit state condition is determined in accordance with DNVGL-ST-F101, EN 14161 and Ministerial Decree 17/04/2008 for the pipeline section within Italian territorial waters. Subsection 5.3.1 further details the calculation methodologies as outlined in these codes.

The pipeline is divided in location class sections; the minimum water depth per pipeline section is applied to determine the wall thickness for the bursting limit state condition.

Local buckling limit state

The local buckling limit state is the condition at which the net external pressure, axial loading and bending cause the stresses in the pipe to exceed the pipe's crushing strength or cause sufficient geometrical deformation to make the cross-section unstable. The local buckling limit state is considered in terms of three sub-states:

- Collapse without bending,
- Collapse with bending (local buckling during installation),
- Buckle propagation.

Note that local buckling of spanning pipeline sections is addressed in the Bottom Roughness Analysis (Ref. [5]).

For the local buckling limit states, the analyses have been performed in accordance with DNVGL-ST-F101. Sections 5.3.2, 5.3.3 and 5.3.4 detail the calculation methodology for collapse, local buckling and buckle propagation, respectively.

Further to the limit states as listed above, a maximum diameter-over-wall thickness ratio (D/t) of 45 has been adopted. This is further detailed in Subsection 5.3.5.

5.1.3 Fluid Categorisation

The transported fluid is treated dry gas, which is to be considered as fluid category E as per DNVGL-ST-F101 (Ref. [9]).

5.1.4 Location Classification

According to DNVGL-ST-F101 (Ref. [9]), the pipeline system shall be defined in the following location classification:

1. Location Class 1 - This is the area where no frequent human activity is anticipated along the pipeline route,
2. Location Class 2 - The part of the pipeline in the near shore area or in areas with frequent human activity.

As stated in the Design Basis Memorandum (Ref. [1]), the following classification is adopted for the Poseidon pipeline system:

- Location Class 1 for the majority of the pipeline route except for the near shore 500 meter zone,
- Location Class 2 for the pipeline section of 500 meter from the landfall locations.

5.1.5 Safety Classification

The safety classification adopted for the offshore pipeline is in accordance with requirements as specified in Ref. [9] and is summarized in Table 5-1 below.

Table 5-1 Safety Classification

Phases	**Location Class**	
	1	**2**
Temporary[1]	Low	Low
Operational	Medium	High

Note: 1. Temporary phase comprises installation, hydrotesting and empty condition after commissioning.

5.1.6 Mechanical Design Data

The line pipe dimensional and material properties are presented in Table 5-2. The pipeline process and environmental data is presented in Table 5-3.

Table 5-2 Line Pipe Dimensional and Material Data

Description	Symbol	Value	Unit
Line Pipe Dimensional Data			
Pipe nominal outside diameter[1]	OD	32	inch
		812.8	mm
Pipe nominal inside diameter	ID	Varies	-
Internal corrosion allowance	-	0	mm
Wall thickness fabrication tolerance	-	±1	mm
Ovality at pipe body[2] for WT < 30.0mm	f_0	1.00	%
for WT > 30.0mm		0.75	%
Line Pipe Steel Material Properties			
Steel density	ρ_s	7,850	kg/m^3
Young's modulus	E	$2.07 \cdot 10^5$	MPa
Poisson's ratio	ν	0.3	-
Material grade (per DNVGL-ST-F101)	-	SAWL 485 FDU	-
Manufacturing process	-	UOE / JCOE	-
Specified minimum yield strength	$SMYS$	485	MPa
Specified minimum tensile strength	$SMTS$	570	MPa

Notes: 1. The 32-inch pipeline outside diameter (OD) is constant along pipeline route.
2. For deep water pipeline sections (i.e. wall thicknesses in excess of 30.0mm) an ovality of 0.75% applied otherwise an ovality of 1.00% is applied. Pipe body ovality of 1.00% is in accordance with DNVGL-ST-F101.

Table 5-3 Process and Environmental Data

Description	Symbol	Value	Unit
Operational Data			
Design pressure	p_d	170	barg
Maximum allowable operating pressure	$MAOP$	162	barg
Maximum operating pressure	MOP	151	barg
Elevation at pressure reference level	h_{ref}	400	m
Contents density	ρ_{cont}	50 – 130	kg/m³
Maximum design temperature[1]	$T_{\max}$	70	°C
Hydrotest Data			
Hydrotest pressure at sea level[2]	p_t	209	barg
Hydrotest pressure at pressure reference level	p_t	208	barg
Elevation at pressure reference level	h_{test}	10	m
Test medium		seawater	
Environmental Data			
Maximum water depth[3]	$h_{\max}$	800	m
Seawater density[4]	ρ_{sw}	1,025 – 1,035	kg/m³
Maximum 1-year significant wave height	h_{wave}	6.5	m
Installation Criteria			
Maximum allowable sagbend bending strain[5]	ε_b	0.15	%

Notes:
1. Maximum design temperature is at the Greek side of the pipeline system.
2. Value corresponds to the maximum test pressure in accordance with DNVGL-ST-F101, Italian DM and EN 14161 codes; see Appendix A for details of calculation.
3. Water depth at KP 140.0
4. Seawater density profile included in Appendix B.
5. Total bending strain including allowance for dynamic behaviour (i.e. 0.12% functional and 0.03% environmental strain).

5.1.7 Summary Load, Material and Resistance Factors

The applied load effect factors, safety class resistance and material resistance factors related to the limit states, derived in accordance with DNVGL-ST-F101 requirements (Ref. [9]), are summarized in Table 5-4 for reference.

Table 5-4 Summary Load, Material and Resistance Factors

Description	Symbol	Value	DNVGL-ST-F101
Incidental to design pressure ratio	γ_{inc}	1.1	Table 3-1
Material strength factor	α_u	1.0	Table 5-3
Fabrication factor	α_{fab}	0.85	Table 5-4
Material resistance factor	γ_m	1.15	Table 5-1
Functional load effect factor - System check (combination *a*) - Local check (combination *b*)	γ_F	 1.2 1.1	Table 4-4
Environmental load effect Factor - System check (combination *a*) - Local check (combination *b*)	γ_E	 0.7 1.3	Table 4-4
Condition load factor (for local buckling)	γ_C	1.0	Table 4-5
Safety class resistance factor - Pressure containment[1] - Other[1]	γ_{SC}	 1.046, 1.138, 1.308 1.04, 1.14, 1.26	Table 5-2

Note: 1. For safety classes Low, Medium and High, respectively.

5.1.8 Pipeline Route Profile

The pipeline route profile in Italy is provided in Figure 5-1 as extracted from Ref. [1].

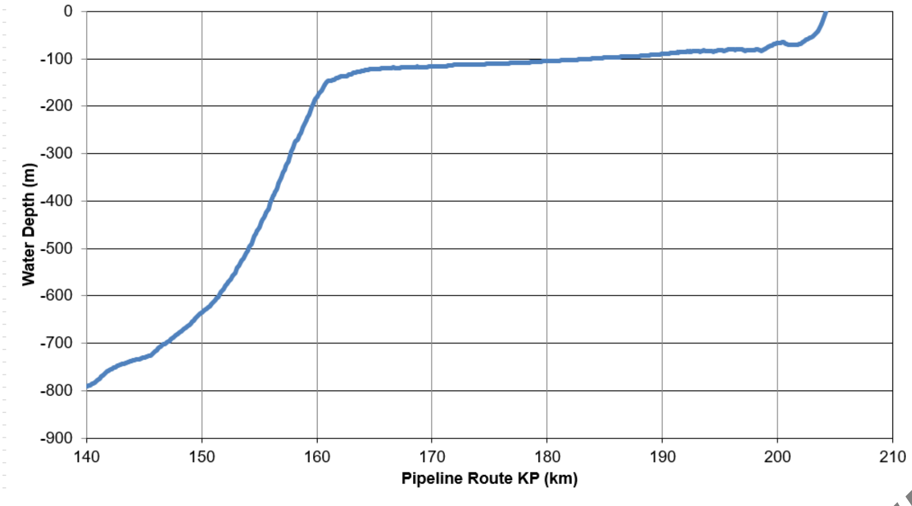


Figure 5-1 Offshore Pipeline Water Depth along Italian Route Profile

5.2 Design Considerations and Assumptions

The wall thickness of the offshore pipeline is assessed along the entire pipeline route from the Greek landfall to Italian landfall with consideration of the minimum and maximum water depths along this route. The following Design Limit States as per DNVGL-ST-F101 (Ref. [9]), EN 14161 (Ref. [11]) and Ministerial Decree 17/04/2008 (Ref. [12]) are analysed:

- Pressure Containment,
- Pipe Collapse,
- Local Buckling,
- Buckle Propagation.

The governing wall thickness design parameters are discussed for each Design Limit State in the following sub-sections.

5.2.1 Pressure Containment

The wall thickness requirements to resist internal pressure loading during operating and hydrotest conditions are derived in accordance with Section 5 of DNVGL-ST-F101 (Ref. [9]), EN 14161 (Ref. [11]) and Ministerial Decree 17/04/2008 (Ref. [12]). The pressure containment resistance is determined from the minimum value derived from the yielding limit state and bursting limit state. The primary considerations associated with the pressure containment calculations are the following:

- No internal and external corrosion allowances have been applied. The pipeline will transport dry, sweet gas and will be internally coated to improve hydraulic performance. The external surface of the pipeline will be protected using a combination of high quality anti-corrosion coating and sacrificial anodes.
- Since the pipeline content temperature for the Italian pipeline section is below 50°C no material strength de-rating is applied in accordance with DNVGL-ST-F101 (Ref. [9])

- As this design condition is governing in shallow water due to the low external pressure, the minimum encountered seawater density in shallow water is adopted for this design condition, i.e. 1,025 kg/m^3; see Appendix B.

5.2.2 Pipe Collapse

The wall thickness requirements to resist pipe collapse due to net external pressure during installation and after commissioning are derived in accordance with Section 5 of DNVGL-ST-F101 (Ref. [9]). The primary considerations associated with the pipe collapse calculations are the following:

- A maximum ovality at pipe body of 0.75% of the OD for the deep water sections (i.e. WT > 30.0mm), otherwise 1.0%, is specified.
- The DNVGL collapse formulation requires the introduction of a fabrication factor to account for a reduction in circumferential compressive strength resulting from the line pipe UOE and JCOE fabrication process. DNVGL-ST-F101 (Ref. [9]) allows for a maximum fabrication factor of 0.85 for UOE and JCOE pipes without further documentation of the manufacturing process (Table 5-4, Ref. [9]).
- For this design condition, the maximum encountered seawater density is adopted, i.e. 1,035 kg/m^3. From Appendix B, it can be seen that this density occurs in deep water. A more accurate (i.e. less conservative) approach could be adopted by integration of the seawater density over the water column. Calculations show only marginal impact on the wall thickness requirement by using this approach, and is therefore not applied.

5.2.3 Local Buckling during Installation

Local buckling (pipe wall buckling) implies gross deformation of the cross section due to combined collapse (due to hydrostatic pressure) and bending. This combination of loading occurs during installation where the pipeline is suspended in the sagbend of the pipelay catenary or when the pipeline is spanning on the seabed.

The collapse part of the local buckling criterion is primarily related to the water depth on the load side, and the material hoop compressive strength and ovality on the resistance side.

The bending part of the limit state is more complex. The bending condition relates to the axial stress in the sagbend, which is composed of an axial force component and a bending moment component (refer to DNVGL-ST-F101 Equation 5.28 for Load Controlled Condition). On the resistance side this condition is again determined by the material properties. On the load side this condition is determined by the installation condition: water depth, configuration (i.e. bending moments), and lay tension.

The applied axial load is determined based on an estimated tension in the sagbend.

The applied bending moment is derived from the maximum allowable bending strain within the sagbend. The maximum allowable value for the bending strain within the sagbend during installation will be limited to 0.15%, whereof 0.12% as functional loading and 0.03% as environmental loading, according to the common industry practice criteria. The selection of this value is based on experience, where a maximum value of 0.15% strain has been proposed and proven feasible and acceptable by installation contractors, while providing a robust basis for the design activities.

For this design condition, the same seawater density is applied as for the Collapse condition as discussed in Subsection 5.2.2 (i.e. 1,035 kg/m^3).

5.2.4 Buckle Propagation

The wall thickness requirements to resist propagation buckling are derived in accordance with Section 5.4.5 of DNVGL-ST-F101 (Ref. [9]). The Poseidon pipeline will be protected against propagating buckling using buckle arrestors, since this criterion will otherwise require excessive wall thickness for deep water section. Reference is made to Section 7 of this report for more details on buckle propagation and buckle arrestors.

5.3 Wall Thickness Calculation Methodology

Analyses have been performed to determine the wall thickness requirements for installation, hydrotest and operational conditions based on the following design conditions:

- Pressure containment,
- Pipe collapse due to external overpressure,
- Local buckling due to a combination of bending, external over pressure and axial loads.

The analysis is performed in accordance with DNVGL-ST-F101 (Ref. [9]), EN 14161 (Ref. [11]) and Ministerial Decree 17/04/2008 (Ref. [12]); with the data, parameters and factors described in Section 5.1 and Section 5.2. The following Sub-Sections detail the calculation methodology for the above limit states.

5.3.1 Pressure Containment

5.3.1.1 DNVGL-ST-F101

The following limit state formula has been adopted for pressure containment. The pipe pressure differential must be less than the minimum of the yielding and bursting limits and fulfil the following criteria

$$p_{li} - p_e \le Min\left(\frac{p_b(t)}{\gamma_{SC}\cdot\gamma_m}; \frac{p_{lt}}{\alpha_{spt}} - p_e; \frac{p_h\cdot\alpha_U}{\alpha_{mpt}}\right) \text{ and}$$

$$p_{lt} - p_e \le Min\left(\frac{p_b(t)}{\gamma_{SC}\cdot\gamma_m}; p_h\right)$$

in which

$$p_b(t) = \frac{2\cdot t}{D-t}\cdot f_{cb}\cdot\frac{2}{\sqrt{3}}$$

and

$$f_{cb} = Min\left(f_y; \frac{f_u}{1.15}\right)$$

where

$p_b(t)$	=	Pressure containment resistance
γ_{SC}	=	Safety class resistance factor
γ_m	=	Material resistance factor
α_{mpt}	=	Mill pressure test factor
α_U	=	Material strength factor
p_e	=	Local external pressure
p_h	=	Mill test pressure
p_{li}	=	Local incidental pressure
p_{lt}	=	Local test pressure

$p_{li} = \gamma_{inc} \cdot p_d + \rho_{gas} \cdot g \cdot (h_{ref} - h_l)$ (Operating case)

$p_{lt} = p_t + \rho_t \cdot g \cdot (h_{test} - h_l)$ (System pressure test)

and $p_{plt} \geq p_{pli} \cdot \alpha_{spt}$

in which

p_d	=	Design pressure at reference level
p_t	=	Hydrotest pressure at pressure test reference level
γ_{inc}	=	Incidental to design pressure ratio
h_{ref}	=	Elevation of the reference point for the operational load condition
h_{test}	=	Elevation of the reference point for the testing load condition
h_l	=	Elevation of the local pressure point
ρ_{gas}	=	Maximum density of the exported gas
ρ_t	=	Density of the testing water
α_{spt}	=	System pressure test factor
g	=	Gravitational acceleration

and

D = Nominal outside diameter

t = Minimum wall thickness, which is equal to:

$t = t_{nom} - t_{fab} - t_{corr}$ (Operating case)

$t = t_{nom} - t_{fab}$ (System pressure test)

in which

t_{nom} = Nominal wall thickness

t_{fab} = Fabrication thickness tolerance

t_{corr} = Corrosion allowance, equal to 0 mm

and

f_y, f_u = Yield stress and tensile strength to be used in design according to:

$f_y = (SMYS - f_{y,temp}) \cdot \alpha_U$

$f_u = (SMTS - f_{u,temp}) \cdot \alpha_U$

in which

$SMYS$ = Specified minimum yield stress

$SMTS$ = Specified minimum tensile strength

$f_{y,temp}$ = Temperature derating on yield stress to be used in design

$f_{u,temp}$ = Temperature derating on tensile stress to be used in design

5.3.1.2 EN 14161

The following formula has been adopted for pressure containment during the operational load condition. The minimum wall thickness is calculated based on the hoop stress formula.

$$t_{\min} = (p_{d\_loc} - p_e) \cdot \frac{D - t_{\min}}{2 \cdot \sigma_{hp\_allowable}}$$

p_{d_loc} = Design pressure plus static head of the gas product

$\sigma_{hp\_allowable}$ = Permissible circumferential stress, which is equal to

$\sigma_{hp\_allowable} = F_h \cdot SMYS_{TD}$

in which

F_h = Hoop stress design factor

The hoop stress design factor is 0.77 for the general route and 0.67 for the landfalls of the offshore pipeline.

$SMYS_{TD}$ = Specified minimum yield strength at the maximum design temperature

In absence of documented material performance under elevated temperature (maximum design temperature) the de-rating is performed as per Figure 5-2 of DNVGL-ST-F101 Section 5 (Ref. [9]) is adopted for operating conditions as per design temperature.

The nominal wall thickness is calculated using the formula:

$$t_{nom} = t_{\min} + t_{fab} + t_{corr}$$

5.3.1.3 Italian Ministerial Decree

The following formula is considered in strict compliance with Ministerial Decree 17/04/2008 for pressure containment during the operational load condition. The minimum wall thickness is calculated in mm based on the hoop stress formula.

$$t_{\min} = \frac{p_{d\_loc} \cdot D}{20 \cdot S_p}$$

p_{d_loc} = Pressure equal to or higher than maximum operating pressure; see Table 5-3 for the maximum operating pressure

D = Nominal outside diameter in mm

S_p = Permissible circumferential stress in MPa, which is equal to:

$$S_p = F \cdot R_{t0.5}$$

in which

F = Utilization factor; this factor shall not exceed 0.72 for offshore pipelines

$R_{t0.5}$ = Specified minimum yield strength in MPa

The nominal wall thickness is calculated from the formula:

$$t_{nom} = t_{\min} + t_{fab} + t_{corr}$$

As Ministerial Decree 17/04/2008 is a code for onshore pipelines, the contribution of the external pressure is omitted in above formula. For prudent engineering and to increase level of compatibility with international offshore design codes, the minimum wall thickness is also calculated for the following modified formula:

$$t_{\min} = \frac{(p_{d\_loc} - p_e) \cdot D}{20 \cdot S_p}$$

Where the maximum allowable operating pressure is adopted for the internal pressure (p_{d_loc}); the increase in internal pressure compared to the first formula, is balanced by the introduction of the external pressure term (p_e).

In Section 6, the reported minimum wall thickness value for the Ministerial Decree 17/04/2008 is the highest value using both formula's as presented in this subsection.

5.3.2 Collapse

The pipe may collapse due to external pressure only (for empty condition) or the external differential pressure (for operating condition). Collapse depends on the D/t-ratio, material strength and the manufacturing imperfections, mainly the initial out-of-roundness.

The pipe ovality according to DNVGL-ST-F101 is defined as follows:

$$f_0 = \frac{D_{\max} - D_{\min}}{D_{nom}}$$

where

f_0	=	ovality
$D_{\max}$	=	greatest measured inside or outside diameter
$D_{\min}$	=	smallest measured inside or outside diameter
D_{nom}	=	nominal outside diameter

As per Table 5-2, the pipe body out-of-roundness $D_{\max} - D_{\min}$ shall be 0.0075· D_{nom} for deep water sections, otherwise 0.0100· D_{nom}.

The external pressure at any point along the pipeline shall meet the following criterion (system collapse check):

$$p_e - p_{\min} \leq \frac{p_c}{\gamma_m \cdot \gamma_{SC}}$$

where

p_c	=	Characteristic collapse pressure
$p_{\min}$	=	Minimum internal pressure that can be sustained

The characteristic collapse pressure is derived from the following equation:

$$(p_c - p_{el})(p_c^2 - p_p^2) = p_c \cdot p_{el} \cdot p_p \cdot f_0 \cdot \frac{D}{t}$$

in which

$$p_{el} = \frac{2 \cdot E}{1 - \nu^2} \left(\frac{t}{D} \right)^3$$

$$p_p = f_y \cdot \alpha_{fab} \frac{2 \cdot t}{D}$$

where

p_{el}	=	Elastic collapse pressure
p_p	=	Plastic collapse pressure
E	=	Young's modulus
ν	=	Poisson's ratio
α_{fab}	=	Fabrication factor
t	=	Minimum wall thickness, which is equal to:

$$t = t_{nom} - t_{fab} - t_{corr}$$

5.3.3 Local Buckling

Local buckling, i.e. collapse failure under combined action of bending, external pressure and axial loads, is considered by the equations described hereafter. These equations are used for the evaluation of the installation case when the pipe is empty and experiences the highest bending. These equations are also used for the as-installed empty or drying conditions.

The pipe subject to bending, axial force and external over-pressure during installation (Load Controlled Condition), shall be designed to satisfy the following condition:

$$\left(\gamma_m \cdot \gamma_{SC} \cdot \left(\frac{|M_{Sd}|}{\alpha_c \cdot M_P} \right) + \left(\frac{\gamma_m \cdot \gamma_{SC} \cdot S_{Sd}}{\alpha_c \cdot S_P} \right)^2 \right)^2 + \left(\gamma_m \cdot \gamma_{SC} \cdot \left(\frac{p_e - p_{min}}{p_c} \right) \right)^2 \leq 1$$

in which

M_{Sd} = Design moment, which is equal to:

$$M_{Sd} = M_F \cdot \gamma_F \cdot \gamma_C + M_E \cdot \gamma_E$$

S_{Sd} = Design effective axial force, which is equal to:

$$S_{Sd} = S_F \cdot \gamma_F \cdot \gamma_C + S_E \cdot \gamma_E$$

where

M_F	=	Functional bending moment
M_E	=	Environmental bending moment
S_F	=	Functional effective axial force

S_E = Environmental effective axial force

γ_F = Load effect factor for functional load

γ_C = Condition load effect factor

and

M_p = Plastic moment capacity of the pipe, which is equal to:

$$M_p = f_y \cdot (D - t_2)^2 \cdot t_2$$

S_p = Plastic axial force capacity, which is equal to:

$$S_p = f_y \cdot \pi \cdot (D - t_2) \cdot t_2$$

α_c = Flow stress parameter

t_2 = Wall thickness, which is equal to t_{nom}

As detailed in Subsection 5.2.3, the basis for the loads (bending moment and axial force) is the maximum bending strain in the sagbend during installation, which is selected equal to 0.15%. The loads associated with the maximum bending strain are treated as a functional load (0.12%) and environmental load (0.03%). This means that load combination *b* (local check) as per Table 5-4 is governing. The results are reported in Section 6.

As S-lay is one of the possible pipeline installation methods, a local buckling check is also required for the overbend section. The results of this verification can be found in the Pipeline Installation Analysis Report (Ref. [15]).

5.3.4 Propagation Buckling

Propagation buckling cannot be initiated unless local buckling of a pipe section has occurred.

The propagating pressure is lower than the initiating pressure, and the buckle will stop when the external pressure is less than the propagating pressure, viz. the resistance of the pipe against propagation buckling depends on the D/t-ratio, material strength and the manufacturing process.

The propagating pressure is given by:

$$p_{pr} = 35 \cdot f_y \cdot \alpha_{fab} \cdot \left(\frac{t_2}{D}\right)^{2.5}$$

in which

t_2 = Wall thickness, which is equal to t_{nom}

The propagating buckling criterion reads:

$$p_e \le \frac{p_{pr}}{\gamma_m \cdot \gamma_{sc}}$$

Buckle arrestors are required where the selected wall thickness is less than the wall thickness that is required to prevent buckle propagation.

5.3.5 Other Conditions

5.3.5.1 D/t Ratio

Further to the limit states as listed above, a maximum diameter-over-wall thickness ratio (D/t) of 45 (Ref. [9]) has been adopted. The maximum D/t-ratio is based on the following:

- This ratio corresponds to the limit of applicability of the DNVGL-ST-F101 equations for local buckling. For thinner walled pipes, the pressure plus bending buckling becomes more elastic dominated than plastic and so the imperfection sensitivity increases. Therefore, D/t ratios higher than 45 would require additional finite element modelling to further analyse the elastic buckling failure mode.
- Practical limit; handling and transportation of pipe joints become complicated for a high D/t ratio as thin walled pipes have a lower mechanical robustness.
- Applying a high D/t ratio can be unacceptable for other design conditions such as bottom roughness assessment and third party interaction.

5.3.5.2 Specific Gravity Requirement

In order to avoid flotation in water, the submerged weight of pipelines shall meet the requirement stipulated in Section 3.2 of DNVGL-RP-F109 (Ref. [10]):

$$\frac{\gamma_w}{s_g} \leq 1.00$$

in which

s_g = Pipe specific density

γ_w = Safety factor

As per Ref. [10], the safety factor can be taken equal to 1.1 if a sufficiently low probability of negative buoyancy is not documented. This safety factor covers for potential weight differences between pipe joints; applying a value of 1.1 provides a 10% margin to ensure that even the lightest pipe joint is still negatively buoyant.

In general, pipe weight variations are introduced by tolerances in steel wall thickness, concrete coating thickness and concrete coating density. Concrete weight coating variations could also be introduced by local damage, i.e. loss of coating. For the Poseidon offshore pipeline, this criterion is applied to obtain the nominal wall thickness value for the non-concrete coated pipe sections in deep water.

As non-concrete coated pipeline sections are applied in deep water the maximum encountered seawater density in the applicable water depth range (200m to 800m) is applied, i.e. 1,035 kg/m^3; see Appendix B.

5.3.5.3 Air Pressure

As part of pre-commissioning activities and in case of a wet buckle in deep water, the pipeline is subject to a high air pressure to dewater the pipeline. The air pressure will be in the order of 85bar, i.e. 800m hydrostatic head of water and de-watering pig train friction. This pressure is less than the design pressure of 170bar; as such, this case is not governing for the wall thickness design and not further considered in this report.

6 OFFSHORE WALL THICKNESS RESULTS

The wall thickness design along the Italian offshore pipeline route is based on a constant OD (of 32-inch (812.8mm)).

6.1 WT Results along Pipeline Route

6.1.1 Minimum Wall Thickness Requirement

For each location along the offshore route the minimum required wall thickness is analysed following a two-step approach:

- Wall thickness design as per DNVGL-ST-F101 (Ref. [9]),
- Wall thickness design as per other applicable codes, including EN 14161 (Ref. [11]) and Italian Ministerial Decree of 17/04/2008 (Ref. [12]), and maximum diameter-over-wall thickness ratio (D/t).

DNVGL-ST-F101 requires de-rating of yield stress and tensile strength for temperatures above 50°C. As such, a conservative design temperature profile is applied; see Figure 6-1.

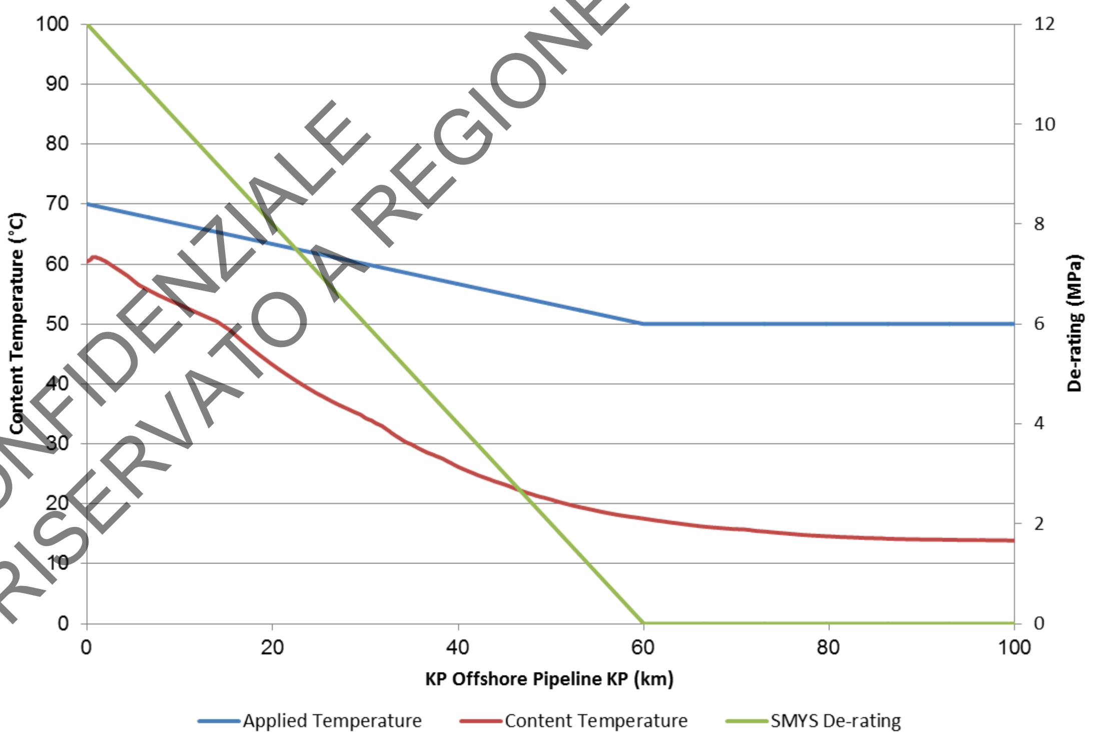


Figure 6-1 Applied Temperature (Conservative) Profile for Mechanical (WT) Design (with Content Temperature Profile in Red and Applied SMYS De-Rating in Green (Right Axis)

As detailed in Section 5.3, the wall thickness design as per DNVGL-ST-F101 contains the following failure modes:

- Pressure containment for pressure testing and operational load condition,
- Collapse,
- Local buckling,
- Propagation buckling.

Given the variation in water depth, design temperature and location zone definition along the pipeline route, the minimum required wall thickness varies along the route. The obtained wall thickness results as per DNVGL-ST-F101 are presented in Figure 6-2

From this Figure 6-2, the following can be concluded:

- Pressure containment for the operational load condition is governing for the near-shore area. An increase in the minimum required wall thickness is observed for the 500 meter zones nearshore (DNV Location Class 2).
- The minimum required wall thickness for pressure containment during the pressure testing load condition is constant over the pipeline as seawater is used for pressure testing.
- Pressure containment during pressure testing load condition is governing from KP 158.3 to KP 163.6, not considering the wall thickness requirement related to propagating buckling.
- The load controlled local buckling design condition is governing over the system collapse design condition as the local buckling design condition takes into consideration an effective axial force and a bending moment in addition to the external overpressure (collapse design condition).
- The local buckling design condition dominates a large section of the pipeline (KP 140.0 through KP 158.3), not considering the wall thickness requirement related to propagating buckling.
- The propagation buckling design condition dominates a large section of the pipeline (KP 140.0 through KP 180.0). This design condition is not considered for the minimum wall thickness requirement as it would significantly increase the minimum required wall thickness over a large section of the pipeline. As a mitigation measure, buckle arrestors are designed to reduce the consequential damage during a propagating buckle situation; see Section 7.

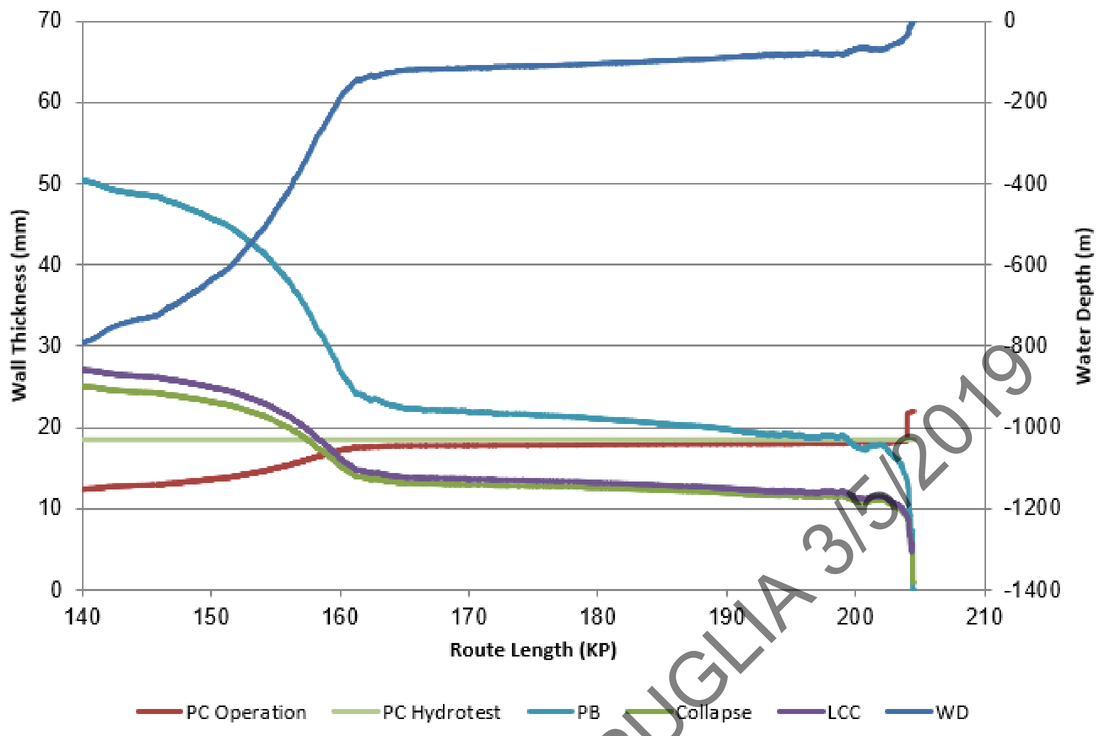


Figure 6-2 Wall Thickness Analysis Results as per DNVGL-ST-F101

Besides the minimum wall thickness requirements as per DNVGL code, the minimum required wall thickness has been determined for the pressure containment condition as per EN 14161 (Ref. [11]) and the Italian Ministerial Decree (Ref. [12]). The results for these design conditions are reported below.

According to the European Standard EN 14161, the offshore pipeline can be defined in two location types, i.e. the general route location and the landfall location. The landfall location is considered 500 meter from shore up to the shoreline, in analogy to the location class definition in DNVGL-ST-F101. The remainder of the pipeline is defined as the general route location. See Table 6-1 for the wall thickness requirements as per EN 14161.

Table 6-1 Wall Thickness Requirements as per EN 14161

Section (-)	Design Condition (-)	WT Requirement (mm)
Landfall (from shore to 500m offshore)	Pressure containment	Variable up to 22.4
Other (KP 140.0 – KP 204.3)		Variable up to 19.3

The pressure containment design condition according to the Italian Ministerial Decree is only applicable for the pipeline section in Italian territorial waters, i.e. the 12 nautical mile zone. This corresponds with a pipeline length of approximately 41 km from the Otranto landfall (KP 163.6

through KP 204.8). See Table 6-2 for the wall thickness requirements as per Italian Ministerial Decree.

Table 6-2 Wall Thickness Requirements as per Italian Ministerial Decree

Section (km)	Design Condition (-)	WT Requirement (mm)
Italian territory (KP 163.6 – KP 204.8)	Pressure containment	Variable up to 20.5

As detailed in Subsection 5.3.5.1, a maximum diameter over wall thickness ratio (D/t) of 45 has been adopted. This D/t ratio has been employed over the entire offshore pipeline, and results are given in Table 6-3.

Table 6-3 Maximum Diameter-over-Wall Thickness Ratio

Section (km)	Design Condition (-)	WT Requirement (mm)
Entire route (KP 140.0 – KP 204.8)	NA	18.1

As detailed in Subsection 5.3.5.2, in order to avoid flotation in water, the submerged weight of pipelines shall meet the requirement stipulated in Section 3.2 of DNVGL-RP-F109 (Ref. [10]). Table 6-4 shows the minimum wall thickness for non-concrete coated pipeline sections to ensure with sufficient confidence that even the pipe geometry resulting in the lowest pipe specific density is negatively buoyant.

Table 6-4 Specific Gravity (SG) Requirement

Section (-)	Design Condition (-)	WT Requirement (mm)
Non-concrete coated section	Vertical stability	30.7

Figure 6-3 presents the minimum required nominal wall thickness based on all applicable design conditions presented in Figure 6-2 (except the propagating buckling design condition) and Table 6-1 through Table 6-3. Note that the specific gravity requirement for non-concrete coated pipeline sections is not included in Figure 6-3.

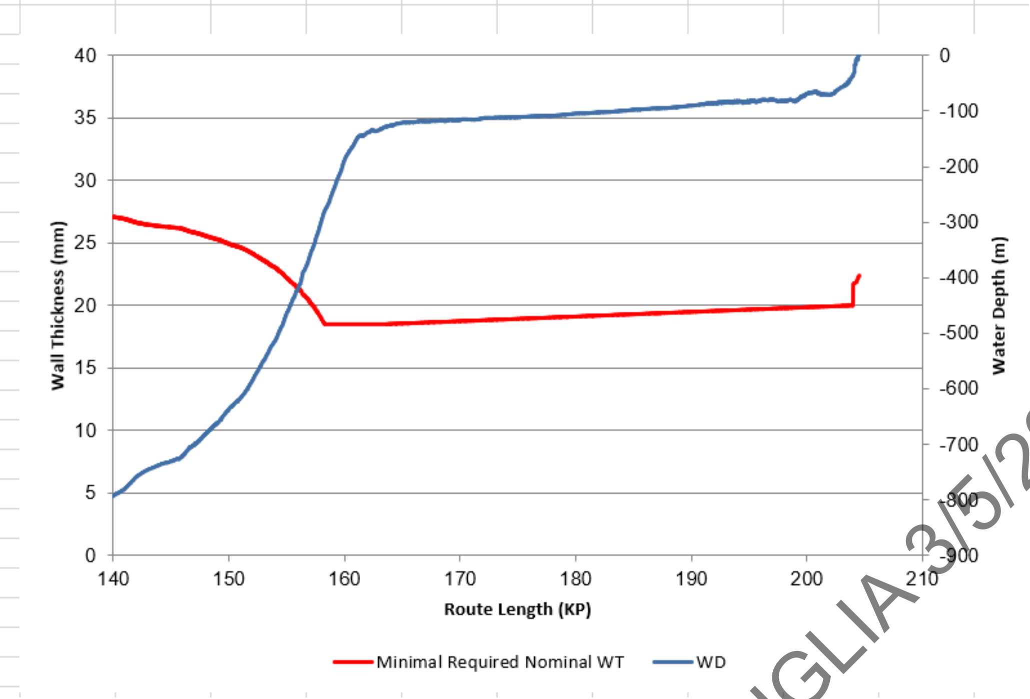


Figure 6-3 Minimum Required Nominal Wall Thickness – All Design Conditions

Table 6-5 shows for each offshore pipeline section, which design condition is governing for the minimum wall thickness requirement.

Table 6-5 Minimum Wall Thickness Requirement – Offshore

Section (km)	Design Code (-)	Design Condition (-)	WT Requirement (mm)
KP 140.0 – KP 158.3[1]	DNVGL-ST-F101	Local buckling	Variable; 26.6 to 18.9
KP 158.3 – KP 163.6[2]	DNVGL-ST-F101	Hydrotest	18.9
KP 163.6 – KP 204.3	Ministerial Decree	Pressure containment	Variable; 19.1 to 20.1
KP 204.3 – KP 204.8	EN 14161	Pressure containment	Variable; 21.9 to 22.4

Notes: 1. The wall thickness for a specific gravity of 1.1 is 30.7mm for the 32-inch line pipe. For deep water section where no concrete weight coating will be applied, the minimum wall thickness will be 30.7mm.

From above table, it can be seen that the minimum required nominal wall thickness for most pipeline sections are variable, i.e. water depth dependant. The largest variation is seen for the (deep) water section where the local buckling condition is governing.

To facilitate line pipe procurement, a sectionalized (or stepped) wall thickness is applied for the Poseidon pipeline system. This is further detailed in Section 6.1.2.

6.1.2 Sectionalized Wall Thickness Requirement

The selection of sectionalized wall thickness values along the offshore section of the Poseidon pipeline is made by accounting for the following:

- Satisfy for all locations the minimum wall thickness requirement as shown in Figure 6-3,
- Eliminate concrete weight coating requirement for deep water section by satisfying specific gravity requirement as per DNVGL-RP-F109 (Ref. [10]); see Table 6-4.

Applying above criteria, the wall thickness requirement for the offshore pipeline section can be grouped into multiple wall thickness values, a reduction of wall thickness numbers can be achieved by reducing the number of wall thickness values on the Italian shelve. This optimisation results in two (2) wall thickness values:

<u>32-inch Constant OD Section from KP140.0 – KP204.8:</u>

- Minimum required wall thickness for the shallow water sections equals 20.0mm. This wall thickness is sufficient for a water depth of 52.0m at KP203.7 (and deeper). In the shore crossing area at KP203.7 a wall thickness transition to 30.7mm is applied. Note that the minimum required wall thickness of 20.1mm, presented in Table 6-5, has been calculated at KP204.3 representing a shallower water depth (with less external pressure from the water head).

- For the remaining sections (i.e. deep water and shore approach/crossing) the wall thickness equal to 30.7mm; this wall thickness meets the specific gravity requirement for non-concrete coated pipe.

It is anticipated that reduction of wall thickness numbers has the following main advantages (+) or disadvantages (-), all with associated cost impact:

+ To facilitate logistics in construction phase,

+ To reduce the complexity of plate and line pipe manufacturing processes, including a reduction of MPQT's (Manufacturing Procedure Qualification Test) and weld qualifications and a reduced need for mill modifications,

+ Reduction of concrete weight coating requirement,

+ More robustness to resist spans and third party interaction loads,

− Increase of carbon steel requirement.

The sectionalized minimum required wall thickness numbers along the offshore route, using three (3) wall thicknesses and up to eight (8) wall thicknesses, is shown in Table 6-6.

Table 6-6 Sectionalized Minimum Wall Thickness Requirement

Section (km)	WT Requirement (mm)	3 WT (mm)	2 WT (mm)	1 WT (mm)
KP 140.0 – KP 158.3[1]	30.7	30.7	30.7	30.7
KP 158.3 – KP 163.6[2]	18.9	20.0	20.0	
KP 163.6 – KP 203.7	up to 20.0			
KP 203.7 – KP 204.3	up to 20.1	22.4	30.7	
KP 204.3 – KP 204.8	up to 22.4			
Steel tonnage (tons)	NA	29,268	29,441	38,635

Notes: 1. The wall thickness for a specific gravity of 1.1 is 30.7mm. The corresponding local buckling design condition water depth a WT 30.7mm is 1,240m which is deeper than the maximum water depth of 800m at KP 140.0 of the 32-inch pipeline.

2. The corresponding local buckling design condition water depth a WT 18.9mm is 300m. Water depth 300m corresponds with route KP 158.3

From Table 6-6, it can be seen that the differences in steel tonnage, i.e. up to 31% between the one (1) wall thickness phasing option and the two (2) wall thickness phasing option.

The difference between the two (2) wall thickness phasing option and the three (3) wall thickness phasing option is just 0.6%.

It is considered that the advantages of a reduction of wall thicknesses to two (2) wall thickness (from three (3)) outweigh the disadvantage of the slightly increased carbon steel requirement.

6.2 Selected Wall Thicknesses

A wall thickness phasing comprising two (2) wall thickness values has been selected as basis for the Italian section of the Poseidon pipeline system.

For the selected wall thickness phasing, it is confirmed that all design code criteria as discussed in Section 5.3 are met.

Compared to the minimum wall thickness requirement, the following adjustment is made:

- To improve the on-bottom pipeline stability and to prevent excessive concrete coating thicknesses at the shore approaches the 30.7mm wall thickness pipeline section is selected at 600m for the Italian shore approach.

The selected wall thicknesses for the Poseidon offshore pipeline system are presented Table 6-7 and Figure 6-4. In Figure 6-5 the selected and minimum required wall thicknesses are presented along the Poseidon offshore pipeline route.

Table 6-7 Selected Sectionalized Wall Thickness

Section (km)	Outside diameter (mm)	Inside Diameter (mm)	Selected WT (mm)
KP 140.0 – KP 160.2	812.8 (32”)	751.4	30.7
KP 160.2 – KP 203.7		772.8	20.0[1]
KP 203.7 – KP 204.8		751.4	30.7

Note: 1. The wall thickness has been adjusted to the corresponding water depth at KP 203.7.

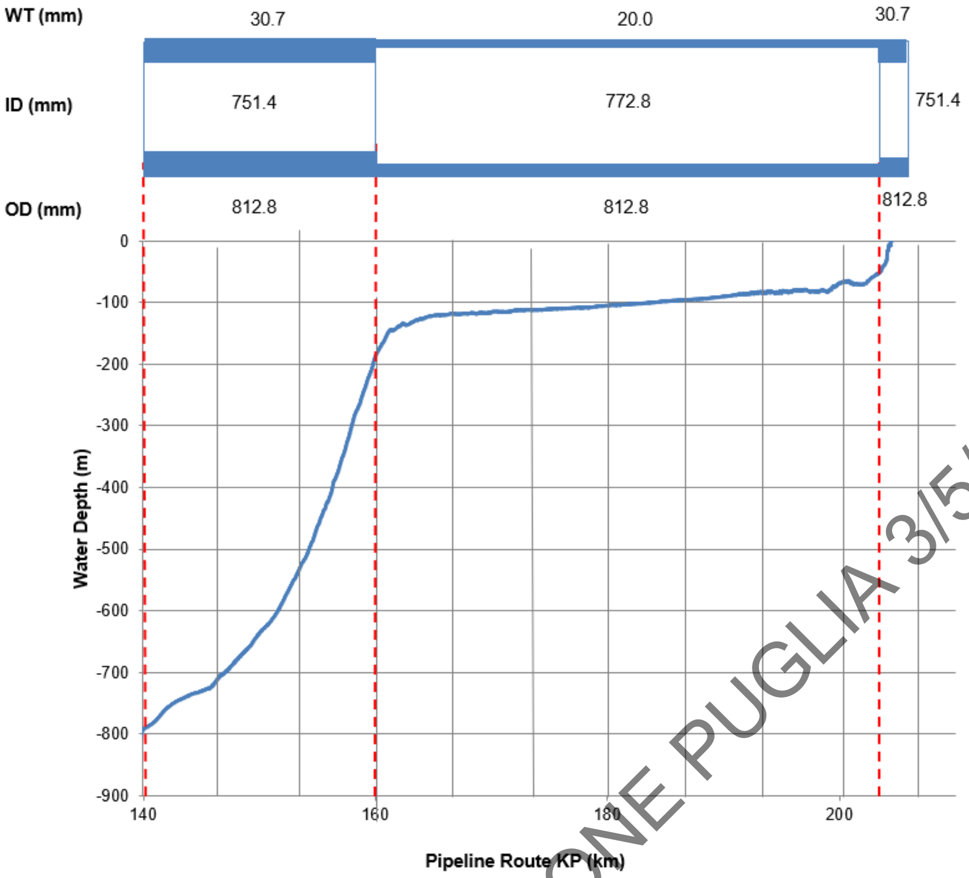


Figure 6-4 Selected Wall Thickness Phasing

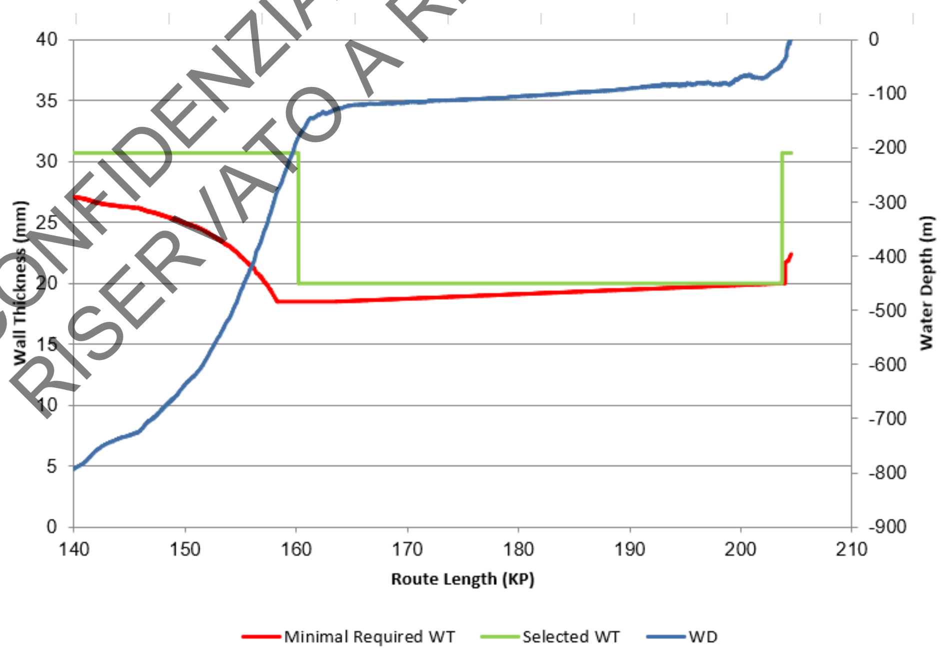


Figure 6-5 Selected Wall Thickness (Green) and Minimum Required Wall Thickness (Red)

Note that transition locations between the wall thickness values as presented in Table 6-7 are used as starting point for the offshore pipeline design activities, including on-bottom stability, pipeline installability, pipeline protection design and on-bottom stress analysis. The final selected transition points (KP's) will be shown on the Pipeline Alignment Sheets (Ref. [6]) and included in the Material Take-Off (Ref. [7]).

6.2.1 Unequal Wall Thicknesses

From Figure 6-4, it can be seen that the step size occurs between 20.0mm and 30.7mm. This step size is an acceptable butt welded joint design, according to the international design standard ASME B31.8 (Ref. [16]). As such no intermediate pipe wall thickness is required given that materials joined have equal specified minimum yield strengths. Figure 6-6 illustrates acceptable preparations for joining pipe ends having unequal wall thicknesses and equal specified minimum yield strengths as per Ref. [16].

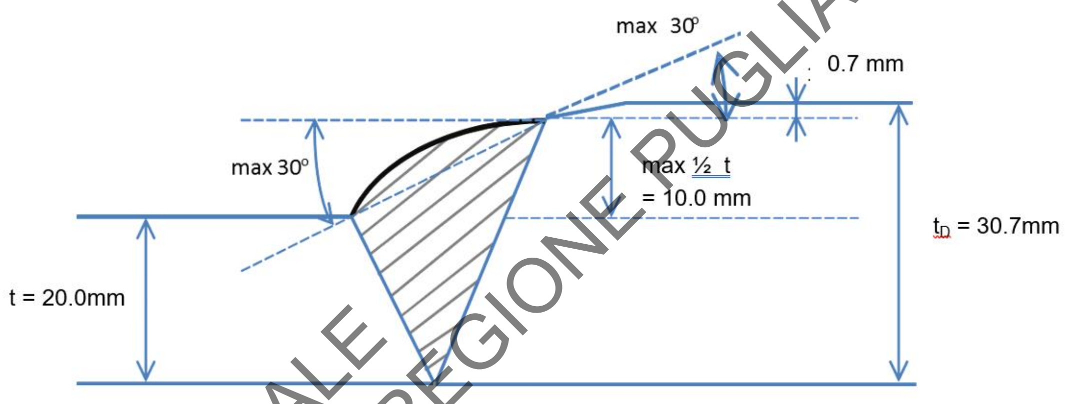


Figure 6-6 Butt Welded Joint Design for Unequal Wall Thicknesses (Ref. [16])

7 BUCKLE ARRESTOR DESIGN

7.1 Buckle Propagation

Pipeline wall thickness design against collapse, as presented in Section 6, is based on avoiding the initiation of a local buckle in deep water, primarily during installation. However, once the pipeline is damaged, e.g. during installation due to loss of vessel position, buckle propagation might occur after local buckling. The nature of a propagating buckle is that a greater pressure level is required to initiate a buckle than the pressure required to maintain propagation of the buckle. As a consequence to this, a buckle once initiated in an offshore pipeline propagates and collapses the pipeline until the external pressure becomes equal to or less than the propagating pressure.

A buckle can propagate at high speed down a pipeline resulting in a catastrophic deformation of the pipe and considerable financial loss. Buckle arrestor design is based on limiting the length of pipeline that would be affected by a propagating buckle. Arrestors are characterised as cylindrical rings with sufficient thickness and length to stop a propagating buckle and are incorporated into the pipeline at a spacing driven by cost and the installation method.

7.2 Types of Buckle Arrestors

Buckle arrestors are manufactured from the same steel grade as the line pipe, either from forging or rolling practice. Typically the rolled buckle arrestor is cheaper and faster to manufacture but its thickness is limited by the size and material combination. The testing requirements of the buckle arrestor material are given in the DNVGL-ST-F101 (Ref. [9]).

Compared to the line pipe, buckle arrestors are basically cylindrical rings with larger thickness to stop a propagating buckle.

Various types of buckle arrestors exist, including:

- Integral ring - heavy wall ring with the same ID and greater OD,
- Welded ring - sleeve welded to the OD of the pipe,
- Free ring - sleeve slipped over the pipe with the annular space grouted,
- Internal ring - heavy wall ring with the same OD and lower ID.

The integral ring type is generally considered to be the most effective type of arrestor and was the configuration specified for similar relatively deep water projects.

The buckle arrestor design depends also on the pipeline installation methods, either S-lay with tensioners, J-lay with tensioners, or J-lay with installation collars.

For J-lay with installation collars, the buckle arrestor is normally used as the installation collar and installed every 4 or 6 joints to hold the pipe joints on the hang-off point during installation. This type of buckle arrestor / installation collar is normally made from forged material and has a larger thickness than the press-rolled one.

During this FEED study only press-rolled buckle arrestors, applied for pipeline installation using tensioners, are presented. The forged (collar) buckle arrestor will not be further detailed.

J-lay vessels, which utilize tensioners to hold the pipe by friction, normally use ‘traditional’ (integral type) buckle arrestors. Similarly, if the pipeline is installed using the S-lay method, integral type buckle arrestors are employed as collar type buckle arrestors would be unsuitable due to significant difference in thicknesses between the line pipe and buckle arrestor.

The design for the buckle arrestor involves optimization of the buckle arrestor thickness, length, and spacing based on the pipeline length subject to propagating buckle risk, which is further detailed in the next sections. The (long) buckle arrestors used in case of S-lay or J-lay utilising tensioners are manufactured by means of press rolling or JCOE / UOE.

7.3 Design Methodology

The buckle propagation phenomenon can be considered to occur in three phases:

1. Buckle initiation,

2. Buckle propagation,

3. Buckle arrest at the arrestor.

According to DNVGL-ST-F101 (Ref. [9]), an integral buckle arrestor may be designed by using the following formula:

$$p_e \leq \frac{p_X}{1.1 \cdot \gamma_m \cdot \gamma_{sc}}$$

in which

$$p_X = p_{pr} + \left(p_{pr,BA} - p_{pr}\right) \cdot \left[1 - EXP\left(-20 \frac{t \cdot L_{BA}}{D^2}\right)\right]$$

where

t	=	Minimum wall thickness of the line pipe, which is equal to t_n
$p_{pr,BA}$	=	Propagating buckle capacity of an infinite arrestor, which is equal to:

$$p_{pr,BA} = 35 \cdot f_{y,BA} \cdot \alpha_{fab,BA} \cdot \left(\frac{t_{BA}}{D_{BA}}\right)^{2.5}$$

in which (in case the buckle arrestor is made from the same steel grade as the line pipe)

$f_{y,BA}$	=	Yield stress of the buckle arrestor, which is equal to f_y
$\alpha_{fab,BA}$	=	Fabrication factor of the buckle arrestor
L_{BA}	=	Length of the buckle arrestor
t_{BA}	=	Nominal thickness of the buckle arrestor
D_{BA}	=	Outside diameter of the buckle arrestor, which is equal to:

$$D_{BA} = D - 2 \cdot t_n + 2 \cdot t_{BA}$$

7.4 Buckle Arrestor Dimensions

In Figure 7-1, the selected pipeline wall thicknesses (green line) and the required wall thicknesses for resisting a propagating buckle (red line) are plotted along the pipeline route. Furthermore, this figure shows the water depth profile (blue line). As detailed in Subsection 6.1.1, buckle arrestors are required for those pipeline sections where the required wall thickness for resisting propagating buckling is larger than the selected wall thickness.

From Figure 7-1, it can be seen that the pipeline sections that require buckle arrestors extend from KP 140.0 to KP 180.0. This results in a total pipeline length of approximately 40 km.

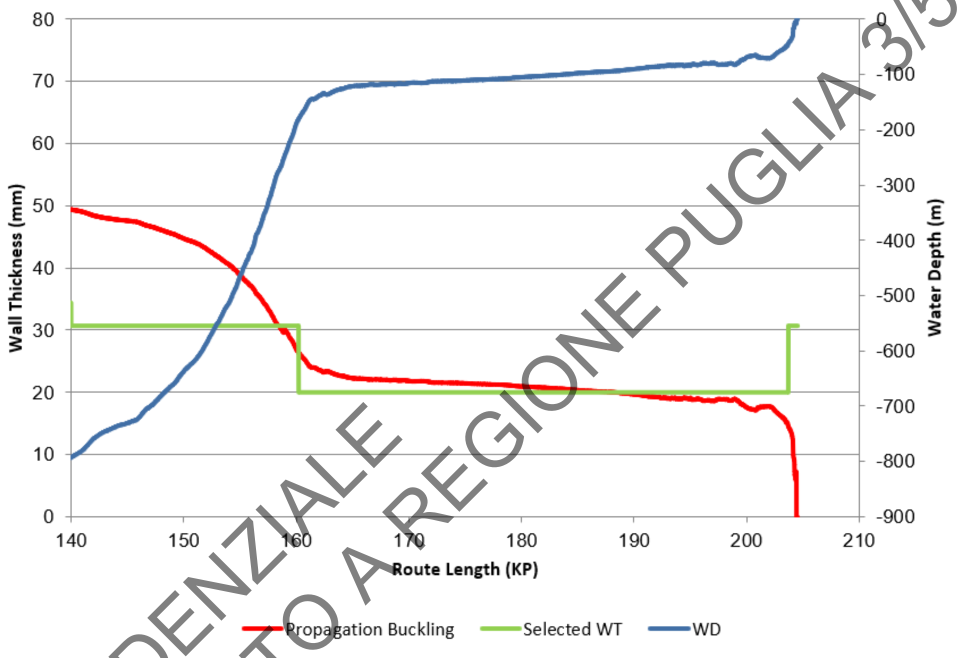


Figure 7-1 Selected Wall Thickness (Green), Required Wall Thickness for Propagating Buckle (Red) along Pipeline Route (Blue)

7.4.1 Buckle Arrestor Dimensions

This subsection presents the dimensions for long buckle arrestors. The specific factors and parameters for the long buckle arrestor design are summarised in Table 7-1.

Table 7-1 Summary of Specific Factors and Parameters for Buckle Arrestors

Parameter	Symbol	Value	DNVGL-ST-F101
Fabrication method	-	UOE, JCOE or TRB	-
Fabrication factor[1] • UOE, JCOE • TRB	$\alpha_{fab,BA}$	 0.85 0.93	Table 5-4
Material Grade	-	SAWL 485	-
Nominal Inside Diameter	ID	Per Table 6-7	-

Note: 1. Selected manufacturing method depends on capability of manufacturer in combination to wall thickness. Analyses are performed for a fabrication factor of 0.85 for WT 20.0mm and 0.93 for WT 30.7mm allowing for expansion as last step in manufacturing process.

The buckle arrestor dimensions determined for each offshore pipeline section are given in Table 7-2. Figure 7-2 presents the dimension sketch for a buckle arrestor. The length of the buckle arrestor is selected equal to 4 m. Furthermore, the thinner section, C is selected approximately 3 times the taper length, (C ≈ 3 x A). This is to keep the HAZ of the girth weld away from the buckle arrestor, but also from the strain concentration spot during installation.

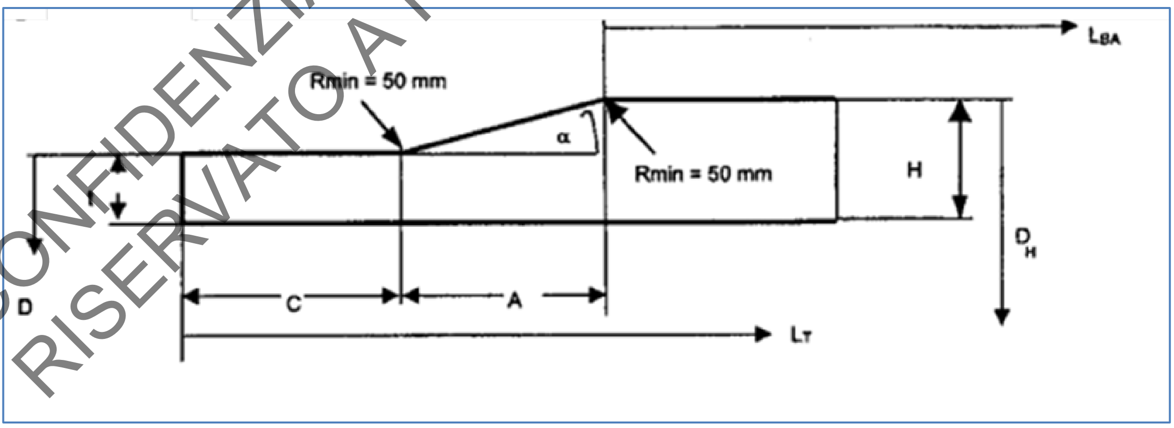


Figure 7-2 Buckle Arrestors Dimension Definition

Table 7-2 Buckle Arrestors Dimensions

Symbol (-)	Parameter (-)	Value (mm)	
Pipeline string OD	D	812.8	812.8
Pipeline string WT	T	30.7	20.0
BA thinner section	C	428.4	-
BA taper section	A	71.6	-
BA wall thickness	H	48.6	30.7
BA thicker section	L_{BA}	3,000	-
Taper angle	α	1:4	-
BA length	L_T	4,000	-
BA outer diameter	D_H	848.6	812.8
Full joint length incl. BA	-	12,200	12,200
Comments	-	-	Note 1

Note: 1. As buckle arrestor a regular line pipe with a wall thickness of 30.7mm shall be used.

The length of the buckle arrestor is selected equal to 4 m. This length is normally utilized for press-rolled buckle arrestors as it equals roughly to 1/3 of pipe joint length (12.2 m). This enables the buckle arrestor to be optimally combined with two sections of line pipe with each 4 m length, as schematically shown in Figure 7-3 .

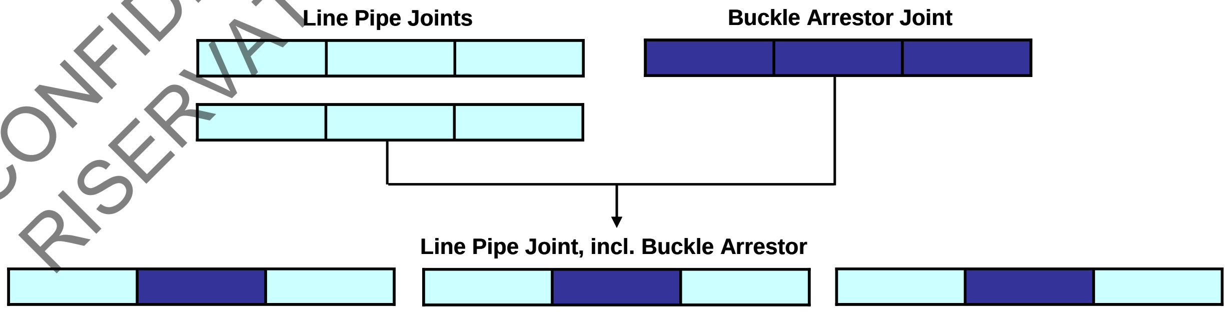


Figure 7-3 Schematic Buckle Arrestor Joints

Hence, the buckle arrestor assembly consists of three uniform sections with two line pipe sections at either end, and one buckle arrestor in the centre. This approach results in a minimum material waste while maintaining the amount of welds and weld consumables.

To facilitate procurement, manufacturing, logistics and installation of the buckle arrestors, the selected buckle arrestor thicknesses are rationalised minimizing the number of types. This is done by taking into account the line pipe matching wall thicknesses. A single buckle arrestor thickness per pipeline wall thickness is selected (independent of the water depth variation within the respective sections). Per wall thickness section, the governing point for the buckle arrestor thickness is the location with the greatest water depth.

The selected buckle arrestor wall thicknesses per section of the route are presented in Table 7-3.

Further details of the buckle arrestor are laid down in Buckle Arrestor Typical Drawing (Ref. [13]).

Table 7-3 Selected Buckle Arrestor Wall Thickness

<table>
<tr><th>Section
(km)</th><th>Line Pipe OD
(mm)</th><th>Selected Pipeline WT
(mm)</th><th>Buckle Arrestor WT[1]
(mm)</th></tr>
<tr><td>KP 140.0 – KP 158.0</td><td rowspan="5">812.8 (32”)</td><td rowspan="2">30.7</td><td>48.6</td></tr>
<tr><td>KP 158.0 – KP 160.2</td><td>-</td></tr>
<tr><td>KP 160.2 – KP 180.0</td><td rowspan="2">20.0</td><td>30.7[1, 2]</td></tr>
<tr><td>KP 180.0 – KP 203.7</td><td rowspan="2">-</td></tr>
<tr><td>KP 203.7 – KP 204.8</td><td>30.7</td></tr>
</table>

Notes: 1. The calculated buckle arrestor thickness is 27.9mm, however 30.7mm is selected in order to allow deep water line pipe to be used as buckle arrestor

2. A full line pipe joint of 30.7mm is considered as buckle arrestor. By use of a 30.7mm line pipe as buckle arrestor the concrete coating applied on the 20.0mm line pipe might be tapered on one side for smooth roller box passage during installation.

7.5 Buckle Arrestor Spacing

The spacing for buckle arrestors is determined by performing a simplified economic assessment of the potential cost associated with the use of buckle arrestors.

As indicated in the Spares Philosophy (Ref. [14]), spare pipe is required in the event that damage occurs to the pipeline during installation or its operational life. For the deep water section, the spare pipe should as a minimum include the distance between two successive buckle arrestors, to account for the propensity of damage to propagate along the pipeline. The wall thickness of the spare joints should be the deep water wall thickness to allow insertion into any section of the route.

In the performed assessment the spacing is based on the procurement cost of the spare joints plus the additional procurement costs of the buckle arrestors themselves. For this assessment, the following ball park figures are used:

- Line pipe supply costs (UOE/JCOE) 1,000 EUR/ton
- Buckle arrestor supply costs (TRB) 10,000 EUR/ton

Note that the construction costs related to the replacement of a damaged pipe section are not accounted for, as it is expected that the major part of these costs are related to the start-up / mobilization of the repair activity, which is independent of the length of pipe section that needs to be replaced.

Following the assessment, a buckle arrestor spacing in the order of 1,500m to 3,000m has been found most cost efficient. For the 20.0mm pipeline section where a regular line pipe with a wall thickness of 30.7mm is used as buckle arrestor the buckle arrestor spacing length is considerably less since the line pipe cost is applied instead of the buckle arrestor cost for the buckle arrestor spacing calculations.

Taking into account the above results and general industry practice, a buckle arrestor is determined based on the catenary length (1.85 times average water depth) of the pipeline during installation and the vessel length (assumed 100m between stern and welding station) plus a safety distance from TDP (assumed 60m) to avoid having one buckle arrestor in the sagbend while another one is being welded on the vessel.

The spacing and number of buckle arrestors required is presented in Table 7-4.

Table 7-4 Buckle Arrestor Wall Thickness, Spacing and Number

Section	Pipeline OD	Selected Pipeline WT	Buckle Arrestor Data			
			WT	Spacing		No.
(km)	(mm)	(mm)	(mm)	(m)	(# Joint)	(#)
KP 140.0 – KP 158.0	812.8	30.7	48.6	1,623	133	11
KP 160.2 – KP 180.0		20.0	30.7[1]	403	33	49

Notes: 1. A full regular line pipe joint of 30.7mm is considered as buckle arrestor.

8 REFERENCES

Ref. [1] INTECSEA, Poseidon Pipeline Project – Offshore Section Update, Design Basis Memorandum, Doc. No. IGI-1201-10-PL-BOD-001

Ref. [2] INTECSEA, Poseidon Pipeline Project – Offshore Section Update, Code Selection Report, Doc. No. IGI-201-10-PL-RPT-001

Ref. [3] INTECSEA, Poseidon Pipeline Project – Offshore Section Update, Onshore Pipeline Mechanical Design Report – Italy, Doc. No.IGI-1404-46-PL-RPT-002

Ref. [4] INTECSEA, Poseidon Pipeline Project – Offshore Section Update, Material Selection Report, Doc. No. IGI-207-10-PL-RPT-001

Ref. [5] INTECSEA, Poseidon Pipeline Project – Offshore Section Update, Bottom Roughness Analysis , Doc. No. IGI-306-30-PL-CAL-001

Ref. [6] INTECSEA, Poseidon Pipeline Project – Offshore Section Update, Pipeline Alignment Sheets, Doc. No. IGI-1316-30-PL-DWG-001

Ref. [7] INTECSEA, Poseidon Pipeline Project – Offshore Section Update, Material Take-Off, Doc. No. IGI-1207-10-PL-MTO-001

Ref. [8] INTECSEA, Poseidon Pipeline Project – Offshore Section Update, Specification for Line Pipe, Doc. No. IGI-1207-10-PL-SPC-001

Ref. [9] DNVGL-ST-F101, Submarine Pipeline Systems, 2017

Ref. [10] DNVGL-RP-F109, On-Bottom Stability Design Of Submarine Pipelines, 2017

Ref. [11] EN 14161:2011+A12015, Petroleum and Natural Gas Industries – Pipeline Transportation Systems

Ref. [12] Decreto del Ministero dello Sviluppo Economico 17 aprile 2008, Regola technica per la progettazione, costruzione, collaudo, esercizio e sorveglianza delle opere e degli impianti di transporto di gas naturale con densità non superiore a 0.8

Ref. [13] INTECSEA, Poseidon Pipeline Project – Offshore Section Update, Buckle Arrestor Typical Drawing, Doc. No. IGI-1308-30-PL-DWG-001

Ref. [14] INTECSEA, Poseidon Pipeline Project – Offshore Section Update , Spares Philosophy, Doc. No. IGI-209-10-PL-PHL-002

Ref. [15] INTECSEA, Poseidon Pipeline Project – Offshore Section Update, Pipeline Installation Analysis Report, Doc. No. IGI-317-30-CM-RPT-001

Ref. [16] ASME B31.8, Gas Transmission and Distribution Piping Systems, 2016

Appendix A Hydrotest Pressure Calculation

INTECSEA
WorleyParsons Group

CLIENT:	IGI Poseidon S.A.	BY:	WHH
PROJECT:	406010 00159 - Poseidon Pipeline Project	DATE:	Oct 2017
DOCUMENT TITLE:	Hydrotest Pressure for offshore section	CHK:	______
REVISION No.:	A		

CALCULATION OF HYDROTEST PRESSURE OF THE OFFSHORE SECTION ACCORDING TO DNV-OS-F101, ITALIAN MINISTERIAL DECREE AND EN 14161.

Input

Design pressure	$P_d := 170bar$
Maximum operating pressure	$P_o := 151bar$
Maximum content density	$\rho_c := 130kg \cdot m^{-3}$
Seawater density	$\rho_{sw} := 1030kg \cdot m^{-3}$
Pressure elevation	$h := 400m$
Maximum offshore pressure elevation	$h_{max} := 10m$

Operational Data

Pressure variation between the compressor elevation and the maximum offshore elevation

$$dP := (h - h_{max}) \cdot \rho_c \cdot g = 4.972 \cdot bar$$

DNV OS F101

Design pressure
At maximum offshore elevation

$$P_{d0} := dP + P_d = 174.972 \cdot bar$$

Hydrotest pressure

$$P_{test\_DNV} := P_{d0} \cdot 1.10 \cdot 1.05 + h_{max} \cdot g \cdot \rho_{sw}$$

$$\boxed{P_{test\_DNV} = 203.103 \cdot bar}$$

Italian Ministerial Decree

Maximum operating pressure
At maximum offshore elevation

$$P_{o0} := dP + P_o = 155.972 \cdot bar$$

Hydrotest pressure

$$P_{test\_Italian} := P_{o0} \cdot 1.3 + h_{max} \cdot g \cdot \rho_{sw}$$

$$\boxed{P_{test\_Italian} = 203.8 \cdot bar}$$

EN 14161

Maximum Allowable Operating Pressure
At maximum offshore elevation

$$P_{MAOP} := P_{d0} \cdot 0.95 = 166.223 \cdot bar$$

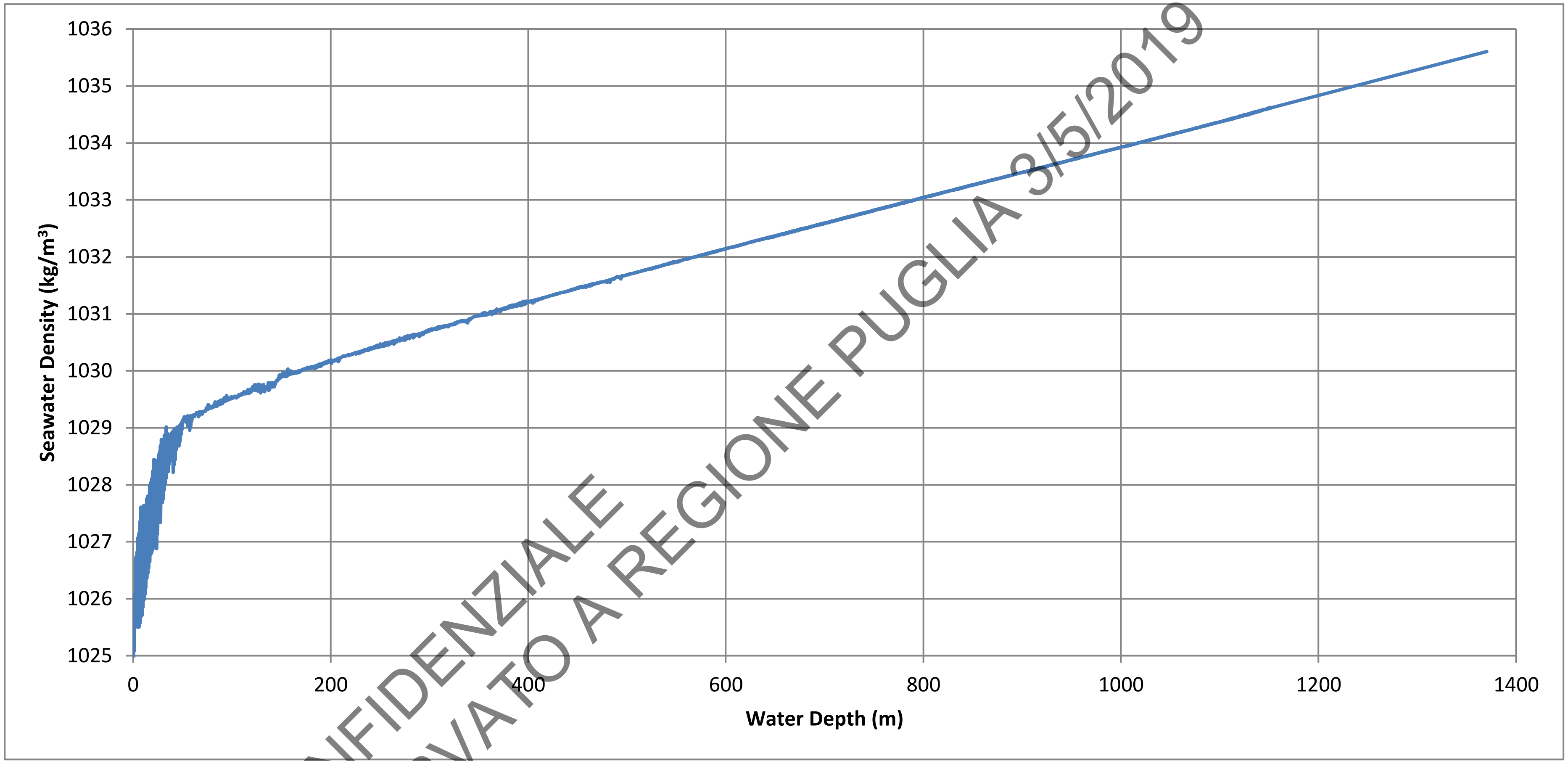
Hydrotest pressure

$$P_{test\_EN} := P_{MAOP} \cdot 1.25 + h_{max} \cdot g \cdot \rho_{sw}$$

$$\boxed{P_{test\_EN} = 208.8 \cdot bar}$$

The methodology to obtain the pressure test for offshore design codes is detailed in Ref. [1]

Appendix B Seawater Density Profile


Seawater Density (kg/m³)
1036
1035
1034
1033
1032
1031
1030
1029
1028
1027
1026
1025
0
200
400
600
800
1000
1200
1400
Water Depth (m)