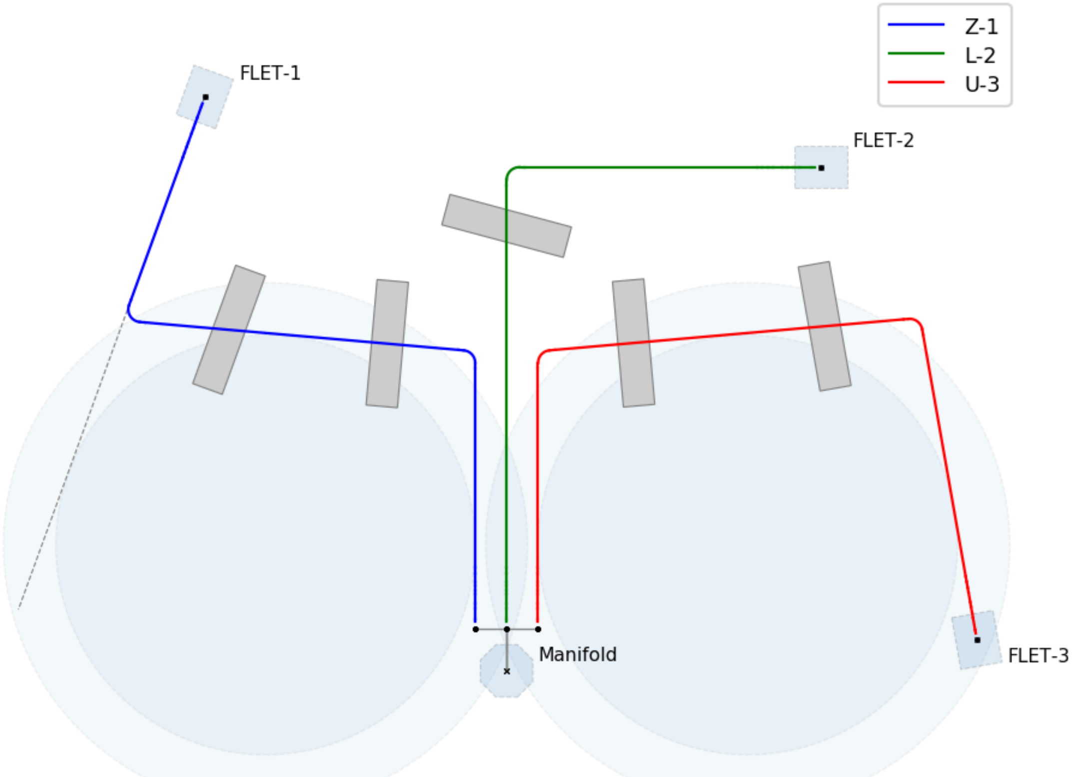
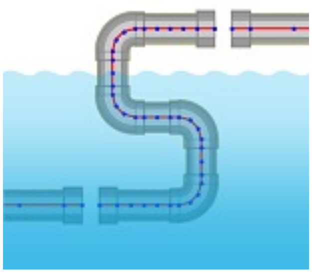
Detailed Results for Spool Z-1



PROJECT	FIELD	SPOOL
Project Name	Ozean F-1	Z-1



SDP

Spool Design Program
by
in2Spools Pty Ltd

CLIENT
CLIENT LOGO

REV	DATE (yy-mm-dd)	DESCRIPTION	ORIGINATOR			COMP
			PREP	CHK	APPR	
A	18-08-19	Issued for demonstration purpose	JW	AE	OO	

This document has been automatically generated by SDP 18.1 (Spool Design Program, version 18.1)

TABLE OF CONTENTS

1 INTRODUCTION

The results presented in this document have been automatically calculated using the i2S developed spool / jumper design program SDP (www.in2spools.com/software).

1.1 SCOPE OF DOCUMENT

This document presents the detailed results for spool Z-1, comprising of the following assessed configurations:

- min
- nom
- max
- min_L2
- min_L3
- max_L2
- max_L3

Where the following is presented for each configuration:

- FE-model
- Spool geometry
- Load cases
- Load steps
- Spool CLC / ASD utilisation
- Spool ASME utilisation
- Spool HISC utilisation
- Spool end reaction loads
- Fatigue damage due to VIV
- Support loads

The spool output data, which are based on all assessed configurations, are summarized in Section 2 of this document. This also includes data relevant for interfacing disciplines.

1.2 ABBREVIATIONS

ASD	Allowable Stress Design
ASME	The American Association of Mechanical Engineers
CF	Cross Flow
CLC	Combined Loading Criteria
DNV	Det Norske Veritas
FE	Finite Element
HISC	Hydrogen Induced Stress Cracking
i2S	in2Spools Pty Ltd (www.in2spools.com)
ID	Inner Diameter
IL	In-Line
IP	Intersection Point
MTO	Material Take Off
N/A	Not Available / Not Applicable

SDP	Spool Design Program (developed by i2S)
ULS	Ultimate Limit State
VIV	Vortex Induced Vibrations
WT	Wall Thickness

1.3 Definitions

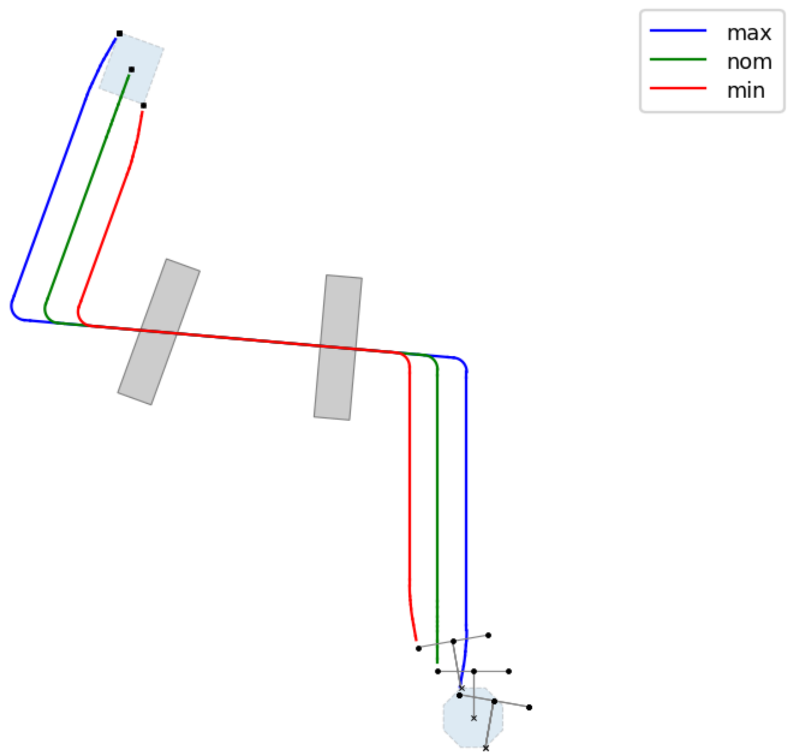
End 1	Manifold end of the spool
End 2	FLET-1 end of the spool
RFi	Reaction Force in i-direction, where i stands for either the x-, y-, or z-axis
RMi	Reaction Moment about i-axis, where i stands for either the x, y, or z
RMb	Reaction Moment bending
ui	Displacement in i-direction, where i stands for the x-, y-, or z-axis
ri	Rotation about the i-axis, where i stands for the x, y, or z

1.3.1 Configurations

The analysed configurations consist of the minimum, nominal and maximum configurations, as well as the configurations where any individual spool leg is shorter / longer than on the minimum / maximum configurations.

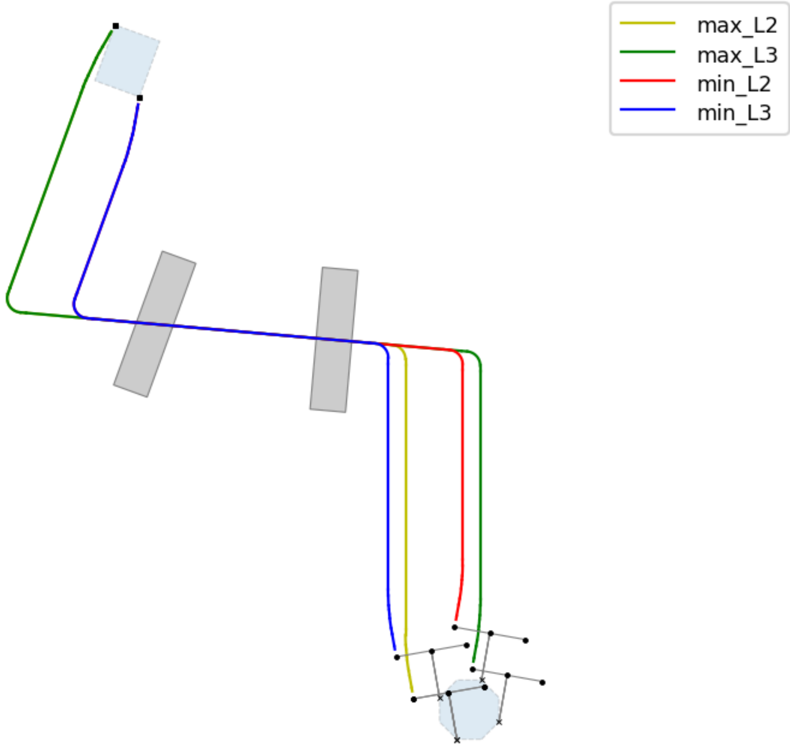
The minimum and maximum configurations refer to the total length of the spools, and are presented in Figure 1.1.

Figure 1.1 – Analysed Configurations - Min / Nom / Max



The configurations with individual leg lengths shorter or longer than the corresponding legs on the minimum and maximum configurations are shown in Figure 1.2.

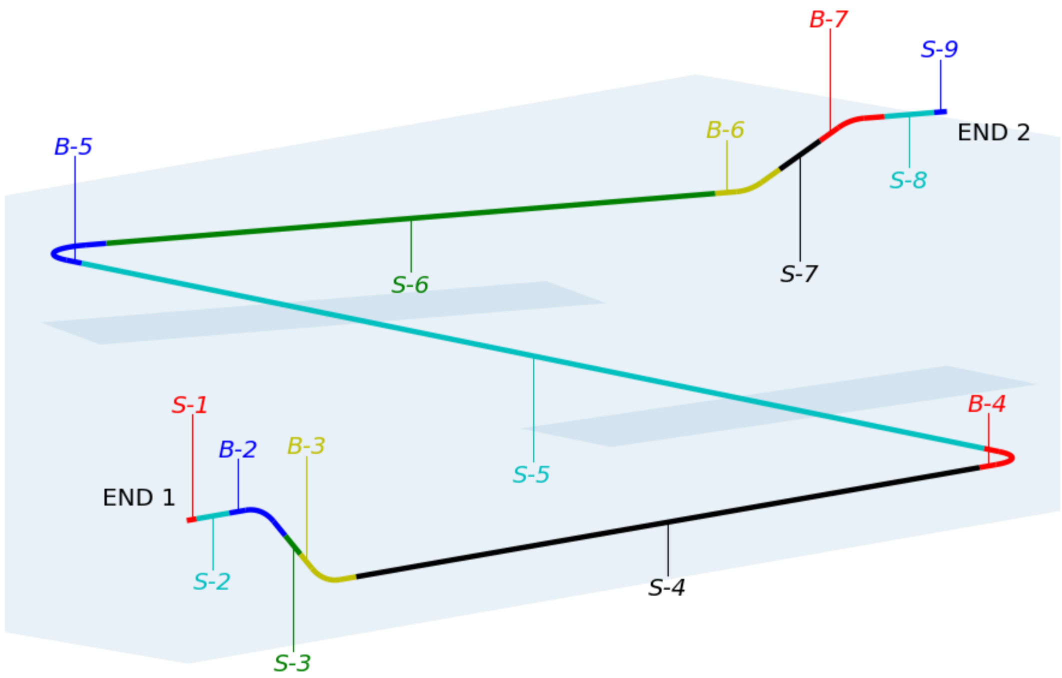
Figure 1.2 – Analysed Configurations - Min / Max Individual Legs



1.3.2 Spool Section Labels

Figure 1.3 shows the spool section labels used in this document; where the prefix "B" and "S" stands for bend (including tangents) and straight section respectively.

Figure 1.3 – Spool Section Labels

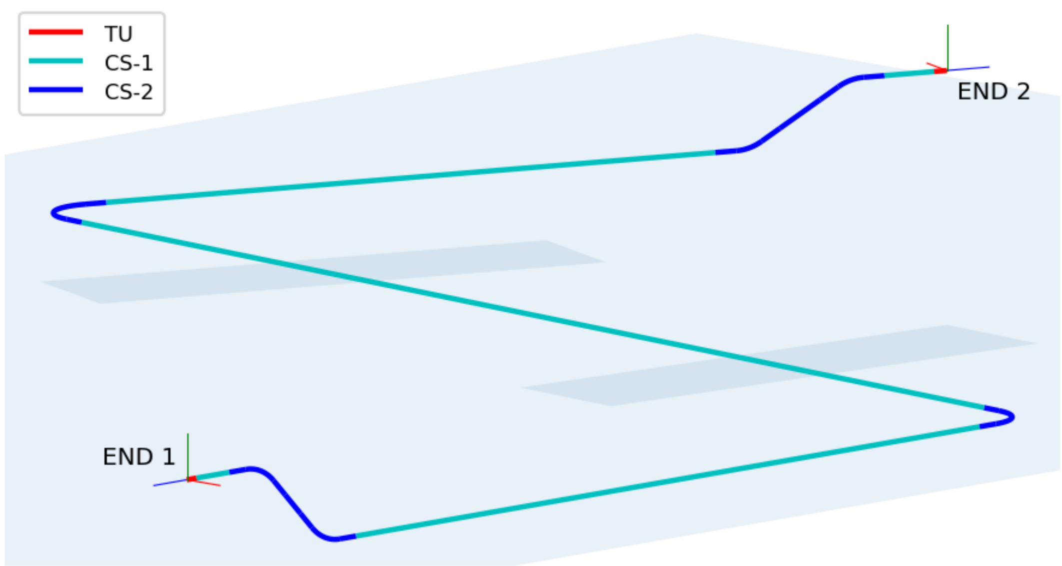


1.3.3 Coordinate Systems

Global coordinates are denoted with the capital letters X (Easting), Y (Northing) and Z (Vertical), and local coordinates are denoted x, y and z.

The spool end coordinate systems are defined as right-handed orthogonal systems; with the z-axes aligned with the vertical axis and the x-axes corresponding to the heading of each spool end, as shown in Figure 1.4.

Figure 1.4 – End Coordinate Systems



The blue, red and green lines shown at both ends of the spool represent the local x-, y- and z-axes respectively.

1.3.4 Supports

Figure 1.5 shows a top-view of the nominal spool, with support labels used in this document.

Figure 1.5 – Support Labels

1.3.5 Design Criteria Utilisations

The utilisations are defined as the maximum calculated magnitude divided by the maximum allowable magnitude. The design criteria utilisations are denoted as follows:

ASD	Applicable to spool bends and calculated according to "Allowable Stress Design", Section F 200, Ref. [DNV-OS-F101]
CLC	Applicable to straight spool sections and calculated according to "Local buckling - combined loading criteria, Load Controlled condition", Section D 600, Ref. [DNV-OS-F101] and [DNV Clad JIP]
ASME	Applicable to whole spool and calculated according to Ref. [ASME B31.8]
HISC	Applicable to straight spool sections and calculated according to "linear elastic stress criteria", Section D, Ref. [DNV-RP-F112]
VIV Fatigue	Applicable at spool welds and calculated based on Ref. [DNV-RP-F105]
Connector / Hub	Applicable to connectors or the weakest link in terms of allowable hub face loads. Calculated based on maximum magnitude end reaction moments, as forces are typically not critical

1.4 References

SDP 18.1	in2Spools Pty Ltd, SDP, "Spool Design Program", Version 18.1 (www.in2spools.com/software)
DNV-OS-F101	Det Norske Veritas, DNV-OS-F101, "Submarine Pipeline Systems", August 2012
DNV Clad JIP	Det Norske Veritas, JIP Lined and Clad Pipelines, Phase 3, "Guideline for Design and Construction of Lined and Clad Pipelines", Revision 01
ASME B31.8	The American Association of Mechanical Engineers, ASME B31.8-2010, "Gas Transmission and Distribution Piping Systems", 2010
DNV-RP-F112	Det Norske Veritas, DNV-RP-F112, "Design of Duplex Stainless Steel Subsea Equipment Exposed to Cathodic Protection", October 2008
DNV-RP-F105	Det Norske Veritas, DNV-RP-F105, "Free Spanning Pipelines", February 2006

2 OUTPUT DATA

This section presents the following results:

- Maximum utilisations
- Dimensions and coordinates
  - Total spool lengths and hub to hub distances
  - Spool section lengths
  - Bend angles
  - Nominal spool coordinates
  - Structure coordinates and headings
- MTO and bend quantities
  - Spool MTO
  - Bend quantities
- Reaction loads and masses
  - Spool masses
  - End reaction loads
  - Vertical support forces

2.1 MAXIMUM UTILISATIONS

The maximum utilisations for all evaluated criteria are presented in Table 2.1.

Table 2.1 – Maximum Utilisations

Configuration	DNV ULS		ASME	HISC		VIV Fatigue	Connector / Hub	
	CLC	ASD		Straights	Bends		End 1	End 2
min	1.01	1.13	1.22	1.38	N/A	22.57	1.32	1.37
nom	0.44	0.79	1.01	1.01	N/A	0.0	0.96	1.1
max	0.5	0.73	1.03	1.0	N/A	0.05	0.93	1.07
min_L2	0.63	0.91	0.98	1.1	N/A	33.73	1.2	1.21
min_L3	1.1	1.17	1.27	1.44	N/A	19.2	1.38	1.38
max_L2	0.55	0.77	1.03	1.04	N/A	0.04	0.85	1.12
max_L3	0.54	0.76	1.04	1.04	N/A	0.08	0.95	1.12
Max	1.1	1.17	1.27	1.44	N/A	33.73	1.38	1.38

The maximum allowable utilisation is exceeded by 3273%.

2.2 DIMENSIONS AND COORDINATES

2.2.1 Total Spool Lengths and Hub to Hub Distances

Total lengths and hub to hub distances, for all assessed configurations, are presented in Table 2.2.

Table 2.2 – Total Lengths and Hub to Hub Distances

Configuration	Total Length [m]	Hub to Hub Distance [m]
min	72.6	50.1
nom	82.7	55.9
max	93.2	61.8
min_L2	75.9	51.0
min_L3	72.7	50.8
max_L2	89.8	61.1
max_L3	93.1	61.2

The hub to hub distances refers to the projected distance (onto the horizontal plane) between the two spool hub faces.

2.2.2 Spool Section Lengths

The nominal spool section lengths with tolerances are presented in Table 2.3.

Table 2.3 – Section Lengths with Tolerances

Section	Cross-Section	Nominal Length[m]	Length Tolerances [m]	
			Negative	Positive
S-1	TU	0.3	-	-
S-2	CS-1	1.003	-	-
B-2	CS-2	1.942	-	-
S-3	CS-2	0.656	-0.132	0.152
B-3	CS-2	1.942	-	-
S-4	CS-1	19.029	-3.238	3.425
B-4	CS-2	2.78	-	-
S-5	CS-1	30.012	-5.214	5.306
B-5	CS-2	3.199	-	-
S-6	CS-1	14.466	-3.392	3.418
B-6	CS-2	1.628	-	-
S-7	CS-2	1.105	-0.17	0.234
B-7	CS-2	1.628	-	-
S-8	CS-1	1.178	-	-
S-9	TU	0.3	-	-

The pitch installation tolerances of the connecting structures have been disregarded, since the effect on length tolerances will depend on the location of the field welds.

2.2.3 Bend Angles

Table 2.4 presents each bend angle for all analysed configurations.

Table 2.4 – Bend Angles

Configuration	Bend Angle [deg]					
	B-2	B-3	B-4	B-5	B-6	B-7
All	45.0	45.0	85.0	105.0	30.0	30.0

2.2.4 Nominal Spool Coordinates

The coordinates at the nominal spool ends and at the intersection points between the extended straight lines / sections, are presented in Table 2.5.

Table 2.5 – Nominal Spool Coordinates at Ends and Intersection Points

Location	Coordinates [m]		
	X / Easting	Y / Northing	Z / Vertical
End 1	-3.0	4.65	2.5
IP-1	-3.0	4.95	2.5
IP-2	-3.0	6.95	2.5
IP-3	-3.0	8.824	0.626
IP-4	-3.0	30.45	0.626
IP-5	-36.547	33.385	0.626
IP-6	-30.613	49.69	0.626
IP-7	-29.799	51.926	2.0
IP-8	-29.115	53.806	2.0
End 2	-29.012	54.088	2.0

2.2.5 Structure Coordinates and Headings

The nominal structure coordinates and headings, corresponding to this spool design, are presented in Table 2.6.

Table 2.6 – Nominal Structure Coordinates and Headings

Structure	Easting X [m]	Northing Y [m]	Heading [deg]
Manifold	0.0	0.0	90.0
FLET-1	-28.79	54.698	-110.0
Support-1	-11.387	31.184	85.0
Support-2	-26.483	32.505	70.0

2.3 MTO and Bend Quantities

2.3.1 Spool MTO

The spool MTO is presented in Table 2.7.

Table 2.7 – MTO

Cross-Section	ID [mm]	WT [mm]	Total Length [m]
CS-1	350.0	25.0	77.838
CS-2	350.0	30.0	15.269
TU	350.0	150.0	0.6

The length of each cross-section type is based on the summation of the maximum length of each individual spool section, i.e. resulting in a total length greater than the equivalent lengths for the maximum configuration.

The total length of the Termination Units is included for completeness. The presented ID and WT are based on the FE-model values.

2.3.2 Bend Quantities

The spool bend quantities are presented in Table 2.8.

Table 2.8 – Bend Quantities

Bend Angle [deg]	Cross-Section	Radius of Curvature [m]	Tangent Length [m]		Quantity
			Start	End	
30.0	CS-2	1.2	0.5	0.5	2
45.0	CS-2	1.2	0.5	0.5	2
85.0	CS-2	1.2	0.5	0.5	1
105.0	CS-2	1.2	0.5	0.5	1

2.4 Reaction Loads and Masses

2.4.1 Spool Masses

Spool configuration masses are presented in Table 2.9.

Table 2.9 – Spool Masses

Configuration	Mass [t]		
	Empty	Filled	Submerged / Filled
min	28.0	35.9	23.6
nom	30.6	39.6	25.8
max	33.4	43.5	28.0
min_L2	28.9	37.1	24.3
min_L3	28.0	35.9	23.6
max_L2	32.5	42.3	27.3
max_L3	33.3	43.5	28.0

All masses include the coating (if applicable). The mass of the content for the filled alternative has been calculated based on the content density from the first load step. The submerged "mass" refers to an equivalent value, i.e. the mass of the displaced water subtracted from the actual mass.

2.4.2 End Reaction Loads

The maximum magnitude reaction loads at End 1 is presented in Table 2.10.

Table 2.10 – Maximum Magnitude Reaction Loads - End 1

Load Step	End Reaction Forces [kN]			End Reaction Moments [kNm]			
	RFx	RFy	RFz	RMx	RMy	RMz	RMb
Docked	9.9	2.6	88.2	0.0	446.7	-18.5	446.8
Tie-in 1st end	57.8	32.9	93.4	0.0	540.2	-455.6	604.0
Tie-in 2nd end	67.1	49.6	93.1	34.7	565.3	-623.9	705.4
Pressure test	64.8	48.8	93.1	34.1	566.6	-619.0	702.3
Contraction	107.3	75.1	78.0	61.3	418.5	-839.7	856.0
Expansion	-75.3	-66.3	75.6	-113.4	458.6	667.7	757.2
Contraction/sett	108.0	75.2	79.5	70.6	442.5	-871.0	894.1
Expansion/sett	-77.0	-66.4	77.2	-121.5	499.8	668.4	780.4
Max	108.0	75.2	93.4	-121.5	566.6	-871.0	894.1

The loads presented are the maximum magnitude from any of the analysed configurations and load cases.

The maximum magnitude reaction loads at End 2 is presented in Table 2.11.

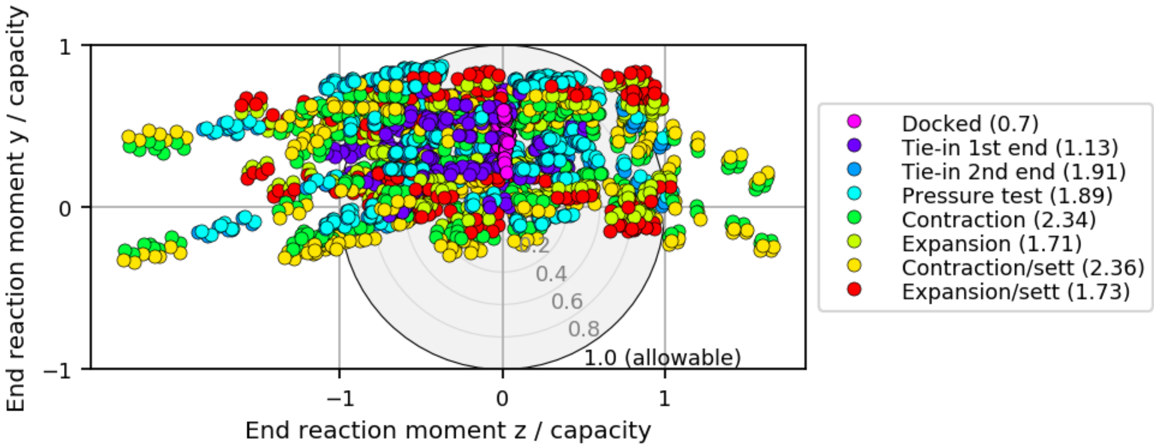
Table 2.11 – Maximum Magnitude Reaction Loads - End 2

Load Step	End Reaction Forces [kN]			End Reaction Moments [kNm]			
	RFx	RFy	RFz	RMx	RMy	RMz	RMb
Docked	5.6	-1.4	86.9	-0.0	453.8	19.0	453.8
Tie-in 1st end	23.6	35.7	87.5	0.0	476.7	-311.5	499.3
Tie-in 2nd end	70.4	77.1	96.3	0.0	563.6	-711.2	862.7
Pressure test	68.4	76.3	96.3	-1.2	564.1	-702.9	855.7
Contraction	92.2	100.1	83.9	32.2	450.9	-805.7	896.6
Expansion	-72.4	-69.9	81.7	-120.4	519.5	574.2	754.6
Contraction/sett	94.3	97.1	86.5	29.0	496.7	-799.2	887.4
Expansion/sett	-72.3	-72.2	84.0	-126.1	546.5	605.5	788.3
Max	94.3	100.1	96.3	-126.1	564.1	-805.7	896.6

The loads presented are the maximum magnitude from any of the analysed configurations and load cases.

The connector / hub bending moment utilisations (RMy vs. RMz) at both ends, for all load cases and load steps, are shown in Figure 2.1.

Figure 2.1 – Reaction Bending Moment Components - Both Ends



2.4.3 Vertical Support Forces

The maximum vertical forces acting on the supports for each load step are presented in Table 2.12.

Table 2.12 – Vertical Support Forces

Load Step	Vertical Force [kN]		
	SEABED	Support-1	Support-2
Docked	0.1	56.5	66.6
Tie-in 1st end	4.9	67.6	61.1
Tie-in 2nd end	12.2	96.5	65.3
Pressure test	12.4	65.3	65.3
Contraction	0.0	44.7	80.2
Expansion	0.0	43.5	45.1
Contraction/sett	16.3	46.2	45.9
Expansion/sett	14.2	49.4	48.0
Max	16.3	96.5	80.2

3 CONFIGURATION MIN

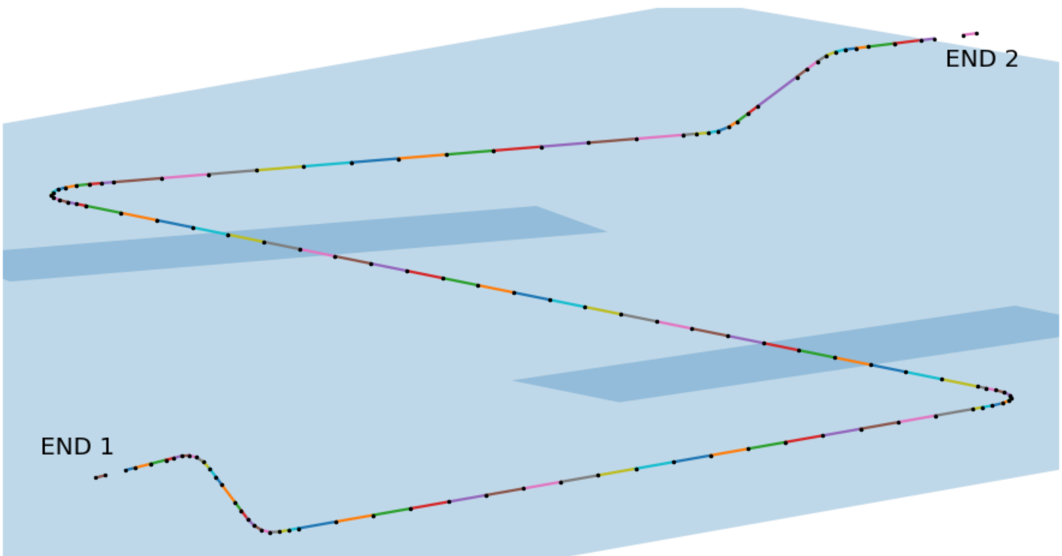
This section presents the following detailed results for configuration "min".

- FE-model
- Spool geometry
- Load cases
- Load steps
- Spool CLC / ASD utilisation
- Spool ASME utilisation
- Spool HISC utilisation
- Spool end reaction loads
- Fatigue damage due to VIV
- Support loads

3.1 FE-Model

The FE-model consists of the spool and two connecting structures at each end. The mesh density used is shown in Figure 3.1.

Figure 3.1 – FE-Model Mesh



The beam / pipe elements are shown as lines and with the associated nodes are shown as black dots. The nodes belonging to the area elements are not shown.

The spool consists of three different cross-section types.

3.2 Spool Geometry

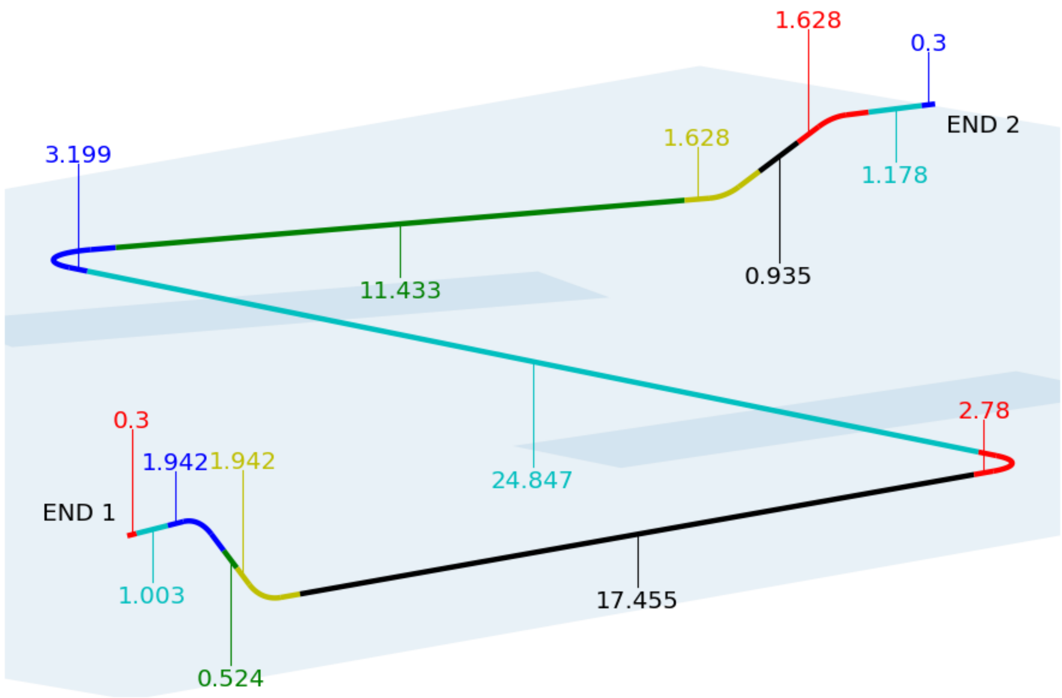
The coordinates at the spool ends and at the intersection points between the extended straight lines / sections, are presented in Table 3.1.

Table 3.1 – Coordinates at Ends and Intersection Points

Location	Coordinates [m]		
	X / Easting	Y / Northing	Z / Vertical
End 1	-4.797	6.558	2.4
IP-1	-4.85	6.854	2.4
IP-2	-5.197	8.823	2.4
IP-3	-5.353	10.604	0.626
IP-4	-5.353	30.656	0.626
IP-5	-33.755	33.141	0.626
IP-6	-28.858	46.595	0.626
IP-7	-28.278	48.76	1.9
IP-8	-27.931	50.73	1.9
End 2	-27.878	51.025	1.9

An isometric view of the spool showing each section length (units in meter) is shown in Figure 3.2.

Figure 3.2 – Isometric View with Section Lengths



3.3 LOAD CASES

A set of 16 load case combinations has been analysed, as presented in Table 3.2. The prescribed end displacement / rotation values refer to uncertainties regarding make-up tolerances at each spool end.

Table 3.2 – Load Case Combinations

Load Case	END 1						END 2					
	Displacements [m]			Rotations [deg]			Displacements [m]			Rotations [deg]		
	ux	uy	uz	rx	ry	rz	ux	uy	uz	rx	ry	rz
1	0.09	0.09	0.1	Free	0.55	-0.7	0.09	0.09	0.1	Free	0.55	-0.7
2	0.09	0.09	0.1	Free	0.55	-0.7	0.09	0.09	-0.1	Free	-0.55	-0.7
3	0.09	0.09	-0.1	Free	-0.55	-0.7	0.09	0.09	0.1	Free	0.55	-0.7
4	0.09	0.09	-0.1	Free	-0.55	-0.7	0.09	0.09	-0.1	Free	-0.55	-0.7
5	0.09	-0.09	0.1	Free	0.55	0.7	0.09	-0.09	0.1	Free	0.55	0.7
6	0.09	-0.09	0.1	Free	0.55	0.7	0.09	-0.09	-0.1	Free	-0.55	0.7
7	0.09	-0.09	-0.1	Free	-0.55	0.7	0.09	-0.09	0.1	Free	0.55	0.7
8	0.09	-0.09	-0.1	Free	-0.55	0.7	0.09	-0.09	-0.1	Free	-0.55	0.7
9	-0.09	0.09	0.1	Free	0.55	-0.7	-0.09	0.09	0.1	Free	0.55	-0.7
10	-0.09	0.09	0.1	Free	0.55	-0.7	-0.09	0.09	-0.1	Free	-0.55	-0.7
11	-0.09	0.09	-0.1	Free	-0.55	-0.7	-0.09	0.09	0.1	Free	0.55	-0.7
12	-0.09	0.09	-0.1	Free	-0.55	-0.7	-0.09	0.09	-0.1	Free	-0.55	-0.7
13	-0.09	-0.09	0.1	Free	0.55	0.7	-0.09	-0.09	0.1	Free	0.55	0.7
14	-0.09	-0.09	0.1	Free	0.55	0.7	-0.09	-0.09	-0.1	Free	-0.55	0.7
15	-0.09	-0.09	-0.1	Free	-0.55	0.7	-0.09	-0.09	0.1	Free	0.55	0.7
16	-0.09	-0.09	-0.1	Free	-0.55	0.7	-0.09	-0.09	-0.1	Free	-0.55	0.7

The parameter "Free" indicates that no tolerances have been applied, i.e. as the termination unit is free to swivel around the pipe axis prior to and during tie-ins.

3.4 LOAD STEPS

The spool have been analysed for the subsequent load steps presented in Table 3.3.

Table 3.3 – Subsequent Load Steps

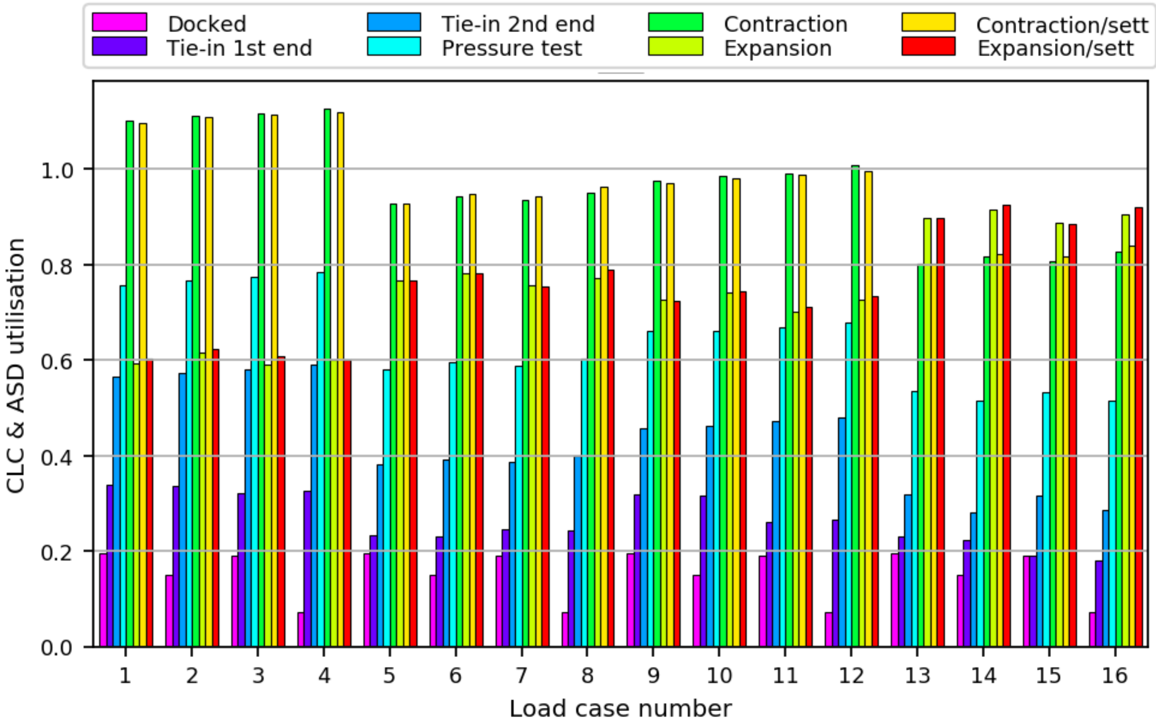
Load Step	Internal Pressure [bara]	Temperature [°C]	Content Density [kg/m3]	Axial Expansion - End 2 [m]
Docked	20	10	1150	0
Tie-in 1st end	20	10	1150	0
Tie-in 2nd end	20	10	1150	0
Pressure test	400	10	1150	0
Contraction	300	-20	250	-1.0
Expansion	300	100	250	3.0
Contraction/sett	300	-20	250	-1.0
Expansion/sett	300	100	250	3.0

Positive axial expansion is in the direction opposite to the tie-in stroking direction.

3.5 SPOOL CLC / ASD UTILISATION

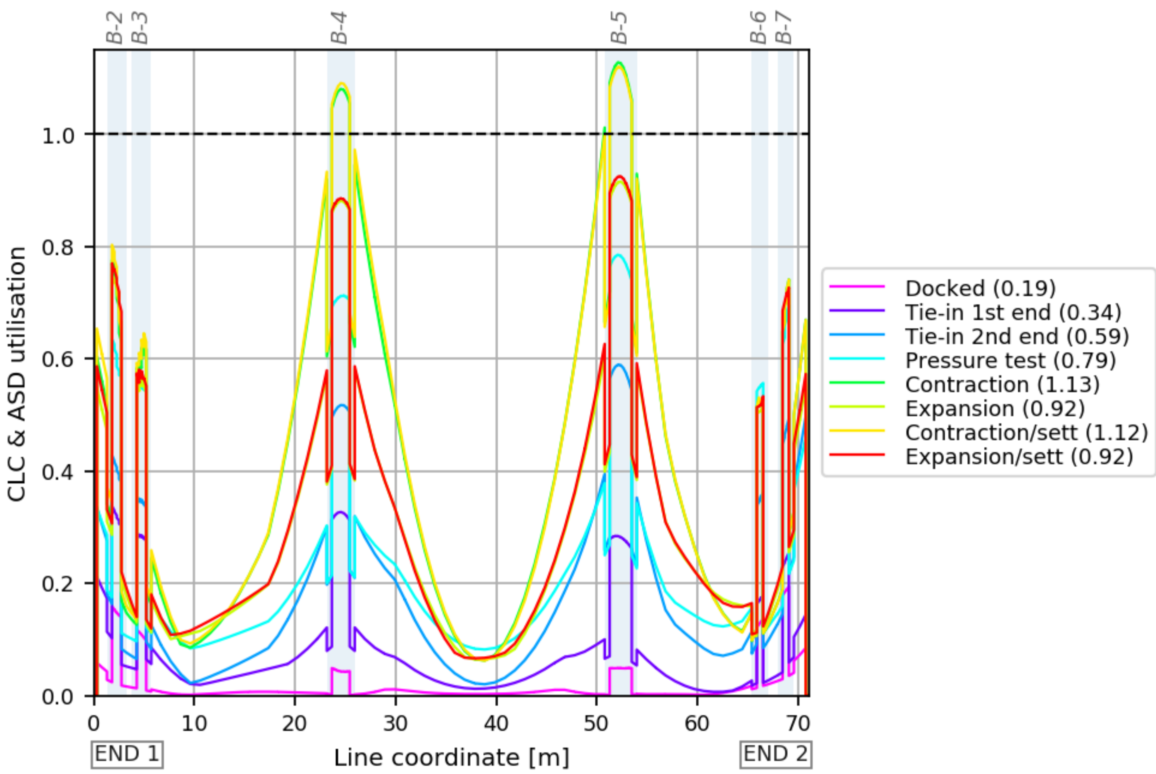
The maximum CLC / ASD utilisation along the spool, for each load case and load step, is shown in Figure 3.3.

Figure 3.3 – Maximum CLC / ASD Utilisation for Each Load Case and Load Step



A CLC / ASD utilisation envelope plot from all load cases and for each analysed subsequent load step is shown in Figure 3.4.

Figure 3.4 – Spool CLC / ASD Utilisation

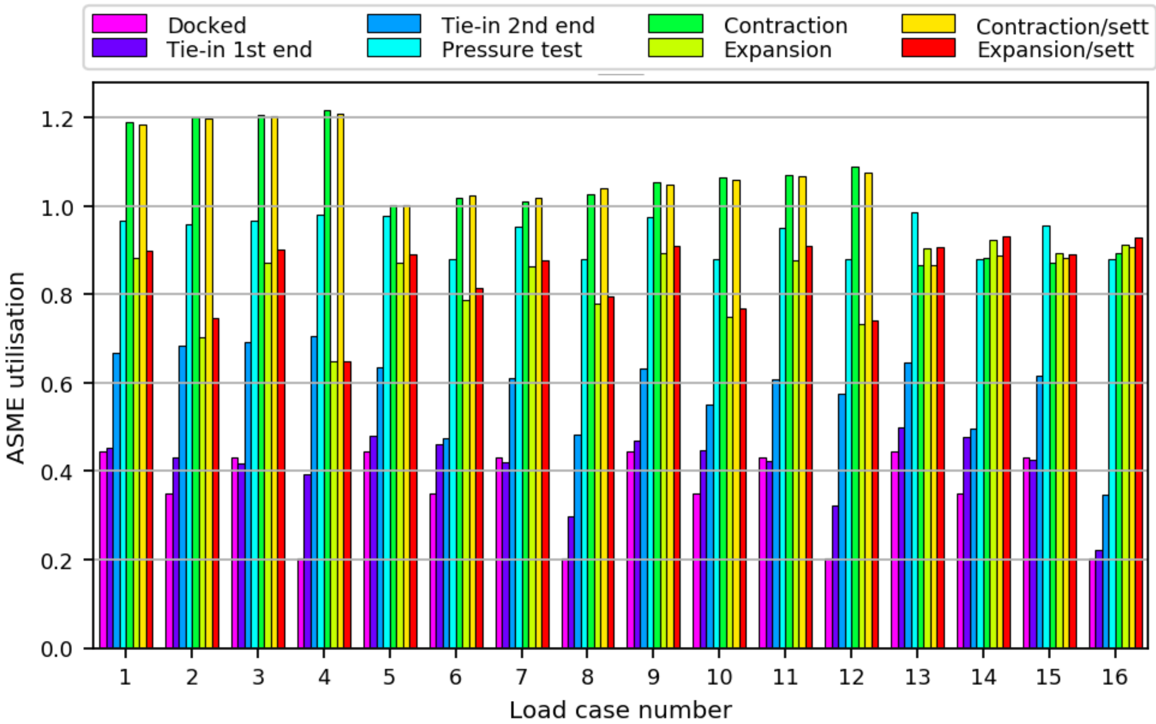


The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

3.6 Spool ASME Utilisation

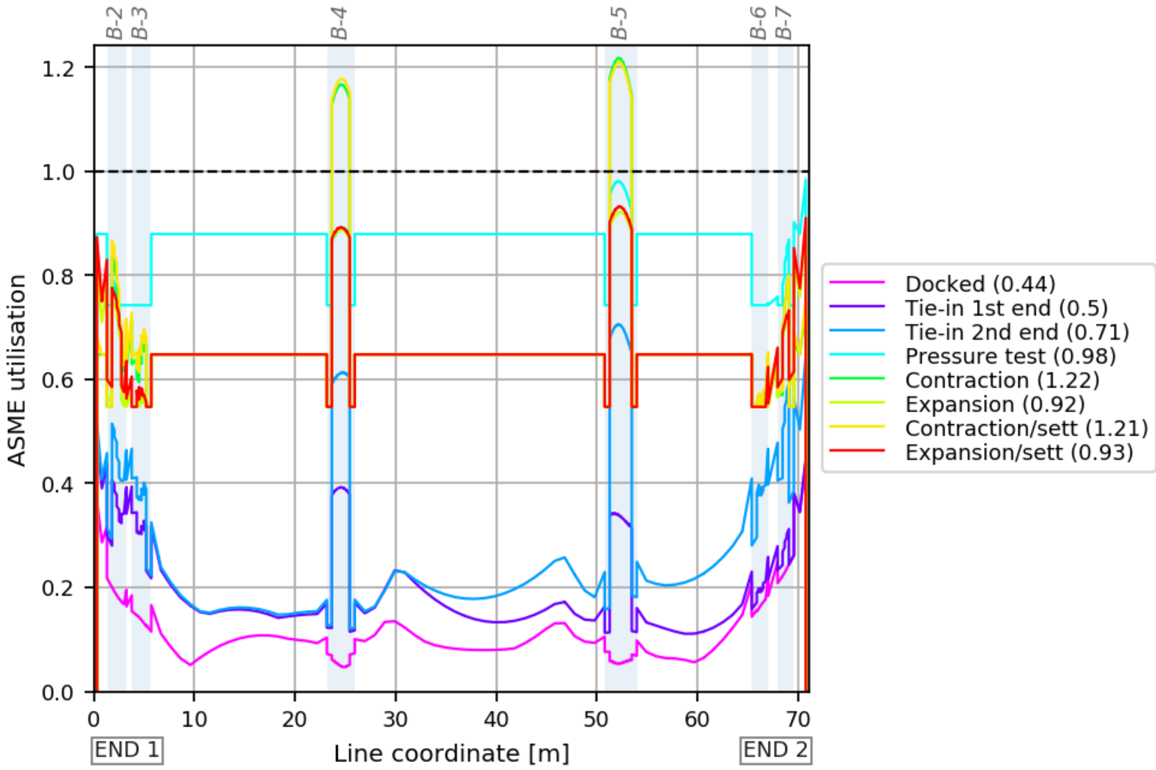
The maximum ASME utilisation along the spool, for each load case and load step, is shown in Figure 3.5.

Figure 3.5 – Maximum ASME Utilisation for Each Load Case and Load Step



An ASME utilisation envelope plot from all load cases and for each analysed subsequent load step is shown in Figure 3.6.

Figure 3.6 – Spool ASME Utilisation



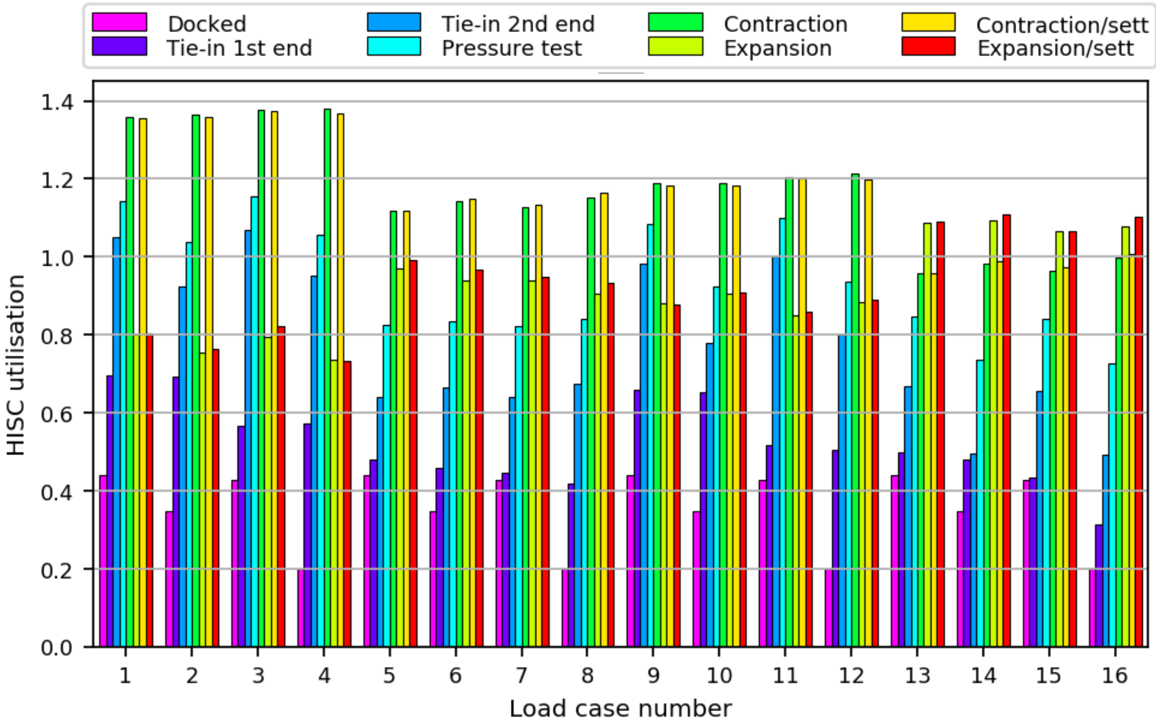
The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

Stress Intensification Factors, according to Ref. [ASME B31.8], have been accounted for when calculating utilisations in the bends and at welds.

3.7 Spool HISC Utilisation

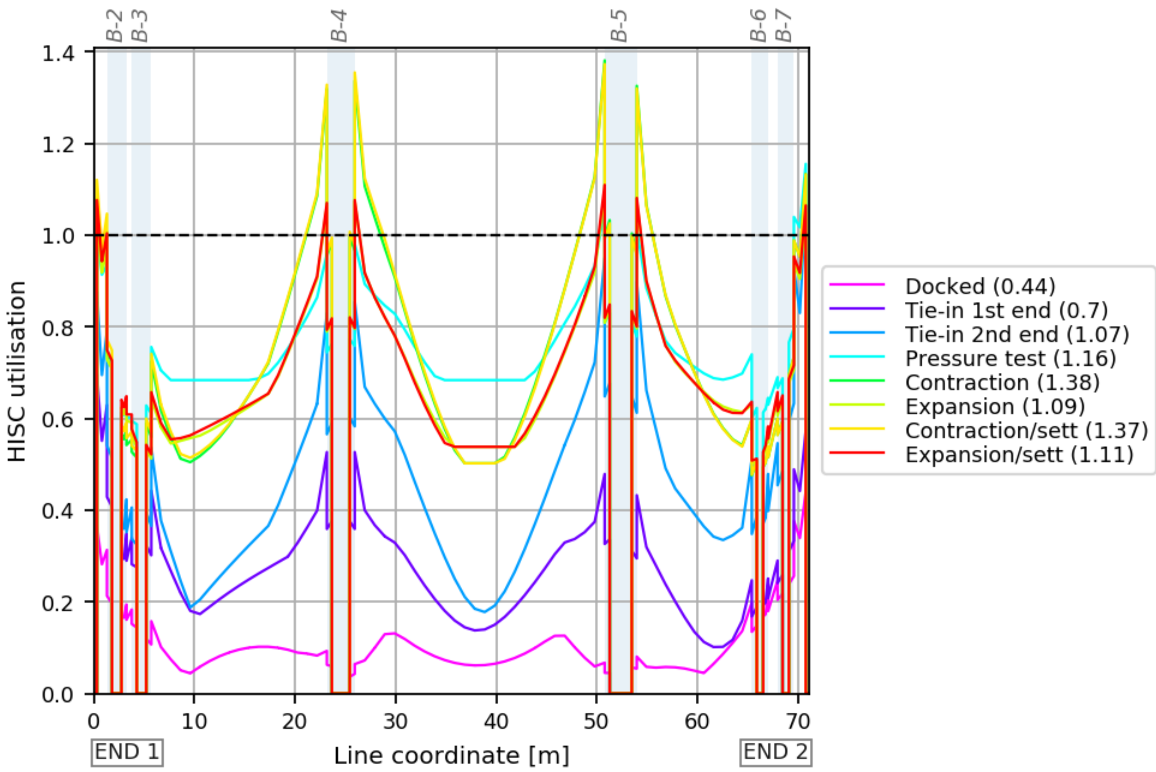
The maximum HISC utilisation along the spool, for each load case and load step, is shown in Figure 3.7.

Figure 3.7 – Maximum HISC Utilisation for Each Load Case and Load Step



A HISC utilisation envelope plot from all load cases and for each analysed subsequent load step is shown in Figure 3.8.

Figure 3.8 – Spool HISC Utilisation



The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

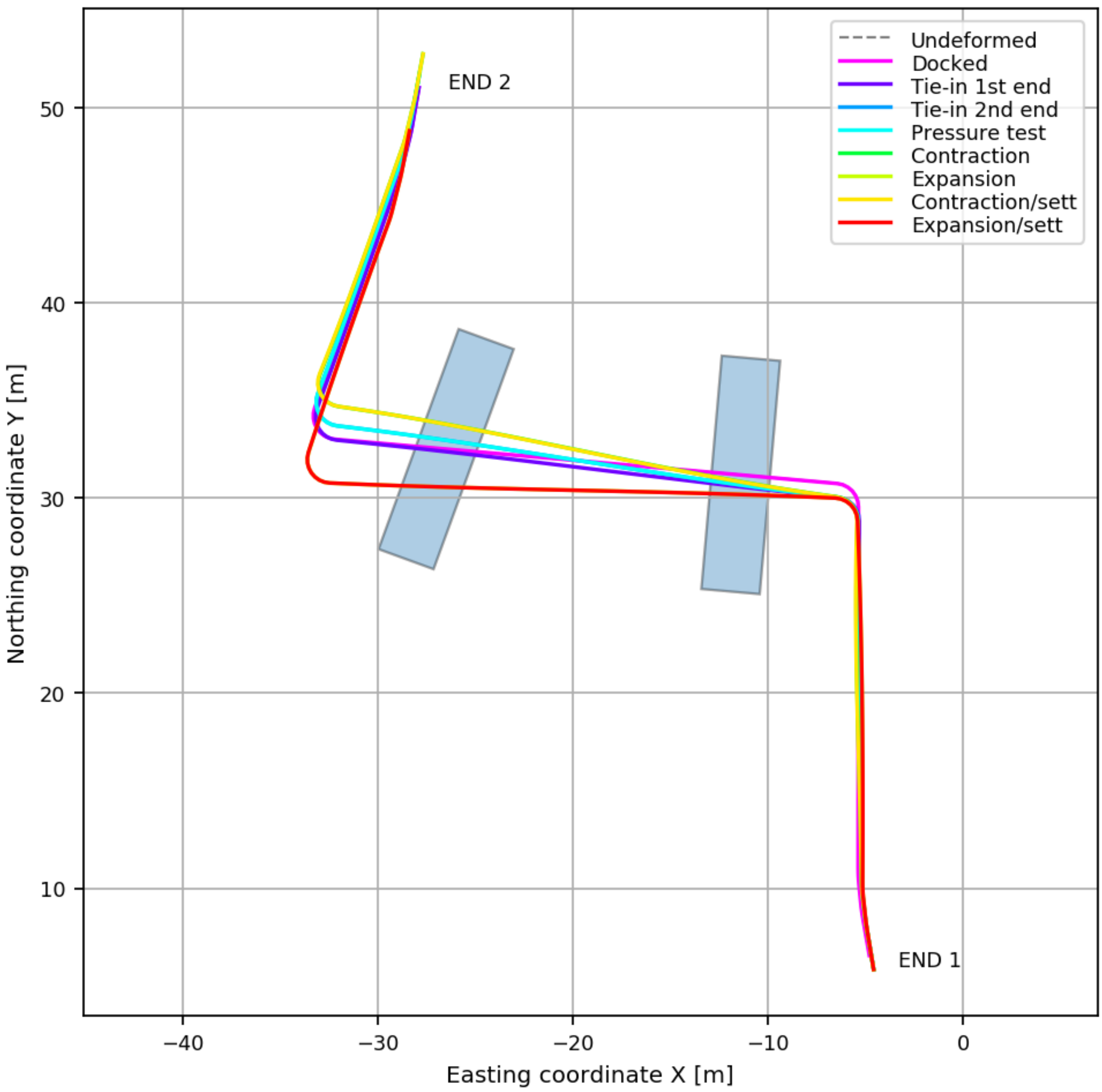
Longitudinal Stress Concentration Factors has been applied at each weld.

The spool bends (curved part) have not been assessed, since beam elements have been used in this assessment. HISC assessment in bends requires the use of either shell- or solid FE-models, in order to capture the ovalisation effects, which are causing high stress gradients across the wall thickness, as well as great stress variations around the circumference.

3.7.1 Most Utilised Load Case - Number 4

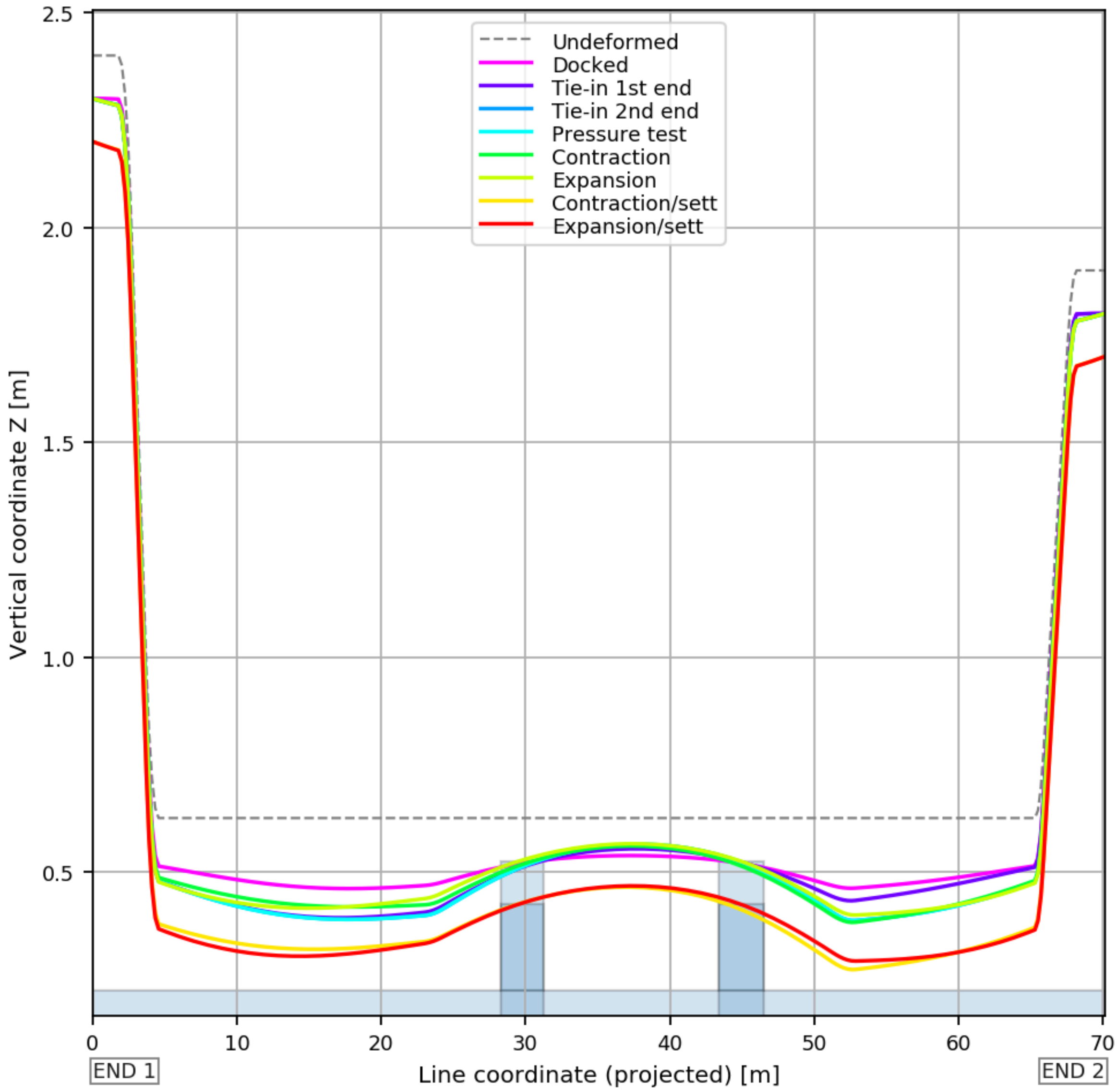
A top-view of the deformed shapes, for the most utilised load case (number 4), are shown for each load step in Figure 3.9.

Figure 3.9 – Top-View of Deformed Shapes of Critical Load Case



A profile view of the deformed shapes, for the most utilised load case (number 4), are shown for each load step in Figure 3.10.

Figure 3.10 – Profile View Deformed Shape of Critical Load Case



3.8 Spool End Reaction Loads

The weight of Termination Units has not been included in the assessment. This will primary affect the vertical reaction force RFz and secondary the reaction moment RMy.

3.8.1 End 1

The maximum magnitude reaction loads at End 1 of the spool, from any of the analysed load cases, are presented in Table 3.4 for each subsequent load step.

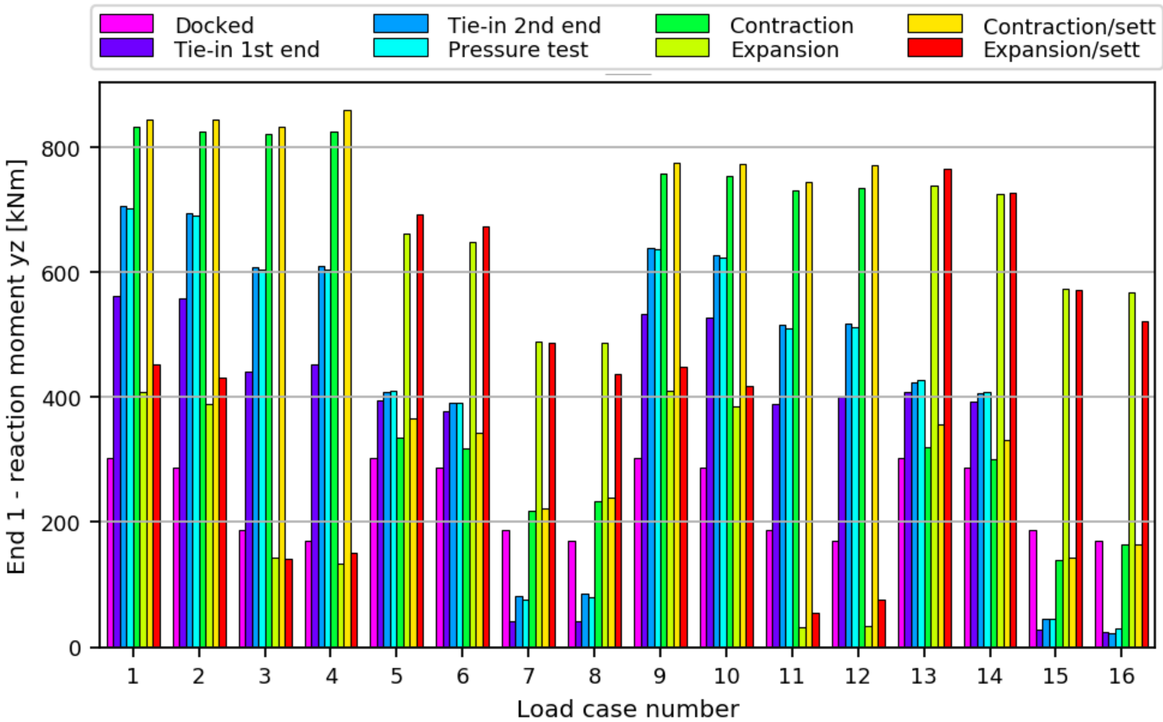
Table 3.4 – Maximum Magnitude Reaction Loads at End 1

Load Step	End Reaction Forces [kN]			End Reaction Moments [kNm]			
	RFx	RFy	RFz	RMx	RMy	RMz	RMb
Docked	7.2	-1.3	81.6	0.0	303.2	13.8	303.5
Tie-in 1st end	55.1	30.4	87.6	0.0	407.0	-452.4	562.3
Tie-in 2nd end	61.0	47.4	88.6	34.7	423.3	-610.1	705.4
Pressure test	59.3	47.1	88.5	34.1	425.7	-604.3	702.3
Contraction	99.3	67.3	75.5	58.2	309.2	-810.6	831.8
Expansion	-69.0	-48.5	72.3	-100.9	458.6	581.5	739.2
Contraction/sett	99.8	69.0	77.2	65.6	348.2	-836.1	860.5
Expansion/sett	-72.2	-48.4	74.0	-100.7	499.8	579.3	765.1
Max	99.8	69.0	88.6	-100.9	499.8	-836.1	860.5

The maximum loads are presented for any of the analysed load cases and do not necessarily occur concurrently.

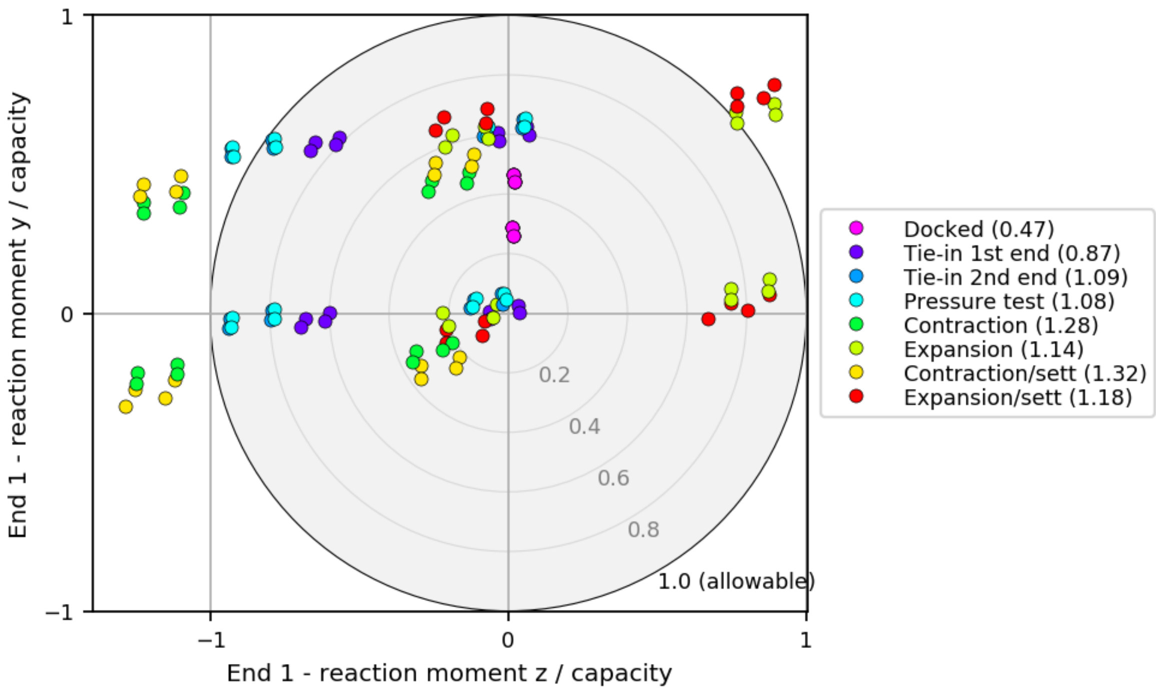
The maximum magnitude reaction bending moment at End 1, for each load case and load step, is shown in Figure 3.11.

Figure 3.11 – Maximum Magnitude Reaction Bending Moment at End 1



The connector / hub bending moment utilisations (RMy vs. RMz) at End 1, for all load cases and load steps, are shown in Figure 3.12.

Figure 3.12 – Reaction Bending Moment Components at End 1



The shaded circular area indicates the allowable. The maximum utilisation is presented for each load step within parenthesis in the figure legend.

3.8.2 End 2

The maximum magnitude reaction loads at End 2 of the spool, from any of the analysed load cases, are presented in Table 3.5 for each subsequent load step.

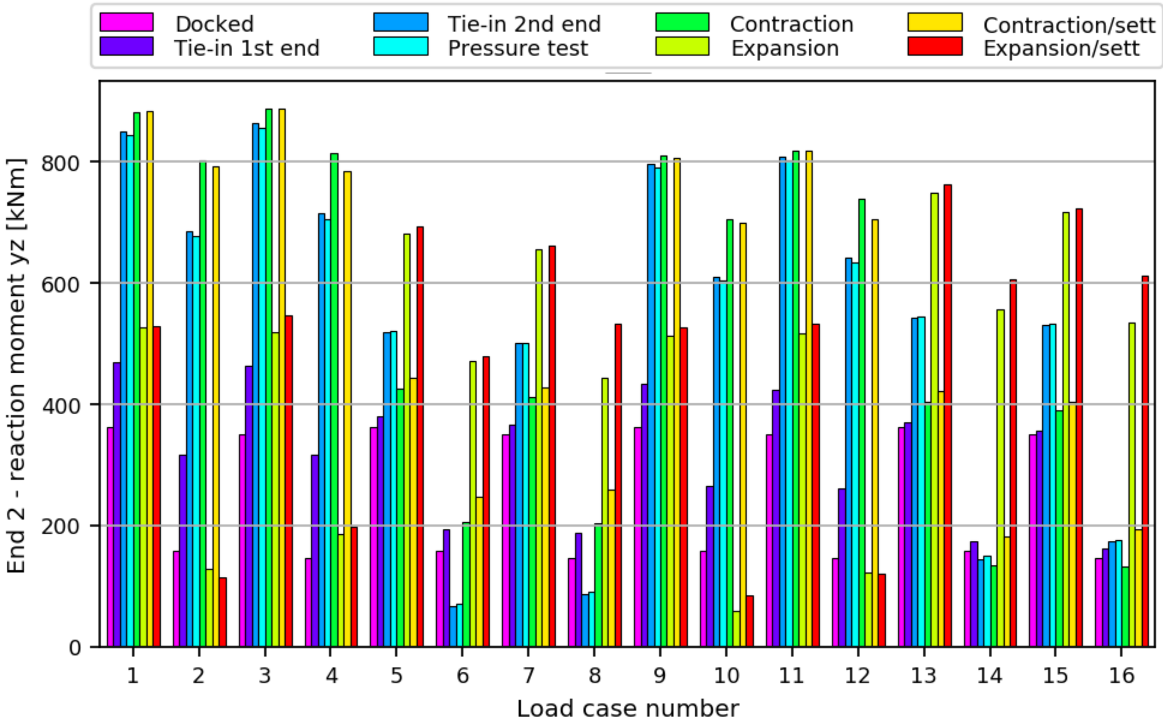
Table 3.5 – Maximum Magnitude Reaction Loads at End 2

Load Step	End Reaction Forces [kN]			End Reaction Moments [kNm]			
	RFx	RFy	RFz	RMx	RMy	RMz	RMb
Docked	3.1	-1.3	82.9	-0.0	361.5	16.0	361.7
Tie-in 1st end	21.0	35.7	85.2	0.0	364.3	-311.5	469.0
Tie-in 2nd end	64.4	75.8	96.3	0.0	523.6	-711.2	862.7
Pressure test	62.4	75.1	96.3	-1.0	523.8	-702.4	855.7
Contraction	83.7	97.9	82.7	22.3	393.5	-805.5	887.9
Expansion	-65.6	-69.0	81.7	-116.1	510.3	556.7	747.7
Contraction/sett	84.7	97.1	83.6	25.9	409.4	-799.2	887.4
Expansion/sett	-64.3	-72.2	82.4	-122.0	523.6	605.5	761.6
Max	84.7	97.9	96.3	-122.0	523.8	-805.5	887.9

The maximum loads are presented for any of the analysed load cases and do not necessarily occur concurrently.

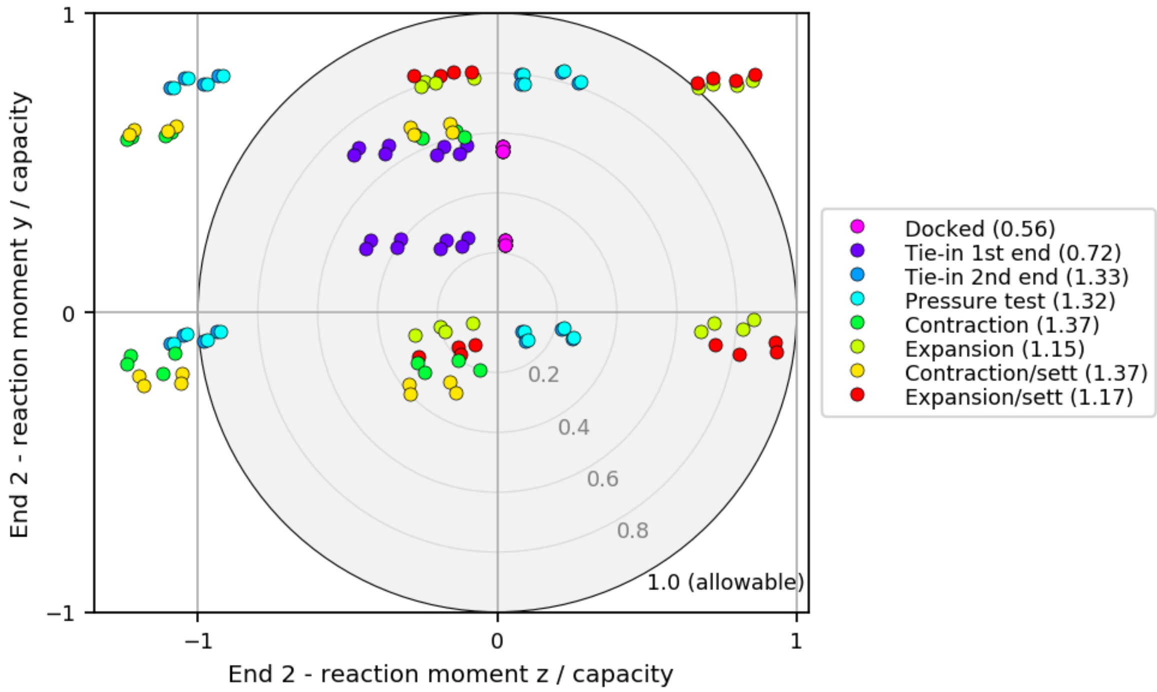
The maximum magnitude reaction bending moment at End 2, for each load case and load step, is shown in Figure 3.13.

Figure 3.13 – Maximum Magnitude Reaction Bending Moment at End 2



The connector / hub bending moment utilisations (RMy vs. RMz) at End 2, for all load cases and load steps, are shown in Figure 3.14.

Figure 3.14 – Reaction Bending Moment Components at End 2

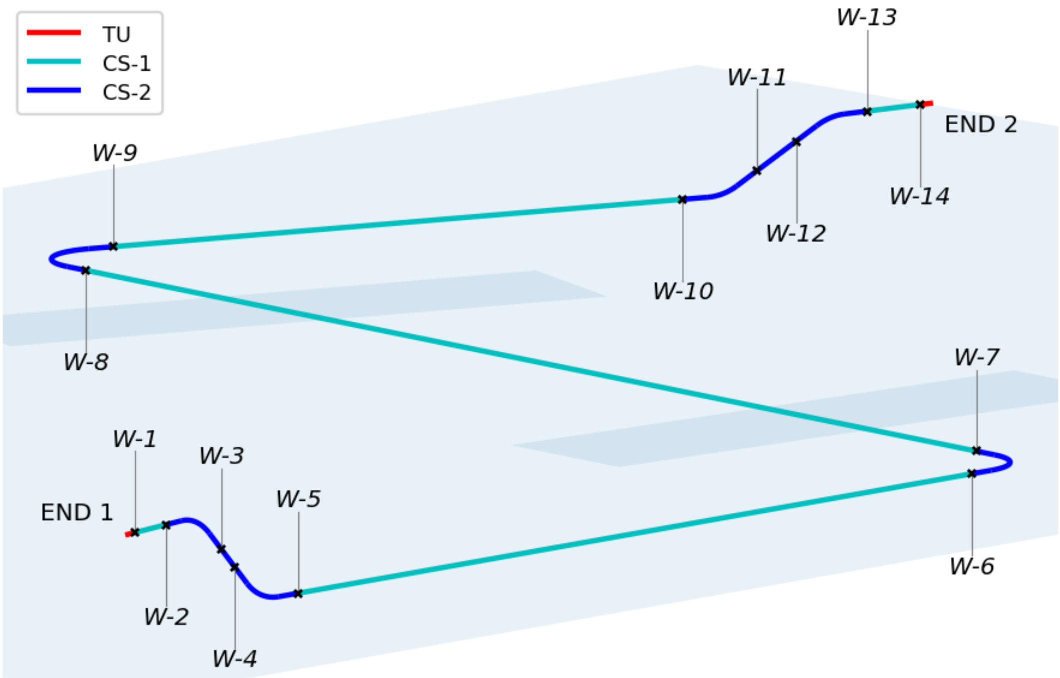


The shaded circular area indicates the allowable. The maximum utilisation is presented for each load step within parenthesis in the figure legend.

3.9 Fatigue Damage due to VIV

The welds assessed for fatigue damage due to VIV are shown in Figure 3.15.

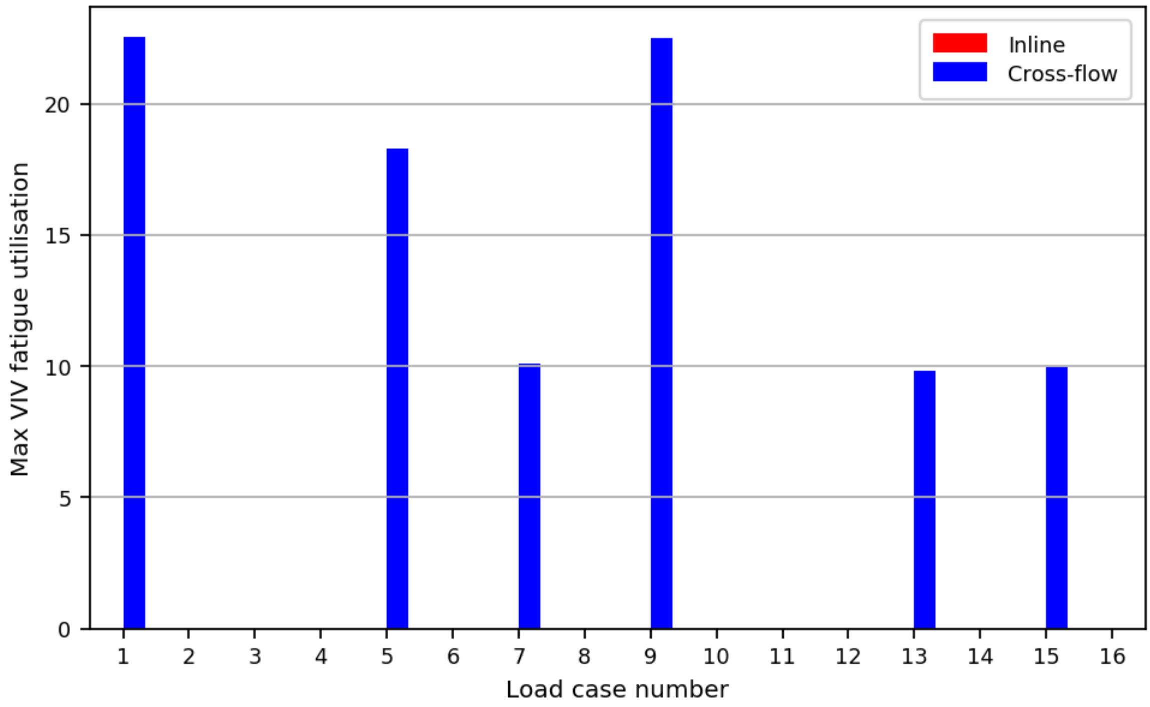
Figure 3.15 – Assessed Welds



Note that additional welds will be present where the pipe section exceeds the pipe joint length.

The maximum VIV fatigue utilisations for each load case are shown in Figure 3.16.

Figure 3.16 – Maximum VIV Fatigue Utilisation for Each Load Case

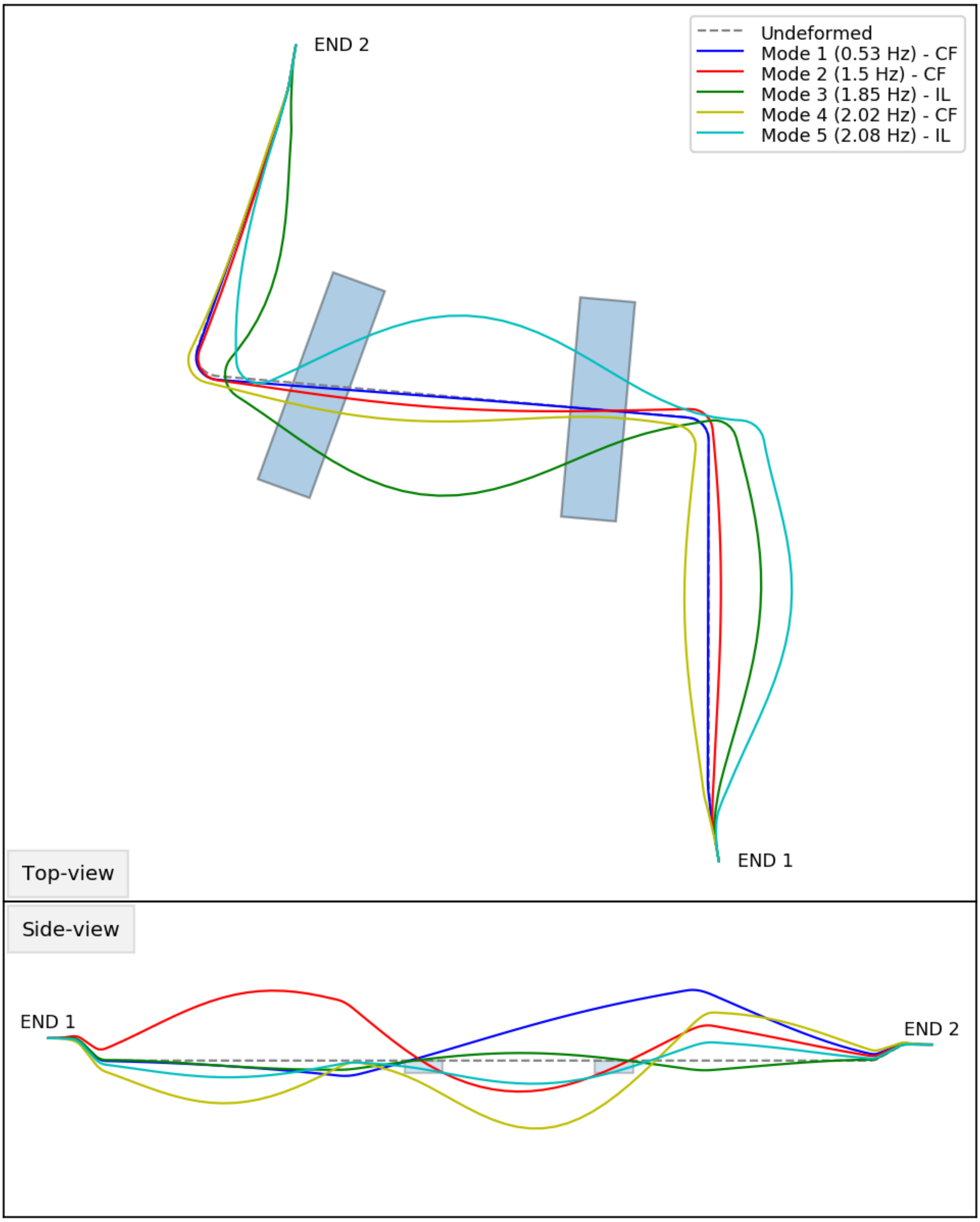


Inline and Cross-Flow utilisations are presented separately, and indicated that the damage has been accumulate at a specific location around the circumference.

It should be noted that both inline and cross-flow induced vibrations can potentially accrue damage at any location around the pipe circumference.

The Eigen-modes corresponding to the five lowest frequencies for load case number 1 (most critical in terms of fatigue damage) are shown in Figure 3.17.

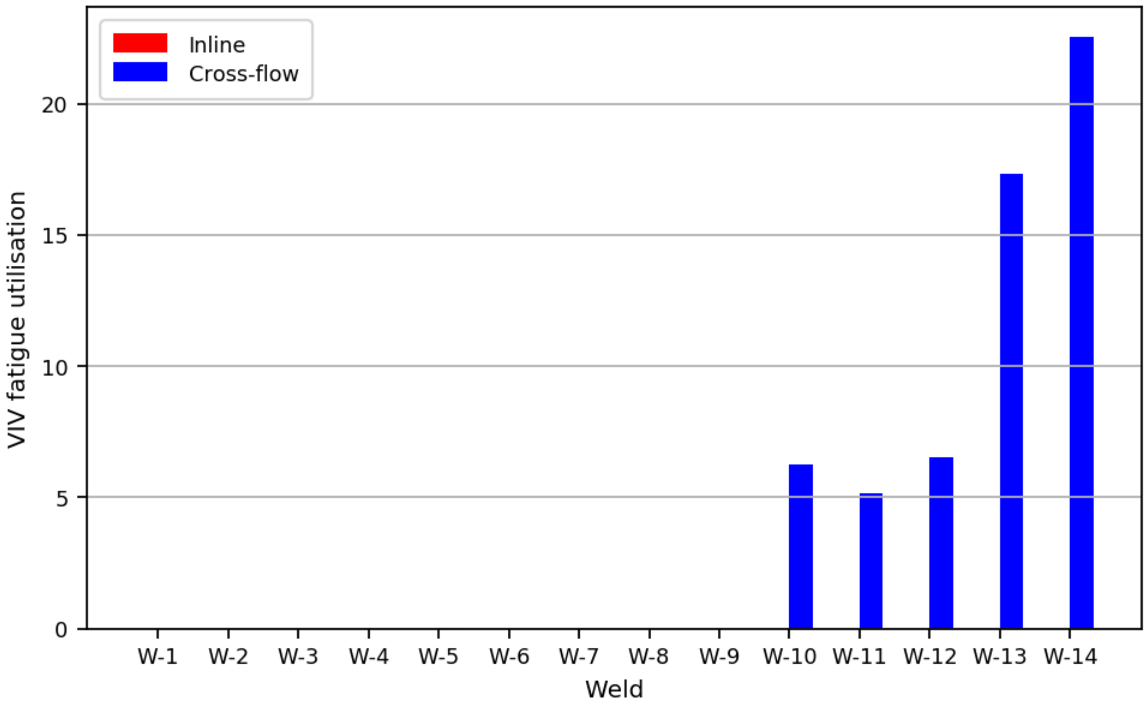
Figure 3.17 – Eigen-Modes of Most Utilised Load Case



The corresponding natural frequencies are presented within parenthesis in the figure legend, where the dominating mode type is denoted IL and / or CF.

The maximum VIV fatigue utilisation (all load cases) in each weld is shown in Figure 3.18.

Figure 3.18 – Maximum VIV Fatigue Utilisation at Each Weld



3.10 Support Loads

The maximum vertical support forces, from any of the analysed load cases, are presented in Table 3.6, for each subsequent load step.

Table 3.6 – Maximum Vertical Forces Acting on Supports and Seabed

Load Step	Vertical Force [kN]		
	SEABED	Support-1	Support-2
Docked	0.0	47.6	43.0
Tie-in 1st end	0.0	57.2	43.5
Tie-in 2nd end	0.0	57.1	53.5
Pressure test	0.0	57.2	51.3
Contraction	0.0	35.6	35.7
Expansion	0.0	39.8	40.3
Contraction/sett	0.0	37.4	38.9
Expansion/sett	0.0	40.9	43.4
Max	0.0	57.2	53.5

Note that the maximum loads are presented for any of the analysed load cases and do not necessarily occur concurrently.

4 CONFIGURATION NOM

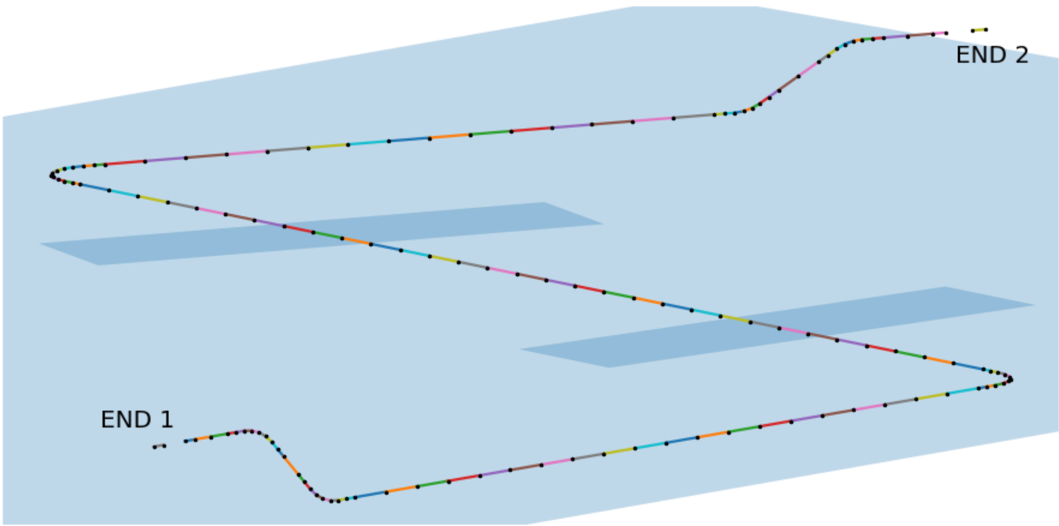
This section presents the following detailed results for configuration "nom".

- FE-model
- Spool geometry
- Load cases
- Load steps
- Spool CLC / ASD utilisation
- Spool ASME utilisation
- Spool HISC utilisation
- Spool end reaction loads
- Fatigue damage due to VIV
- Support loads

4.1 FE-MODEL

The FE-model consists of the spool and two connecting structures at each end. The mesh density used is shown in Figure 4.1.

Figure 4.1 – FE-Model Mesh



The beam / pipe elements are shown as lines and with the associated nodes are shown as black dots. The nodes belonging to the area elements are not shown.

The spool consists of three different cross-section types.

4.2 SPOOL GEOMETRY

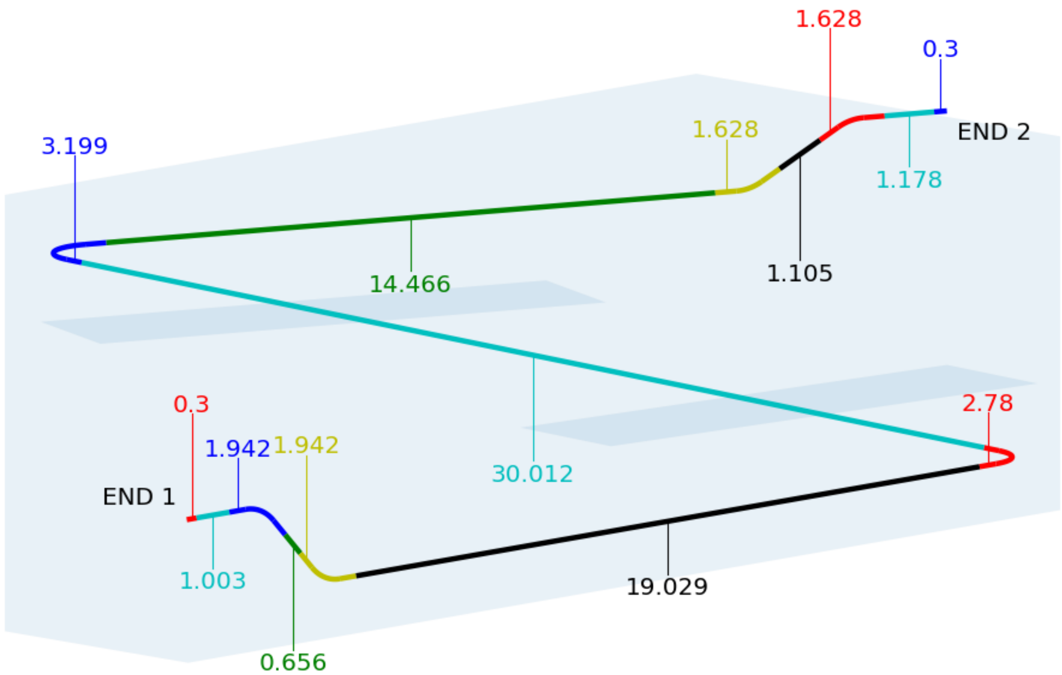
The coordinates at the spool ends and at the intersection points between the extended straight lines / sections, are presented in Table 4.1.

Table 4.1 – Coordinates at Ends and Intersection Points

Location	Coordinates [m]		
	X / Easting	Y / Northing	Z / Vertical
End 1	-3.0	4.65	2.5
IP-1	-3.0	4.95	2.5
IP-2	-3.0	6.95	2.5
IP-3	-3.0	8.824	0.626
IP-4	-3.0	30.45	0.626
IP-5	-36.547	33.385	0.626
IP-6	-30.613	49.69	0.626
IP-7	-29.799	51.926	2.0
IP-8	-29.115	53.806	2.0
End 2	-29.012	54.088	2.0

An isometric view of the spool showing each section length (units in meter) is shown in Figure 4.2.

Figure 4.2 – Isometric View with Section Lengths



4.3 Load Cases

A set of 16 load case combinations has been analysed, as presented in Table 4.2. The prescribed end displacement / rotation values refer to uncertainties regarding make-up tolerances at each spool end.

Table 4.2 – Load Case Combinations

Load Case	END 1						END 2					
	Displacements [m]			Rotations [deg]			Displacements [m]			Rotations [deg]		
	ux	uy	uz	rx	ry	rz	ux	uy	uz	rx	ry	rz
1	0.09	0.09	0.1	Free	0.55	-0.7	0.09	0.09	0.1	Free	0.55	-0.7
2	0.09	0.09	0.1	Free	0.55	-0.7	0.09	0.09	-0.1	Free	-0.55	-0.7
3	0.09	0.09	-0.1	Free	-0.55	-0.7	0.09	0.09	0.1	Free	0.55	-0.7
4	0.09	0.09	-0.1	Free	-0.55	-0.7	0.09	0.09	-0.1	Free	-0.55	-0.7
5	0.09	-0.09	0.1	Free	0.55	0.7	0.09	-0.09	0.1	Free	0.55	0.7
6	0.09	-0.09	0.1	Free	0.55	0.7	0.09	-0.09	-0.1	Free	-0.55	0.7
7	0.09	-0.09	-0.1	Free	-0.55	0.7	0.09	-0.09	0.1	Free	0.55	0.7
8	0.09	-0.09	-0.1	Free	-0.55	0.7	0.09	-0.09	-0.1	Free	-0.55	0.7
9	-0.09	0.09	0.1	Free	0.55	-0.7	-0.09	0.09	0.1	Free	0.55	-0.7
10	-0.09	0.09	0.1	Free	0.55	-0.7	-0.09	0.09	-0.1	Free	-0.55	-0.7
11	-0.09	0.09	-0.1	Free	-0.55	-0.7	-0.09	0.09	0.1	Free	0.55	-0.7
12	-0.09	0.09	-0.1	Free	-0.55	-0.7	-0.09	0.09	-0.1	Free	-0.55	-0.7
13	-0.09	-0.09	0.1	Free	0.55	0.7	-0.09	-0.09	0.1	Free	0.55	0.7
14	-0.09	-0.09	0.1	Free	0.55	0.7	-0.09	-0.09	-0.1	Free	-0.55	0.7
15	-0.09	-0.09	-0.1	Free	-0.55	0.7	-0.09	-0.09	0.1	Free	0.55	0.7
16	-0.09	-0.09	-0.1	Free	-0.55	0.7	-0.09	-0.09	-0.1	Free	-0.55	0.7

The parameter "Free" indicates that no tolerances have been applied, i.e. as the termination unit is free to swivel around the pipe axis prior to and during tie-ins.

4.4 LOAD STEPS

The spool have been analysed for the subsequent load steps presented in Table 4.3.

Table 4.3 – Subsequent Load Steps

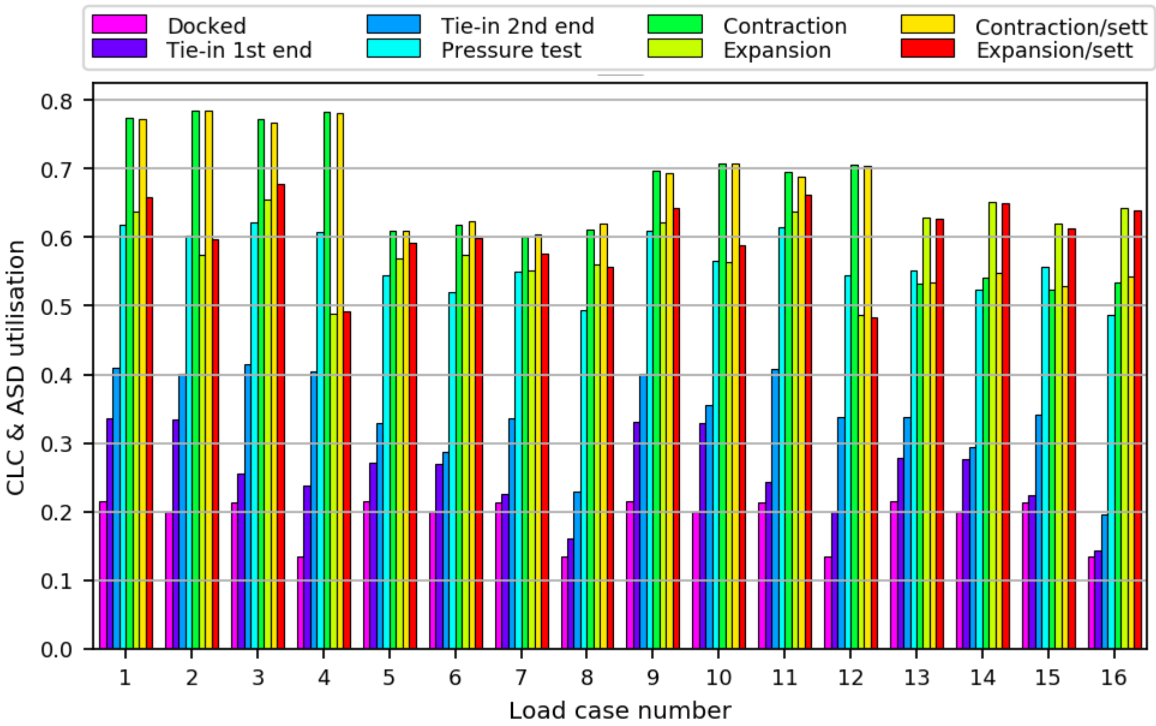
Load Step	Internal Pressure [bara]	Temperature [°C]	Content Density [kg/m3]	Axial Expansion - End 2 [m]
Docked	20	10	1150	0
Tie-in 1st end	20	10	1150	0
Tie-in 2nd end	20	10	1150	0
Pressure test	400	10	1150	0
Contraction	300	-20	250	-1.0
Expansion	300	100	250	3.0
Contraction/sett	300	-20	250	-1.0
Expansion/sett	300	100	250	3.0

Positive axial expansion is in the direction opposite to the tie-in stroking direction.

4.5 SPOOL CLC / ASD UTILISATION

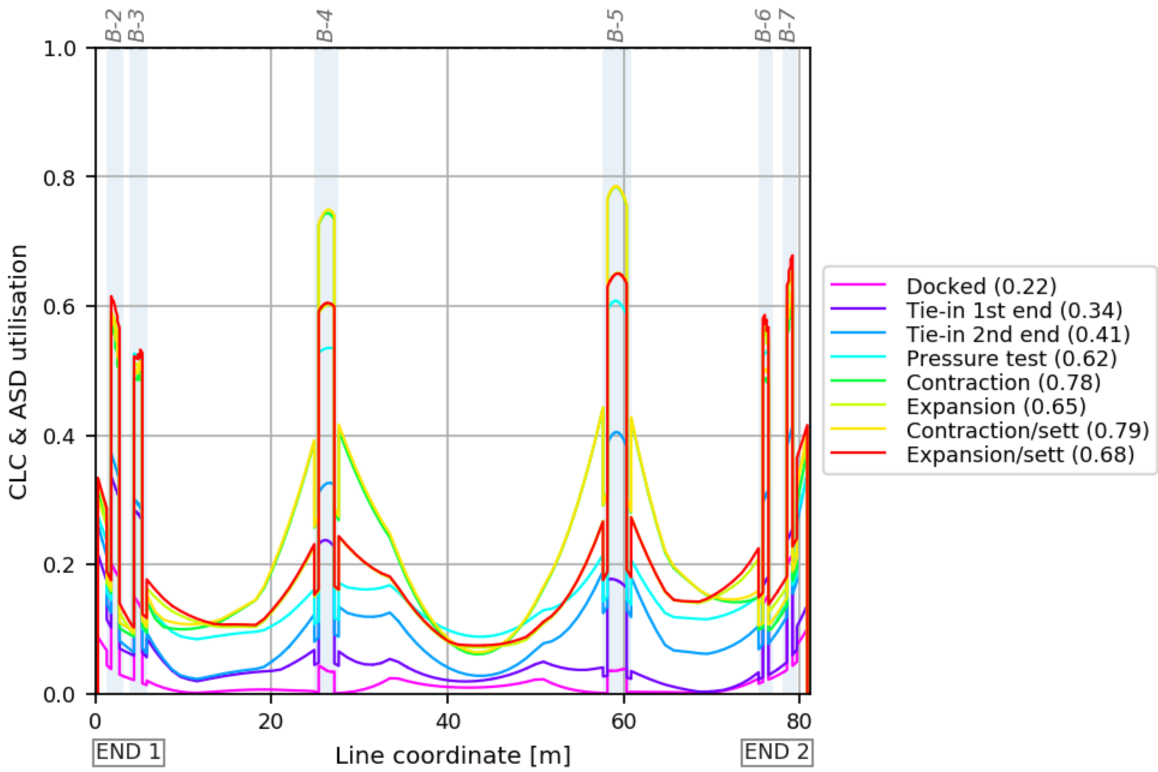
The maximum CLC / ASD utilisation along the spool, for each load case and load step, is shown in Figure 4.3.

Figure 4.3 – Maximum CLC / ASD Utilisation for Each Load Case and Load Step



A CLC / ASD utilisation envelope plot from all load cases and for each analysed subsequent load step is shown in Figure 4.4.

Figure 4.4 – Spool CLC / ASD Utilisation

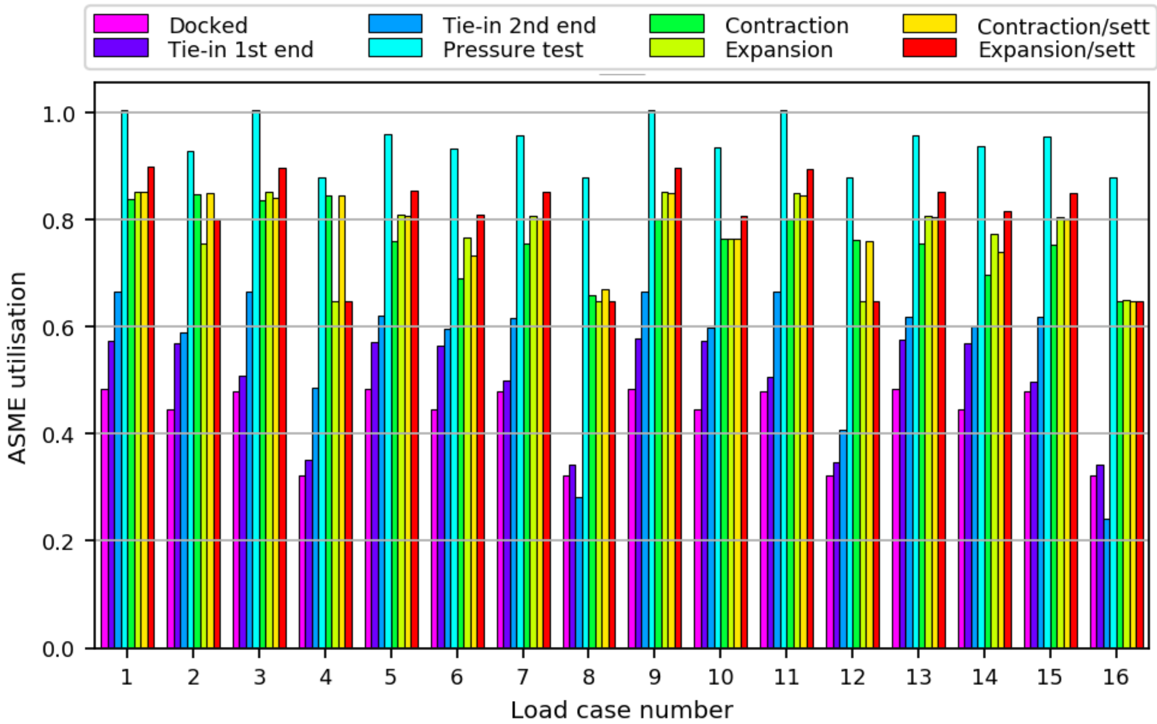


The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

4.6 SPOOL ASME UTILISATION

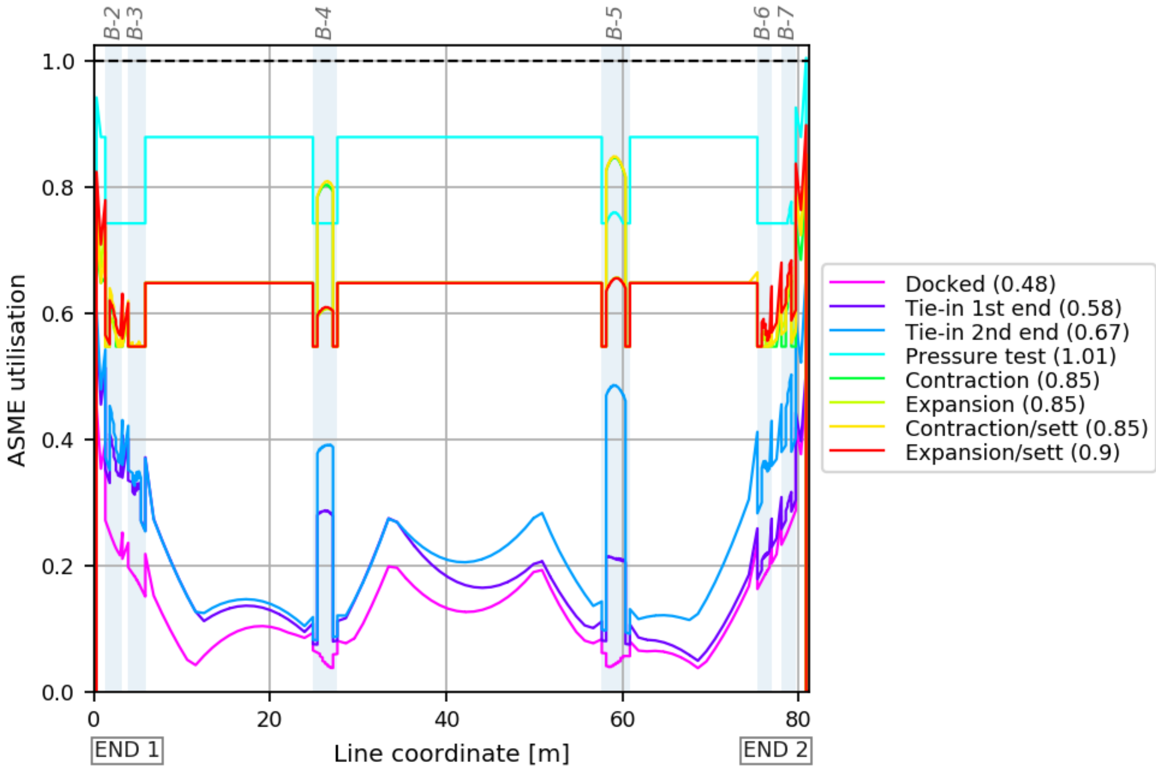
The maximum ASME utilisation along the spool, for each load case and load step, is shown in Figure 4.5.

Figure 4.5 – Maximum ASME Utilisation for Each Load Case and Load Step



An ASME utilisation envelope plot from all load cases and for each analysed subsequent load step is shown in Figure 4.6.

Figure 4.6 – Spool ASME Utilisation



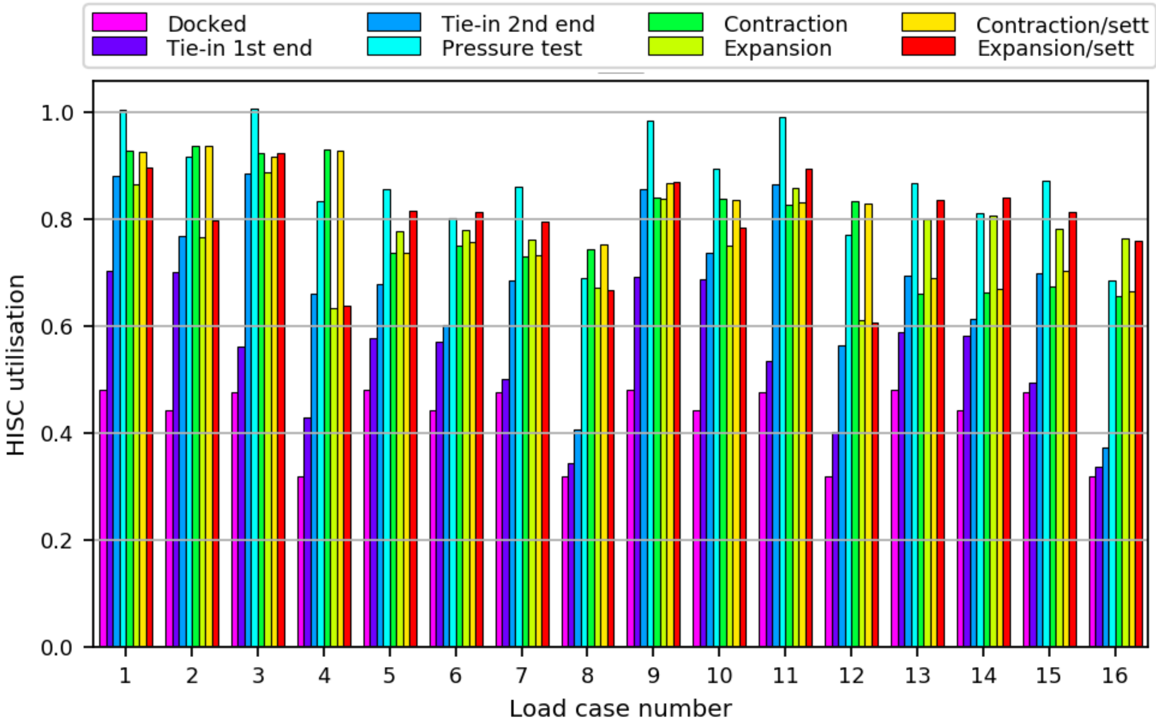
The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

Stress Intensification Factors, according to Ref. [ASME B31.8], have been accounted for when calculating utilisations in the bends and at welds.

4.7 SPOOL HISC UTILISATION

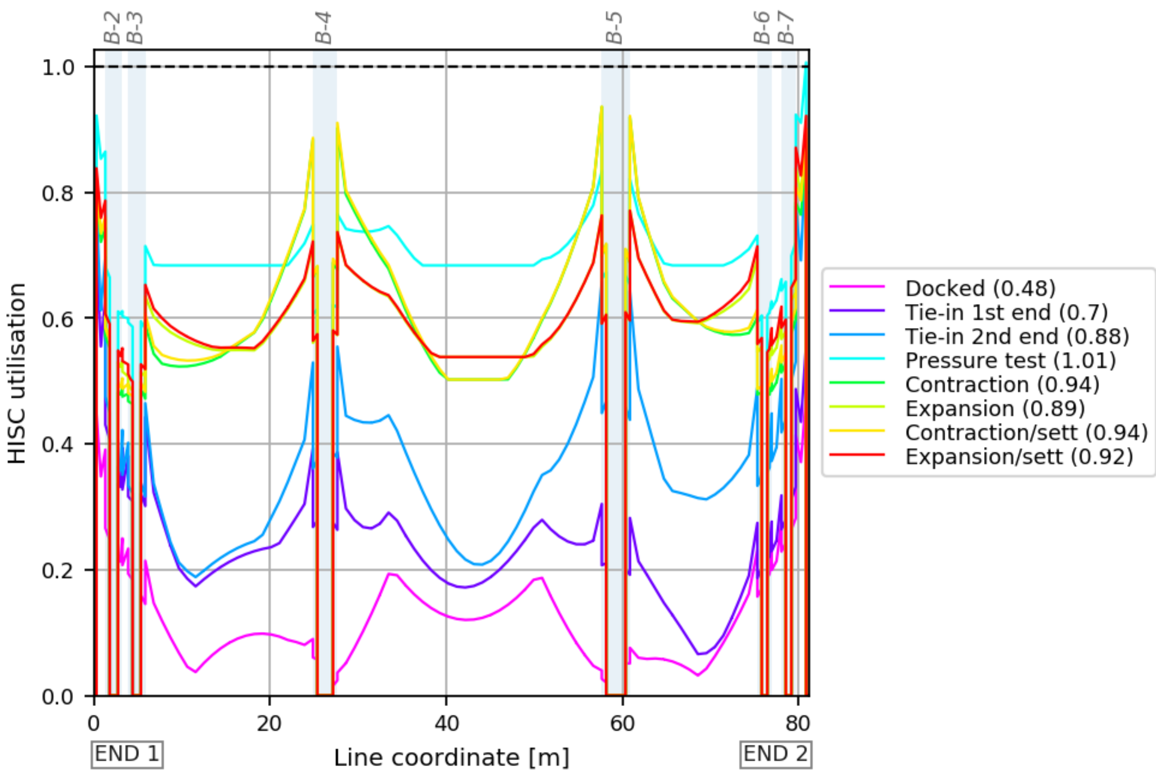
The maximum HISC utilisation along the spool, for each load case and load step, is shown in Figure 4.7.

Figure 4.7 – Maximum HISC Utilisation for Each Load Case and Load Step



A HISC utilisation envelope plot from all load cases and for each analysed subsequent load step is shown in Figure 4.8.

Figure 4.8 – Spool HISC Utilisation



The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

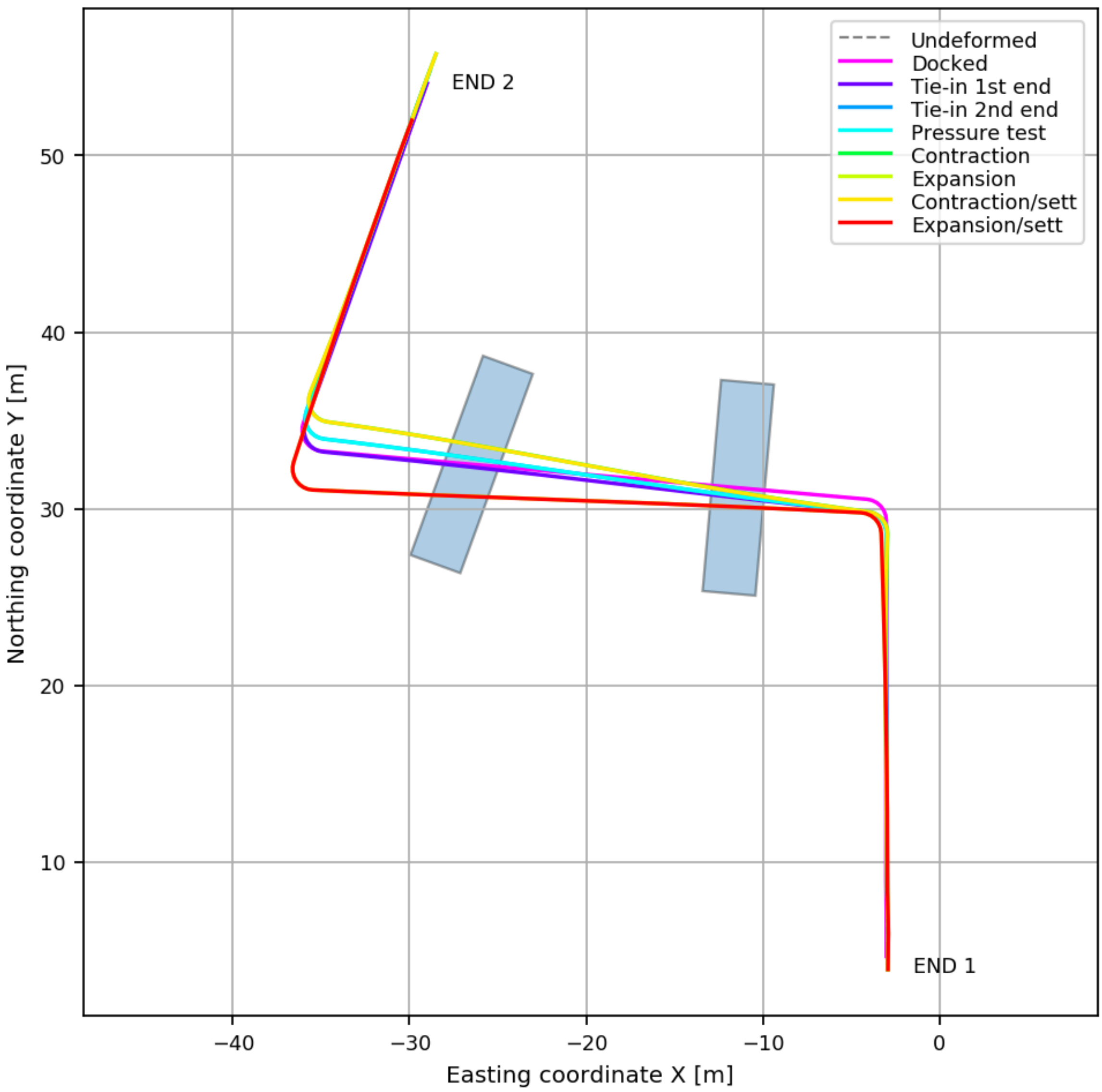
Longitudinal Stress Concentration Factors has been applied at each weld.

The spool bends (curved part) have not been assessed, since beam elements have been used in this assessment. HISC assessment in bends requires the use of either shell- or solid FE-models, in order to capture the ovalisation effects, which are causing high stress gradients across the wall thickness, as well as great stress variations around the circumference.

4.7.1 Most Utilised Load Case - Number 3

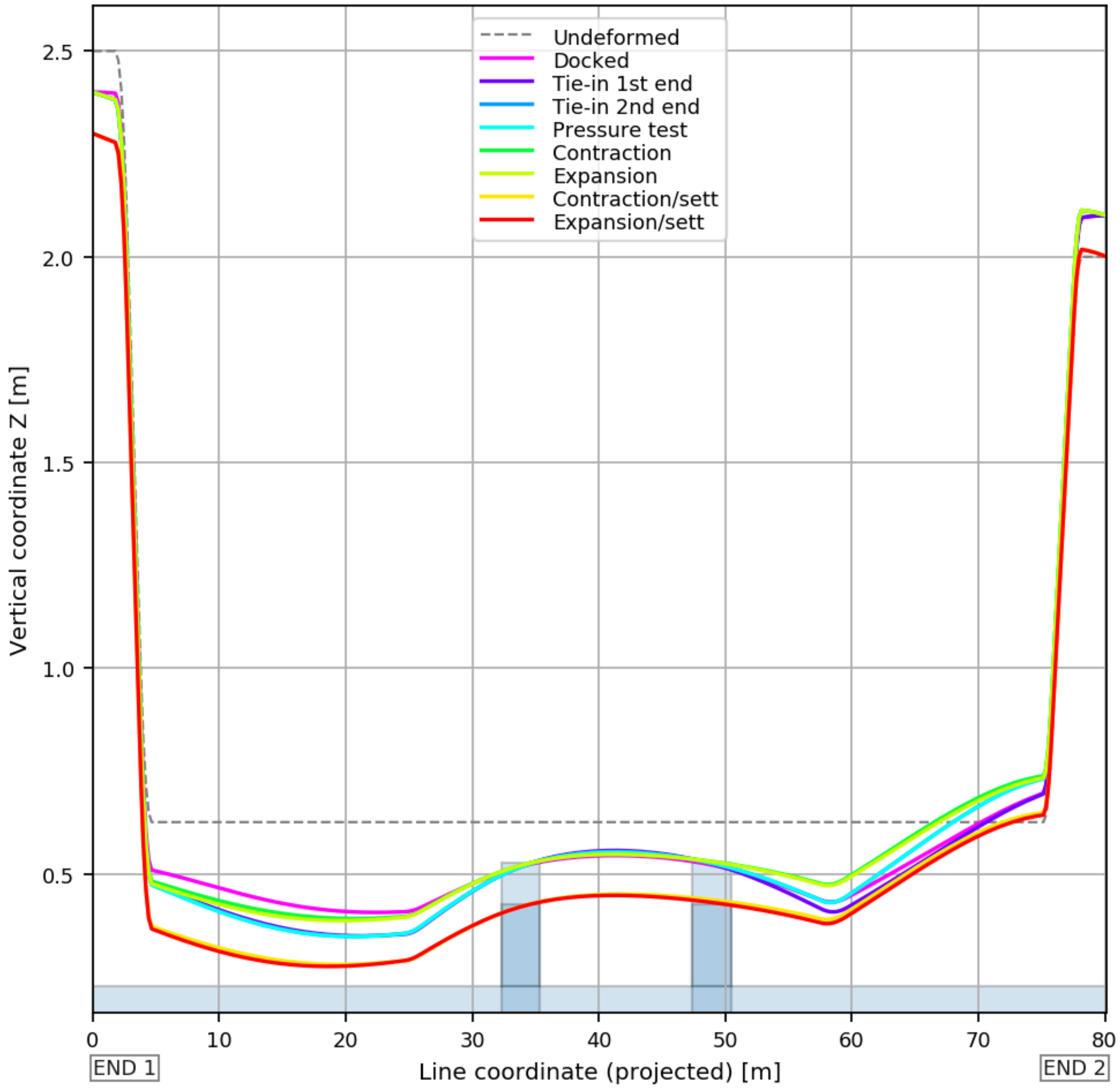
A top-view of the deformed shapes, for the most utilised load case (number 3), are shown for each load step in Figure 4.9.

Figure 4.9 – Top-View of Deformed Shapes of Critical Load Case



A profile view of the deformed shapes, for the most utilised load case (number 3), are shown for each load step in Figure 4.10.

Figure 4.10 – Profile View Deformed Shape of Critical Load Case



4.8 Spool End Reaction Loads

The weight of Termination Units has not been included in the assessment. This will primary affect the vertical reaction force RFz and secondary the reaction moment RMy.

4.8.1 End 1

The maximum magnitude reaction loads at End 1 of the spool, from any of the analysed load cases, are presented in Table 4.4 for each subsequent load step.

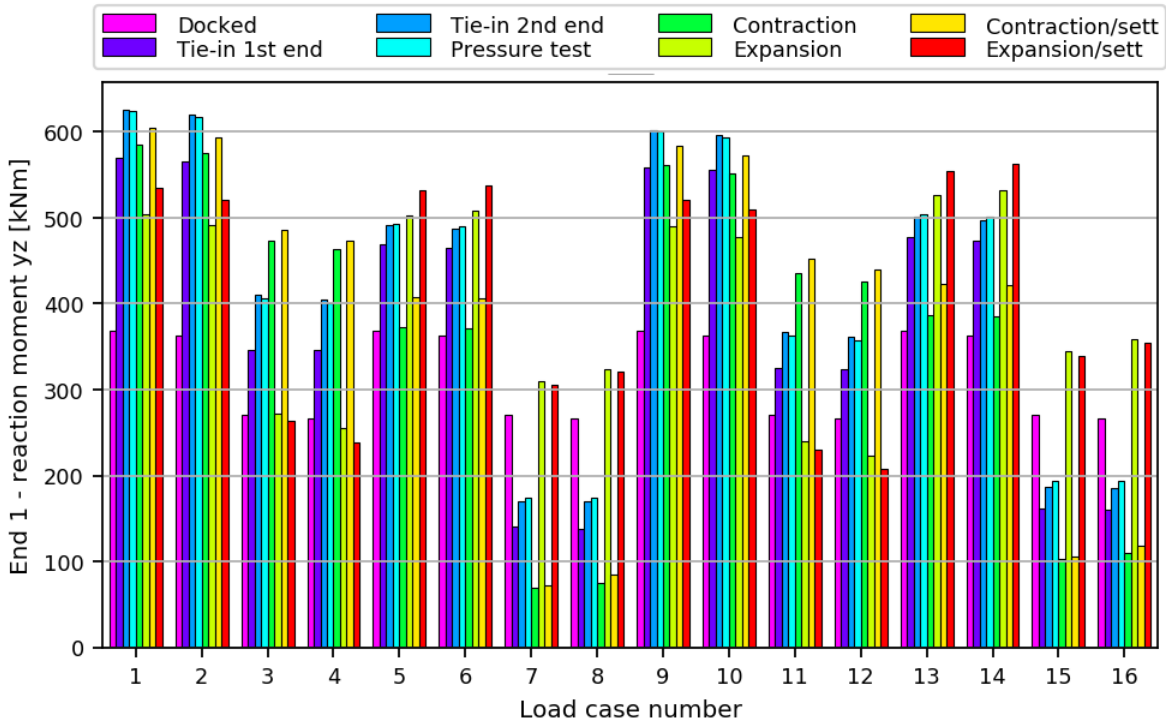
Table 4.4 – Maximum Magnitude Reaction Loads at End 1

Load Step	End Reaction Forces [kN]			End Reaction Moments [kNm]			
	RFx	RFy	RFz	RMx	RMy	RMz	RMb
Docked	4.3	-0.6	84.9	0.0	368.2	14.7	368.2
Tie-in 1st end	35.5	25.8	91.0	-0.0	470.1	-326.3	569.7
Tie-in 2nd end	21.9	33.4	91.1	17.5	489.6	-402.0	626.3
Pressure test	20.7	32.9	91.1	16.7	491.4	-396.4	623.8
Contraction	43.3	45.6	76.3	21.6	369.2	-472.9	585.5
Expansion	-26.4	-32.1	74.9	-77.2	425.9	348.9	532.6
Contraction/sett	43.8	46.4	77.7	25.6	402.5	-486.4	604.9
Expansion/sett	-27.7	-32.3	76.4	-77.5	461.2	351.3	562.1
Max	43.8	46.4	91.1	-77.5	491.4	-486.4	626.3

The maximum loads are presented for any of the analysed load cases and do not necessarily occur concurrently.

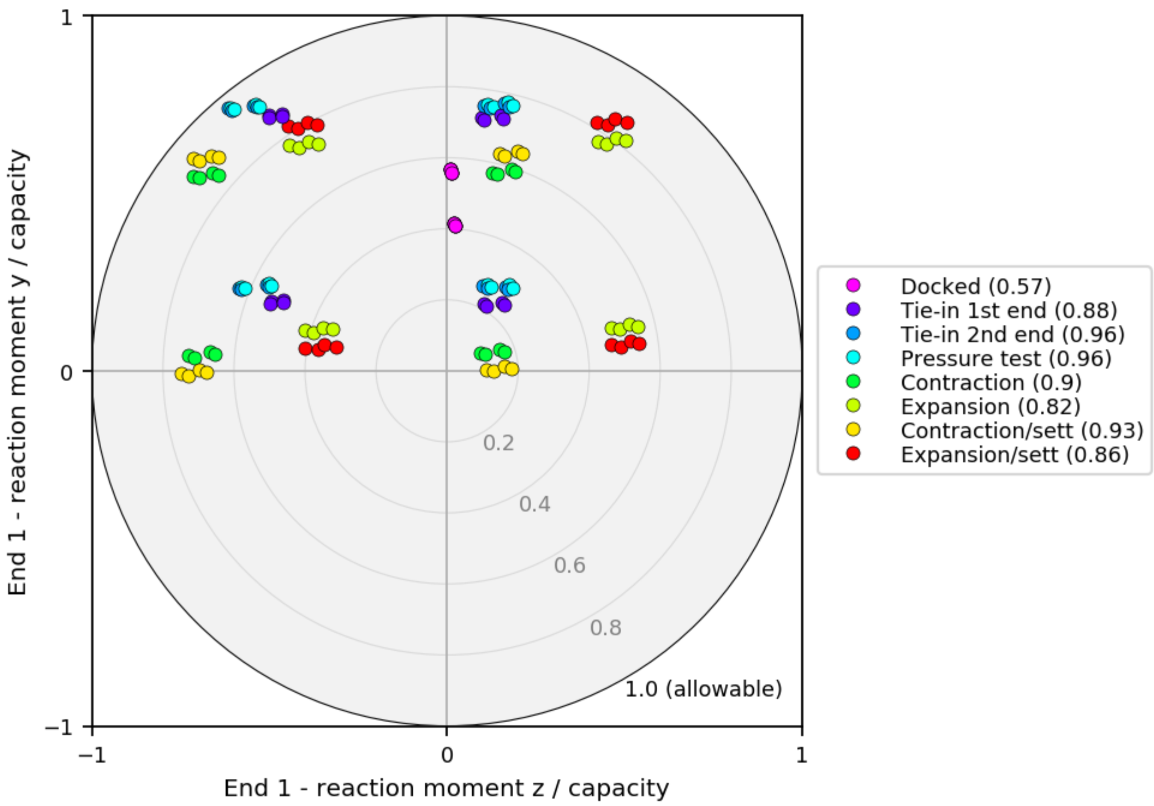
The maximum magnitude reaction bending moment at End 1, for each load case and load step, is shown in Figure 4.11.

Figure 4.11 – Maximum Magnitude Reaction Bending Moment at End 1



The connector / hub bending moment utilisations (RMy vs. RMz) at End 1, for all load cases and load steps, are shown in Figure 4.12.

Figure 4.12 – Reaction Bending Moment Components at End 1



The shaded circular area indicates the allowable. The maximum utilisation is presented for each load step within parenthesis in the figure legend.

4.8.2 End 2

The maximum magnitude reaction loads at End 2 of the spool, from any of the analysed load cases, are presented in Table 4.5 for each subsequent load step.

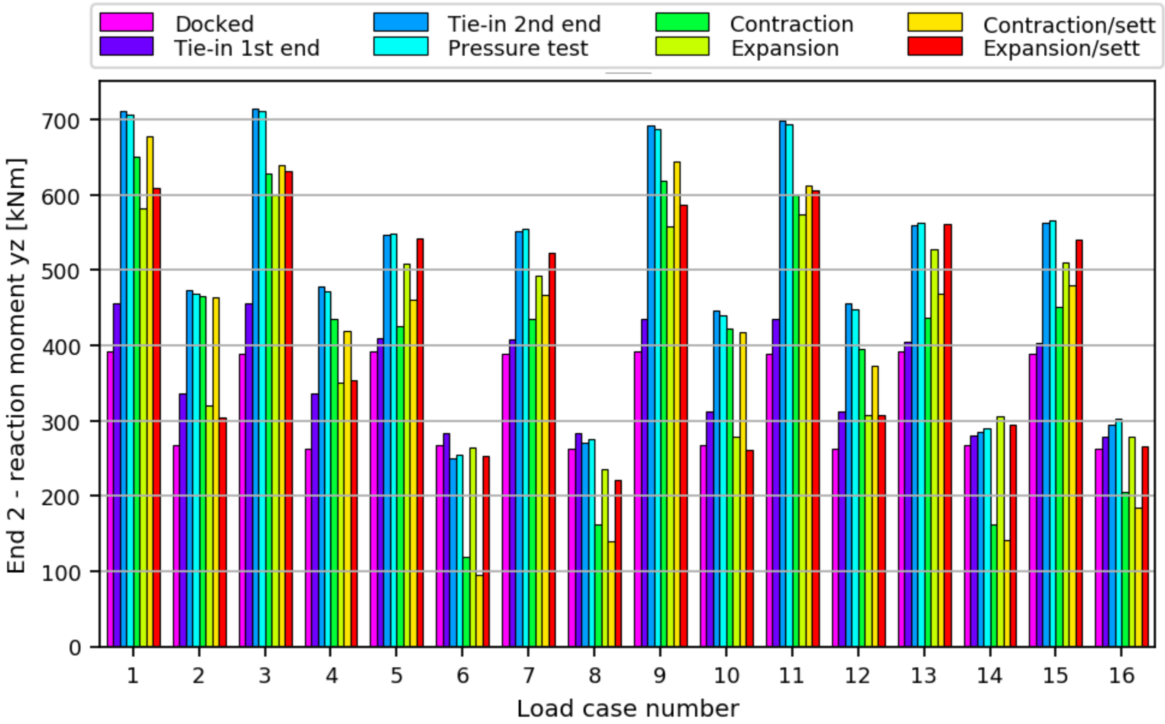
Table 4.5 – Maximum Magnitude Reaction Loads at End 2

Load Step	End Reaction Forces [kN]			End Reaction Moments [kNm]			
	RFx	RFy	RFz	RMx	RMy	RMz	RMb
Docked	2.7	-1.2	84.0	0.0	392.6	19.0	392.6
Tie-in 1st end	-9.2	20.2	85.8	-0.0	412.9	-195.7	456.1
Tie-in 2nd end	34.2	47.9	93.9	-0.0	539.1	-470.9	715.3
Pressure test	33.1	47.2	93.9	-0.8	539.7	-463.6	710.9
Contraction	39.4	56.4	80.7	-11.4	448.1	-471.9	650.8
Expansion	-33.0	-39.0	79.1	-69.9	485.5	-353.5	599.9
Contraction/sett	40.2	56.6	82.7	-17.6	486.3	-471.5	677.3
Expansion/sett	-32.5	-38.7	81.1	-73.0	521.4	-358.3	631.4
Max	40.2	56.6	93.9	-73.0	539.7	-471.9	715.3

The maximum loads are presented for any of the analysed load cases and do not necessarily occur concurrently.

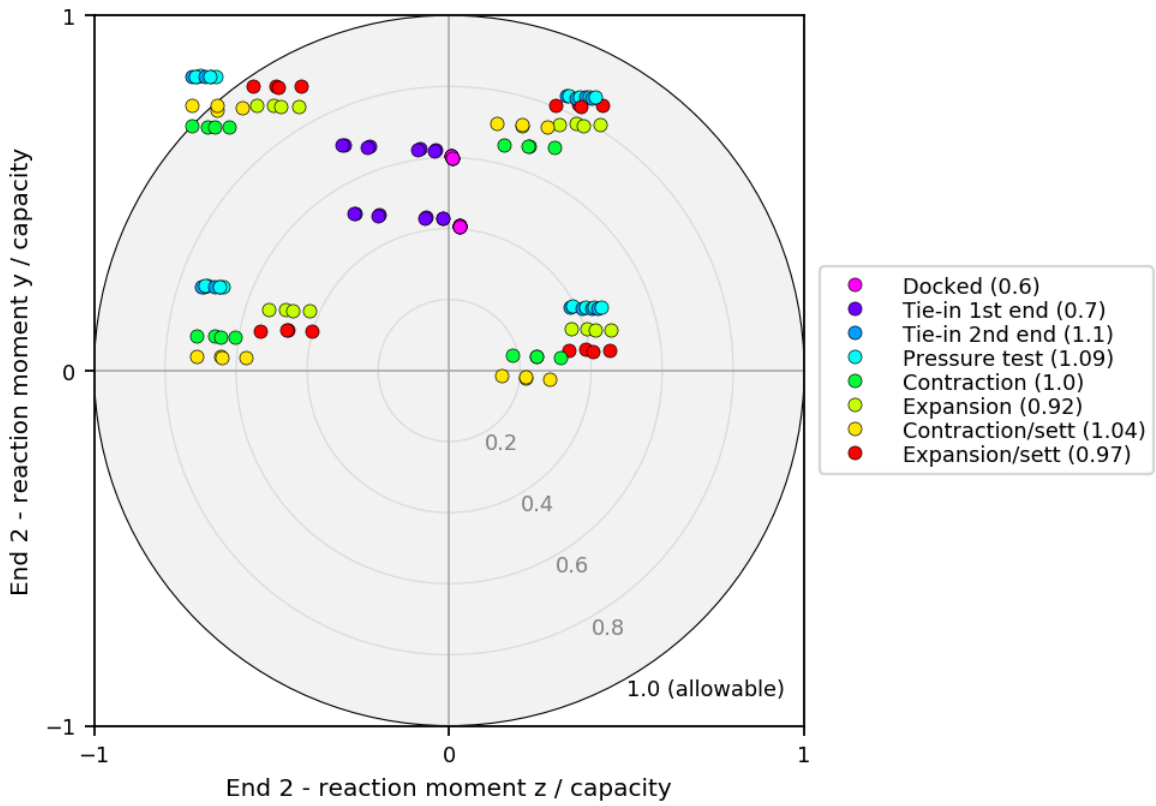
The maximum magnitude reaction bending moment at End 2, for each load case and load step, is shown in Figure 4.13.

Figure 4.13 – Maximum Magnitude Reaction Bending Moment at End 2



The connector / hub bending moment utilisations (RMy vs. RMz) at End 2, for all load cases and load steps, are shown in Figure 4.14.

Figure 4.14 – Reaction Bending Moment Components at End 2

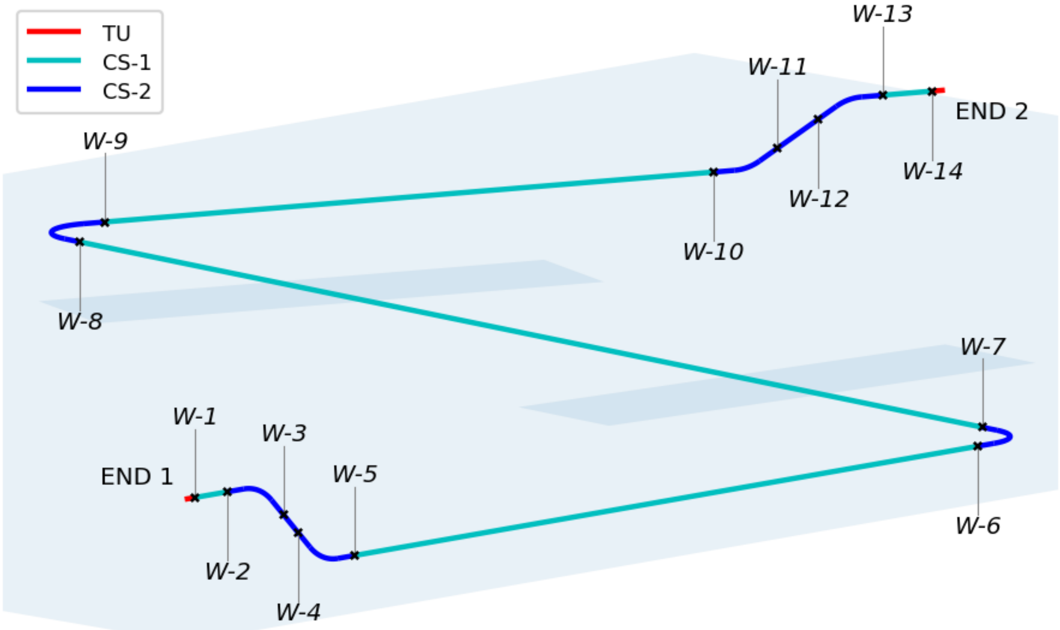


The shaded circular area indicates the allowable. The maximum utilisation is presented for each load step within parenthesis in the figure legend.

4.9 Fatigue Damage due to VIV

The welds assessed for fatigue damage due to VIV are shown in Figure 4.15.

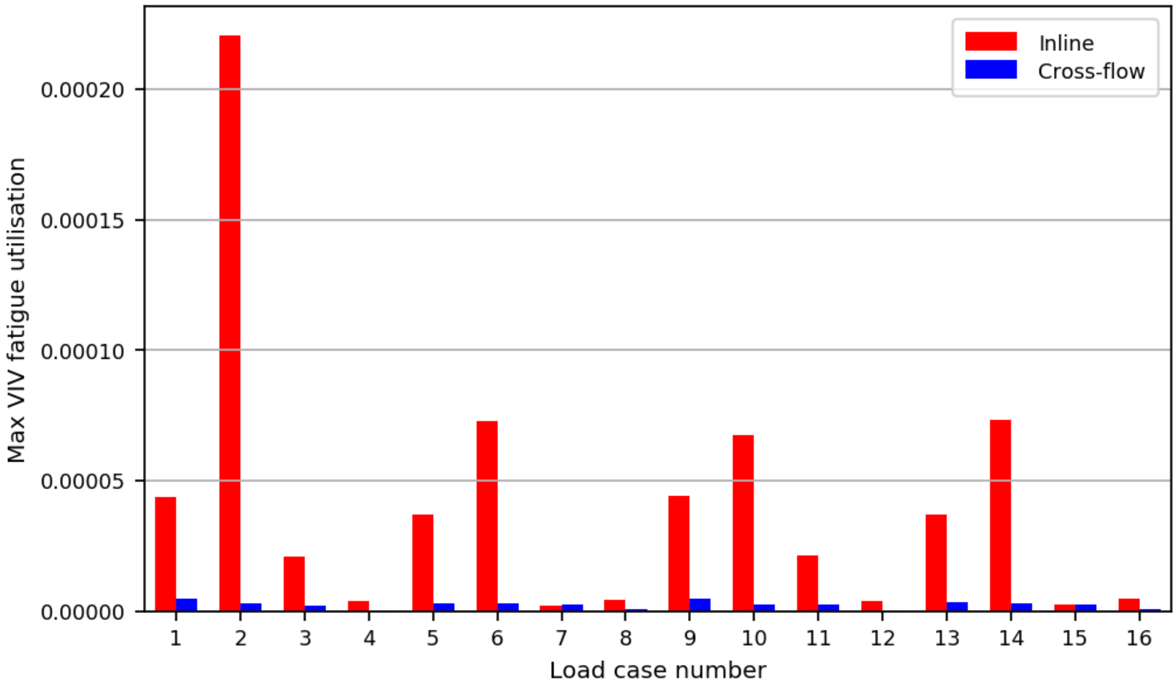
Figure 4.15 – Assessed Welds



Note that additional welds will be present where the pipe section exceeds the pipe joint length.

The maximum VIV fatigue utilisations for each load case are shown in Figure 4.16.

Figure 4.16 – Maximum VIV Fatigue Utilisation for Each Load Case

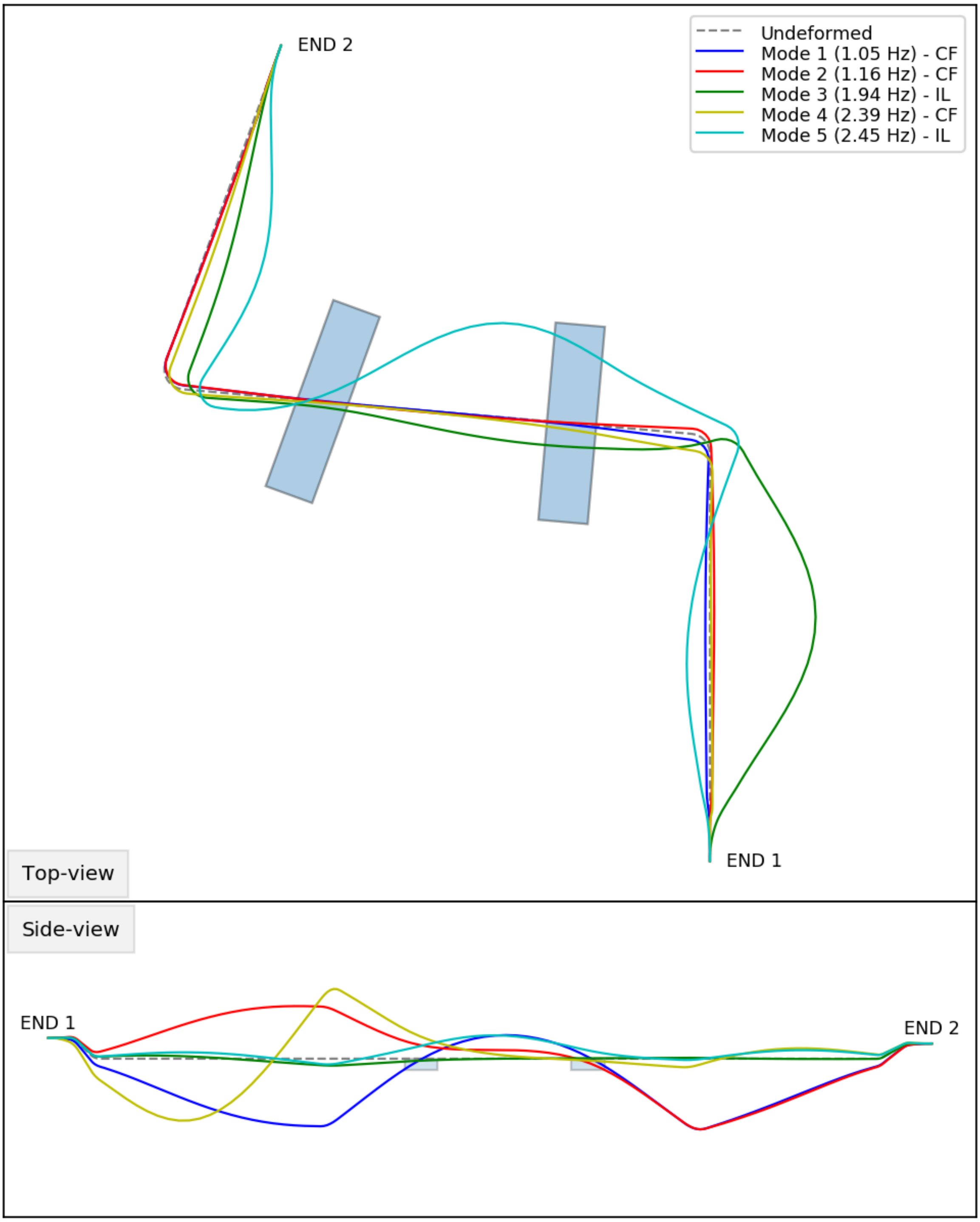


Inline and Cross-Flow utilisations are presented separately, and indicated that the damage has been accumulate at a specific location around the circumference.

It should be noted that both inline and cross-flow induced vibrations can potentially accrue damage at any location around the pipe circumference.

The Eigen-modes corresponding to the five lowest frequencies for load case number 2 (most critical in terms of fatigue damage) are shown in Figure 4.17.

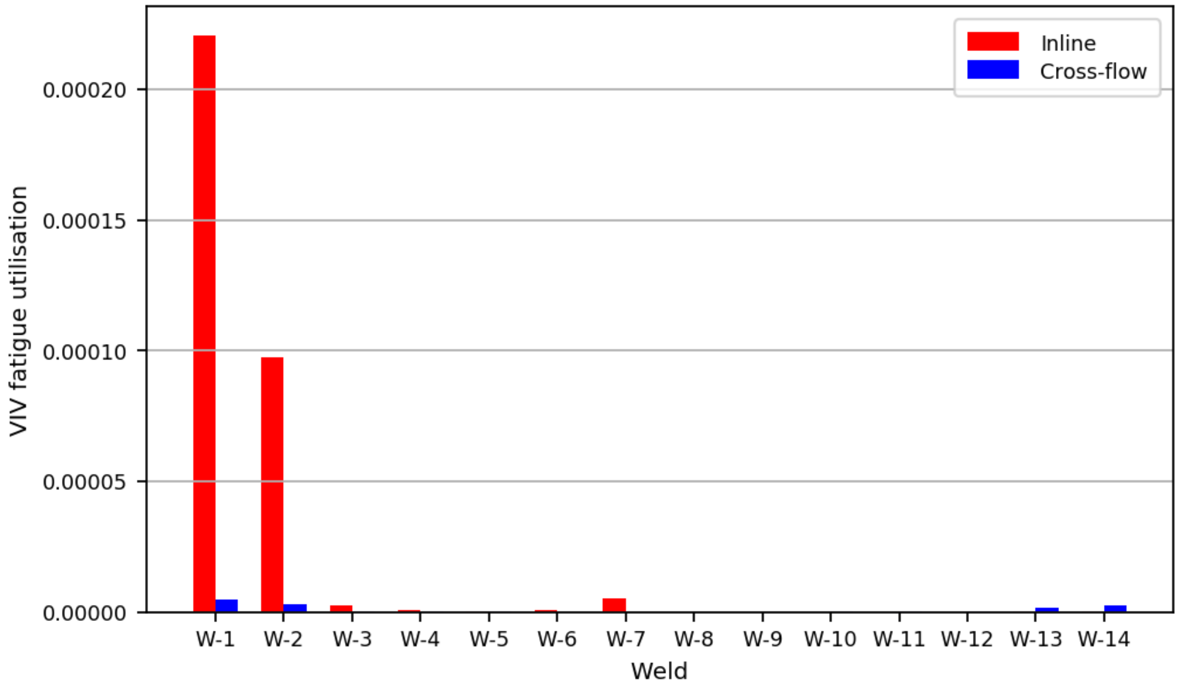
Figure 4.17 – Eigen-Modes of Most Utilised Load Case



The corresponding natural frequencies are presented within parenthesis in the figure legend, where the dominating mode type is denoted IL and / or CF.

The maximum VIV fatigue utilisation (all load cases) in each weld is shown in Figure 4.18.

Figure 4.18 – Maximum VIV Fatigue Utilisation at Each Weld



4.10 Support Loads

The maximum vertical support forces, from any of the analysed load cases, are presented in Table 4.6, for each subsequent load step.

Table 4.6 – Maximum Vertical Forces Acting on Supports and Seabed

Load Step	Vertical Force [kN]		
	SEABED	Support-1	Support-2
Docked	0.0	52.8	47.5
Tie-in 1st end	0.0	59.6	49.8
Tie-in 2nd end	0.0	63.6	57.8
Pressure test	0.0	63.7	57.9
Contraction	0.0	42.5	38.0
Expansion	0.0	43.5	40.2
Contraction/sett	0.0	45.0	40.9
Expansion/sett	0.8	46.0	43.1
Max	0.8	63.7	57.9

Note that the maximum loads are presented for any of the analysed load cases and do not necessarily occur concurrently.

5 CONFIGURATION MAX

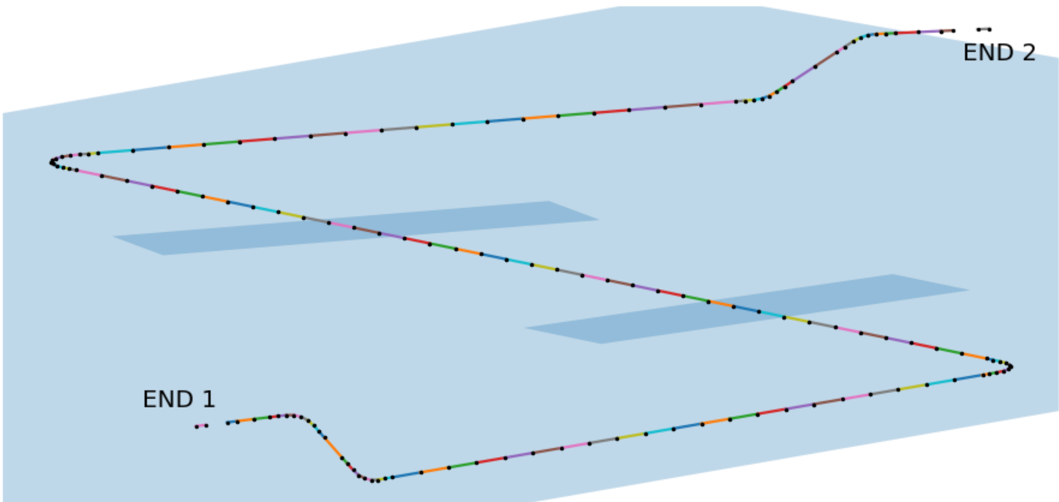
This section presents the following detailed results for configuration "max".

- FE-model
- Spool geometry
- Load cases
- Load steps
- Spool CLC / ASD utilisation
- Spool ASME utilisation
- Spool HISC utilisation
- Spool end reaction loads
- Fatigue damage due to VIV
- Support loads

5.1 FE-MODEL

The FE-model consists of the spool and two connecting structures at each end. The mesh density used is shown in Figure 5.1.

Figure 5.1 – FE-Model Mesh



The beam / pipe elements are shown as lines and with the associated nodes are shown as black dots. The nodes belonging to the area elements are not shown.

The spool consists of three different cross-section types.

5.2 SPOOL GEOMETRY

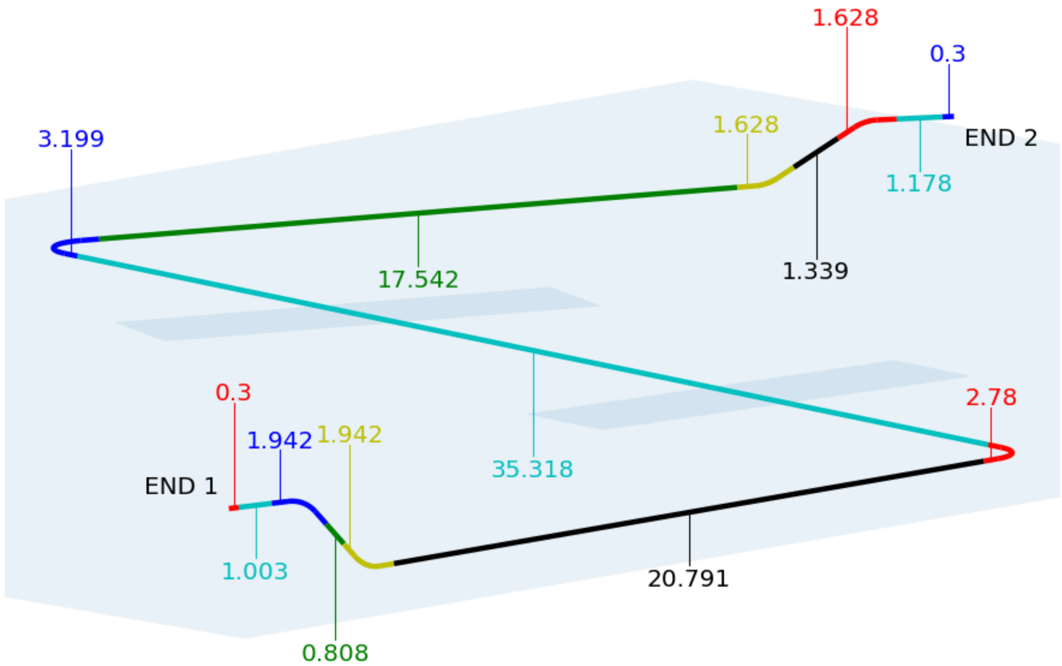
The coordinates at the spool ends and at the intersection points between the extended straight lines / sections, are presented in Table 5.1.

Table 5.1 – Coordinates at Ends and Intersection Points

Location	Coordinates [m]		
	X / Easting	Y / Northing	Z / Vertical
End 1	-1.111	2.6	2.6
IP-1	-1.059	2.896	2.6
IP-2	-0.712	4.865	2.6
IP-3	-0.539	6.847	0.626
IP-4	-0.539	30.235	0.626
IP-5	-39.371	33.632	0.626
IP-6	-32.385	52.827	0.626
IP-7	-31.289	55.177	2.1
IP-8	-30.289	56.909	2.1
End 2	-30.139	57.169	2.1

An isometric view of the spool showing each section length (units in meter) is shown in Figure 5.2.

Figure 5.2 – Isometric View with Section Lengths



5.3 Load Cases

A set of 16 load case combinations has been analysed, as presented in Table 5.2. The prescribed end displacement / rotation values refer to uncertainties regarding make-up tolerances at each spool end.

Table 5.2 – Load Case Combinations

Load Case	END 1						END 2					
	Displacements [m]			Rotations [deg]			Displacements [m]			Rotations [deg]		
	ux	uy	uz	rx	ry	rz	ux	uy	uz	rx	ry	rz
1	0.09	0.09	0.1	Free	0.55	-0.7	0.09	0.09	0.1	Free	0.55	-0.7
2	0.09	0.09	0.1	Free	0.55	-0.7	0.09	0.09	-0.1	Free	-0.55	-0.7
3	0.09	0.09	-0.1	Free	-0.55	-0.7	0.09	0.09	0.1	Free	0.55	-0.7
4	0.09	0.09	-0.1	Free	-0.55	-0.7	0.09	0.09	-0.1	Free	-0.55	-0.7
5	0.09	-0.09	0.1	Free	0.55	0.7	0.09	-0.09	0.1	Free	0.55	0.7
6	0.09	-0.09	0.1	Free	0.55	0.7	0.09	-0.09	-0.1	Free	-0.55	0.7
7	0.09	-0.09	-0.1	Free	-0.55	0.7	0.09	-0.09	0.1	Free	0.55	0.7
8	0.09	-0.09	-0.1	Free	-0.55	0.7	0.09	-0.09	-0.1	Free	-0.55	0.7
9	-0.09	0.09	0.1	Free	0.55	-0.7	-0.09	0.09	0.1	Free	0.55	-0.7
10	-0.09	0.09	0.1	Free	0.55	-0.7	-0.09	0.09	-0.1	Free	-0.55	-0.7
11	-0.09	0.09	-0.1	Free	-0.55	-0.7	-0.09	0.09	0.1	Free	0.55	-0.7
12	-0.09	0.09	-0.1	Free	-0.55	-0.7	-0.09	0.09	-0.1	Free	-0.55	-0.7
13	-0.09	-0.09	0.1	Free	0.55	0.7	-0.09	-0.09	0.1	Free	0.55	0.7
14	-0.09	-0.09	0.1	Free	0.55	0.7	-0.09	-0.09	-0.1	Free	-0.55	0.7
15	-0.09	-0.09	-0.1	Free	-0.55	0.7	-0.09	-0.09	0.1	Free	0.55	0.7
16	-0.09	-0.09	-0.1	Free	-0.55	0.7	-0.09	-0.09	-0.1	Free	-0.55	0.7

The parameter "Free" indicates that no tolerances have been applied, i.e. as the termination unit is free to swivel around the pipe axis prior to and during tie-ins.

5.4 Load Steps

The spool have been analysed for the subsequent load steps presented in Table 5.3.

Table 5.3 – Subsequent Load Steps

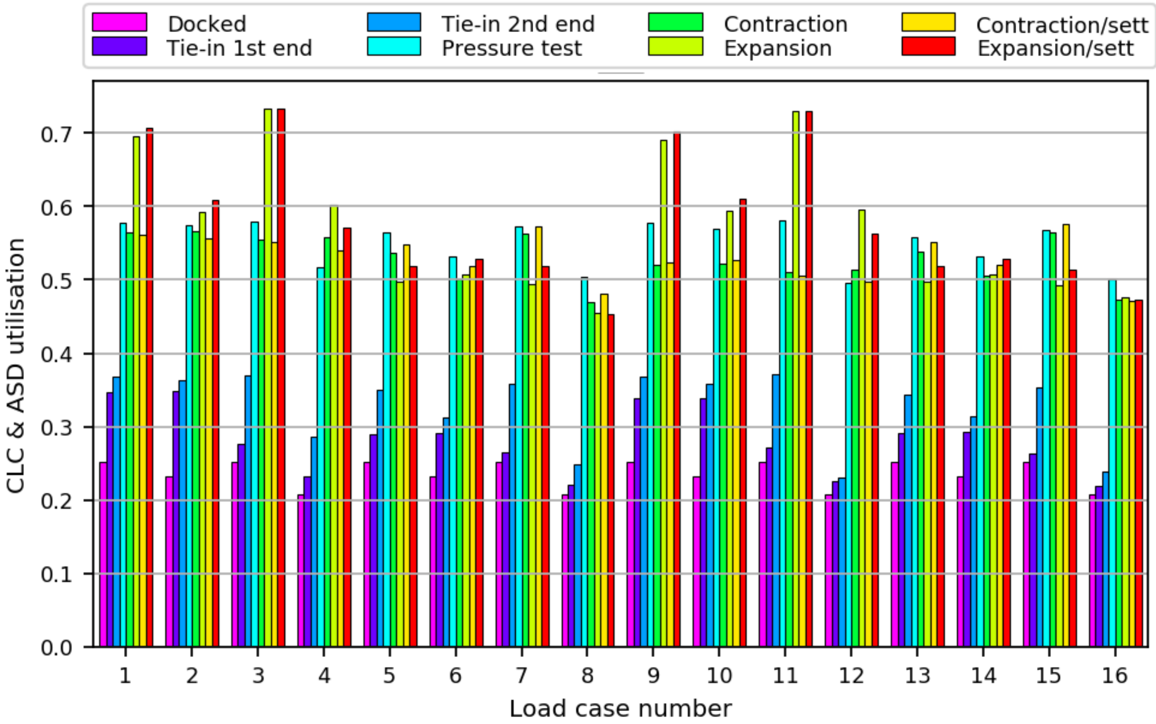
Load Step	Internal Pressure [bara]	Temperature [°C]	Content Density [kg/m3]	Axial Expansion - End 2 [m]
Docked	20	10	1150	0
Tie-in 1st end	20	10	1150	0
Tie-in 2nd end	20	10	1150	0
Pressure test	400	10	1150	0
Contraction	300	-20	250	-1.0
Expansion	300	100	250	3.0
Contraction/sett	300	-20	250	-1.0
Expansion/sett	300	100	250	3.0

Positive axial expansion is in the direction opposite to the tie-in stroking direction.

5.5 Spool CLC / ASD Utilisation

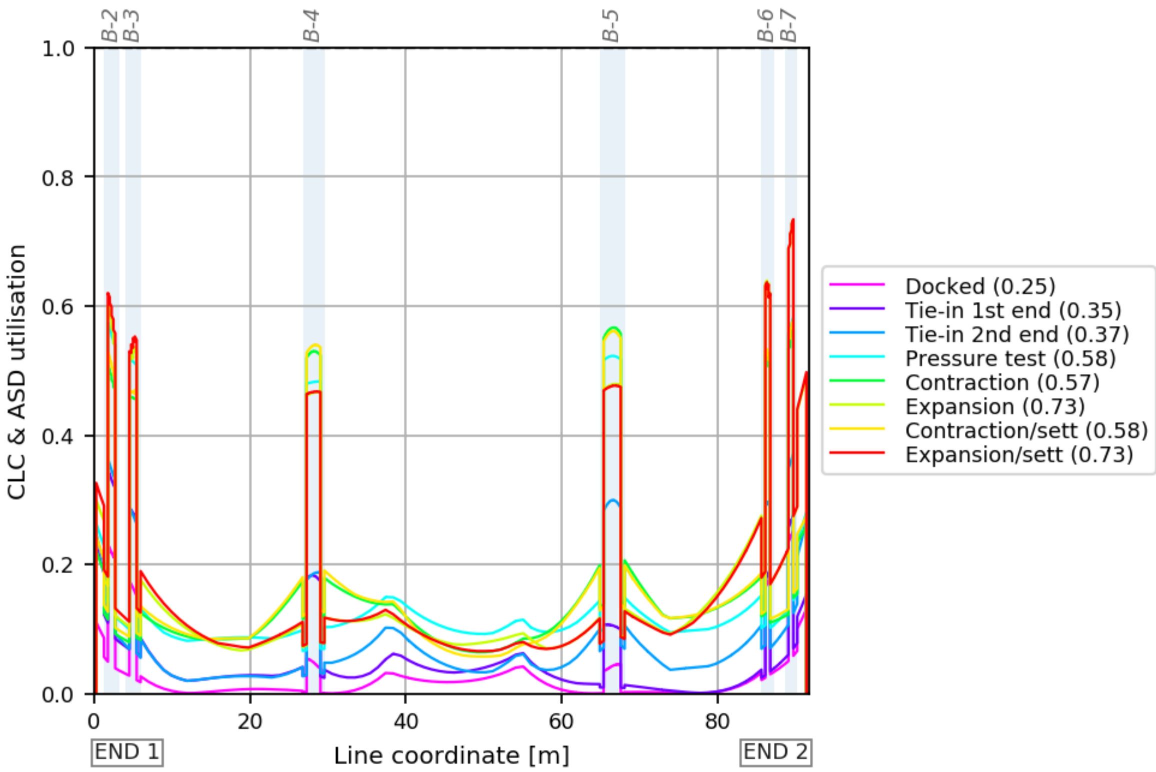
The maximum CLC / ASD utilisation along the spool, for each load case and load step, is shown in Figure 5.3.

Figure 5.3 – Maximum CLC / ASD Utilisation for Each Load Case and Load Step



A CLC / ASD utilisation envelope plot from all load cases and for each analysed subsequent load step is shown in Figure 5.4.

Figure 5.4 – Spool CLC / ASD Utilisation

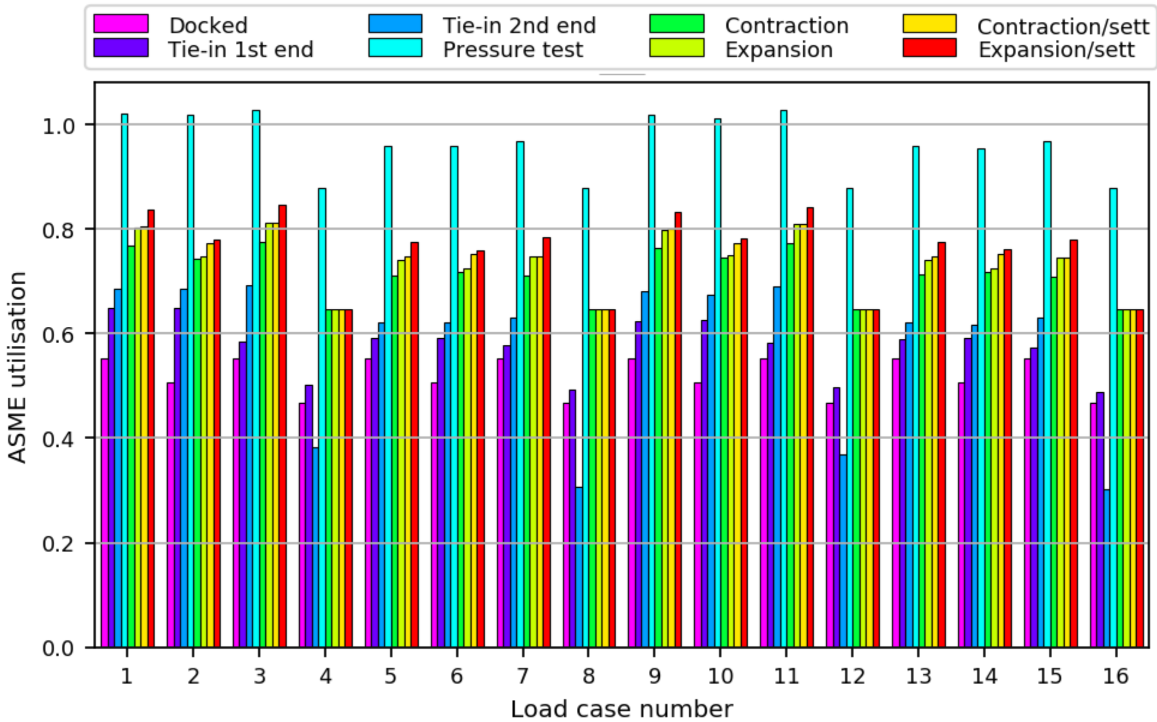


The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

5.6 SPOOL ASME UTILISATION

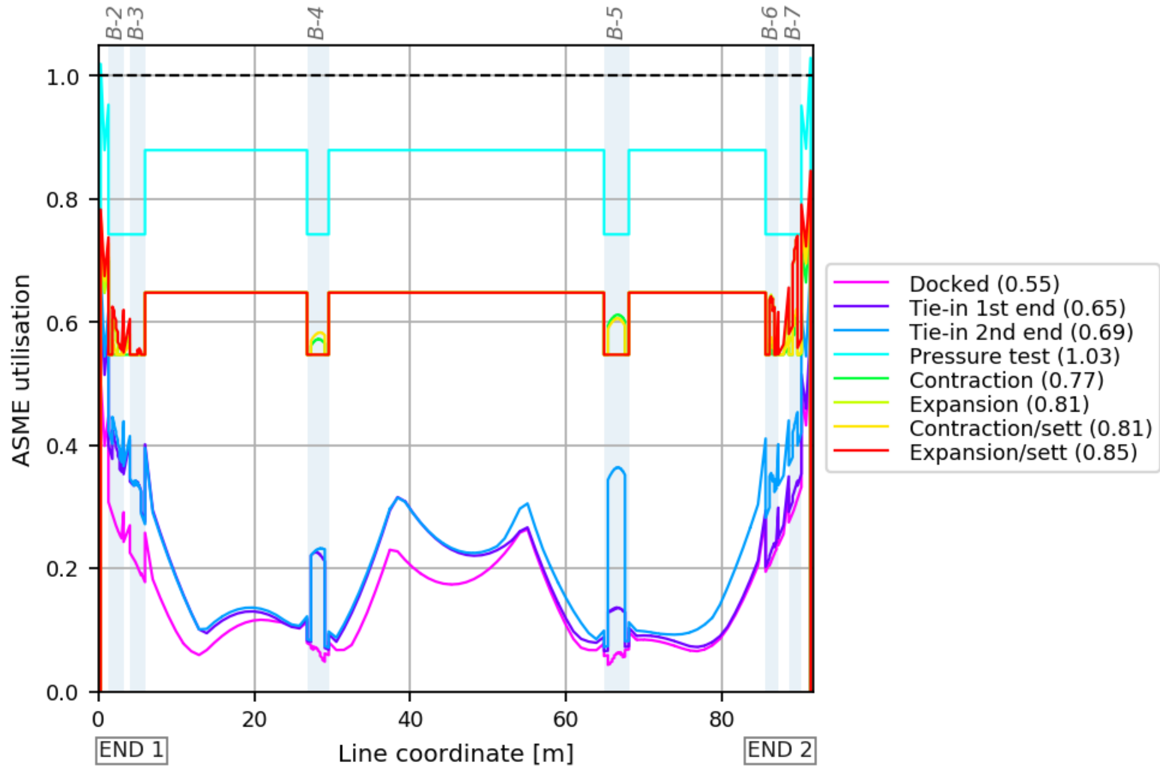
The maximum ASME utilisation along the spool, for each load case and load step, is shown in Figure 5.5.

Figure 5.5 – Maximum ASME Utilisation for Each Load Case and Load Step



An ASME utilisation envelope plot from all load cases and for each analysed subsequent load step is shown in Figure 5.6.

Figure 5.6 – Spool ASME Utilisation



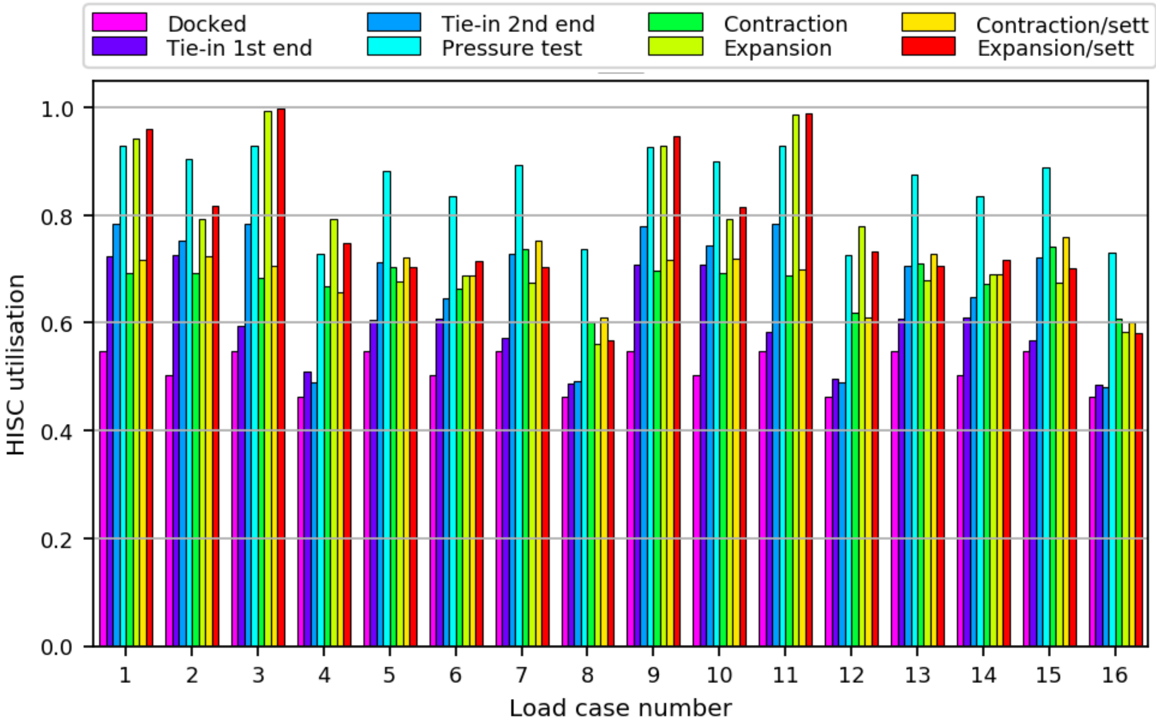
The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

Stress Intensification Factors, according to Ref. [ASME B31.8], have been accounted for when calculating utilisations in the bends and at welds.

5.7 Spool HISC Utilisation

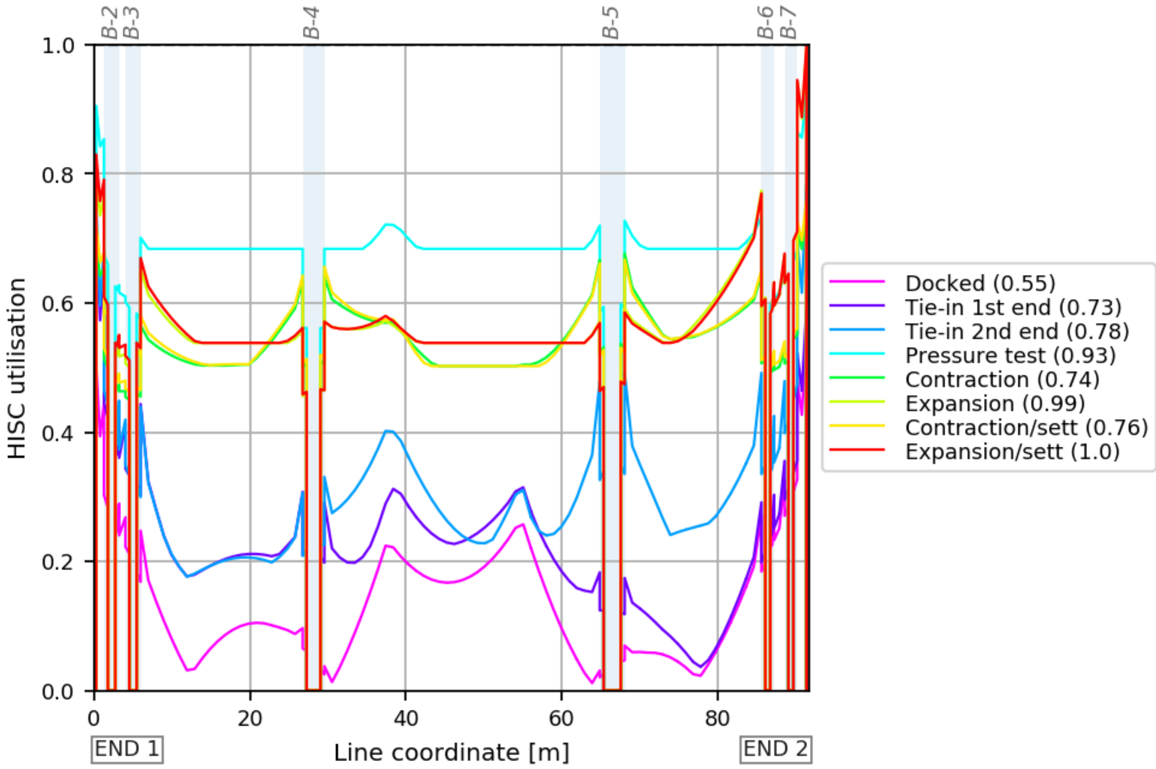
The maximum HISC utilisation along the spool, for each load case and load step, is shown in Figure 5.7.

Figure 5.7 – Maximum HISC Utilisation for Each Load Case and Load Step



A HISC utilisation envelope plot from all load cases and for each analysed subsequent load step is shown in Figure 5.8.

Figure 5.8 – Spool HISC Utilisation



The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

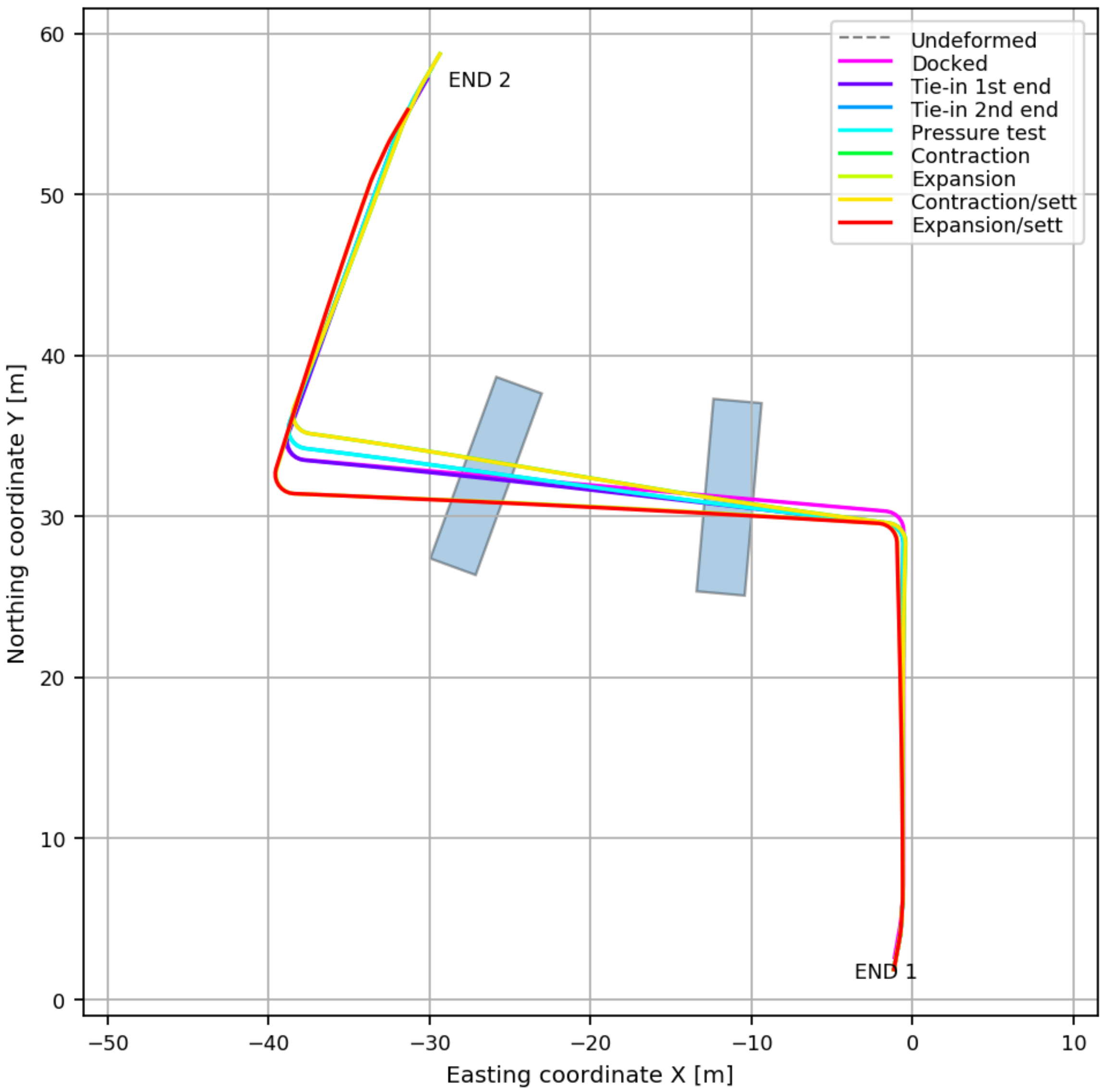
Longitudinal Stress Concentration Factors has been applied at each weld.

The spool bends (curved part) have not been assessed, since beam elements have been used in this assessment. HISC assessment in bends requires the use of either shell- or solid FE-models, in order to capture the ovalisation effects, which are causing high stress gradients across the wall thickness, as well as great stress variations around the circumference.

5.7.1 Most Utilised Load Case - Number 3

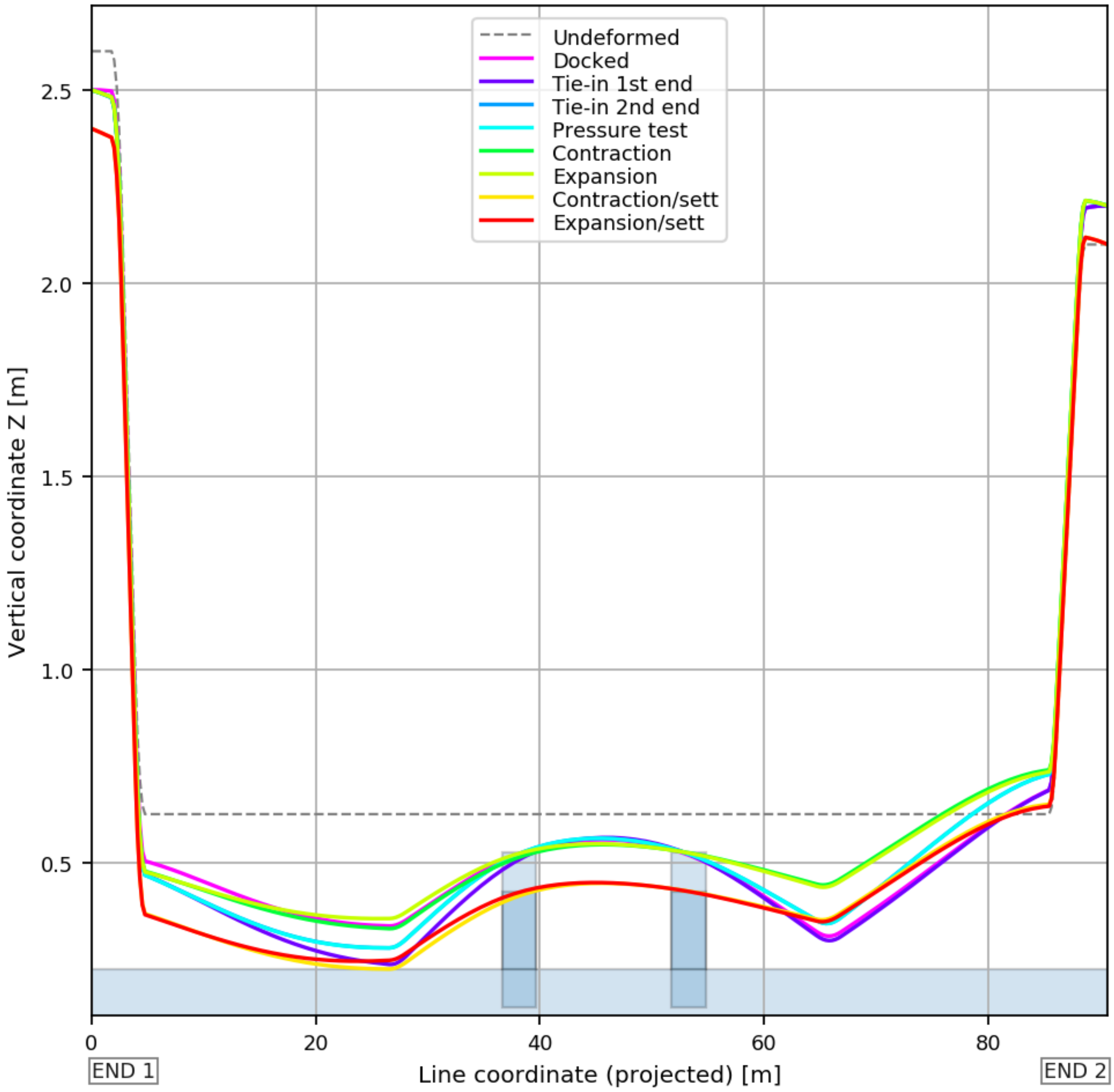
A top-view of the deformed shapes, for the most utilised load case (number 3), are shown for each load step in Figure 5.9.

Figure 5.9 – Top-View of Deformed Shapes of Critical Load Case



A profile view of the deformed shapes, for the most utilised load case (number 3), are shown for each load step in Figure 5.10.

Figure 5.10 – Profile View Deformed Shape of Critical Load Case



5.8 Spool End Reaction Loads

The weight of Termination Units has not been included in the assessment. This will primary affect the vertical reaction force RFz and secondary the reaction moment RMy.

5.8.1 End 1

The maximum magnitude reaction loads at End 1 of the spool, from any of the analysed load cases, are presented in Table 5.4 for each subsequent load step.

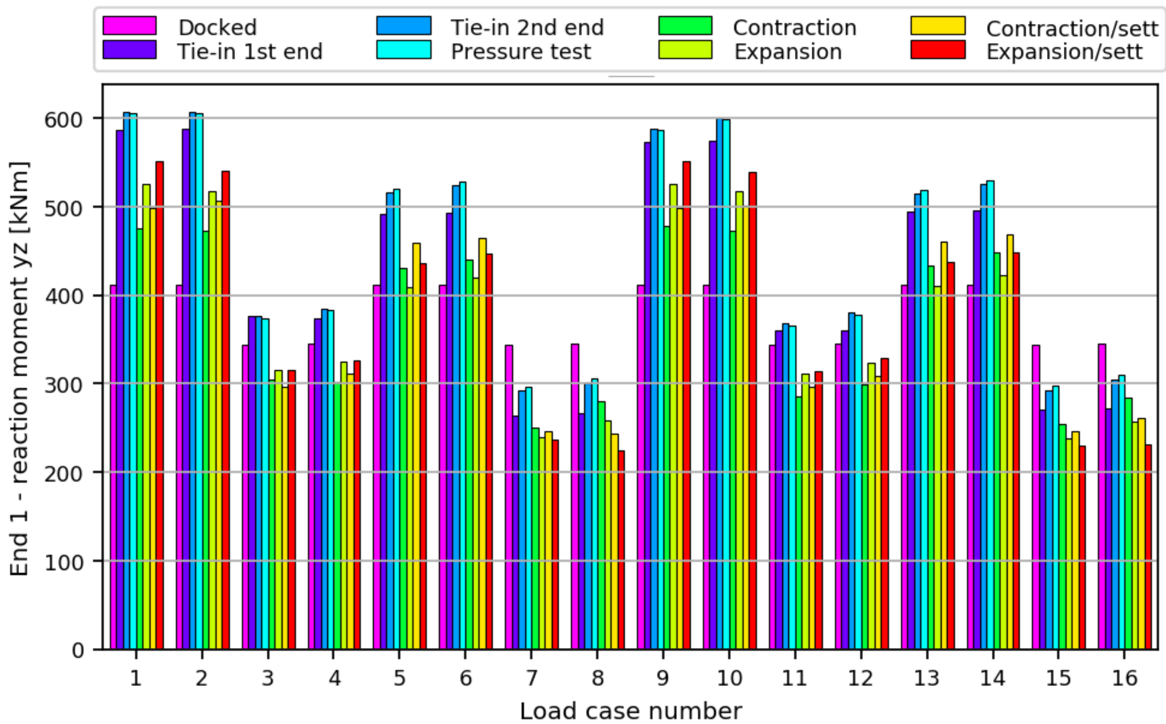
Table 5.4 – Maximum Magnitude Reaction Loads at End 1

Load Step	End Reaction Forces [kN]			End Reaction Moments [kNm]			
	RFx	RFy	RFz	RMx	RMy	RMz	RMb
Docked	4.3	1.8	87.3	-0.0	412.2	-11.9	412.3
Tie-in 1st end	23.6	22.1	92.9	0.0	526.0	-270.6	587.4
Tie-in 2nd end	10.7	19.2	92.7	-11.2	552.3	-261.6	607.6
Pressure test	9.3	18.5	92.7	-12.3	552.4	-253.8	605.9
Contraction	14.8	27.7	75.7	-17.2	403.0	-263.3	477.9
Expansion	10.3	-18.9	75.0	-46.8	406.3	-341.6	525.5
Contraction/sett	15.7	29.1	76.8	-23.9	426.1	-289.3	506.3
Expansion/sett	7.3	-18.7	76.2	-49.3	432.3	-345.6	551.5
Max	23.6	29.1	92.9	-49.3	552.4	-345.6	607.6

The maximum loads are presented for any of the analysed load cases and do not necessarily occur concurrently.

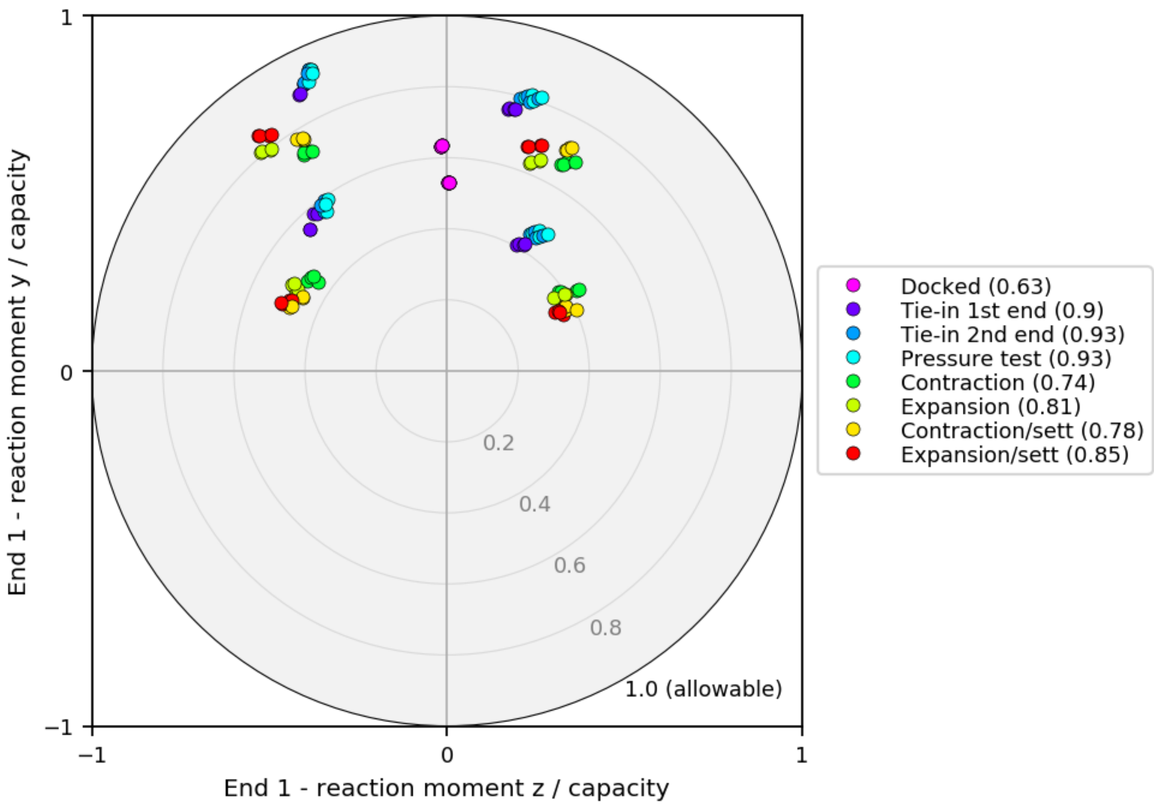
The maximum magnitude reaction bending moment at End 1, for each load case and load step, is shown in Figure 5.11.

Figure 5.11 – Maximum Magnitude Reaction Bending Moment at End 1



The connector / hub bending moment utilisations (RMy vs. RMz) at End 1, for all load cases and load steps, are shown in Figure 5.12.

Figure 5.12 – Reaction Bending Moment Components at End 1



The shaded circular area indicates the allowable. The maximum utilisation is presented for each load step within parenthesis in the figure legend.

5.8.2 End 2

The maximum magnitude reaction loads at End 2 of the spool, from any of the analysed load cases, are presented in Table 5.5 for each subsequent load step.

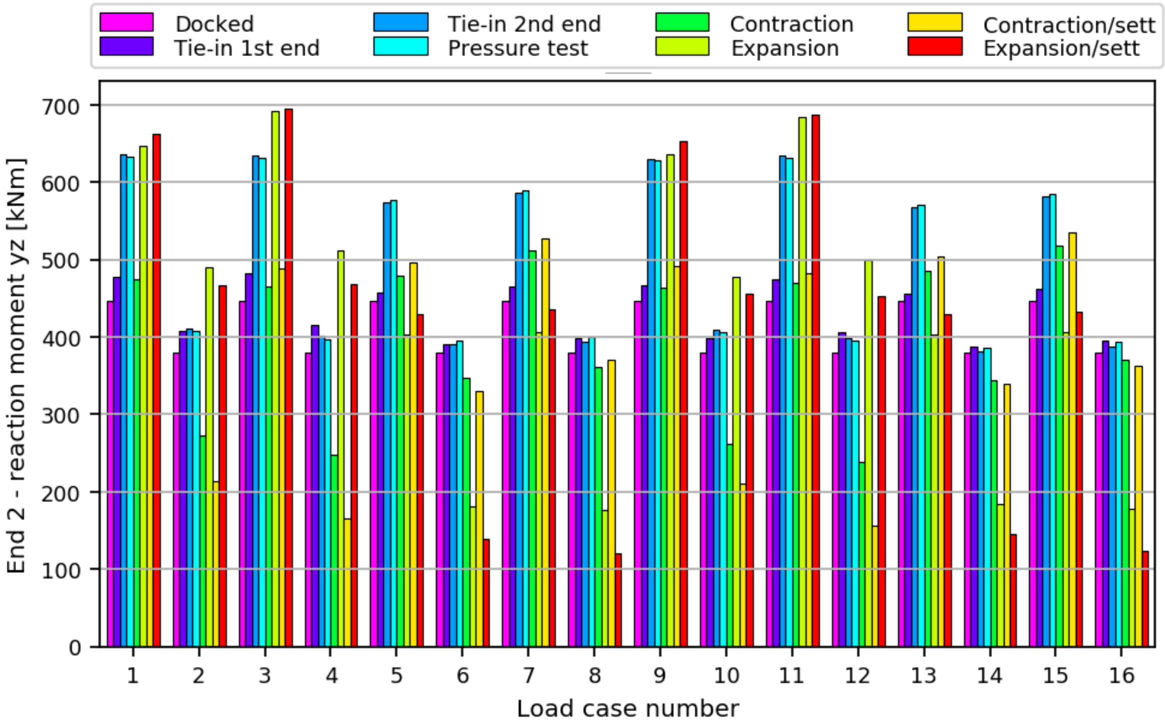
Table 5.5 – Maximum Magnitude Reaction Loads at End 2

Load Step	End Reaction Forces [kN]			End Reaction Moments [kNm]			
	RFx	RFy	RFz	RMx	RMy	RMz	RMb
Docked	2.4	1.3	86.3	0.0	446.5	8.2	446.5
Tie-in 1st end	-13.7	9.0	87.2	0.0	471.9	-106.4	482.6
Tie-in 2nd end	23.3	33.1	92.6	0.0	558.2	-313.6	635.1
Pressure test	22.1	32.5	92.6	-1.2	558.7	312.7	632.4
Contraction	23.2	31.1	76.5	-17.7	425.9	357.7	517.3
Expansion	-20.6	-19.3	75.5	-30.6	457.2	-518.2	691.0
Contraction/sett	22.7	30.7	77.8	-25.7	455.4	362.4	535.2
Expansion/sett	-24.1	-19.0	76.8	-37.8	482.9	-500.6	695.6
Max	-24.1	33.1	92.6	-37.8	558.7	-518.2	695.6

The maximum loads are presented for any of the analysed load cases and do not necessarily occur concurrently.

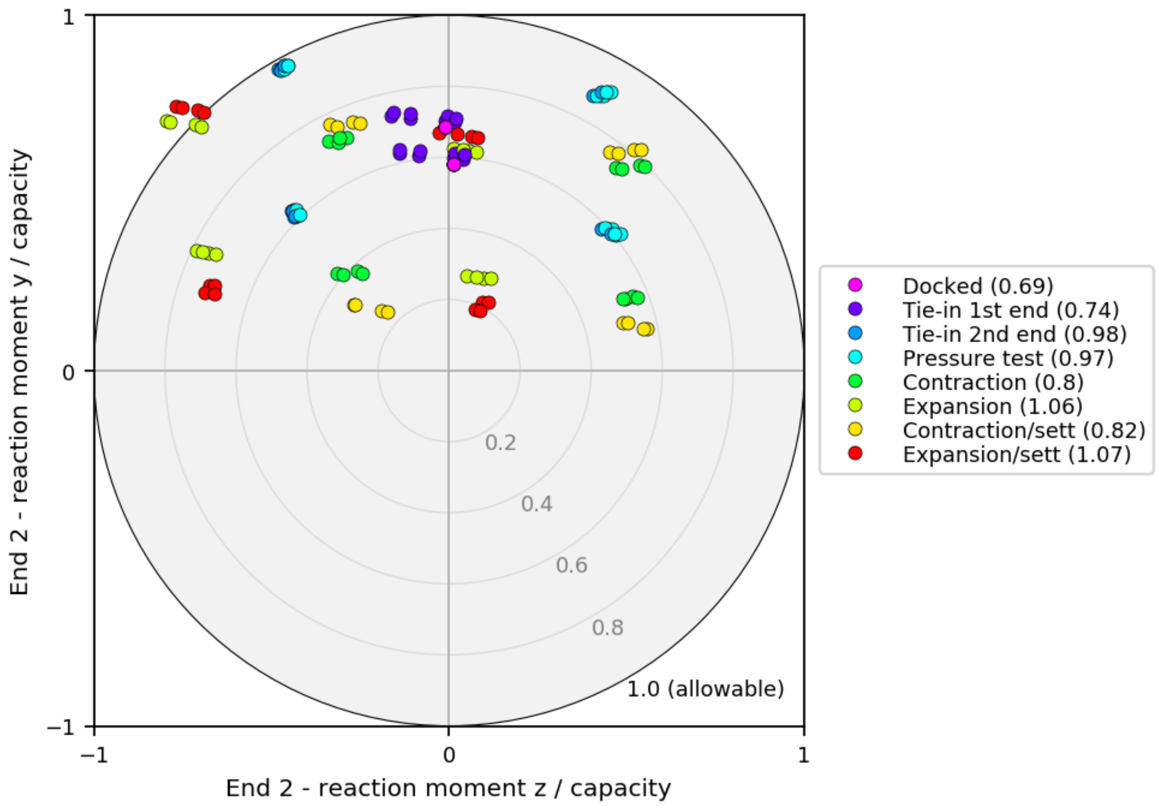
The maximum magnitude reaction bending moment at End 2, for each load case and load step, is shown in Figure 5.13.

Figure 5.13 – Maximum Magnitude Reaction Bending Moment at End 2



The connector / hub bending moment utilisations (RMy vs. RMz) at End 2, for all load cases and load steps, are shown in Figure 5.14.

Figure 5.14 – Reaction Bending Moment Components at End 2

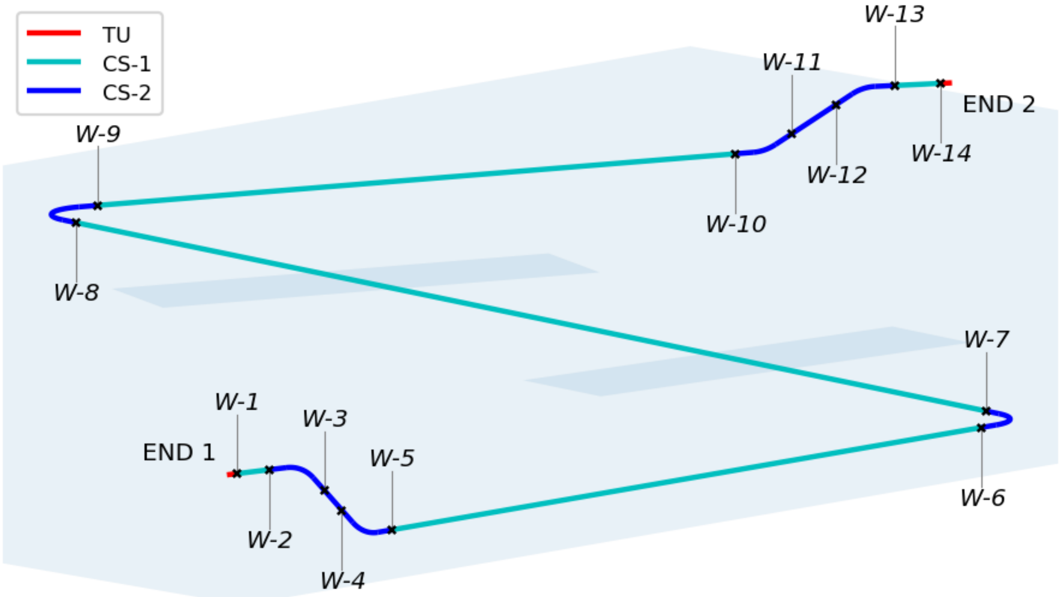


The shaded circular area indicates the allowable. The maximum utilisation is presented for each load step within parenthesis in the figure legend.

5.9 Fatigue Damage due to VIV

The welds assessed for fatigue damage due to VIV are shown in Figure 5.15.

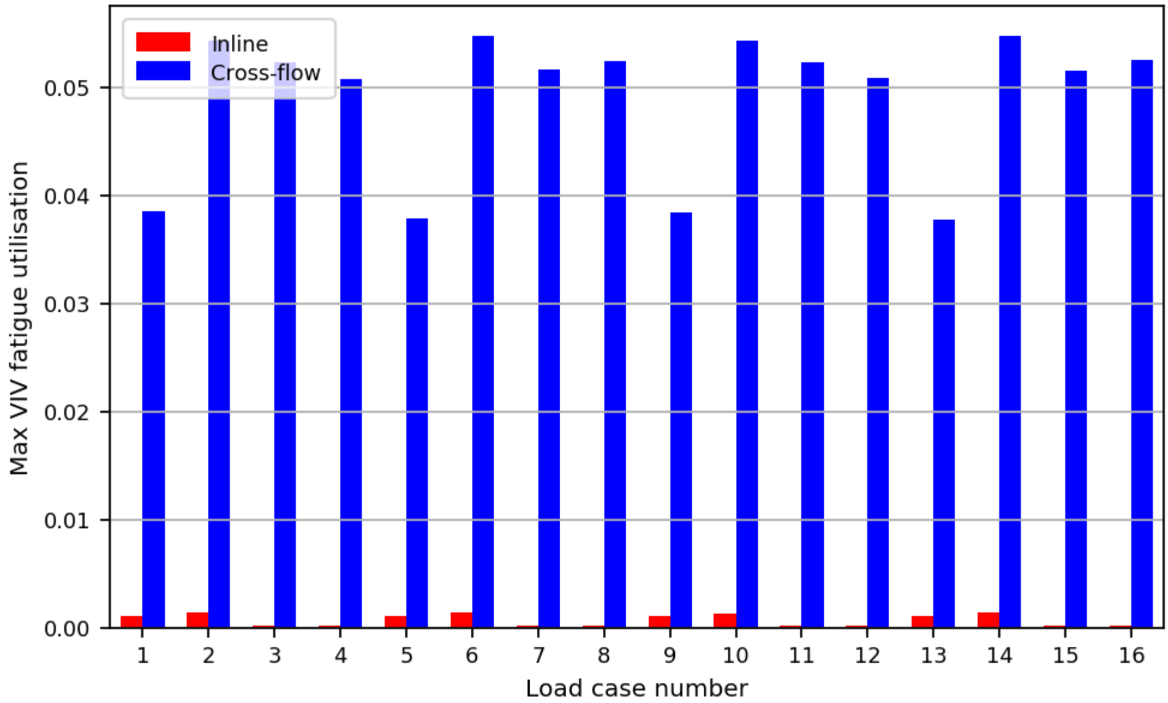
Figure 5.15 – Assessed Welds



Note that additional welds will be present where the pipe section exceeds the pipe joint length.

The maximum VIV fatigue utilisations for each load case are shown in Figure 5.16.

Figure 5.16 – Maximum VIV Fatigue Utilisation for Each Load Case

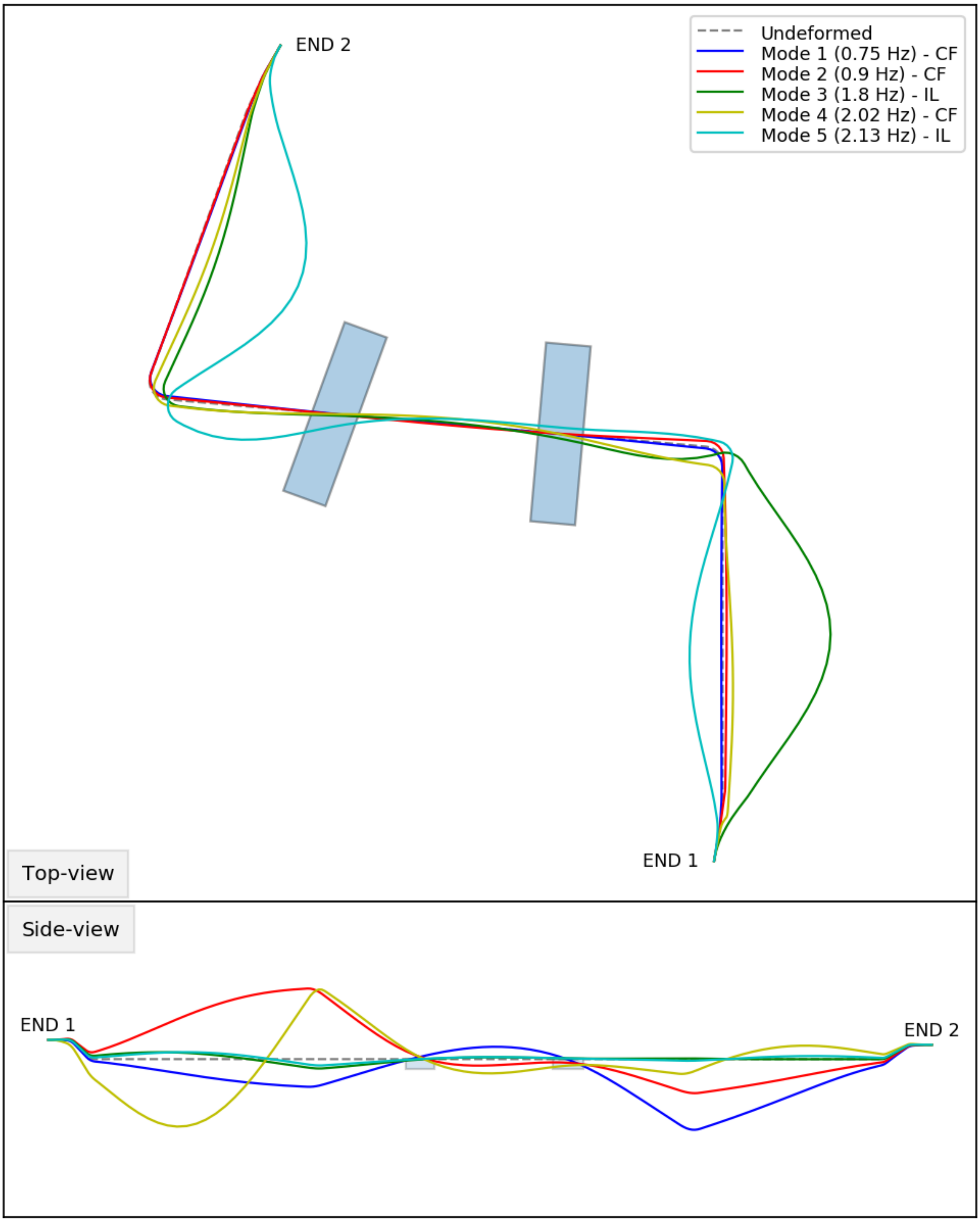


Inline and Cross-Flow utilisations are presented separately, and indicated that the damage has been accumulate at a specific location around the circumference.

It should be noted that both inline and cross-flow induced vibrations can potentially accrue damage at any location around the pipe circumference.

The Eigen-modes corresponding to the five lowest frequencies for load case number 14 (most critical in terms of fatigue damage) are shown in Figure 5.17.

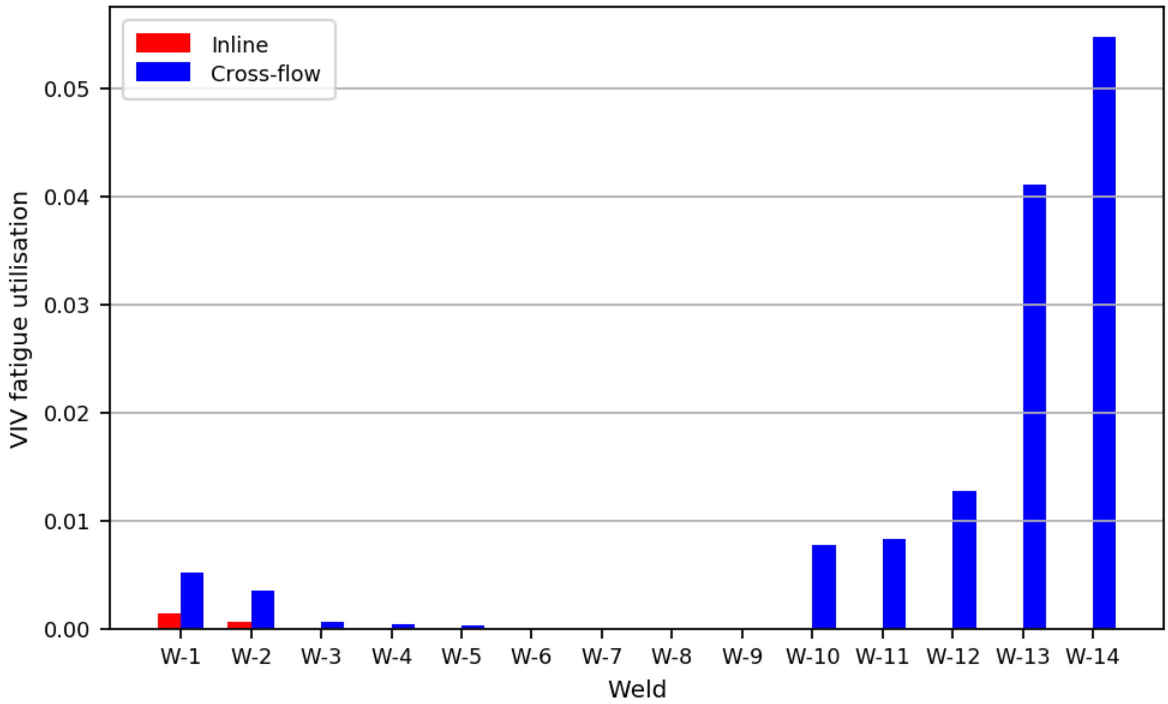
Figure 5.17 – Eigen-Modes of Most Utilised Load Case



The corresponding natural frequencies are presented within parenthesis in the figure legend, where the dominating mode type is denoted IL and / or CF.

The maximum VIV fatigue utilisation (all load cases) in each weld is shown in Figure 5.18.

Figure 5.18 – Maximum VIV Fatigue Utilisation at Each Weld



5.10 Support Loads

The maximum vertical support forces, from any of the analysed load cases, are presented in Table 5.6, for each subsequent load step.

Table 5.6 – Maximum Vertical Forces Acting on Supports and Seabed

Load Step	Vertical Force [kN]		
	SEABED	Support-1	Support-2
Docked	0.0	54.3	57.6
Tie-in 1st end	0.4	67.6	61.1
Tie-in 2nd end	7.5	96.5	65.3
Pressure test	7.6	63.5	65.3
Contraction	0.0	44.7	42.4
Expansion	0.0	42.3	44.6
Contraction/sett	12.8	46.2	41.9
Expansion/sett	10.0	44.7	43.1
Max	12.8	96.5	65.3

Note that the maximum loads are presented for any of the analysed load cases and do not necessarily occur concurrently.

6 CONFIGURATION MIN_L2

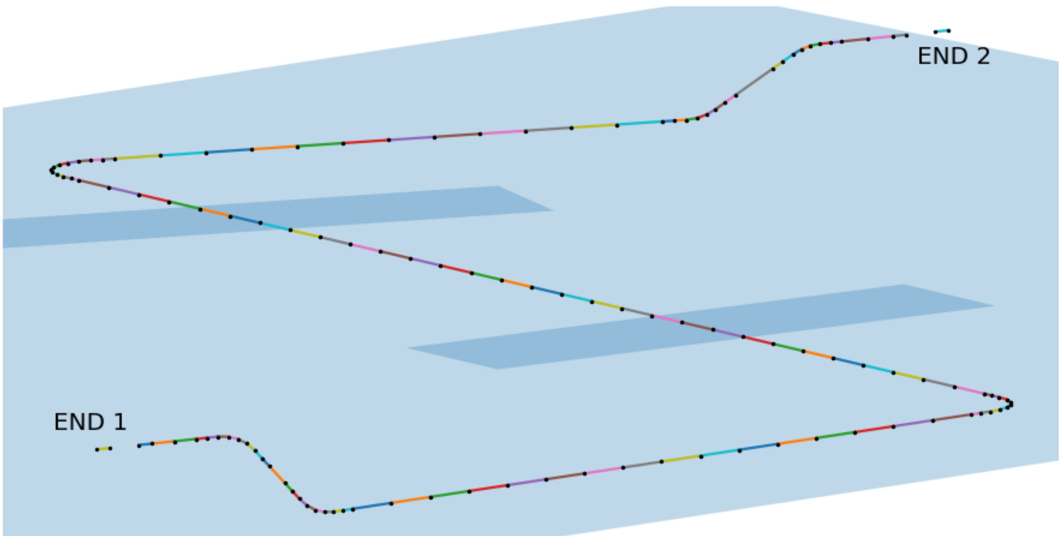
This section presents the following detailed results for configuration "min_L2".

- FE-model
- Spool geometry
- Load cases
- Load steps
- Spool CLC / ASD utilisation
- Spool ASME utilisation
- Spool HISC utilisation
- Spool end reaction loads
- Fatigue damage due to VIV
- Support loads

6.1 FE-MODEL

The FE-model consists of the spool and two connecting structures at each end. The mesh density used is shown in Figure 6.1.

Figure 6.1 – FE-Model Mesh



The beam / pipe elements are shown as lines and with the associated nodes are shown as black dots. The nodes belonging to the area elements are not shown.

The spool consists of three different cross-section types.

6.2 SPOOL GEOMETRY

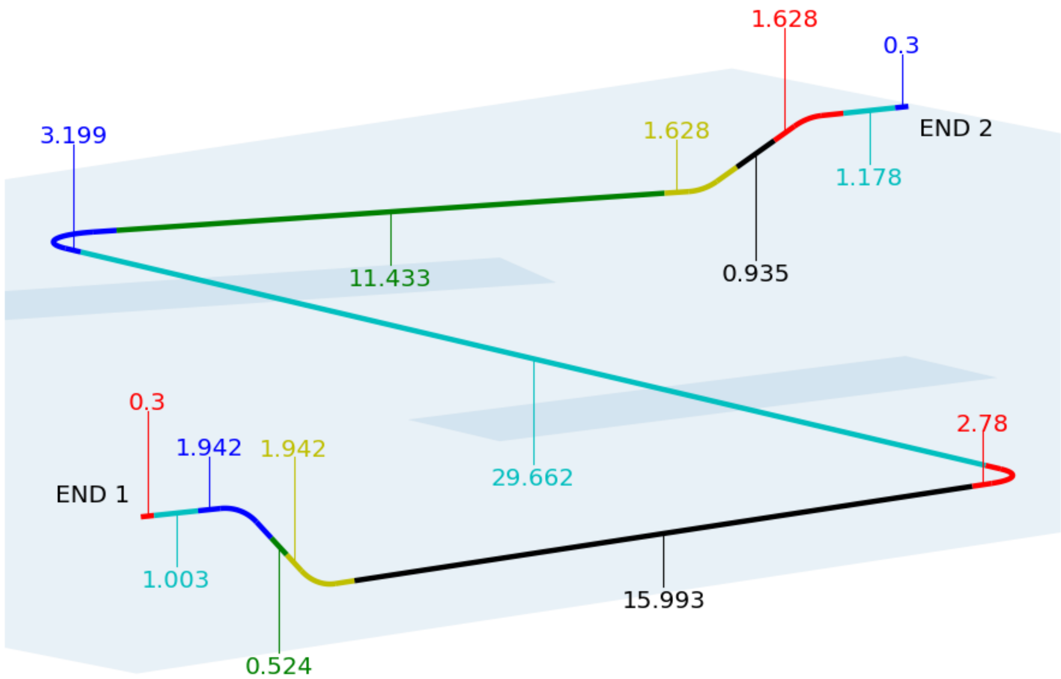
The coordinates at the spool ends and at the intersection points between the extended straight lines / sections, are presented in Table 6.1.

Table 6.1 – Coordinates at Ends and Intersection Points

Location	Coordinates [m]		
	X / Easting	Y / Northing	Z / Vertical
End 1	-1.111	7.6	2.4
IP-1	-1.059	7.896	2.4
IP-2	-0.712	9.865	2.4
IP-3	-0.556	11.646	0.626
IP-4	-0.556	30.236	0.626
IP-5	-33.755	33.141	0.626
IP-6	-28.858	46.595	0.626
IP-7	-28.278	48.76	1.9
IP-8	-27.931	50.73	1.9
End 2	-27.878	51.025	1.9

An isometric view of the spool showing each section length (units in meter) is shown in Figure 6.2.

Figure 6.2 – Isometric View with Section Lengths



6.3 Load Cases

A set of 16 load case combinations has been analysed, as presented in Table 6.2. The prescribed end displacement / rotation values refer to uncertainties regarding make-up tolerances at each spool end.

Table 6.2 – Load Case Combinations

Load Case	END 1						END 2					
	Displacements [m]			Rotations [deg]			Displacements [m]			Rotations [deg]		
	ux	uy	uz	rx	ry	rz	ux	uy	uz	rx	ry	rz
1	0.09	0.09	0.1	Free	0.55	-0.7	0.09	0.09	0.1	Free	0.55	-0.7
2	0.09	0.09	0.1	Free	0.55	-0.7	0.09	0.09	-0.1	Free	-0.55	-0.7
3	0.09	0.09	-0.1	Free	-0.55	-0.7	0.09	0.09	0.1	Free	0.55	-0.7
4	0.09	0.09	-0.1	Free	-0.55	-0.7	0.09	0.09	-0.1	Free	-0.55	-0.7
5	0.09	-0.09	0.1	Free	0.55	0.7	0.09	-0.09	0.1	Free	0.55	0.7
6	0.09	-0.09	0.1	Free	0.55	0.7	0.09	-0.09	-0.1	Free	-0.55	0.7
7	0.09	-0.09	-0.1	Free	-0.55	0.7	0.09	-0.09	0.1	Free	0.55	0.7
8	0.09	-0.09	-0.1	Free	-0.55	0.7	0.09	-0.09	-0.1	Free	-0.55	0.7
9	-0.09	0.09	0.1	Free	0.55	-0.7	-0.09	0.09	0.1	Free	0.55	-0.7
10	-0.09	0.09	0.1	Free	0.55	-0.7	-0.09	0.09	-0.1	Free	-0.55	-0.7
11	-0.09	0.09	-0.1	Free	-0.55	-0.7	-0.09	0.09	0.1	Free	0.55	-0.7
12	-0.09	0.09	-0.1	Free	-0.55	-0.7	-0.09	0.09	-0.1	Free	-0.55	-0.7
13	-0.09	-0.09	0.1	Free	0.55	0.7	-0.09	-0.09	0.1	Free	0.55	0.7
14	-0.09	-0.09	0.1	Free	0.55	0.7	-0.09	-0.09	-0.1	Free	-0.55	0.7
15	-0.09	-0.09	-0.1	Free	-0.55	0.7	-0.09	-0.09	0.1	Free	0.55	0.7
16	-0.09	-0.09	-0.1	Free	-0.55	0.7	-0.09	-0.09	-0.1	Free	-0.55	0.7

The parameter "Free" indicates that no tolerances have been applied, i.e. as the termination unit is free to swivel around the pipe axis prior to and during tie-ins.

6.4 Load Steps

The spool have been analysed for the subsequent load steps presented in Table 6.3.

Table 6.3 – Subsequent Load Steps

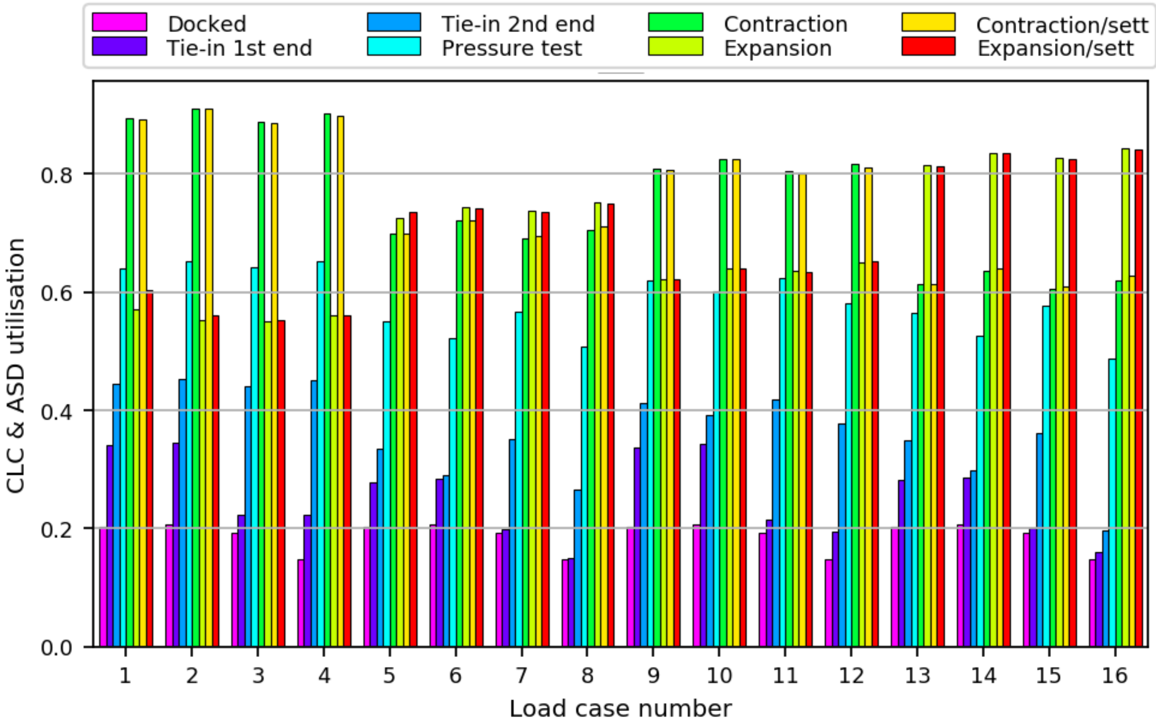
Load Step	Internal Pressure [bara]	Temperature [°C]	Content Density [kg/m3]	Axial Expansion - End 2 [m]
Docked	20	10	1150	0
Tie-in 1st end	20	10	1150	0
Tie-in 2nd end	20	10	1150	0
Pressure test	400	10	1150	0
Contraction	300	-20	250	-1.0
Expansion	300	100	250	3.0
Contraction/sett	300	-20	250	-1.0
Expansion/sett	300	100	250	3.0

Positive axial expansion is in the direction opposite to the tie-in stroking direction.

6.5 Spool CLC / ASD Utilisation

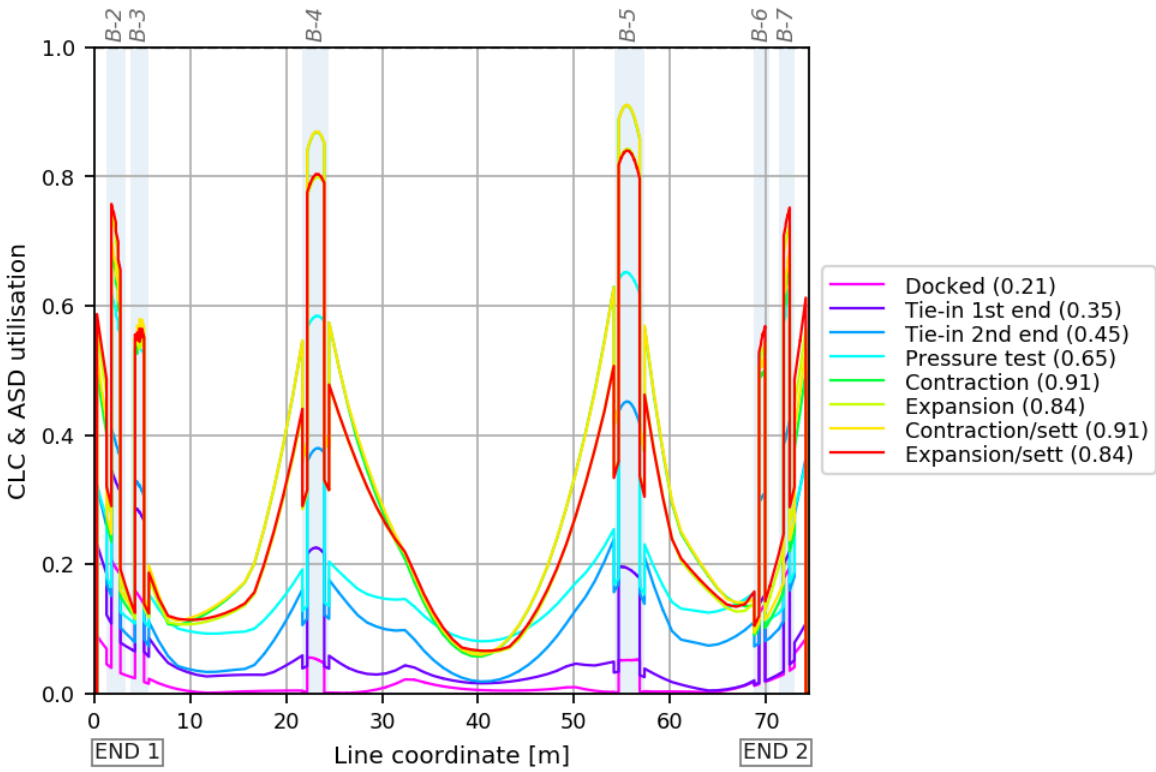
The maximum CLC / ASD utilisation along the spool, for each load case and load step, is shown in Figure 6.3.

Figure 6.3 – Maximum CLC / ASD Utilisation for Each Load Case and Load Step



A CLC / ASD utilisation envelope plot from all load cases and for each analysed subsequent load step is shown in Figure 6.4.

Figure 6.4 – Spool CLC / ASD Utilisation

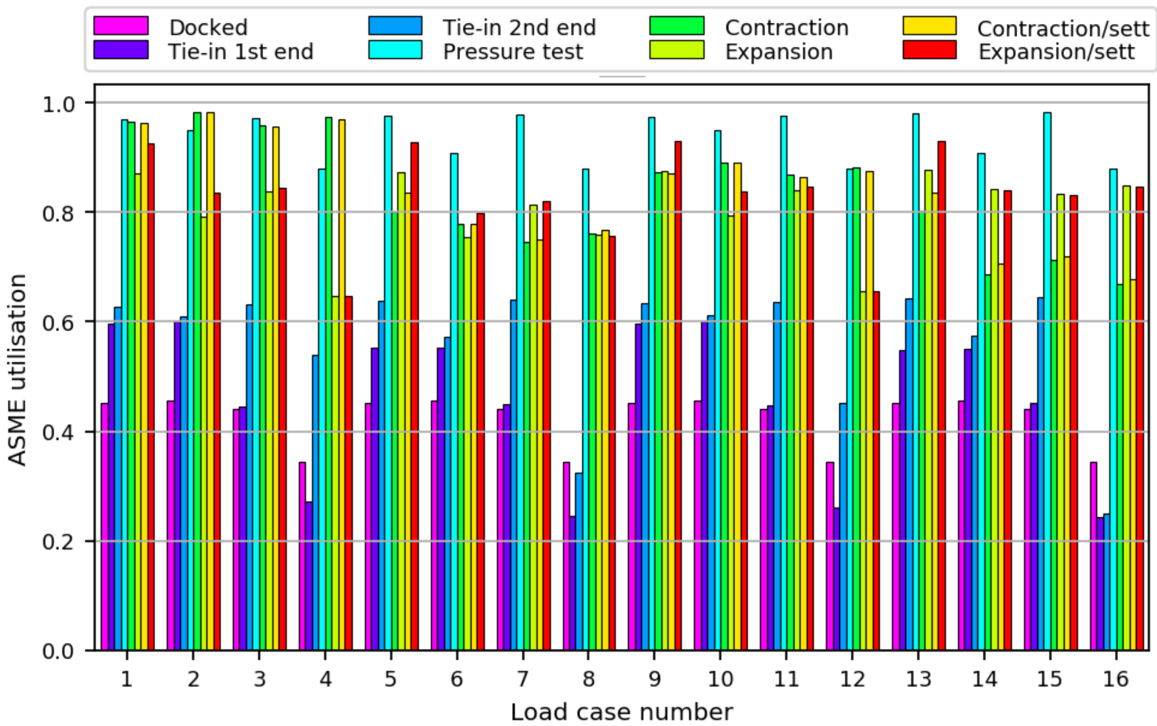


The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

6.6 Spool ASME Utilisation

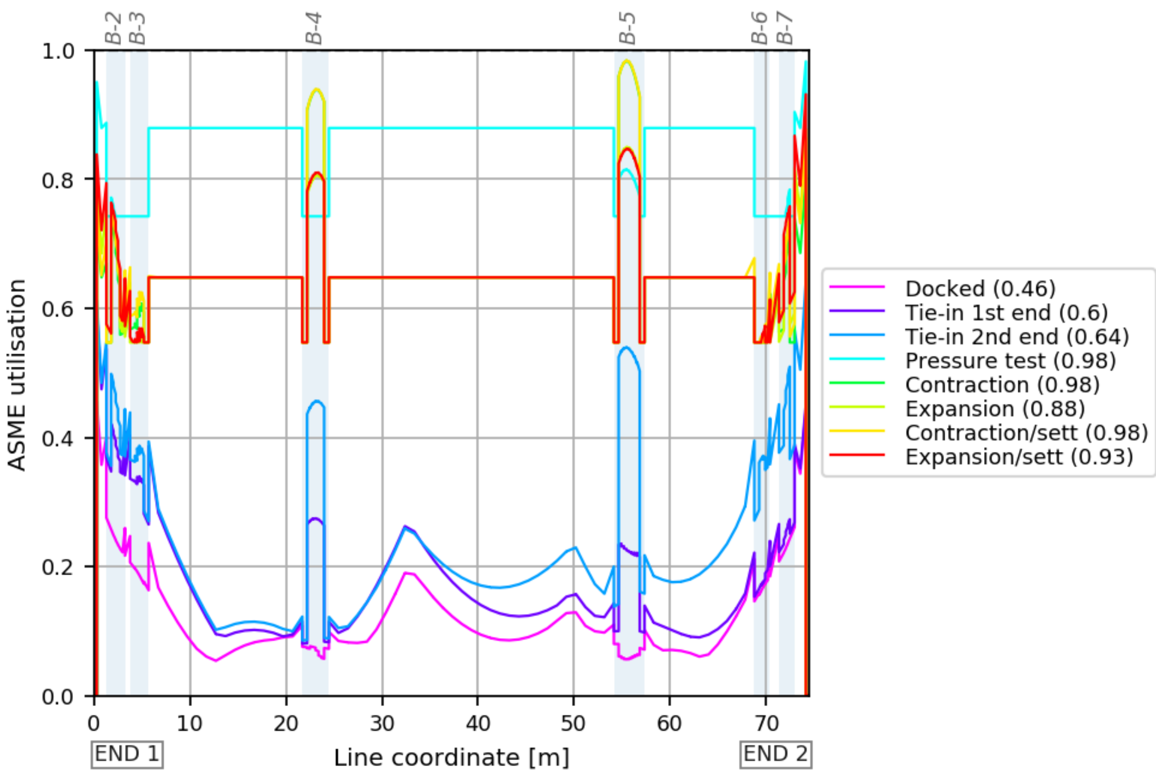
The maximum ASME utilisation along the spool, for each load case and load step, is shown in Figure 6.5.

Figure 6.5 – Maximum ASME Utilisation for Each Load Case and Load Step



An ASME utilisation envelope plot from all load cases and for each analysed subsequent load step is shown in Figure 6.6.

Figure 6.6 – Spool ASME Utilisation



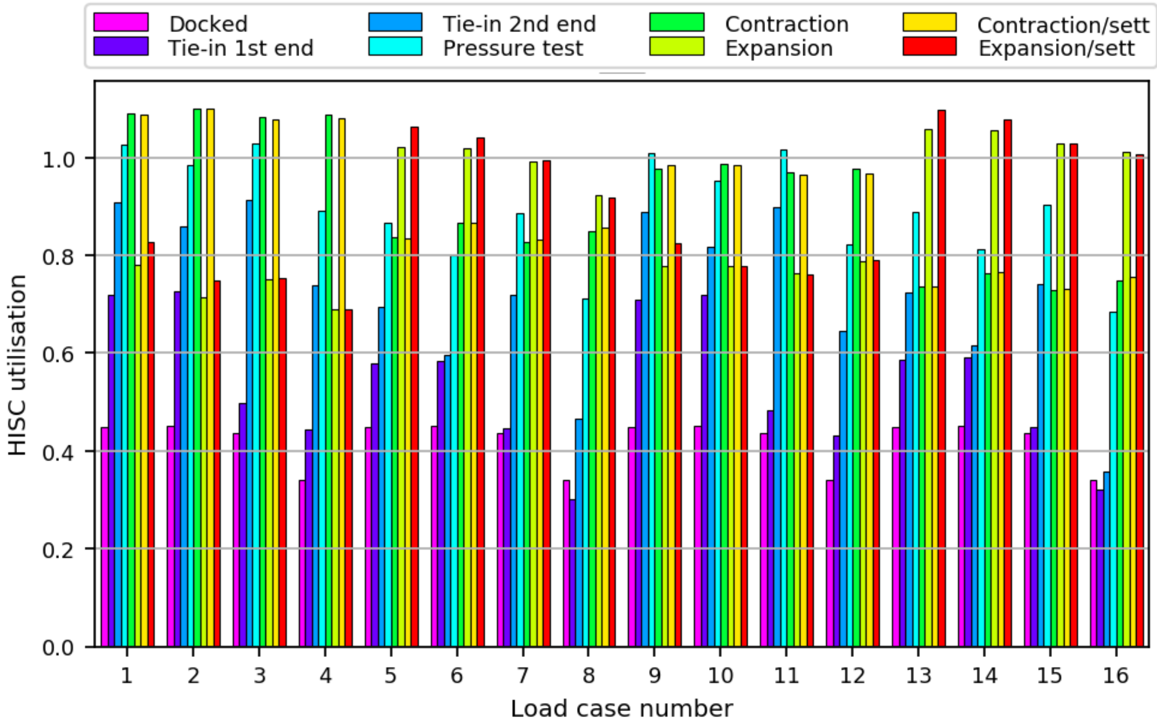
The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

Stress Intensification Factors, according to Ref. [ASME B31.8], have been accounted for when calculating utilisations in the bends and at welds.

6.7 Spool HISC Utilisation

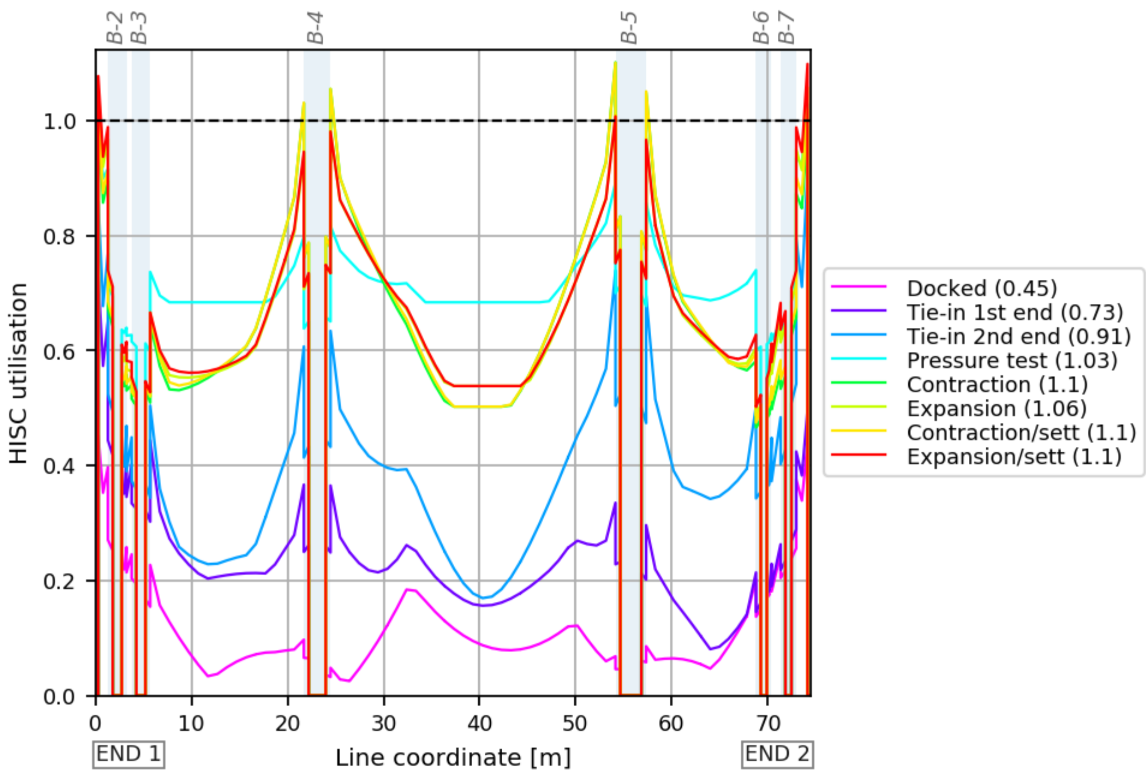
The maximum HISC utilisation along the spool, for each load case and load step, is shown in Figure 6.7.

Figure 6.7 – Maximum HISC Utilisation for Each Load Case and Load Step



A HISC utilisation envelope plot from all load cases and for each analysed subsequent load step is shown in Figure 6.8.

Figure 6.8 – Spool HISC Utilisation



The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

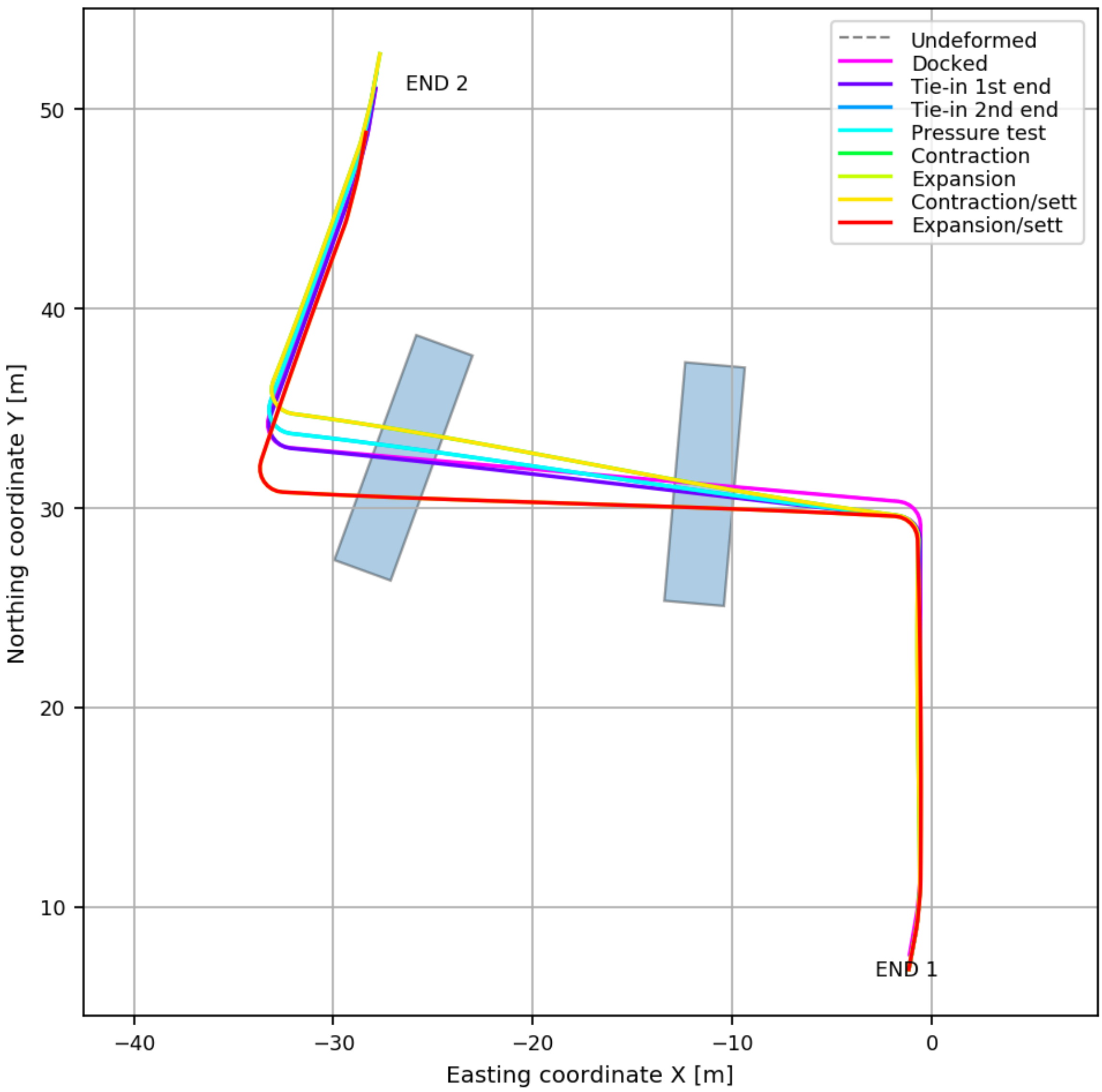
Longitudinal Stress Concentration Factors has been applied at each weld.

The spool bends (curved part) have not been assessed, since beam elements have been used in this assessment. HISC assessment in bends requires the use of either shell- or solid FE-models, in order to capture the ovalisation effects, which are causing high stress gradients across the wall thickness, as well as great stress variations around the circumference.

6.7.1 Most Utilised Load Case - Number 2

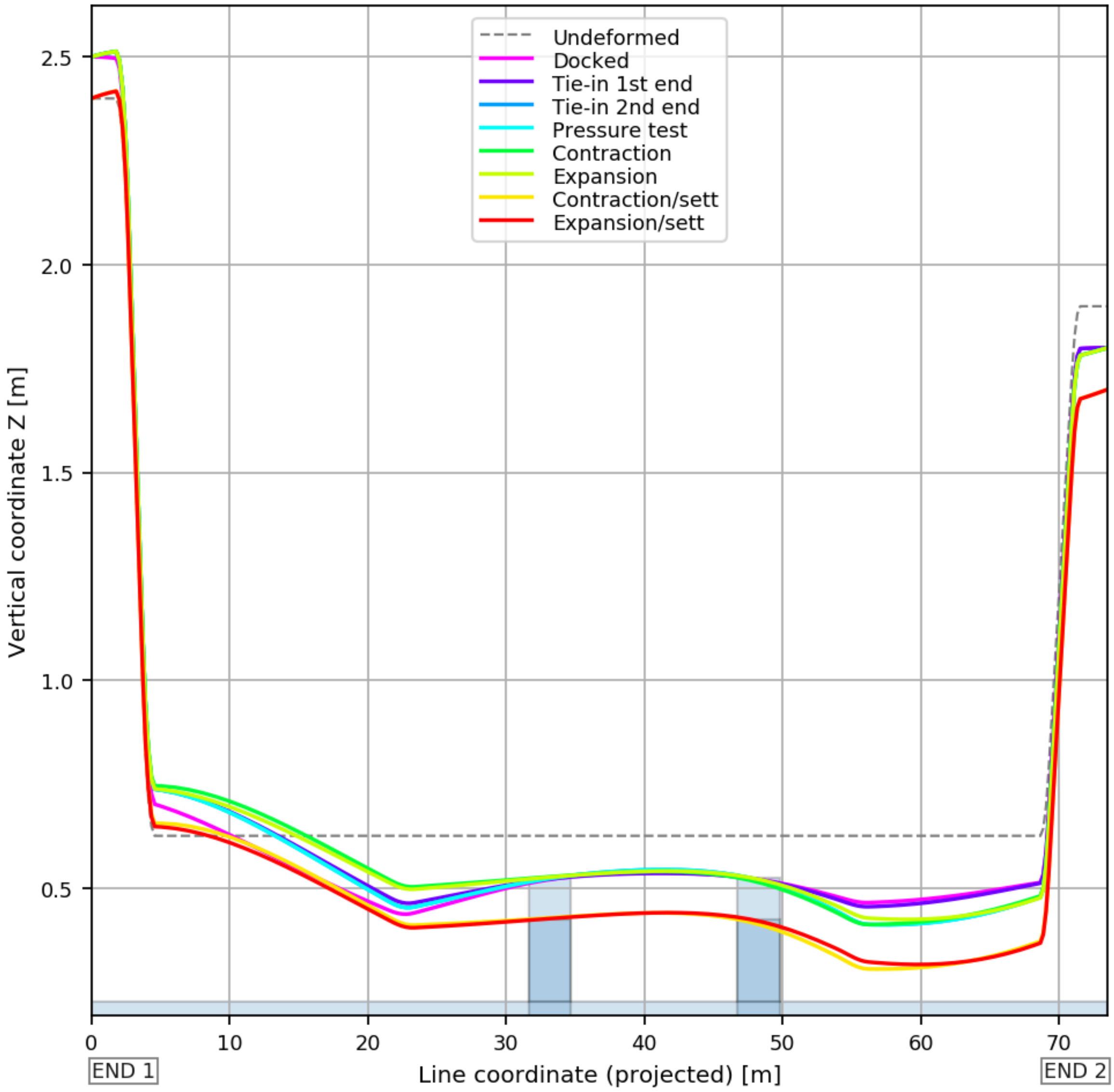
A top-view of the deformed shapes, for the most utilised load case (number 2), are shown for each load step in Figure 6.9.

Figure 6.9 – Top-View of Deformed Shapes of Critical Load Case



A profile view of the deformed shapes, for the most utilised load case (number 2), are shown for each load step in Figure 6.10.

Figure 6.10 – Profile View Deformed Shape of Critical Load Case



6.8 Spool End Reaction Loads

The weight of Termination Units has not been included in the assessment. This will primary affect the vertical reaction force RFz and secondary the reaction moment RMy.

6.8.1 End 1

The maximum magnitude reaction loads at End 1 of the spool, from any of the analysed load cases, are presented in Table 6.4 for each subsequent load step.

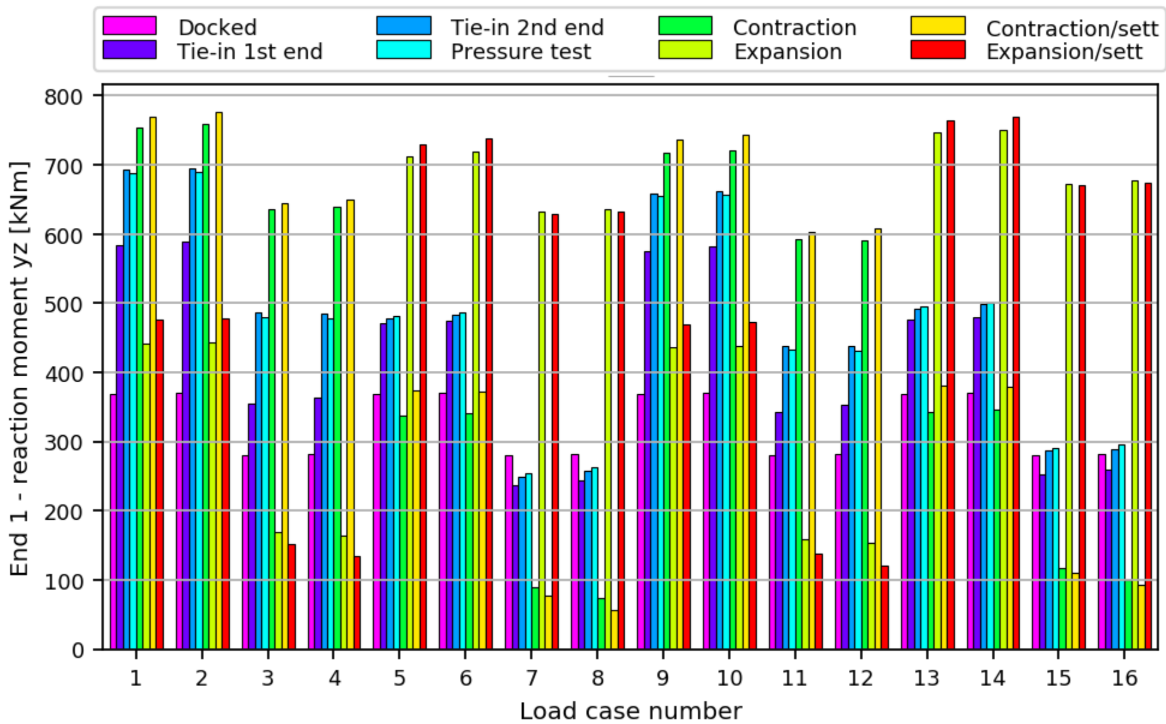
Table 6.4 – Maximum Magnitude Reaction Loads at End 1

Load Step	End Reaction Forces [kN]			End Reaction Moments [kNm]			
	RFx	RFy	RFz	RMx	RMy	RMz	RMb
Docked	4.3	2.6	84.1	0.0	370.3	-18.5	370.6
Tie-in 1st end	27.6	32.9	91.3	0.0	487.4	-331.9	589.7
Tie-in 2nd end	23.9	49.6	91.8	30.0	495.2	-491.4	694.5
Pressure test	23.0	48.8	91.8	28.7	496.3	-484.4	689.5
Contraction	45.0	75.1	78.0	59.7	374.9	-660.3	758.3
Expansion	-33.6	-66.3	75.6	-113.4	436.0	667.7	750.4
Contraction/sett	45.4	75.2	79.5	70.6	406.9	-663.5	777.2
Expansion/sett	-35.6	-66.4	77.2	-121.5	470.2	668.4	769.1
Max	45.4	75.2	91.8	-121.5	496.3	668.4	777.2

The maximum loads are presented for any of the analysed load cases and do not necessarily occur concurrently.

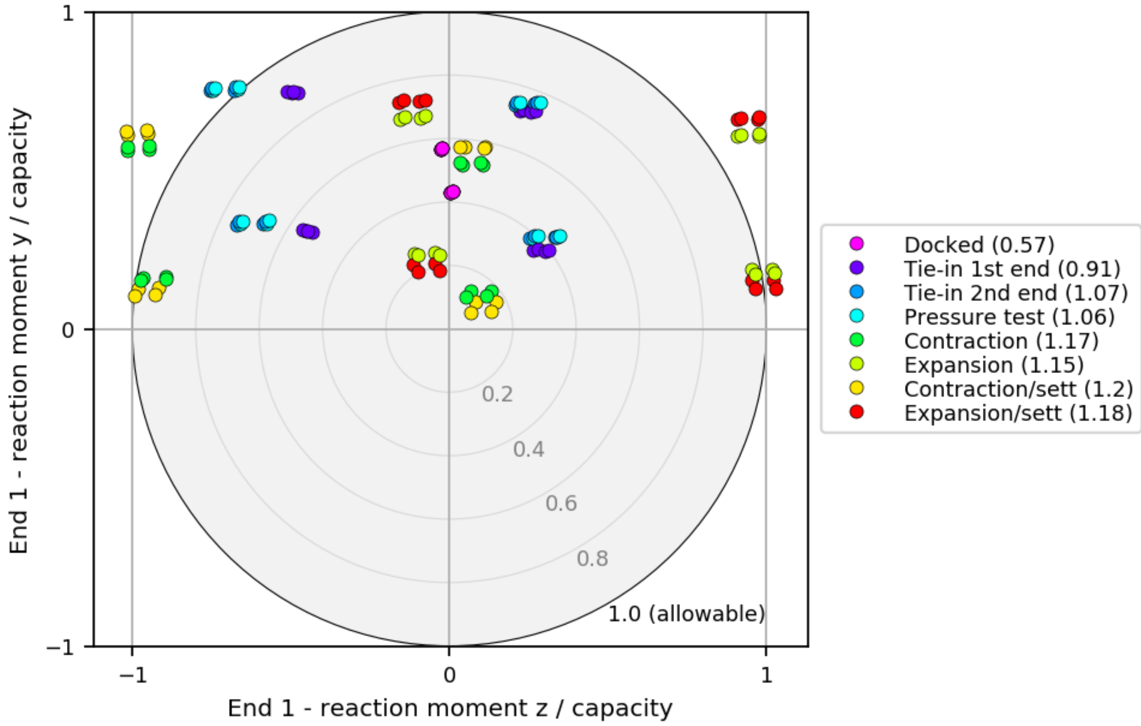
The maximum magnitude reaction bending moment at End 1, for each load case and load step, is shown in Figure 6.11.

Figure 6.11 – Maximum Magnitude Reaction Bending Moment at End 1



The connector / hub bending moment utilisations (RMy vs. RMz) at End 1, for all load cases and load steps, are shown in Figure 6.12.

Figure 6.12 – Reaction Bending Moment Components at End 1



The shaded circular area indicates the allowable. The maximum utilisation is presented for each load step within parenthesis in the figure legend.

6.8.2 End 2

The maximum magnitude reaction loads at End 2 of the spool, from any of the analysed load cases, are presented in Table 6.5 for each subsequent load step.

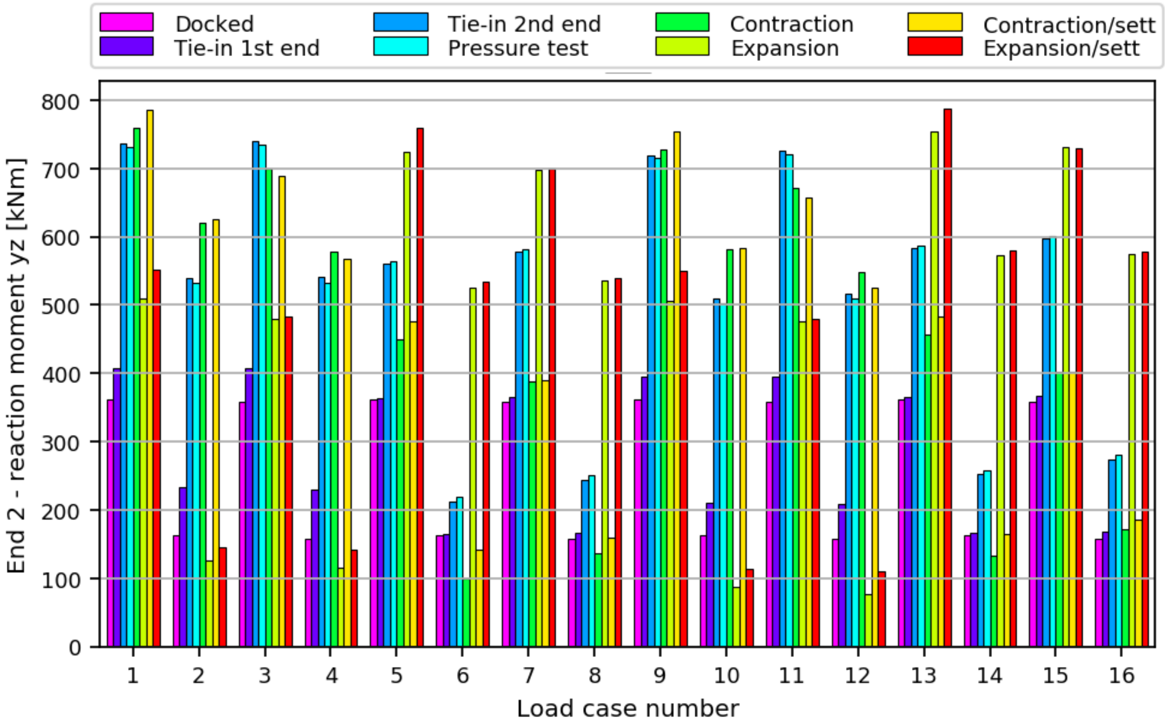
Table 6.5 – Maximum Magnitude Reaction Loads at End 2

Load Step	End Reaction Forces [kN]			End Reaction Moments [kNm]			
	RFx	RFy	RFz	RMx	RMy	RMz	RMb
Docked	5.1	-1.4	83.3	-0.0	361.8	17.5	361.9
Tie-in 1st end	-10.4	23.4	84.0	-0.0	367.0	-190.0	407.8
Tie-in 2nd end	47.0	58.3	94.9	0.0	521.9	-539.2	739.4
Pressure test	44.8	57.6	94.8	-0.8	522.2	-531.3	734.0
Contraction	58.3	75.7	83.9	17.7	450.9	-614.7	758.7
Expansion	-52.8	-66.7	81.3	-102.6	504.4	574.2	754.6
Contraction/sett	59.2	75.5	86.5	17.8	496.7	-611.8	786.0
Expansion/sett	-52.3	-66.5	84.0	-108.6	546.5	575.0	788.3
Max	59.2	75.7	94.9	-108.6	546.5	-614.7	788.3

The maximum loads are presented for any of the analysed load cases and do not necessarily occur concurrently.

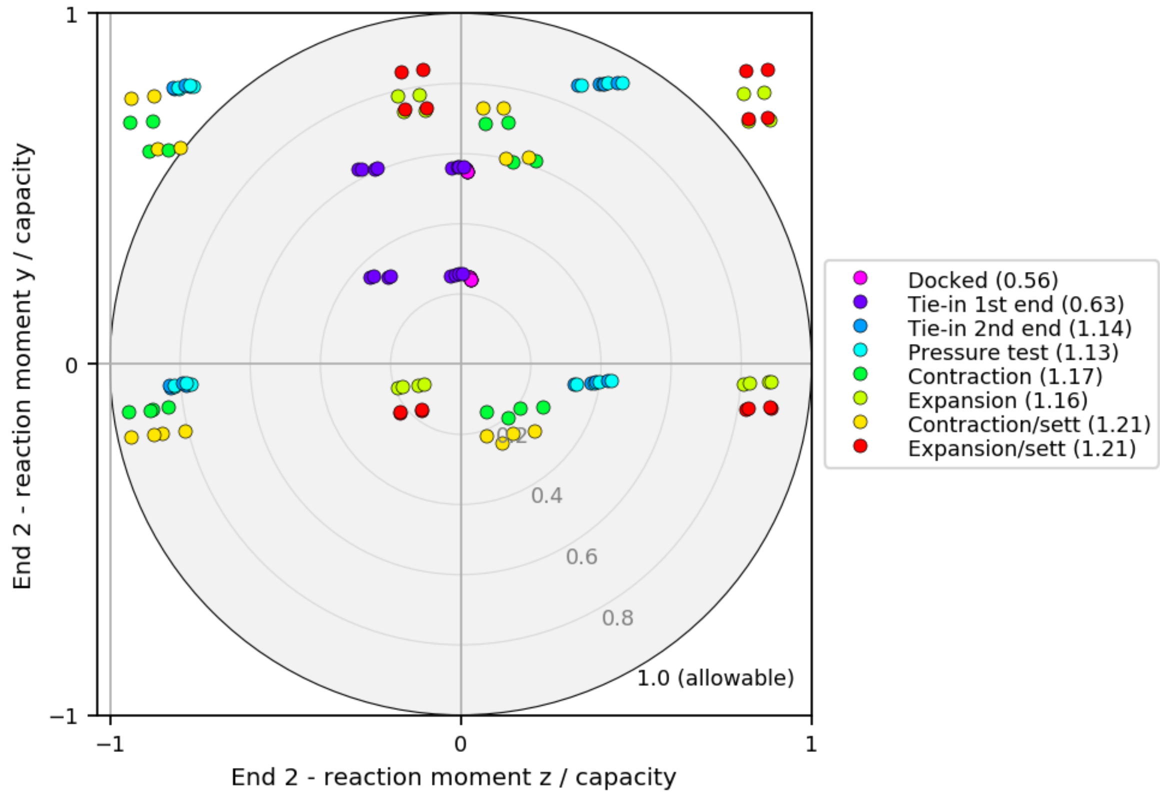
The maximum magnitude reaction bending moment at End 2, for each load case and load step, is shown in Figure 6.13.

Figure 6.13 – Maximum Magnitude Reaction Bending Moment at End 2



The connector / hub bending moment utilisations (RMy vs. RMz) at End 2, for all load cases and load steps, are shown in Figure 6.14.

Figure 6.14 – Reaction Bending Moment Components at End 2

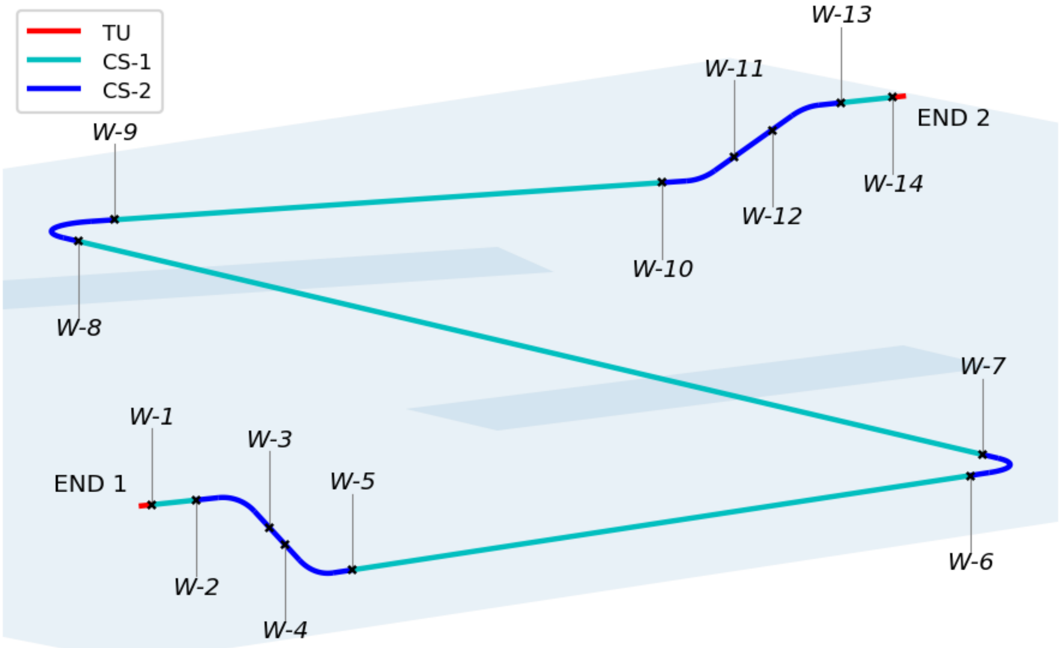


The shaded circular area indicates the allowable. The maximum utilisation is presented for each load step within parenthesis in the figure legend.

6.9 FATIGUE DAMAGE DUE TO VIV

The welds assessed for fatigue damage due to VIV are shown in Figure 6.15.

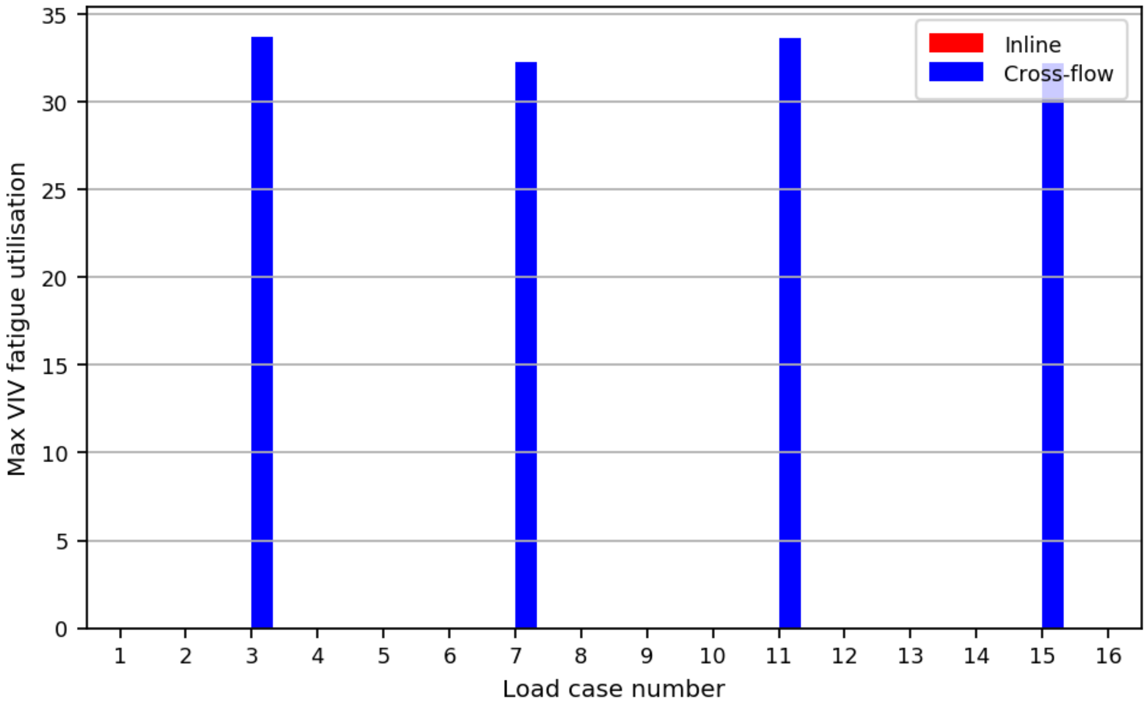
Figure 6.15 – Assessed Welds



Note that additional welds will be present where the pipe section exceeds the pipe joint length.

The maximum VIV fatigue utilisations for each load case are shown in Figure 6.16.

Figure 6.16 – Maximum VIV Fatigue Utilisation for Each Load Case

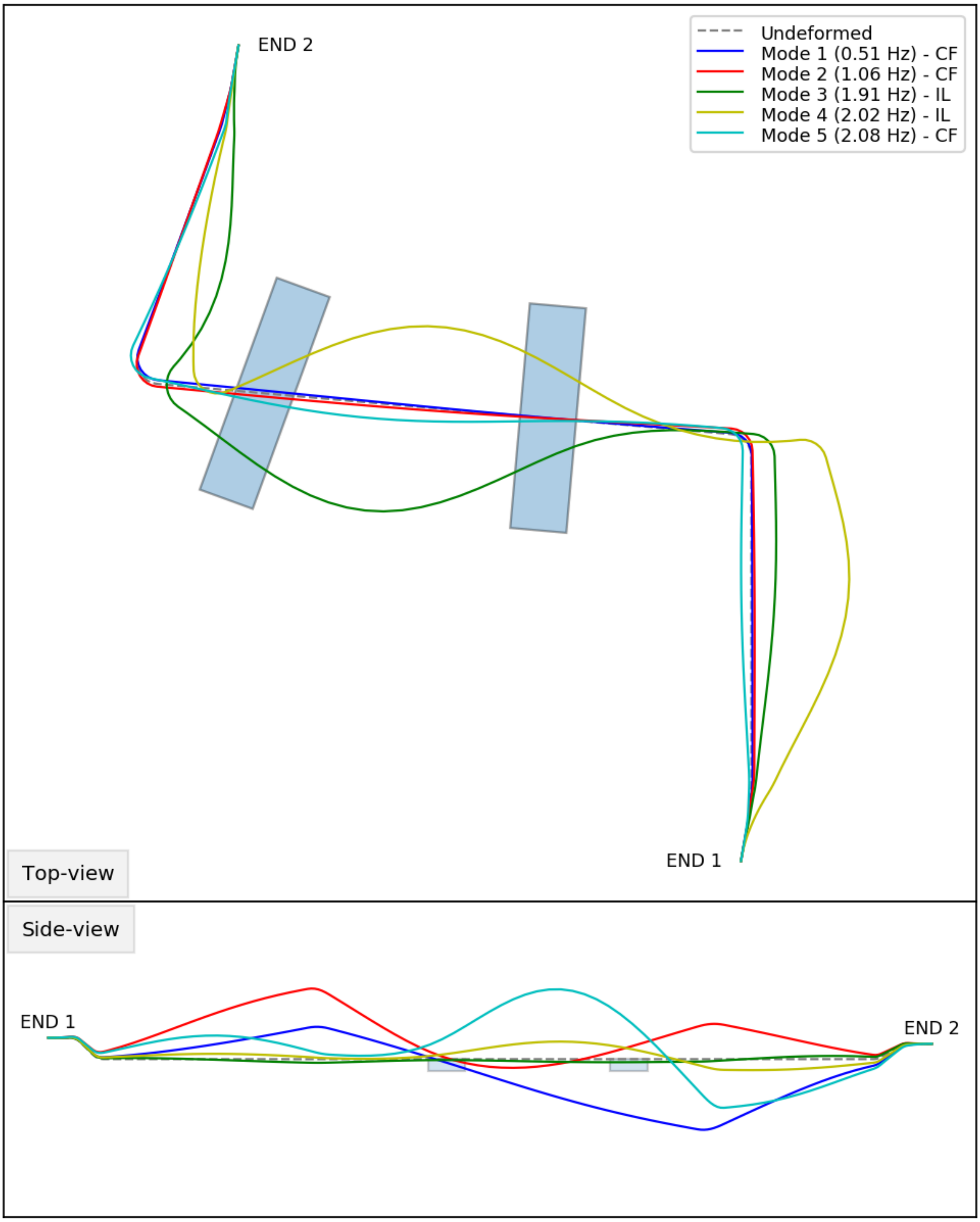


Inline and Cross-Flow utilisations are presented separately, and indicated that the damage has been accumulate at a specific location around the circumference.

It should be noted that both inline and cross-flow induced vibrations can potentially accrue damage at any location around the pipe circumference.

The Eigen-modes corresponding to the five lowest frequencies for load case number 3 (most critical in terms of fatigue damage) are shown in Figure 6.17.

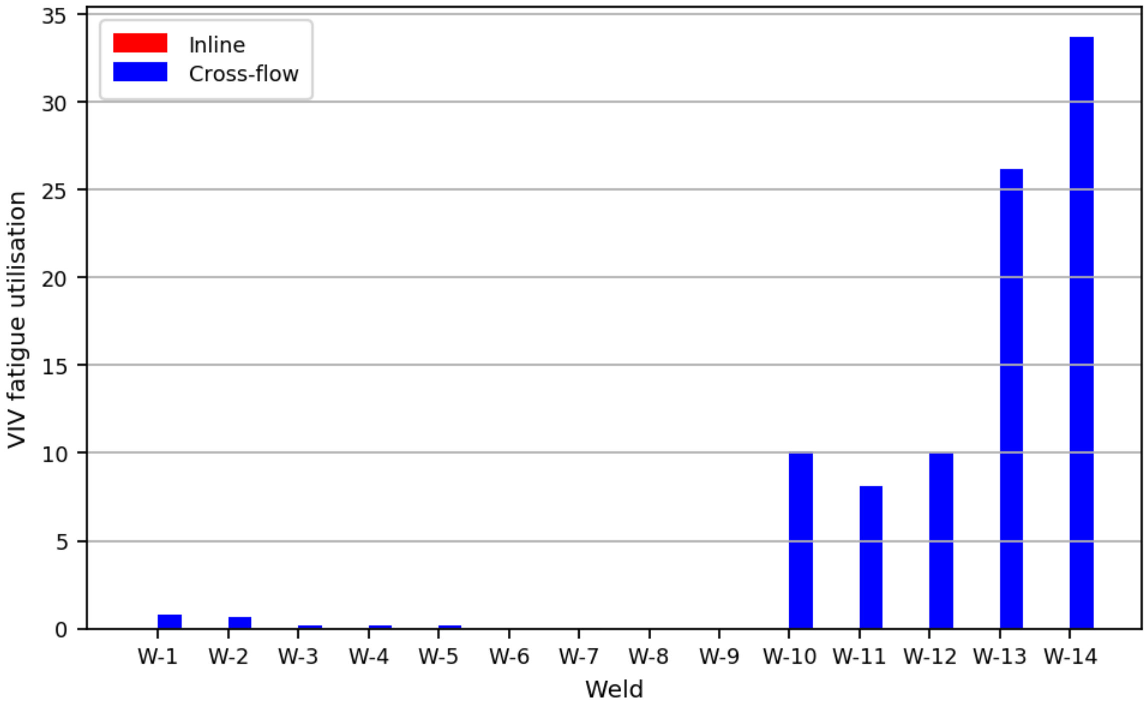
Figure 6.17 – Eigen-Modes of Most Utilised Load Case



The corresponding natural frequencies are presented within parenthesis in the figure legend, where the dominating mode type is denoted IL and / or CF.

The maximum VIV fatigue utilisation (all load cases) in each weld is shown in Figure 6.18.

Figure 6.18 – Maximum VIV Fatigue Utilisation at Each Weld



6.10 Support Loads

The maximum vertical support forces, from any of the analysed load cases, are presented in Table 6.6, for each subsequent load step.

Table 6.6 – Maximum Vertical Forces Acting on Supports and Seabed

Load Step	Vertical Force [kN]		
	SEABED	Support-1	Support-2
Docked	0.0	54.4	39.8
Tie-in 1st end	0.0	60.8	44.5
Tie-in 2nd end	0.0	64.6	56.2
Pressure test	0.0	64.6	56.3
Contraction	0.0	37.2	42.0
Expansion	0.0	40.5	44.1
Contraction/sett	0.0	38.3	45.9
Expansion/sett	0.0	41.6	48.0
Max	0.0	64.6	56.3

Note that the maximum loads are presented for any of the analysed load cases and do not necessarily occur concurrently.

7 CONFIGURATION MIN_L3

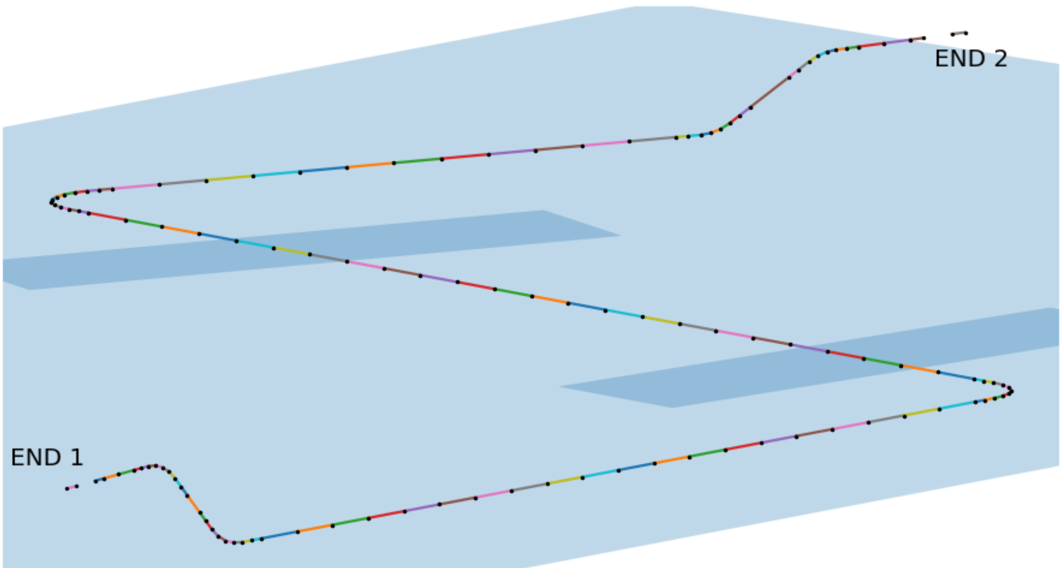
This section presents the following detailed results for configuration "min_L3".

- FE-model
- Spool geometry
- Load cases
- Load steps
- Spool CLC / ASD utilisation
- Spool ASME utilisation
- Spool HISC utilisation
- Spool end reaction loads
- Fatigue damage due to VIV
- Support loads

7.1 FE-MODEL

The FE-model consists of the spool and two connecting structures at each end. The mesh density used is shown in Figure 7.1.

Figure 7.1 – FE-Model Mesh



The beam / pipe elements are shown as lines and with the associated nodes are shown as black dots. The nodes belonging to the area elements are not shown.

The spool consists of three different cross-section types.

7.2 SPOOL GEOMETRY

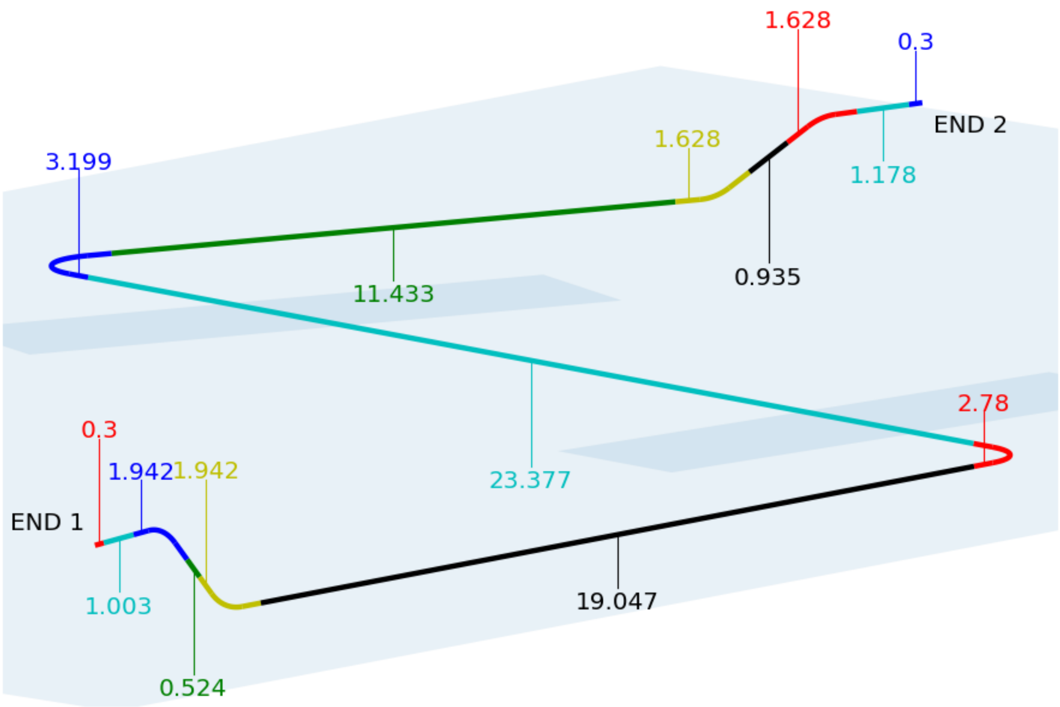
The coordinates at the spool ends and at the intersection points between the extended straight lines / sections, are presented in Table 7.1.

Table 7.1 – Coordinates at Ends and Intersection Points

Location	Coordinates [m]		
	X / Easting	Y / Northing	Z / Vertical
End 1	-6.262	5.094	2.4
IP-1	-6.314	5.389	2.4
IP-2	-6.661	7.359	2.4
IP-3	-6.817	9.14	0.626
IP-4	-6.817	30.784	0.626
IP-5	-33.755	33.141	0.626
IP-6	-28.858	46.595	0.626
IP-7	-28.278	48.76	1.9
IP-8	-27.931	50.73	1.9
End 2	-27.878	51.025	1.9

An isometric view of the spool showing each section length (units in meter) is shown in Figure 7.2.

Figure 7.2 – Isometric View with Section Lengths



7.3 LOAD CASES

A set of 16 load case combinations has been analysed, as presented in Table 7.2. The prescribed end displacement / rotation values refer to uncertainties regarding make-up tolerances at each spool end.

Table 7.2 – Load Case Combinations

Load Case	END 1						END 2					
	Displacements [m]			Rotations [deg]			Displacements [m]			Rotations [deg]		
	ux	uy	uz	rx	ry	rz	ux	uy	uz	rx	ry	rz
1	0.09	0.09	0.1	Free	0.55	-0.7	0.09	0.09	0.1	Free	0.55	-0.7
2	0.09	0.09	0.1	Free	0.55	-0.7	0.09	0.09	-0.1	Free	-0.55	-0.7
3	0.09	0.09	-0.1	Free	-0.55	-0.7	0.09	0.09	0.1	Free	0.55	-0.7
4	0.09	0.09	-0.1	Free	-0.55	-0.7	0.09	0.09	-0.1	Free	-0.55	-0.7
5	0.09	-0.09	0.1	Free	0.55	0.7	0.09	-0.09	0.1	Free	0.55	0.7
6	0.09	-0.09	0.1	Free	0.55	0.7	0.09	-0.09	-0.1	Free	-0.55	0.7
7	0.09	-0.09	-0.1	Free	-0.55	0.7	0.09	-0.09	0.1	Free	0.55	0.7
8	0.09	-0.09	-0.1	Free	-0.55	0.7	0.09	-0.09	-0.1	Free	-0.55	0.7
9	-0.09	0.09	0.1	Free	0.55	-0.7	-0.09	0.09	0.1	Free	0.55	-0.7
10	-0.09	0.09	0.1	Free	0.55	-0.7	-0.09	0.09	-0.1	Free	-0.55	-0.7
11	-0.09	0.09	-0.1	Free	-0.55	-0.7	-0.09	0.09	0.1	Free	0.55	-0.7
12	-0.09	0.09	-0.1	Free	-0.55	-0.7	-0.09	0.09	-0.1	Free	-0.55	-0.7
13	-0.09	-0.09	0.1	Free	0.55	0.7	-0.09	-0.09	0.1	Free	0.55	0.7
14	-0.09	-0.09	0.1	Free	0.55	0.7	-0.09	-0.09	-0.1	Free	-0.55	0.7
15	-0.09	-0.09	-0.1	Free	-0.55	0.7	-0.09	-0.09	0.1	Free	0.55	0.7
16	-0.09	-0.09	-0.1	Free	-0.55	0.7	-0.09	-0.09	-0.1	Free	-0.55	0.7

The parameter "Free" indicates that no tolerances have been applied, i.e. as the termination unit is free to swivel around the pipe axis prior to and during tie-ins.

7.4 LOAD STEPS

The spool have been analysed for the subsequent load steps presented in Table 7.3.

Table 7.3 – Subsequent Load Steps

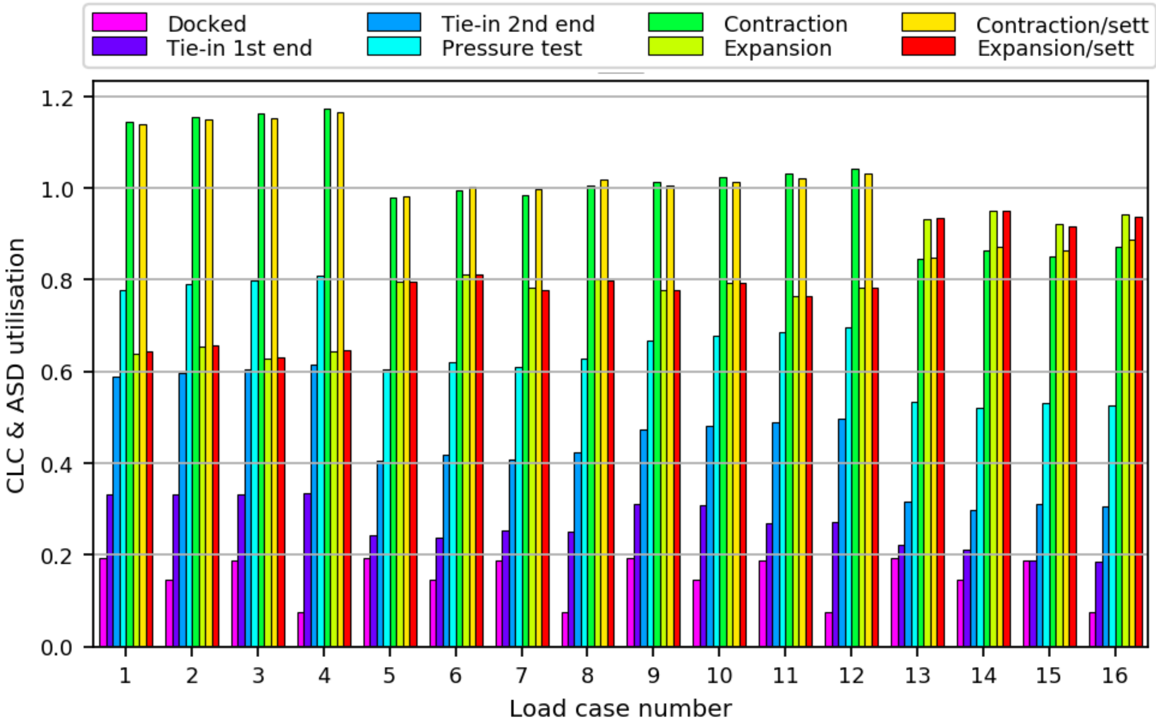
Load Step	Internal Pressure [bara]	Temperature [°C]	Content Density [kg/m3]	Axial Expansion - End 2 [m]
Docked	20	10	1150	0
Tie-in 1st end	20	10	1150	0
Tie-in 2nd end	20	10	1150	0
Pressure test	400	10	1150	0
Contraction	300	-20	250	-1.0
Expansion	300	100	250	3.0
Contraction/sett	300	-20	250	-1.0
Expansion/sett	300	100	250	3.0

Positive axial expansion is in the direction opposite to the tie-in stroking direction.

7.5 SPOOL CLC / ASD UTILISATION

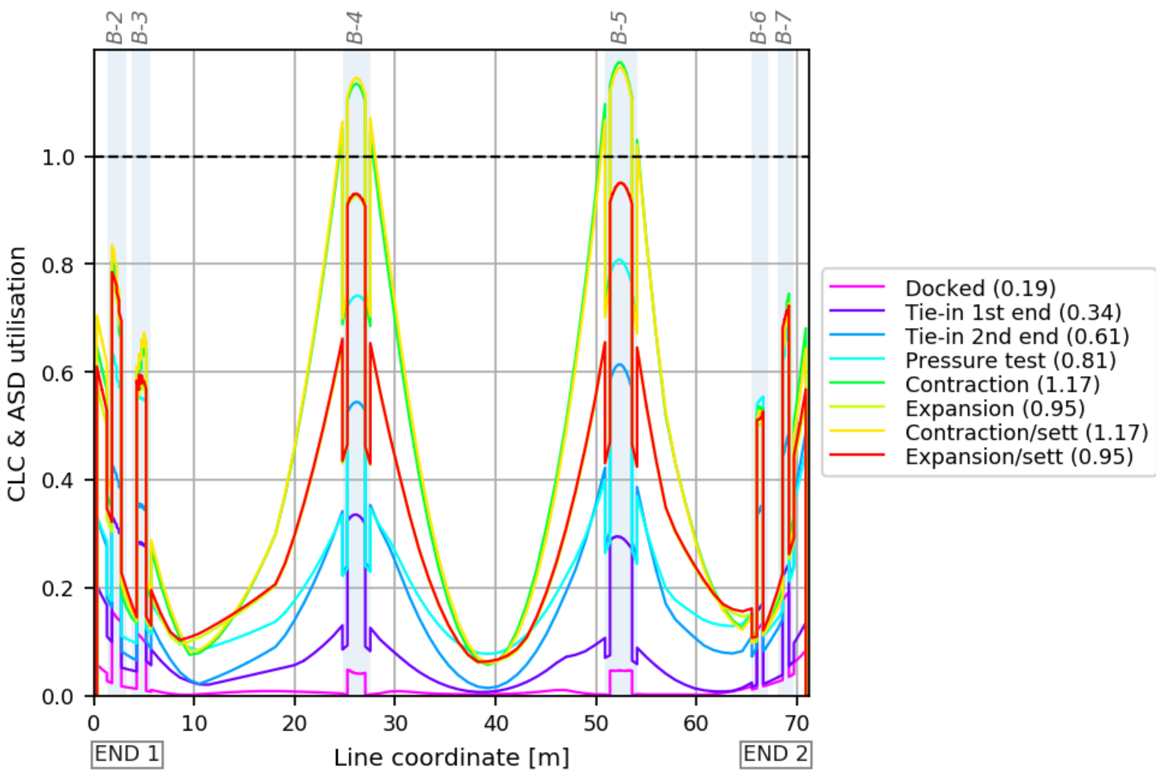
The maximum CLC / ASD utilisation along the spool, for each load case and load step, is shown in Figure 7.3.

Figure 7.3 – Maximum CLC / ASD Utilisation for Each Load Case and Load Step



A CLC / ASD utilisation envelope plot from all load cases and for each analysed subsequent load step is shown in Figure 7.4.

Figure 7.4 – Spool CLC / ASD Utilisation

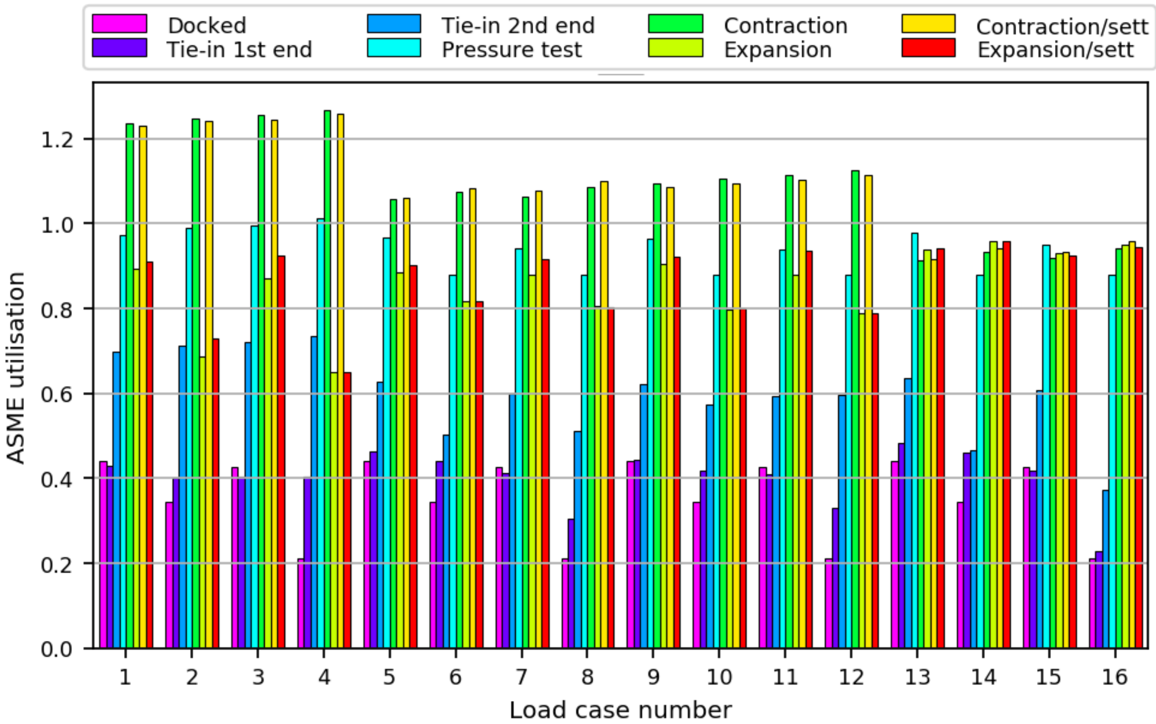


The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

7.6 SPOOL ASME UTILISATION

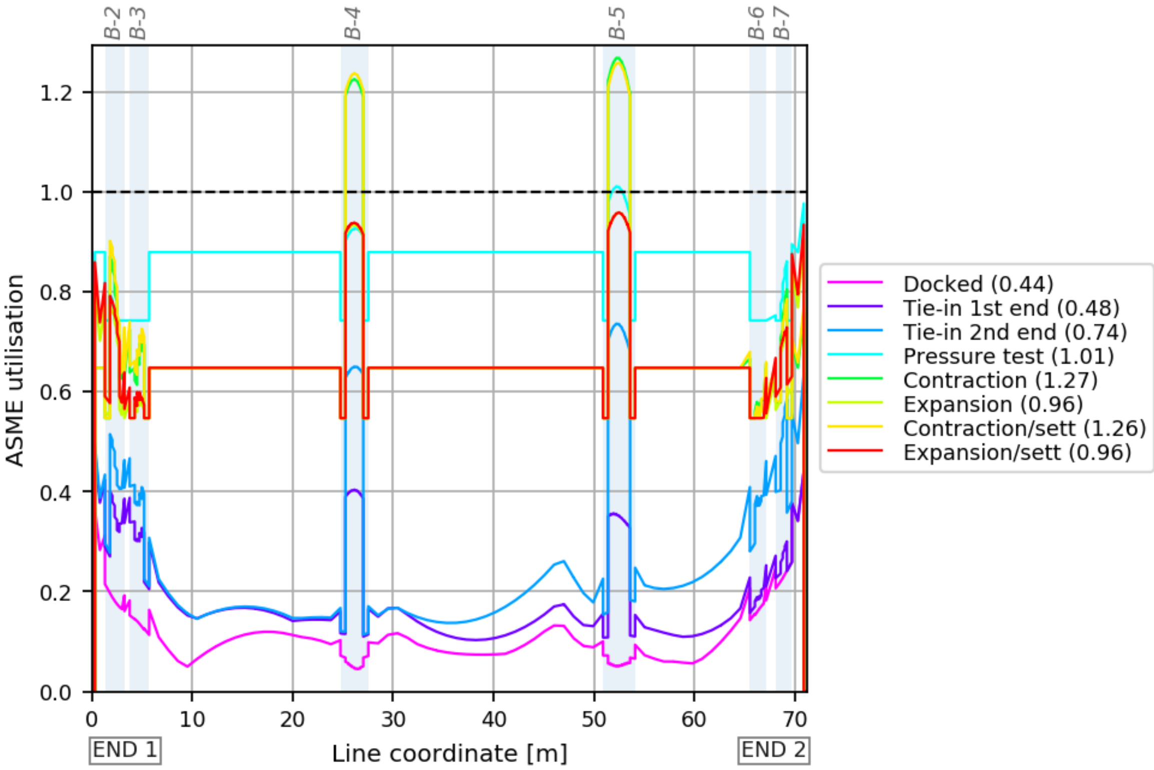
The maximum ASME utilisation along the spool, for each load case and load step, is shown in Figure 7.5.

Figure 7.5 – Maximum ASME Utilisation for Each Load Case and Load Step



An ASME utilisation envelope plot from all load cases and for each analysed subsequent load step is shown in Figure 7.6.

Figure 7.6 – Spool ASME Utilisation



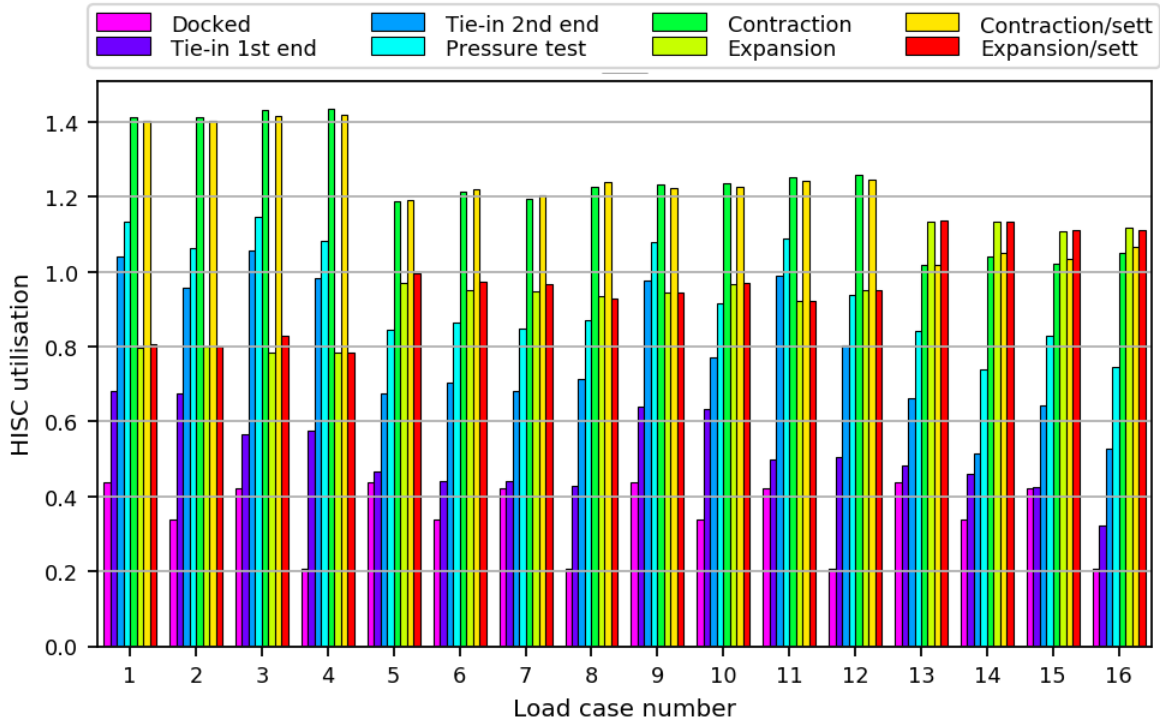
The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

Stress Intensification Factors, according to Ref. [ASME B31.8], have been accounted for when calculating utilisations in the bends and at welds.

7.7 SPOOL HISC UTILISATION

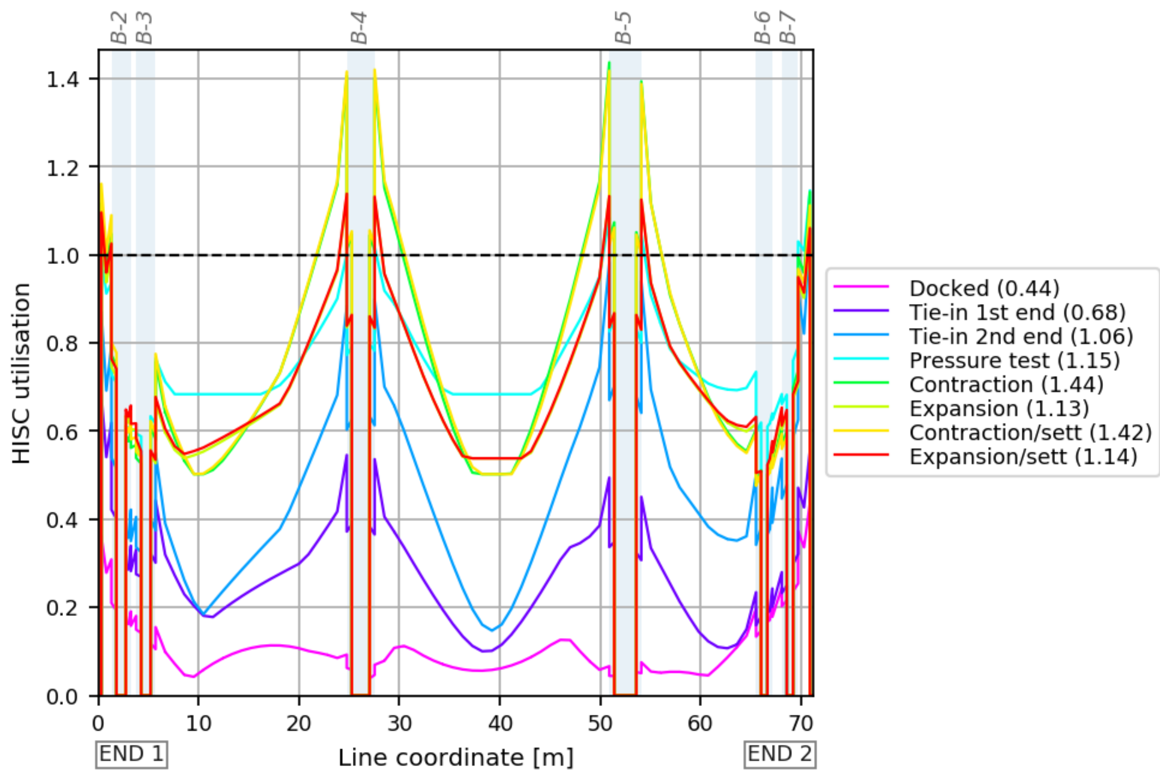
The maximum HISC utilisation along the spool, for each load case and load step, is shown in Figure 7.7.

Figure 7.7 – Maximum HISC Utilisation for Each Load Case and Load Step



A HISC utilisation envelope plot from all load cases and for each analysed subsequent load step is shown in Figure 7.8.

Figure 7.8 – Spool HISC Utilisation



The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

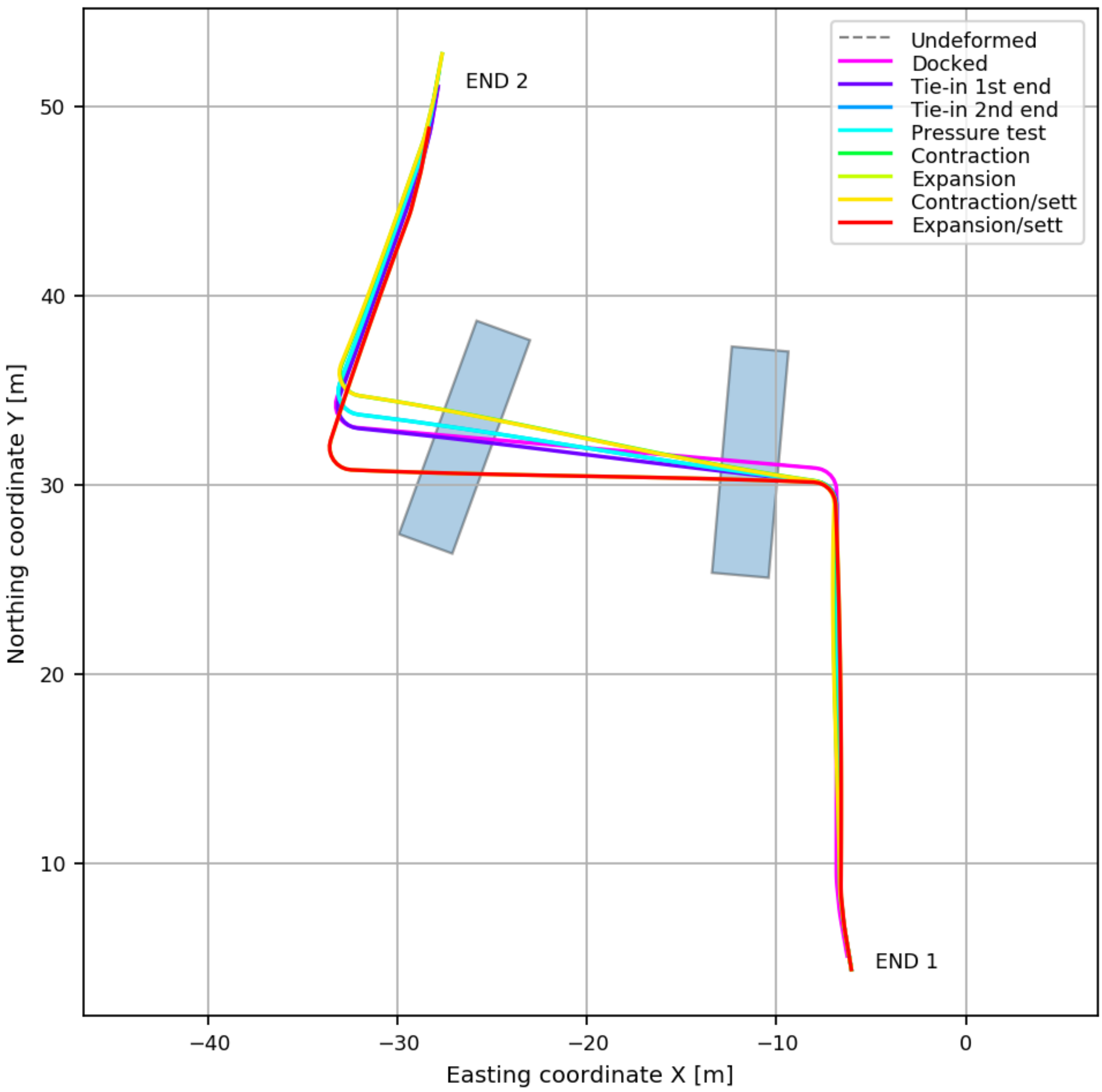
Longitudinal Stress Concentration Factors has been applied at each weld.

The spool bends (curved part) have not been assessed, since beam elements have been used in this assessment. HISC assessment in bends requires the use of either shell- or solid FE-models, in order to capture the ovalisation effects, which are causing high stress gradients across the wall thickness, as well as great stress variations around the circumference.

7.7.1 Most Utilised Load Case - Number 4

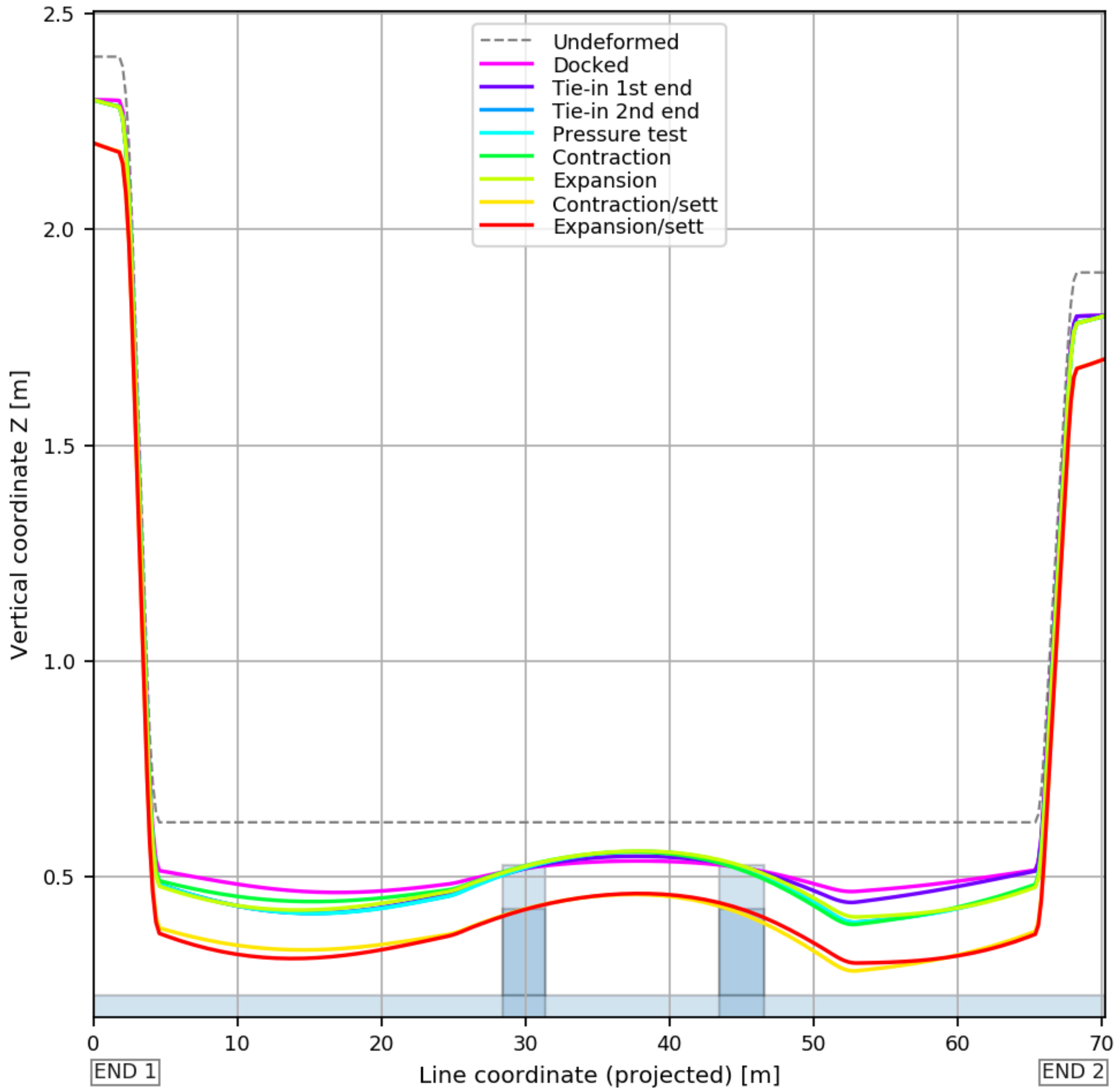
A top-view of the deformed shapes, for the most utilised load case (number 4), are shown for each load step in Figure 7.9.

Figure 7.9 – Top-View of Deformed Shapes of Critical Load Case



A profile view of the deformed shapes, for the most utilised load case (number 4), are shown for each load step in Figure 7.10.

Figure 7.10 – Profile View Deformed Shape of Critical Load Case



7.8 Spool End Reaction Loads

The weight of Termination Units has not been included in the assessment. This will primary affect the vertical reaction force RFz and secondary the reaction moment RMy.

7.8.1 End 1

The maximum magnitude reaction loads at End 1 of the spool, from any of the analysed load cases, are presented in Table 7.4 for each subsequent load step.

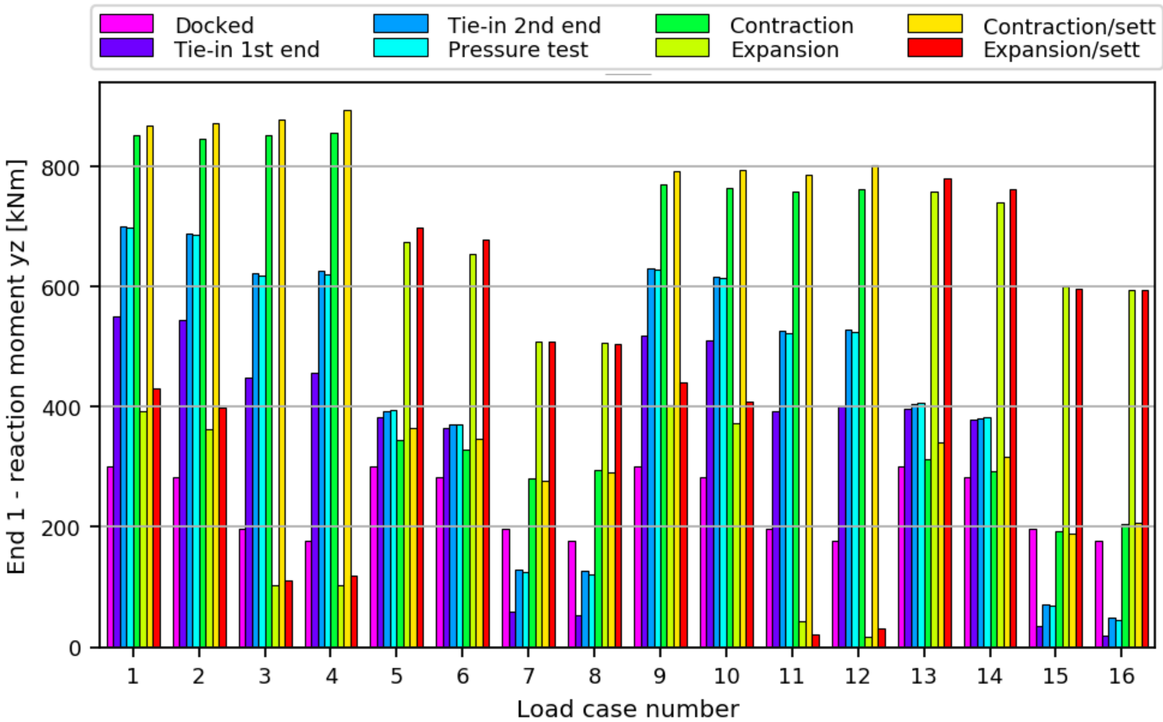
Table 7.4 – Maximum Magnitude Reaction Loads at End 1

Load Step	End Reaction Forces [kN]			End Reaction Moments [kNm]			
	RFx	RFy	RFz	RMx	RMy	RMz	RMb
Docked	9.3	-1.4	82.2	-0.0	300.7	10.7	300.8
Tie-in 1st end	57.8	28.1	87.6	-0.0	395.3	-455.6	550.4
Tie-in 2nd end	67.1	45.2	88.1	34.3	404.2	-623.9	699.9
Pressure test	64.8	45.1	88.0	33.9	407.0	-619.0	697.8
Contraction	107.3	64.5	74.5	61.3	278.9	-839.7	856.0
Expansion	-75.3	-47.0	71.4	-105.7	450.4	608.7	757.2
Contraction/sett	108.0	66.4	76.0	70.1	315.4	-871.0	894.1
Expansion/sett	-77.0	-47.0	72.8	-107.1	488.5	608.6	780.4
Max	108.0	66.4	88.1	-107.1	488.5	-871.0	894.1

The maximum loads are presented for any of the analysed load cases and do not necessarily occur concurrently.

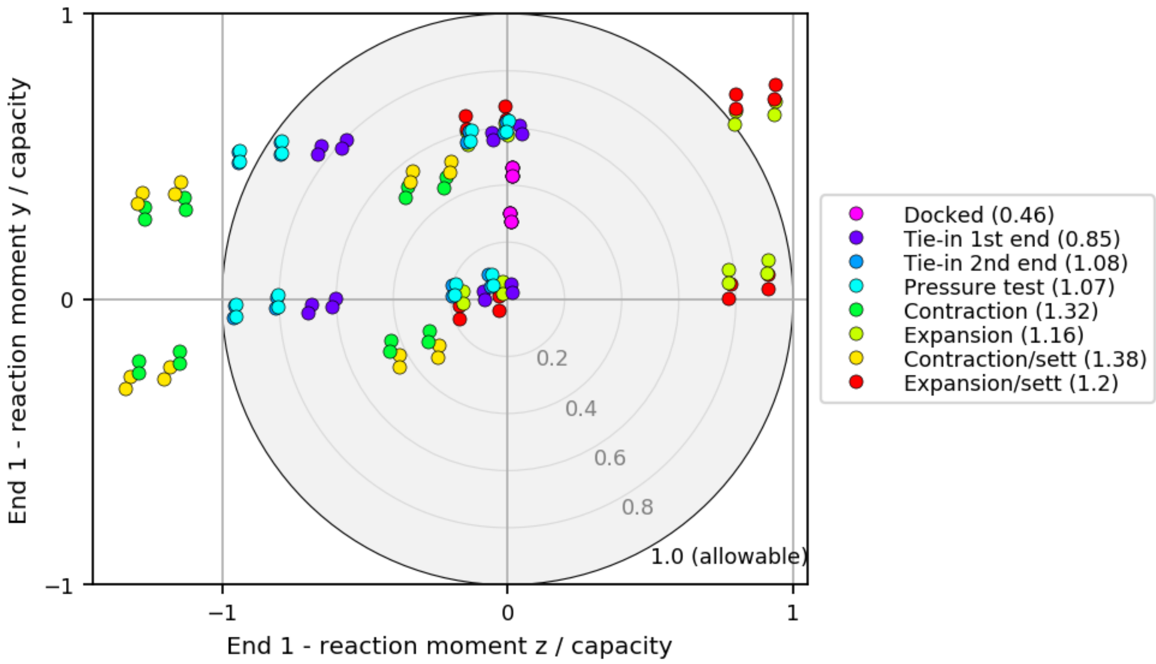
The maximum magnitude reaction bending moment at End 1, for each load case and load step, is shown in Figure 7.11.

Figure 7.11 – Maximum Magnitude Reaction Bending Moment at End 1



The connector / hub bending moment utilisations (RMy vs. RMz) at End 1, for all load cases and load steps, are shown in Figure 7.12.

Figure 7.12 – Reaction Bending Moment Components at End 1



The shaded circular area indicates the allowable. The maximum utilisation is presented for each load step within parenthesis in the figure legend.

7.8.2 End 2

The maximum magnitude reaction loads at End 2 of the spool, from any of the analysed load cases, are presented in Table 7.5 for each subsequent load step.

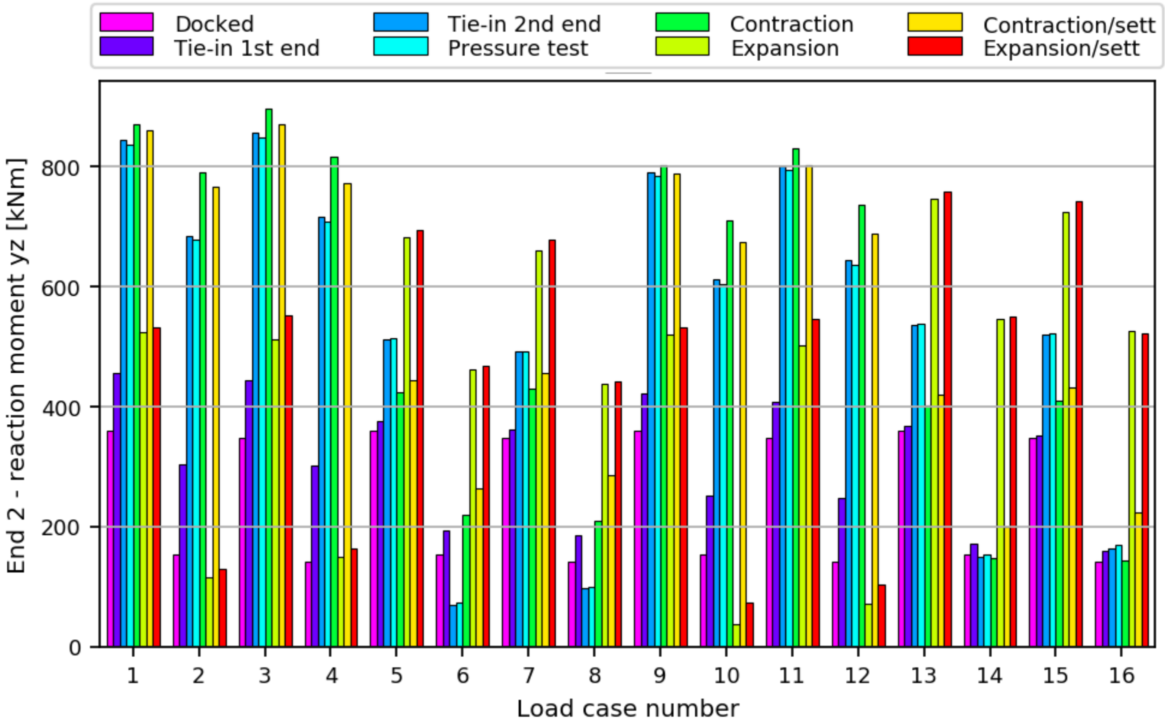
Table 7.5 – Maximum Magnitude Reaction Loads at End 2

Load Step	End Reaction Forces [kN]			End Reaction Moments [kNm]			
	RFx	RFy	RFz	RMx	RMy	RMz	RMb
Docked	3.1	-1.2	82.5	-0.0	358.5	15.1	358.7
Tie-in 1st end	23.6	35.5	84.6	-0.0	360.4	-296.4	454.5
Tie-in 2nd end	70.4	77.1	95.8	0.0	517.3	-711.1	854.7
Pressure test	68.4	76.3	95.7	-1.0	517.6	-702.9	847.2
Contraction	92.2	100.1	83.1	32.2	410.0	-805.7	896.6
Expansion	-72.4	-69.9	81.7	-120.4	519.5	545.9	745.2
Contraction/sett	94.3	97.1	83.8	29.0	420.7	-767.1	870.4
Expansion/sett	-72.3	-69.9	82.4	-126.1	542.8	546.2	758.3
Max	94.3	100.1	95.8	-126.1	542.8	-805.7	896.6

The maximum loads are presented for any of the analysed load cases and do not necessarily occur concurrently.

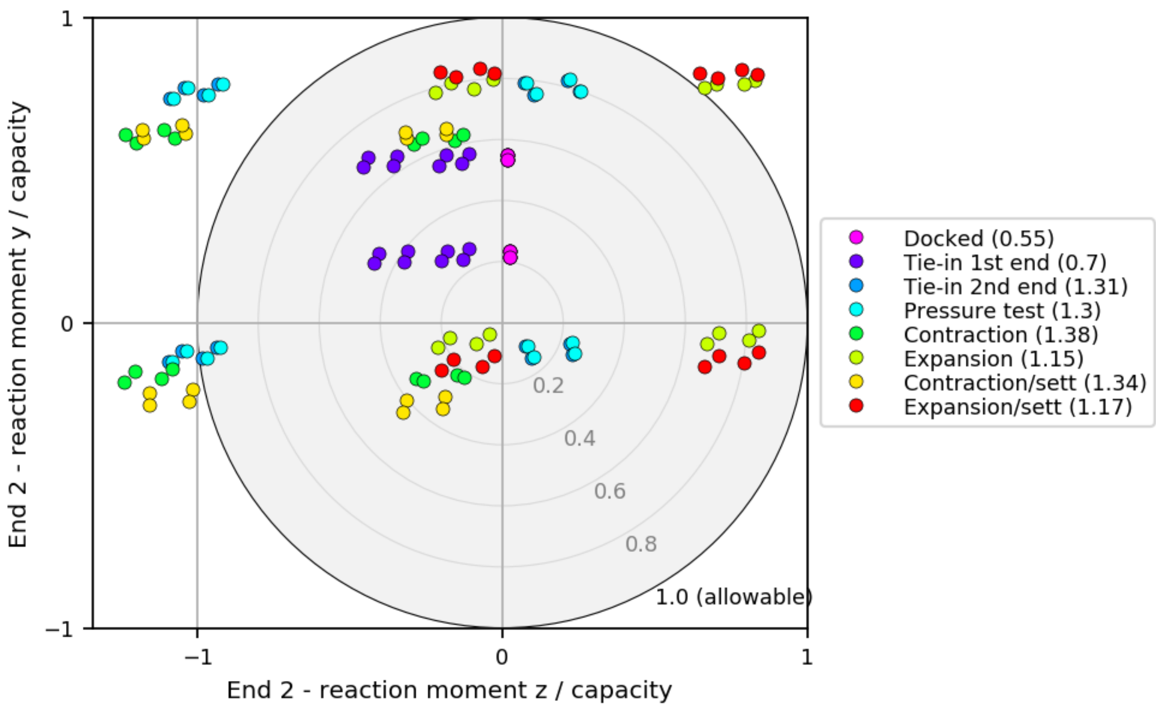
The maximum magnitude reaction bending moment at End 2, for each load case and load step, is shown in Figure 7.13.

Figure 7.13 – Maximum Magnitude Reaction Bending Moment at End 2



The connector / hub bending moment utilisations (RMy vs. RMz) at End 2, for all load cases and load steps, are shown in Figure 7.14.

Figure 7.14 – Reaction Bending Moment Components at End 2

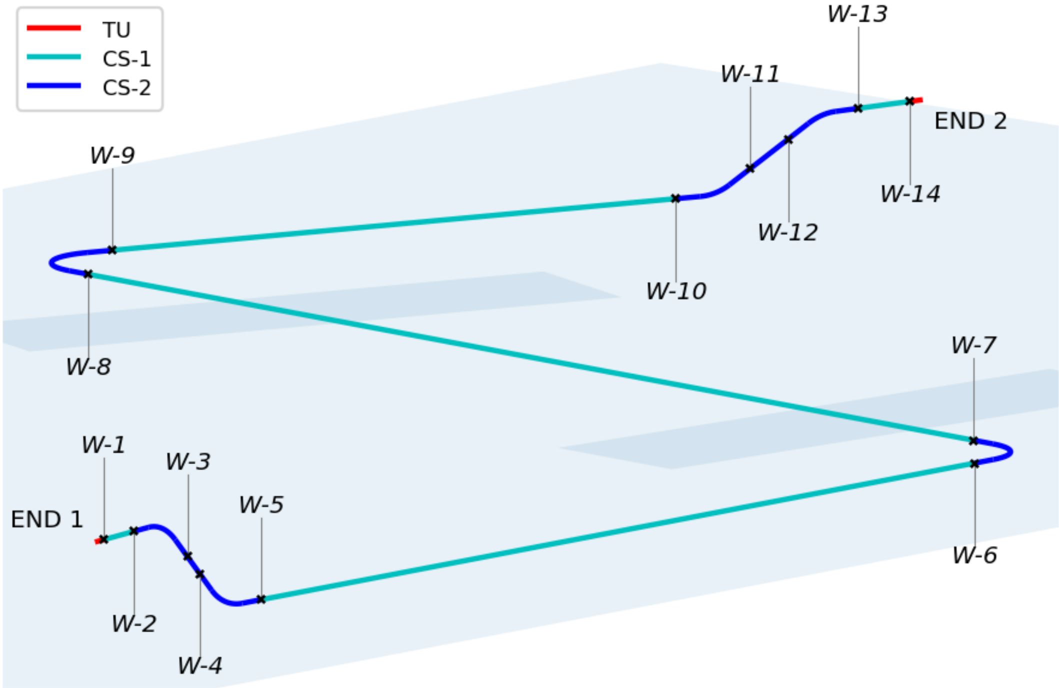


The shaded circular area indicates the allowable. The maximum utilisation is presented for each load step within parenthesis in the figure legend.

7.9 FATIGUE DAMAGE DUE TO VIV

The welds assessed for fatigue damage due to VIV are shown in Figure 7.15.

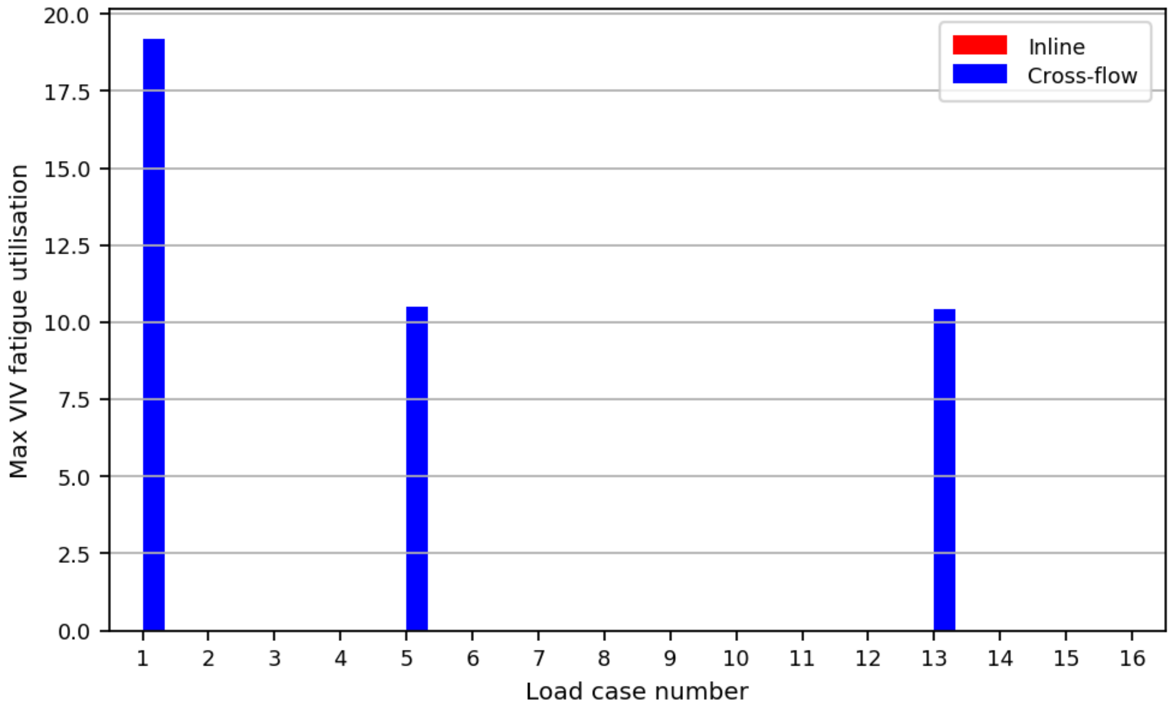
Figure 7.15 – Assessed Welds



Note that additional welds will be present where the pipe section exceeds the pipe joint length.

The maximum VIV fatigue utilisations for each load case are shown in Figure 7.16.

Figure 7.16 – Maximum VIV Fatigue Utilisation for Each Load Case

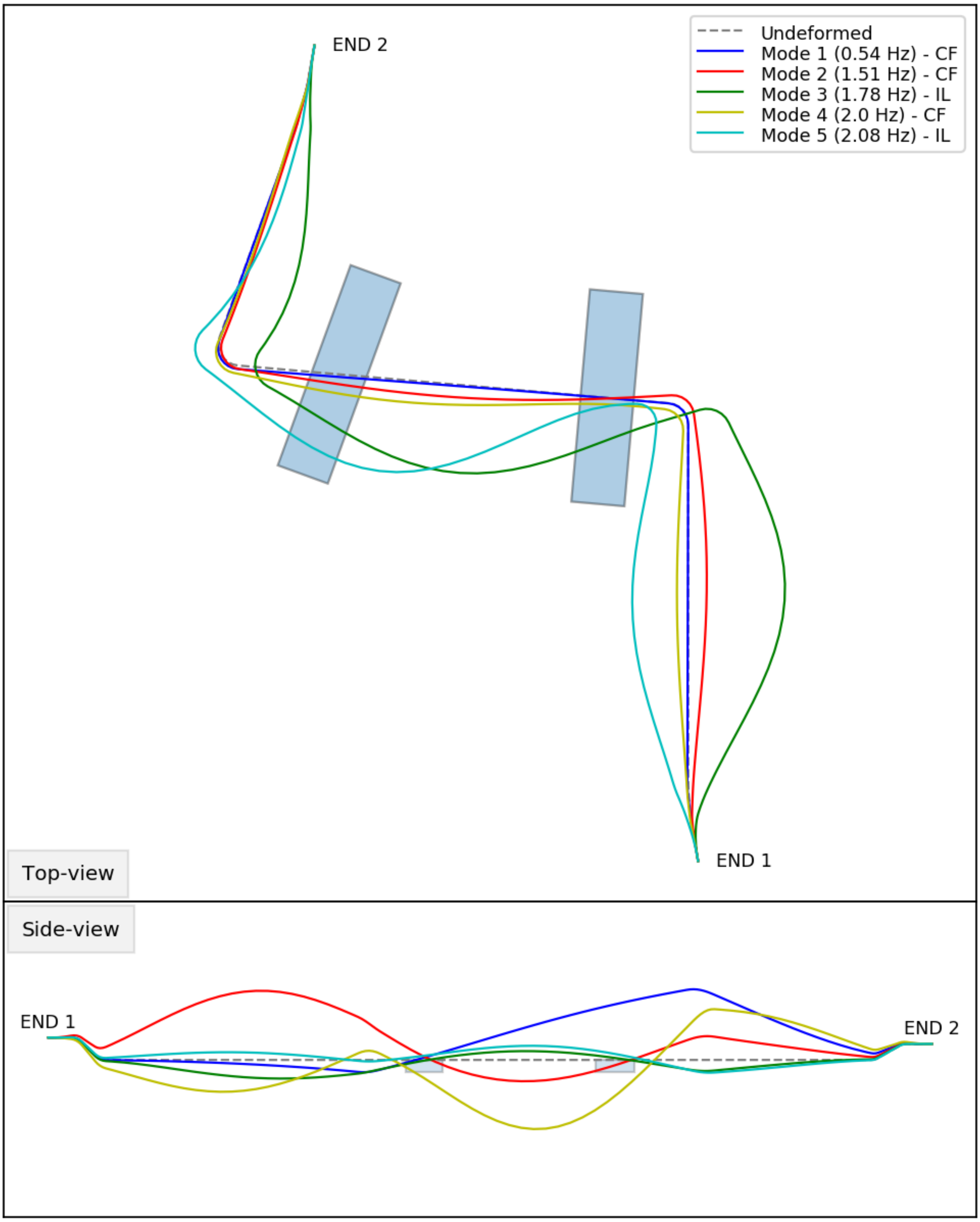


Inline and Cross-Flow utilisations are presented separately, and indicated that the damage has been accumulate at a specific location around the circumference.

It should be noted that both inline and cross-flow induced vibrations can potentially accrue damage at any location around the pipe circumference.

The Eigen-modes corresponding to the five lowest frequencies for load case number 1 (most critical in terms of fatigue damage) are shown in Figure 7.17.

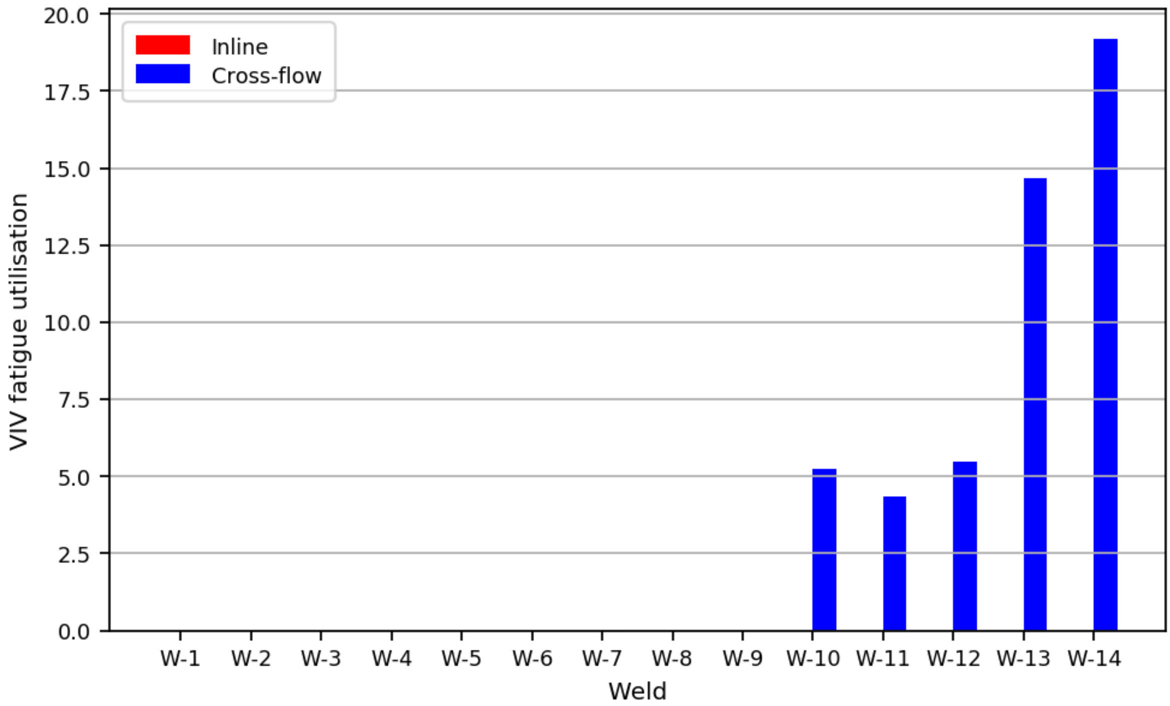
Figure 7.17 – Eigen-Modes of Most Utilised Load Case



The corresponding natural frequencies are presented within parenthesis in the figure legend, where the dominating mode type is denoted IL and / or CF.

The maximum VIV fatigue utilisation (all load cases) in each weld is shown in Figure 7.18.

Figure 7.18 – Maximum VIV Fatigue Utilisation at Each Weld



7.10 Support Loads

The maximum vertical support forces, from any of the analysed load cases, are presented in Table 7.6, for each subsequent load step.

Table 7.6 – Maximum Vertical Forces Acting on Supports and Seabed

Load Step	Vertical Force [kN]		
	SEABED	Support-1	Support-2
Docked	0.0	45.9	44.3
Tie-in 1st end	0.0	51.9	45.3
Tie-in 2nd end	0.0	53.2	56.7
Pressure test	0.0	53.3	56.8
Contraction	0.0	33.0	80.2
Expansion	0.0	37.1	43.3
Contraction/sett	0.0	34.0	41.6
Expansion/sett	0.0	38.6	46.6
Max	0.0	53.3	80.2

Note that the maximum loads are presented for any of the analysed load cases and do not necessarily occur concurrently.

8 CONFIGURATION MAX_L2

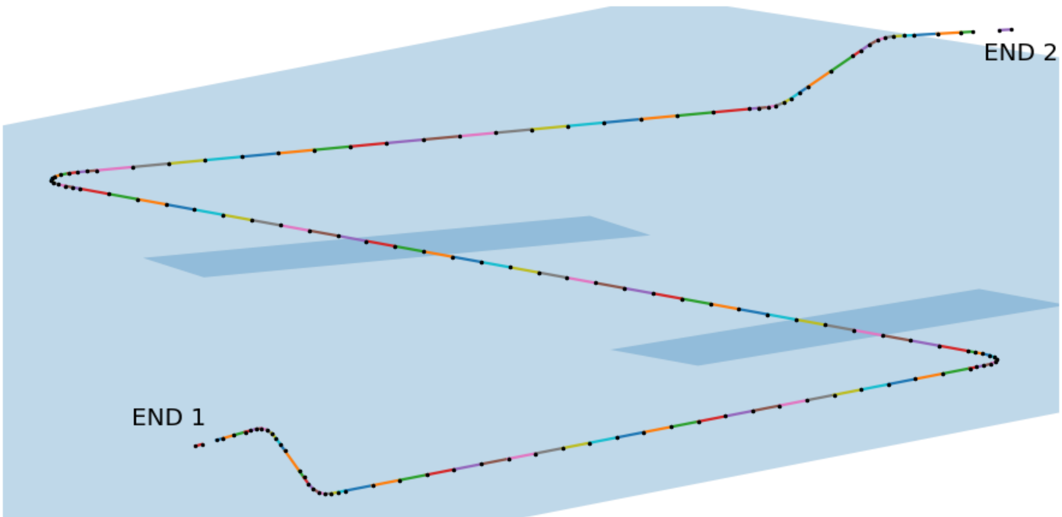
This section presents the following detailed results for configuration "max_L2".

- FE-model
- Spool geometry
- Load cases
- Load steps
- Spool CLC / ASD utilisation
- Spool ASME utilisation
- Spool HISC utilisation
- Spool end reaction loads
- Fatigue damage due to VIV
- Support loads

8.1 FE-MODEL

The FE-model consists of the spool and two connecting structures at each end. The mesh density used is shown in Figure 8.1.

Figure 8.1 – FE-Model Mesh



The beam / pipe elements are shown as lines and with the associated nodes are shown as black dots. The nodes belonging to the area elements are not shown.

The spool consists of three different cross-section types.

8.2 SPOOL GEOMETRY

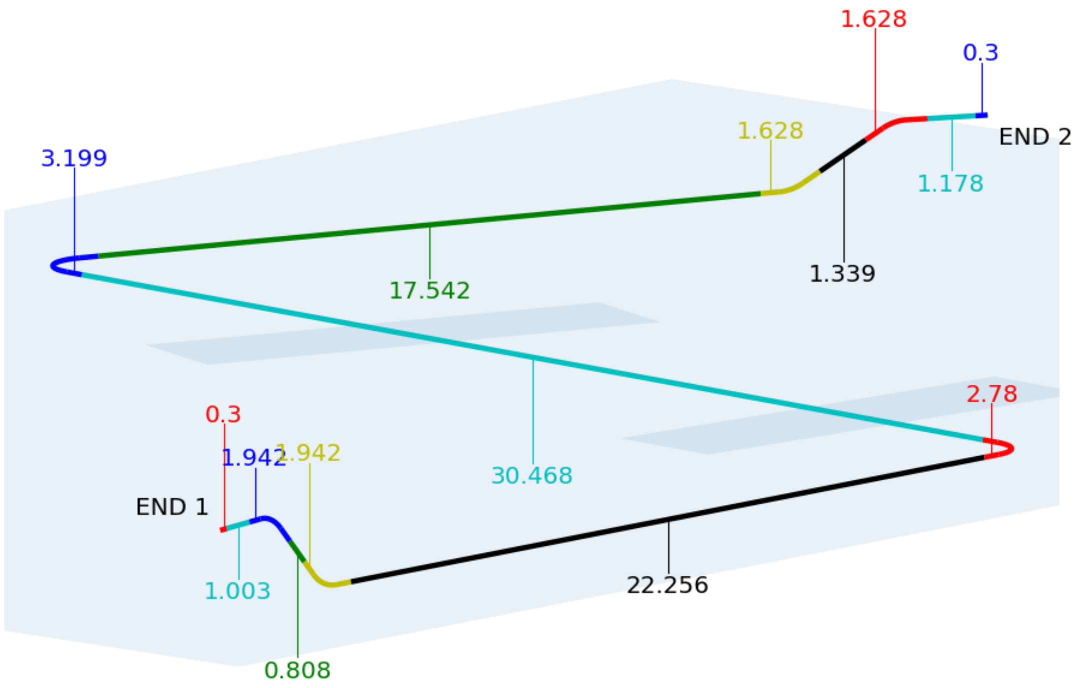
The coordinates at the spool ends and at the intersection points between the extended straight lines / sections, are presented in Table 8.1.

Table 8.1 – Coordinates at Ends and Intersection Points

Location	Coordinates [m]		
	X / Easting	Y / Northing	Z / Vertical
End 1	-4.797	1.558	2.6
IP-1	-4.85	1.854	2.6
IP-2	-5.197	3.823	2.6
IP-3	-5.37	5.805	0.626
IP-4	-5.37	30.657	0.626
IP-5	-39.371	33.632	0.626
IP-6	-32.385	52.827	0.626
IP-7	-31.289	55.177	2.1
IP-8	-30.289	56.909	2.1
End 2	-30.139	57.169	2.1

An isometric view of the spool showing each section length (units in meter) is shown in Figure 8.2.

Figure 8.2 – Isometric View with Section Lengths



8.3 Load Cases

A set of 32 load case combinations has been analysed, as presented in Table 8.2. The prescribed end displacement / rotation values refer to uncertainties regarding make-up tolerances at each spool end.

Table 8.2 – Load Case Combinations

Load Case	END 1						END 2					
	Displacements [m]			Rotations [deg]			Displacements [m]			Rotations [deg]		
	ux	uy	uz	rx	ry	rz	ux	uy	uz	rx	ry	rz
1	0.09	0.09	0.1	Free	0.55	-0.7	0.09	0.09	0.1	Free	0.55	-0.7
2	0.09	0.09	0.1	Free	0.55	-0.7	0.09	0.09	-0.1	Free	-0.55	-0.7
3	0.09	0.09	-0.1	Free	-0.55	-0.7	0.09	0.09	0.1	Free	0.55	-0.7
4	0.09	0.09	-0.1	Free	-0.55	-0.7	0.09	0.09	-0.1	Free	-0.55	-0.7
5	0.09	-0.09	0.1	Free	0.55	0.7	0.09	-0.09	0.1	Free	0.55	0.7
6	0.09	-0.09	0.1	Free	0.55	0.7	0.09	-0.09	-0.1	Free	-0.55	0.7
7	0.09	-0.09	-0.1	Free	-0.55	0.7	0.09	-0.09	0.1	Free	0.55	0.7
8	0.09	-0.09	-0.1	Free	-0.55	0.7	0.09	-0.09	-0.1	Free	-0.55	0.7
9	-0.09	0.09	0.1	Free	0.55	-0.7	-0.09	0.09	0.1	Free	0.55	-0.7
10	-0.09	0.09	0.1	Free	0.55	-0.7	-0.09	0.09	-0.1	Free	-0.55	-0.7
11	-0.09	0.09	-0.1	Free	-0.55	-0.7	-0.09	0.09	0.1	Free	0.55	-0.7
12	-0.09	0.09	-0.1	Free	-0.55	-0.7	-0.09	0.09	-0.1	Free	-0.55	-0.7
13	-0.09	-0.09	0.1	Free	0.55	0.7	-0.09	-0.09	0.1	Free	0.55	0.7
14	-0.09	-0.09	0.1	Free	0.55	0.7	-0.09	-0.09	-0.1	Free	-0.55	0.7
15	-0.09	-0.09	-0.1	Free	-0.55	0.7	-0.09	-0.09	0.1	Free	0.55	0.7
16	-0.09	-0.09	-0.1	Free	-0.55	0.7	-0.09	-0.09	-0.1	Free	-0.55	0.7
17	0.09	0.09	0.1	Free	0.55	-0.7	-0.09	0.09	0.1	Free	0.55	-0.7
18	0.09	0.09	0.1	Free	0.55	-0.7	-0.09	0.09	-0.1	Free	-0.55	-0.7
19	0.09	0.09	-0.1	Free	-0.55	-0.7	-0.09	0.09	0.1	Free	0.55	-0.7
20	0.09	0.09	-0.1	Free	-0.55	-0.7	-0.09	0.09	-0.1	Free	-0.55	-0.7
21	0.09	-0.09	0.1	Free	0.55	0.7	0.09	0.09	0.1	Free	0.55	-0.7
22	0.09	-0.09	0.1	Free	0.55	0.7	0.09	0.09	-0.1	Free	-0.55	-0.7
23	0.09	-0.09	-0.1	Free	-0.55	0.7	0.09	0.09	0.1	Free	0.55	-0.7
24	0.09	-0.09	-0.1	Free	-0.55	0.7	0.09	0.09	-0.1	Free	-0.55	-0.7
25	-0.09	0.09	0.1	Free	0.55	-0.7	-0.09	-0.09	0.1	Free	0.55	0.7
26	-0.09	0.09	0.1	Free	0.55	-0.7	-0.09	-0.09	-0.1	Free	-0.55	0.7
27	-0.09	0.09	-0.1	Free	-0.55	-0.7	-0.09	-0.09	0.1	Free	0.55	0.7
28	-0.09	0.09	-0.1	Free	-0.55	-0.7	-0.09	-0.09	-0.1	Free	-0.55	0.7
29	-0.09	-0.09	0.1	Free	0.55	0.7	0.09	-0.09	0.1	Free	0.55	0.7
30	-0.09	-0.09	0.1	Free	0.55	0.7	0.09	-0.09	-0.1	Free	-0.55	0.7
31	-0.09	-0.09	-0.1	Free	-0.55	0.7	0.09	-0.09	0.1	Free	0.55	0.7
32	-0.09	-0.09	-0.1	Free	-0.55	0.7	0.09	-0.09	-0.1	Free	-0.55	0.7

The parameter "Free" indicates that no tolerances have been applied, i.e. as the termination unit is free to swivel around the pipe axis prior to and during tie-ins.

8.4 LOAD STEPS

The spool have been analysed for the subsequent load steps presented in Table 8.3.

Table 8.3 – Subsequent Load Steps

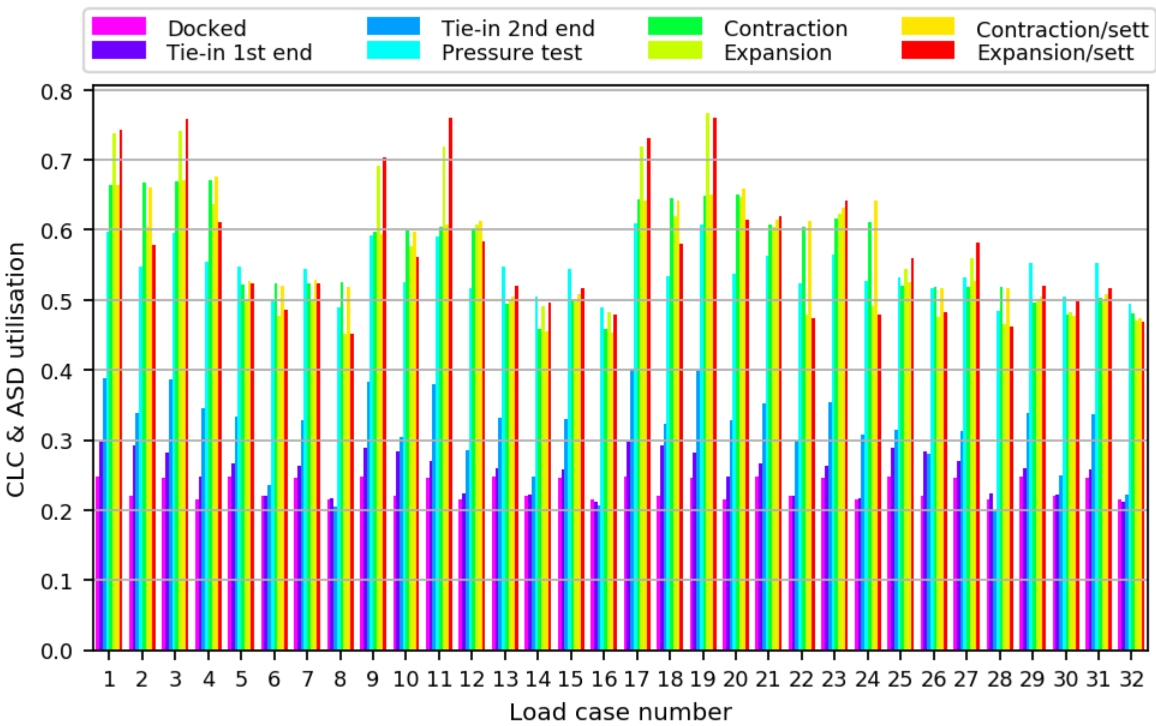
Load Step	Internal Pressure [bara]	Temperature [°C]	Content Density [kg/m3]	Axial Expansion - End 2 [m]
Docked	20	10	1150	0
Tie-in 1st end	20	10	1150	0
Tie-in 2nd end	20	10	1150	0
Pressure test	400	10	1150	0
Contraction	300	-20	250	-1.0
Expansion	300	100	250	3.0
Contraction/sett	300	-20	250	-1.0
Expansion/sett	300	100	250	3.0

Positive axial expansion is in the direction opposite to the tie-in stroking direction.

8.5 Spool CLC / ASD Utilisation

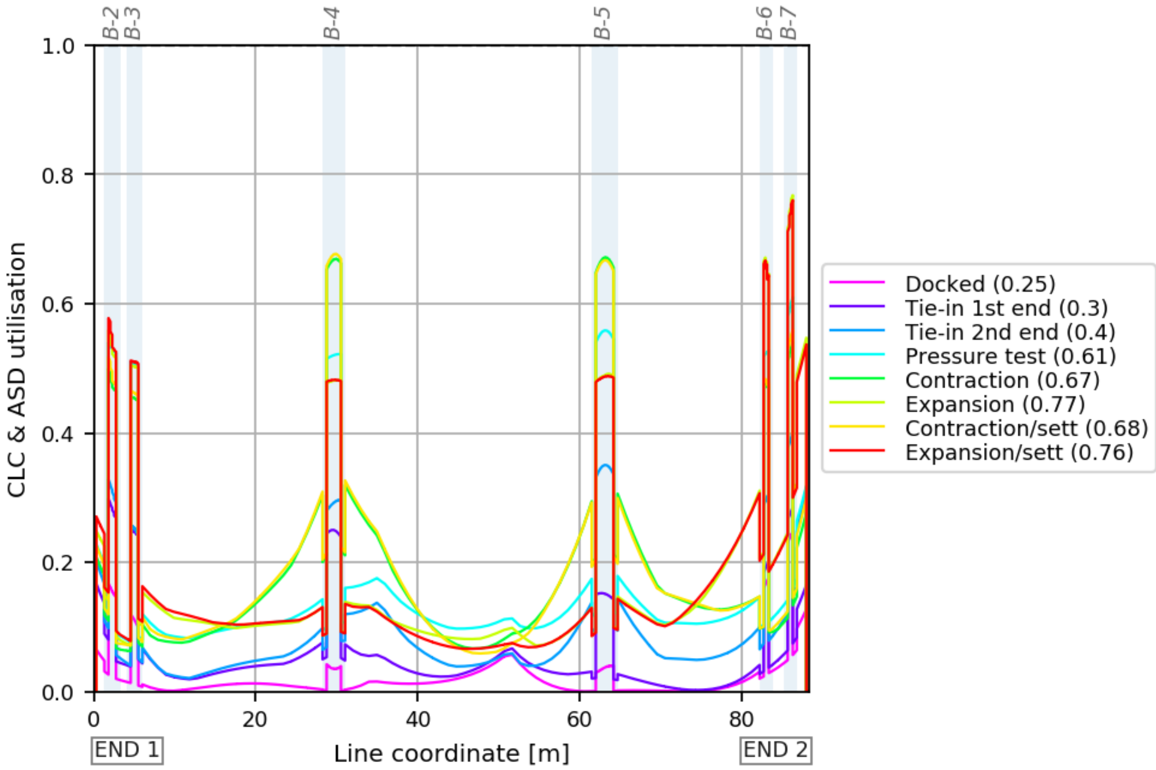
The maximum CLC / ASD utilisation along the spool, for each load case and load step, is shown in Figure 8.3.

Figure 8.3 – Maximum CLC / ASD Utilisation for Each Load Case and Load Step



A CLC / ASD utilisation envelope plot from all load cases and for each analysed subsequent load step is shown in Figure 8.4.

Figure 8.4 – Spool CLC / ASD Utilisation

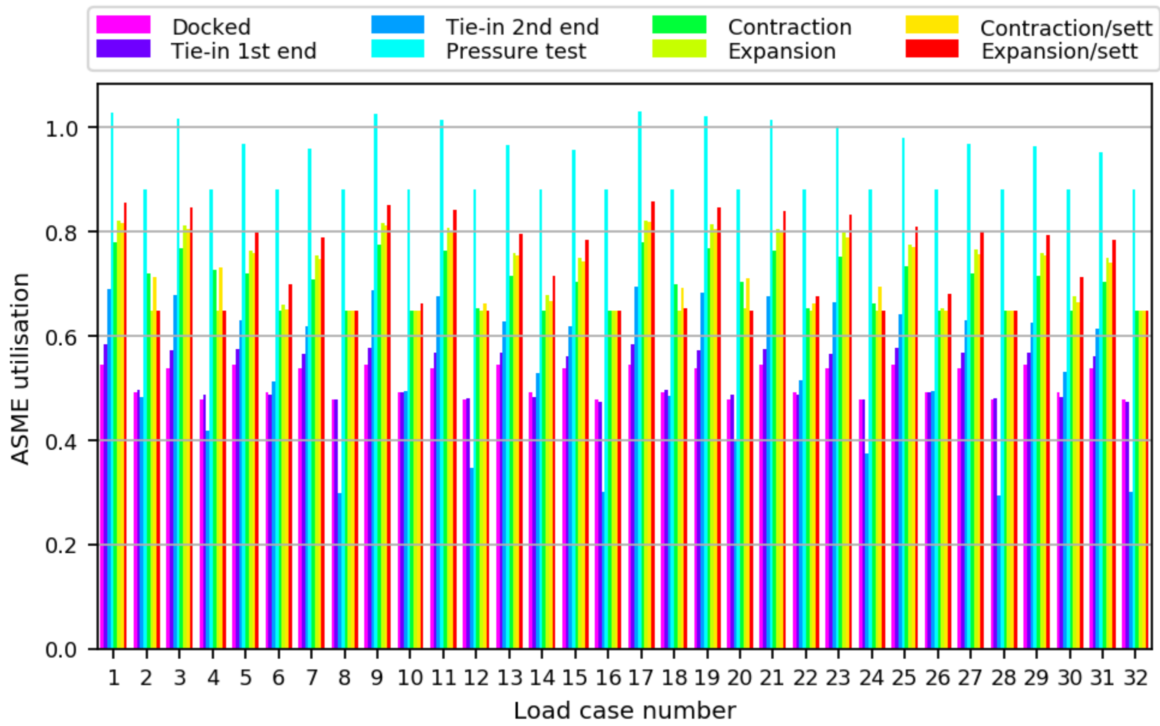


The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

8.6 Spool ASME Utilisation

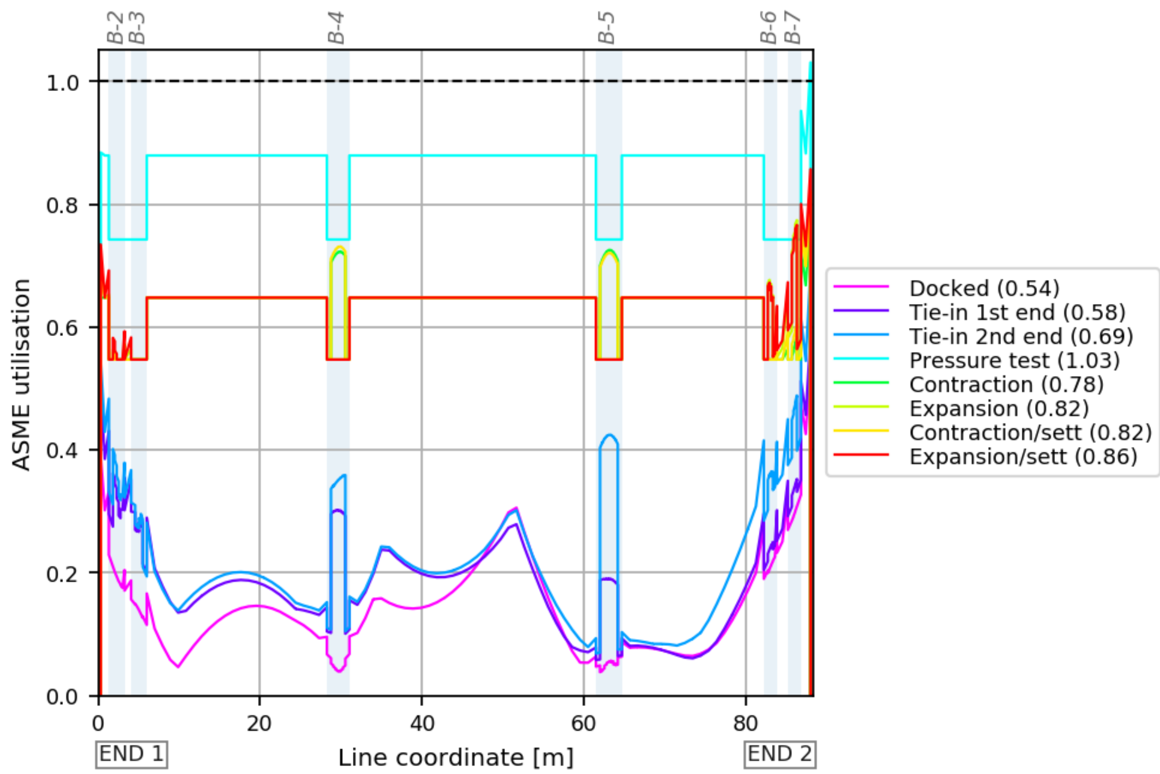
The maximum ASME utilisation along the spool, for each load case and load step, is shown in Figure 8.5.

Figure 8.5 – Maximum ASME Utilisation for Each Load Case and Load Step



An ASME utilisation envelope plot from all load cases and for each analysed subsequent load step is shown in Figure 8.6.

Figure 8.6 – Spool ASME Utilisation



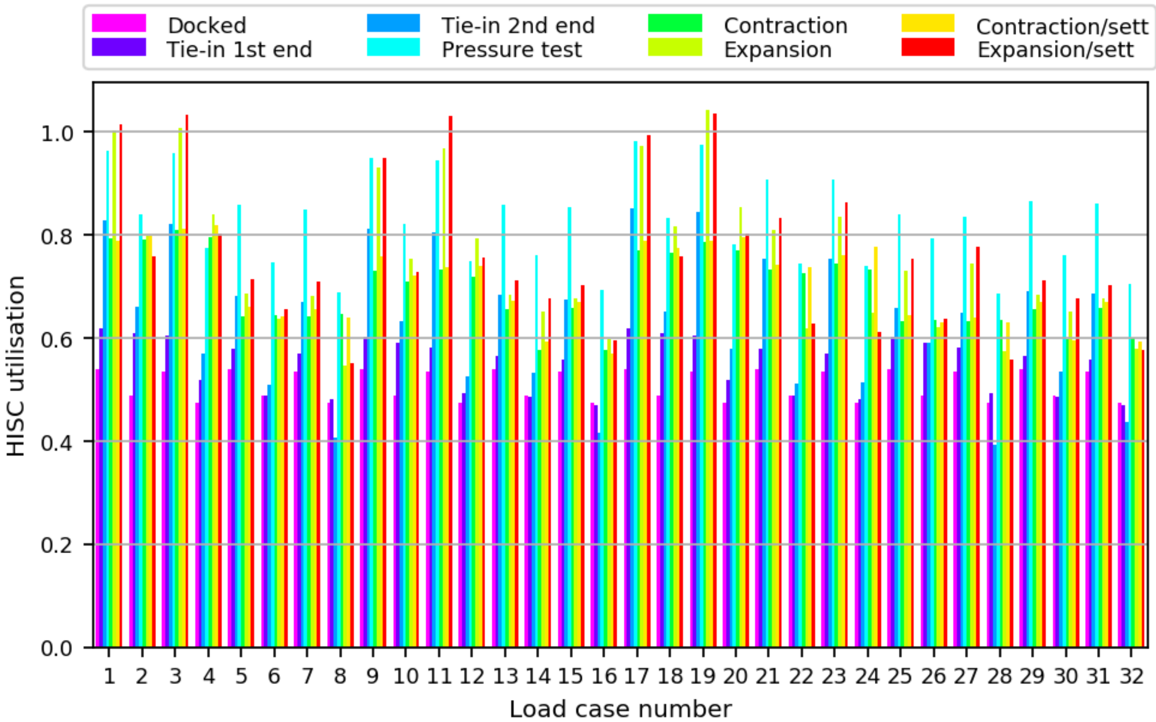
The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

Stress Intensification Factors, according to Ref. [ASME B31.8], have been accounted for when calculating utilisations in the bends and at welds.

8.7 SPOOL HISC UTILISATION

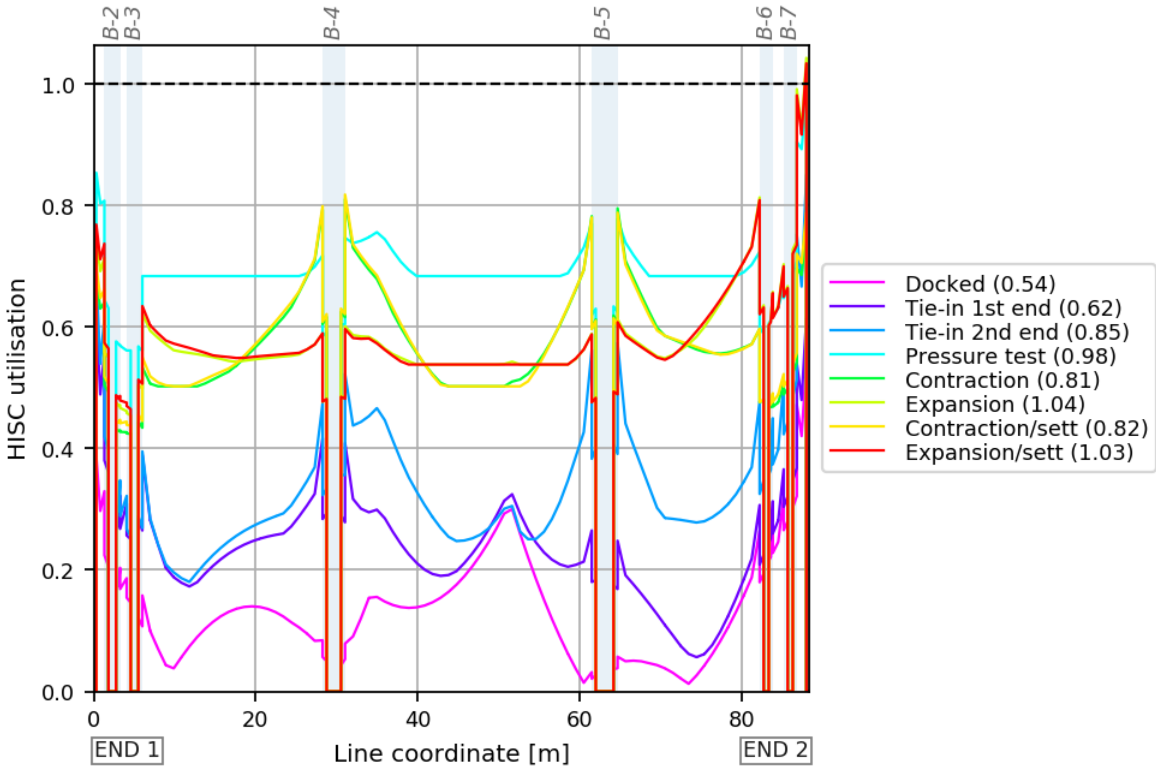
The maximum HISC utilisation along the spool, for each load case and load step, is shown in Figure 8.7.

Figure 8.7 – Maximum HISC Utilisation for Each Load Case and Load Step



A HISC utilisation envelope plot from all load cases and for each analysed subsequent load step is shown in Figure 8.8.

Figure 8.8 – Spool HISC Utilisation



The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

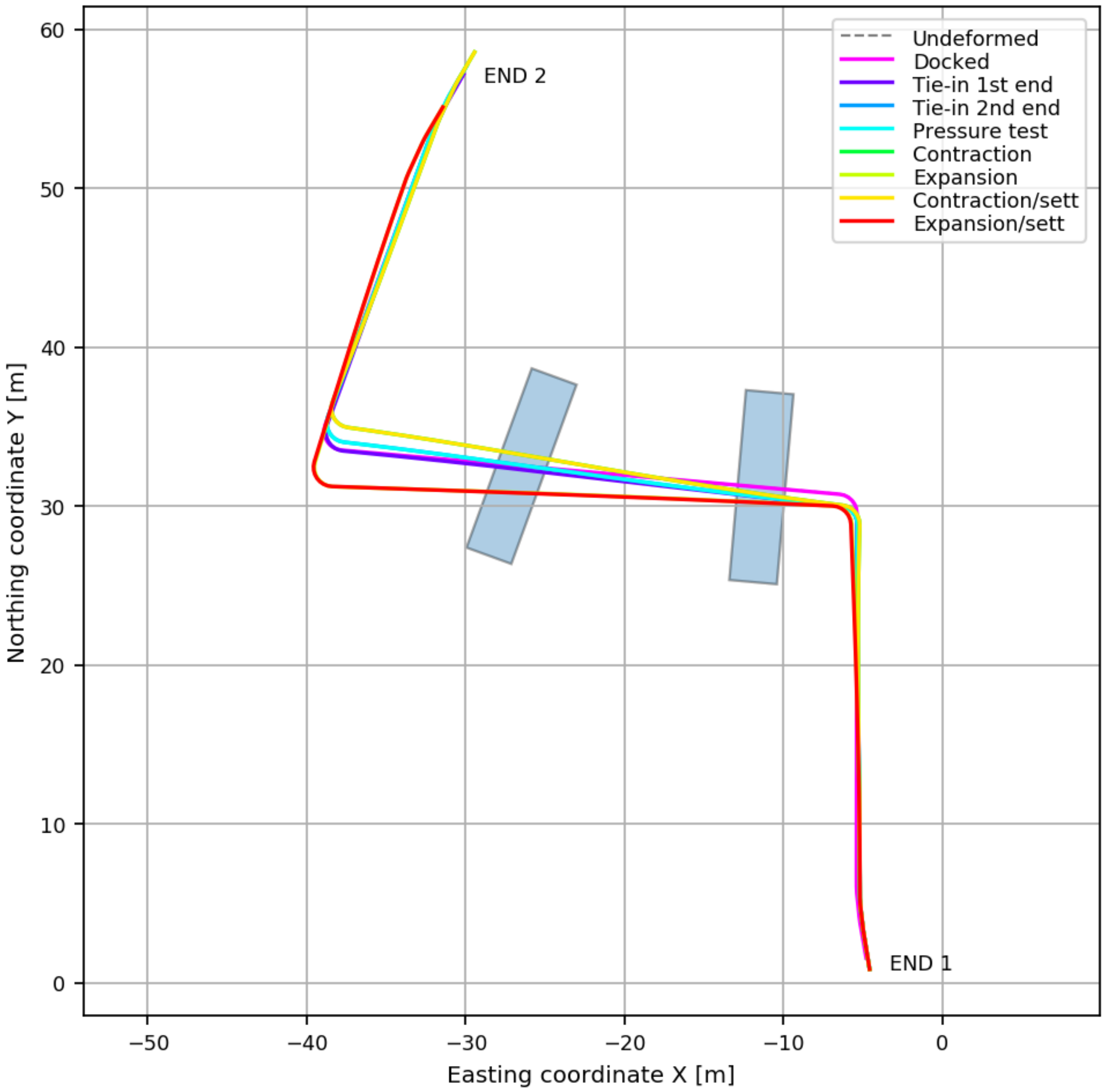
Longitudinal Stress Concentration Factors has been applied at each weld.

The spool bends (curved part) have not been assessed, since beam elements have been used in this assessment. HISC assessment in bends requires the use of either shell- or solid FE-models, in order to capture the ovalisation effects, which are causing high stress gradients across the wall thickness, as well as great stress variations around the circumference.

8.7.1 Most Utilised Load Case - Number 19

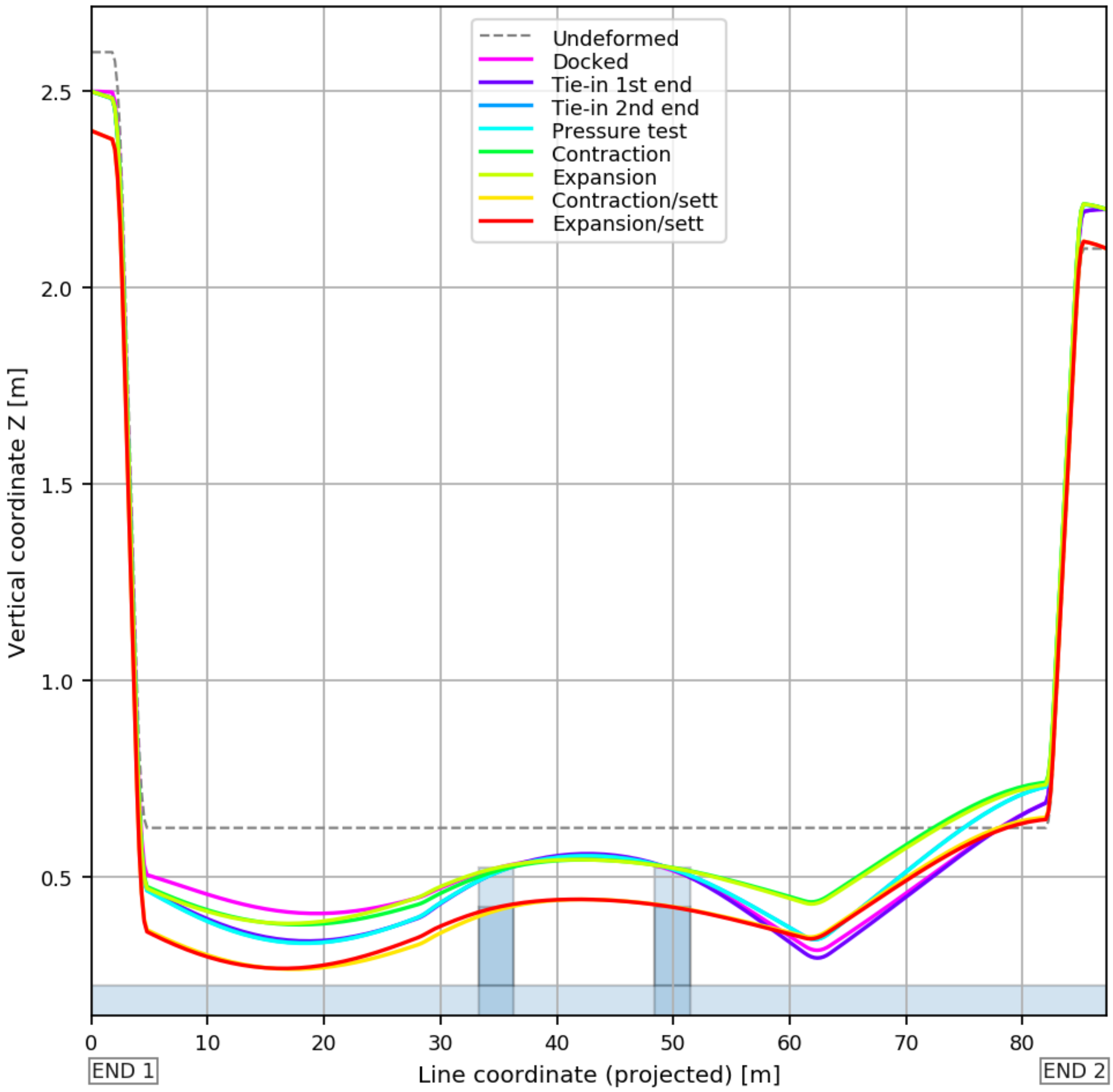
A top-view of the deformed shapes, for the most utilised load case (number 19), are shown for each load step in Figure 8.9.

Figure 8.9 – Top-View of Deformed Shapes of Critical Load Case



A profile view of the deformed shapes, for the most utilised load case (number 19), are shown for each load step in Figure 8.10.

Figure 8.10 – Profile View Deformed Shape of Critical Load Case



8.8 Spool End Reaction Loads

The weight of Termination Units has not been included in the assessment. This will primary affect the vertical reaction force RFz and secondary the reaction moment RMy.

8.8.1 End 1

The maximum magnitude reaction loads at End 1 of the spool, from any of the analysed load cases, are presented in Table 8.4 for each subsequent load step.

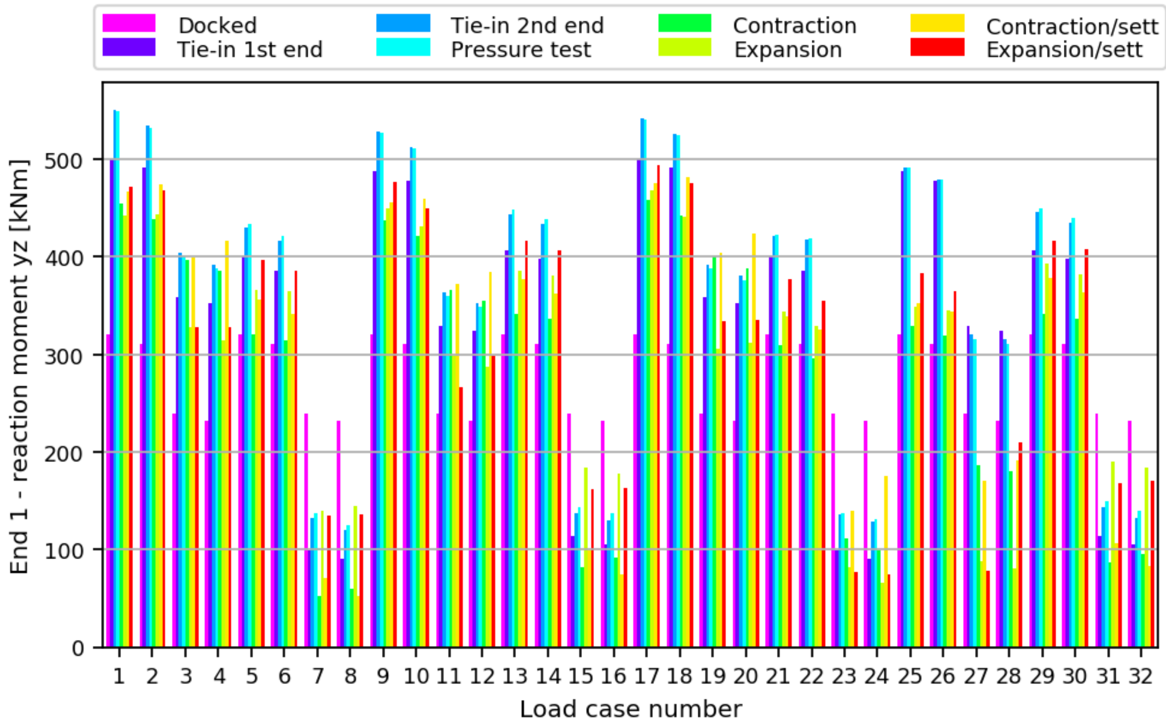
Table 8.4 – Maximum Magnitude Reaction Loads at End 1

Load Step	End Reaction Forces [kN]			End Reaction Moments [kNm]			
	RFx	RFy	RFz	RMx	RMy	RMz	RMb
Docked	9.9	-1.7	84.7	-0.0	319.9	16.1	320.2
Tie-in 1st end	39.4	18.5	89.0	-0.0	402.8	-349.6	500.7
Tie-in 2nd end	17.6	25.7	89.0	13.4	442.3	-387.0	551.2
Pressure test	16.0	25.5	88.9	12.9	445.9	-383.1	549.2
Contraction	37.9	29.2	72.6	-29.3	321.5	-400.4	458.8
Expansion	-16.6	-15.1	71.6	-74.9	360.0	-350.2	468.9
Contraction/sett	37.9	29.8	73.8	-31.7	352.8	-418.9	481.5
Expansion/sett	-18.1	-14.4	72.8	-78.7	393.4	-353.1	493.8
Max	39.4	29.8	89.0	-78.7	445.9	-418.9	551.2

The maximum loads are presented for any of the analysed load cases and do not necessarily occur concurrently.

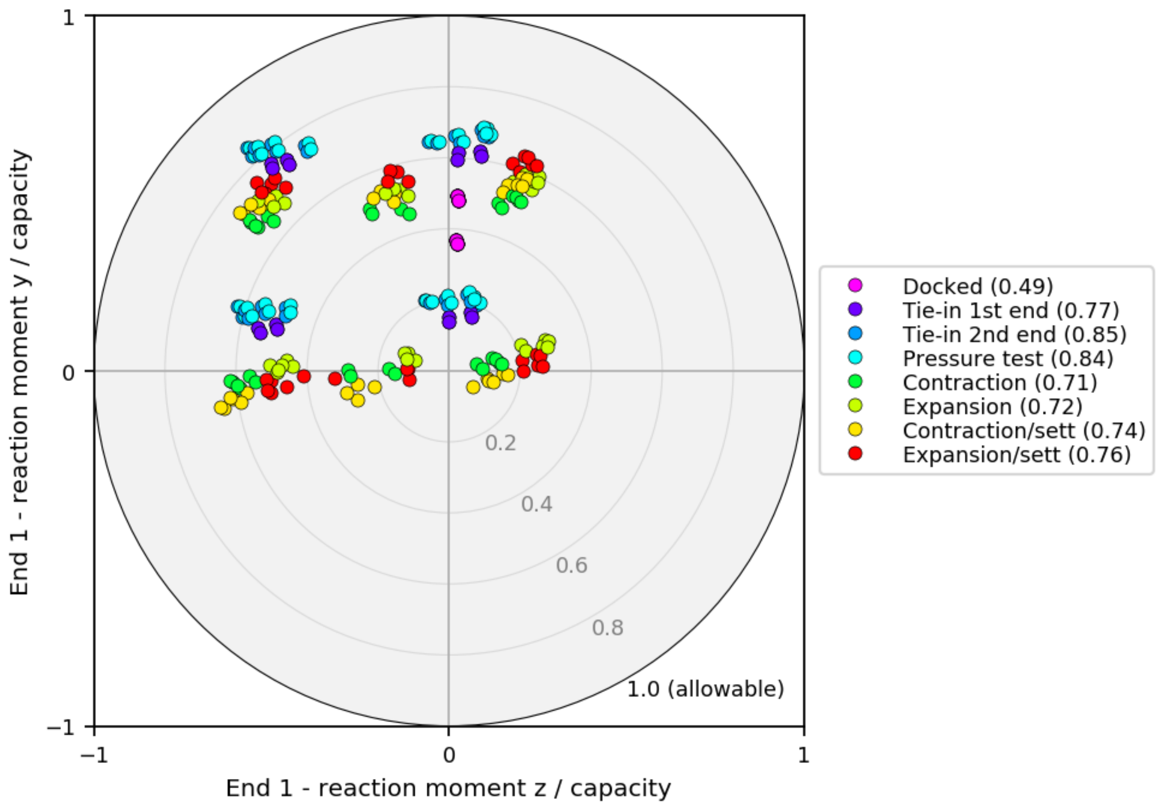
The maximum magnitude reaction bending moment at End 1, for each load case and load step, is shown in Figure 8.11.

Figure 8.11 – Maximum Magnitude Reaction Bending Moment at End 1



The connector / hub bending moment utilisations (RMy vs. RMz) at End 1, for all load cases and load steps, are shown in Figure 8.12.

Figure 8.12 – Reaction Bending Moment Components at End 1



The shaded circular area indicates the allowable. The maximum utilisation is presented for each load step within parenthesis in the figure legend.

8.8.2 End 2

The maximum magnitude reaction loads at End 2 of the spool, from any of the analysed load cases, are presented in Table 8.5 for each subsequent load step.

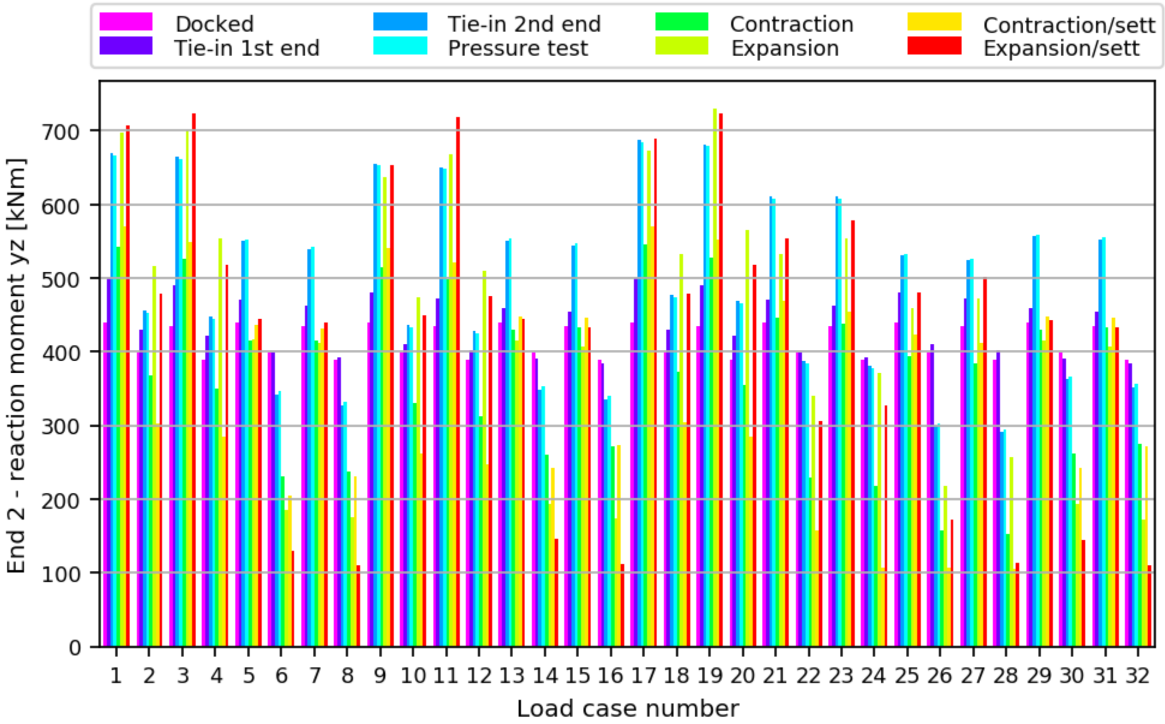
Table 8.5 – Maximum Magnitude Reaction Loads at End 2

Load Step	End Reaction Forces [kN]			End Reaction Moments [kNm]			
	RFx	RFy	RFz	RMx	RMy	RMz	RMb
Docked	5.6	1.2	85.6	-0.0	440.3	8.7	440.3
Tie-in 1st end	-8.8	15.3	87.5	0.0	471.0	-165.8	499.3
Tie-in 2nd end	29.1	39.4	92.9	-0.0	559.8	-401.8	687.1
Pressure test	27.1	38.8	92.9	-1.1	560.2	-395.9	684.1
Contraction	29.0	41.7	77.3	-15.7	430.3	-335.5	545.6
Expansion	-24.0	-20.4	76.1	-44.1	463.4	-570.2	730.8
Contraction/sett	28.4	41.8	78.7	-25.3	460.3	-338.4	570.3
Expansion/sett	-26.6	-20.4	77.5	-51.3	491.1	-539.6	724.0
Max	29.1	41.8	92.9	-51.3	560.2	-570.2	730.8

The maximum loads are presented for any of the analysed load cases and do not necessarily occur concurrently.

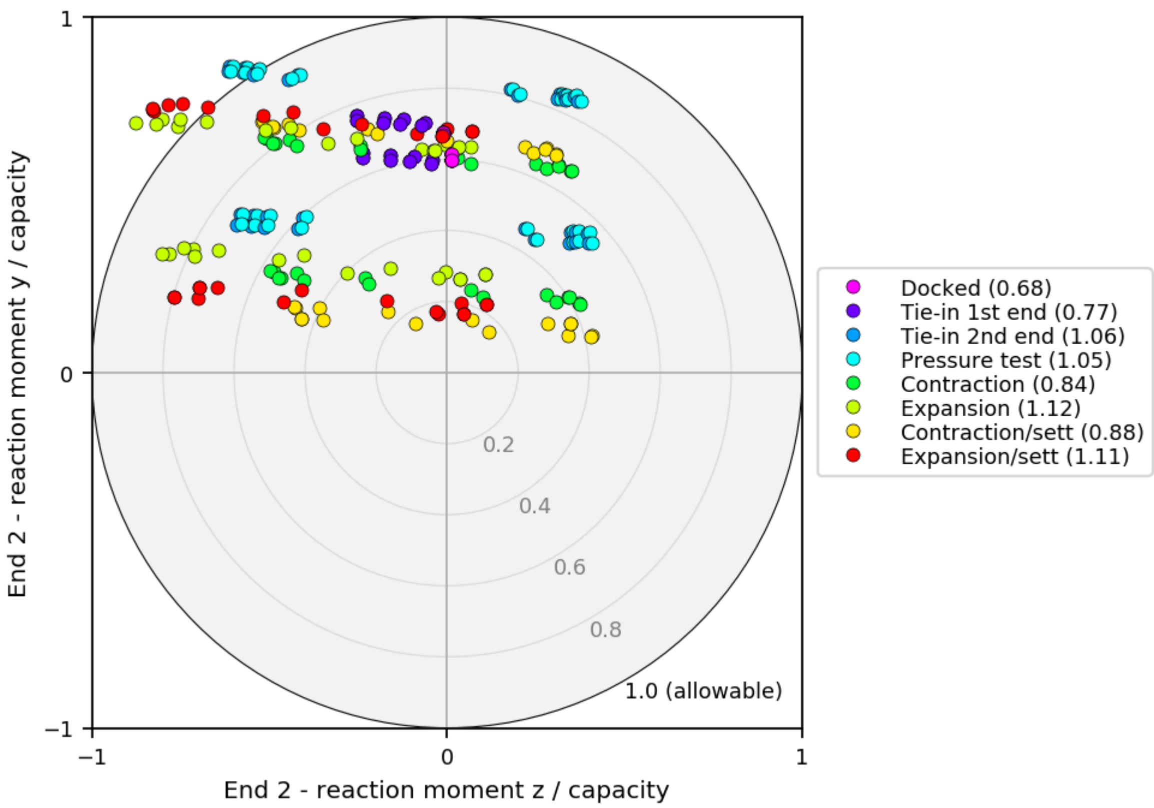
The maximum magnitude reaction bending moment at End 2, for each load case and load step, is shown in Figure 8.13.

Figure 8.13 – Maximum Magnitude Reaction Bending Moment at End 2



The connector / hub bending moment utilisations (RMy vs. RMz) at End 2, for all load cases and load steps, are shown in Figure 8.14.

Figure 8.14 – Reaction Bending Moment Components at End 2

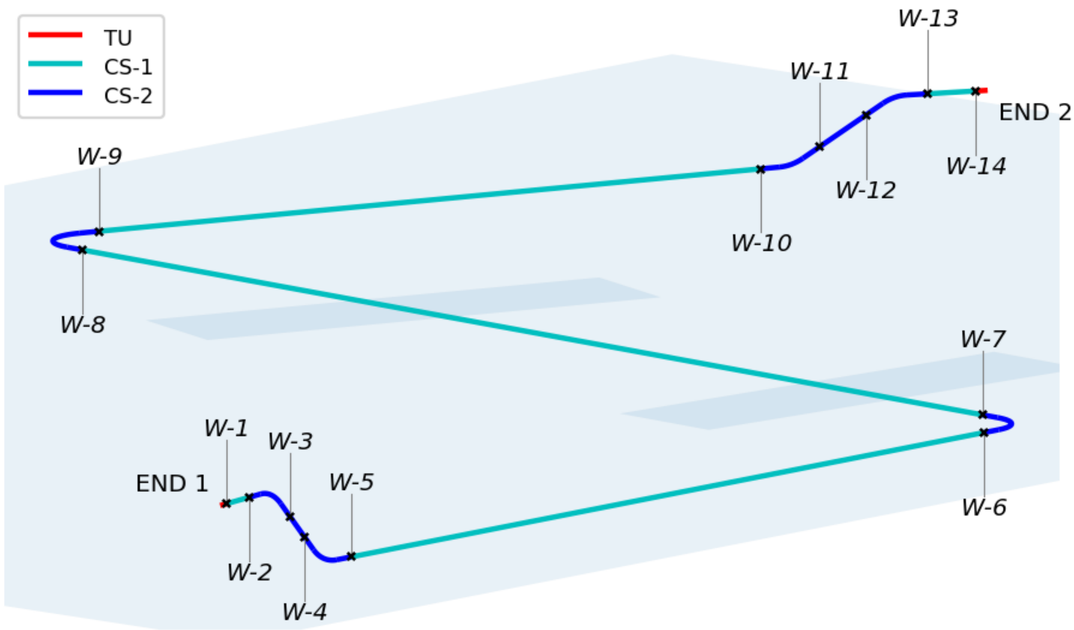


The shaded circular area indicates the allowable. The maximum utilisation is presented for each load step within parenthesis in the figure legend.

8.9 Fatigue Damage due to VIV

The welds assessed for fatigue damage due to VIV are shown in Figure 8.15.

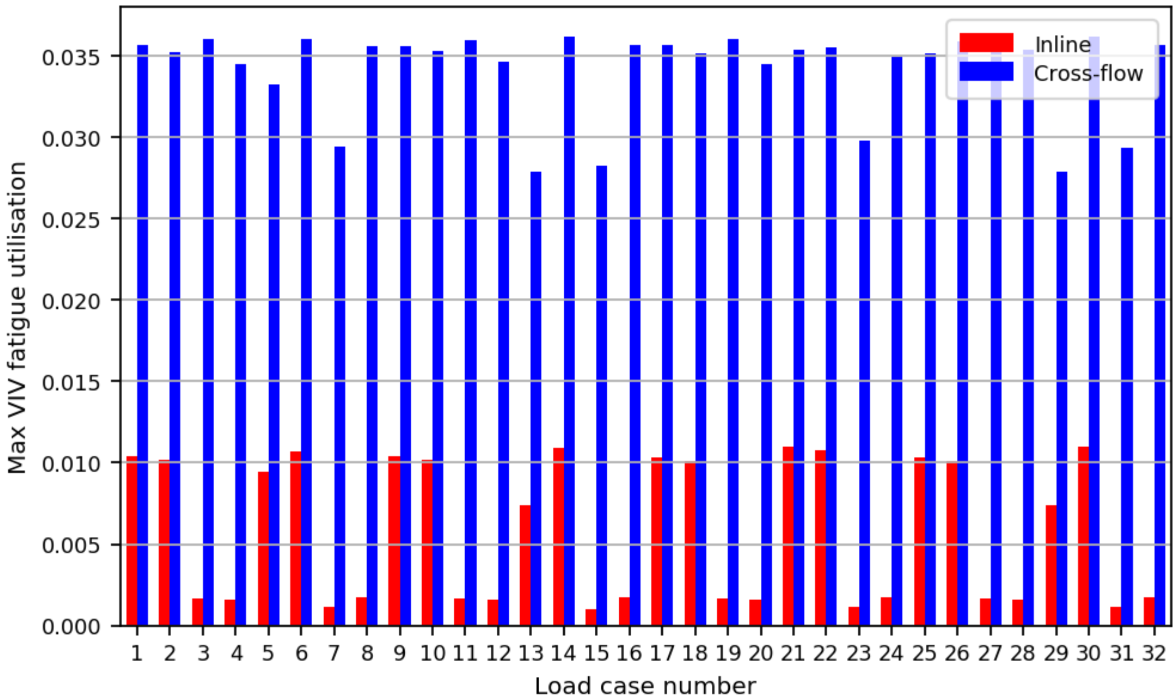
Figure 8.15 – Assessed Welds



Note that additional welds will be present where the pipe section exceeds the pipe joint length.

The maximum VIV fatigue utilisations for each load case are shown in Figure 8.16.

Figure 8.16 – Maximum VIV Fatigue Utilisation for Each Load Case

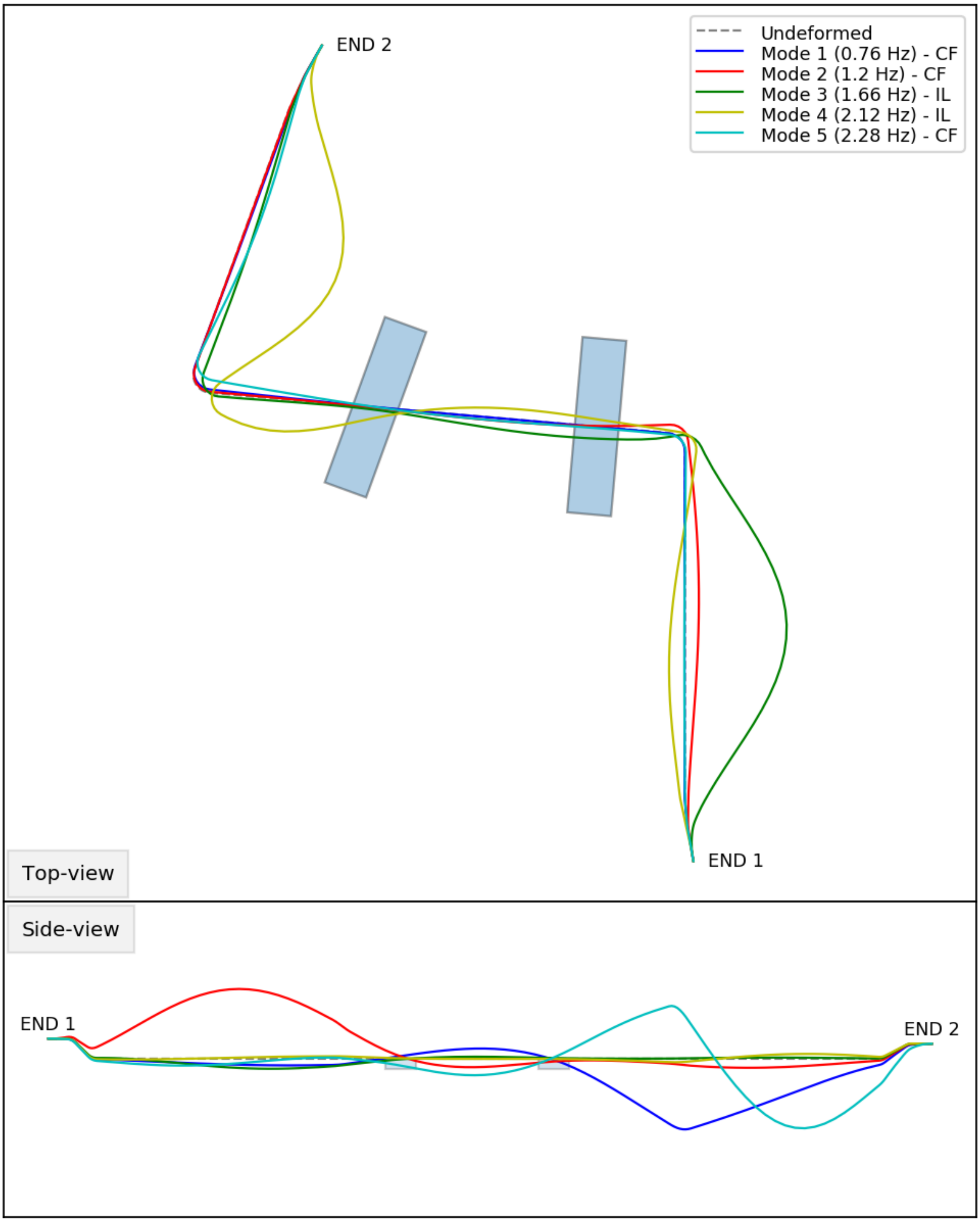


Inline and Cross-Flow utilisations are presented separately, and indicated that the damage has been accumulate at a specific location around the circumference.

It should be noted that both inline and cross-flow induced vibrations can potentially accrue damage at any location around the pipe circumference.

The Eigen-modes corresponding to the five lowest frequencies for load case number 30 (most critical in terms of fatigue damage) are shown in Figure 8.17.

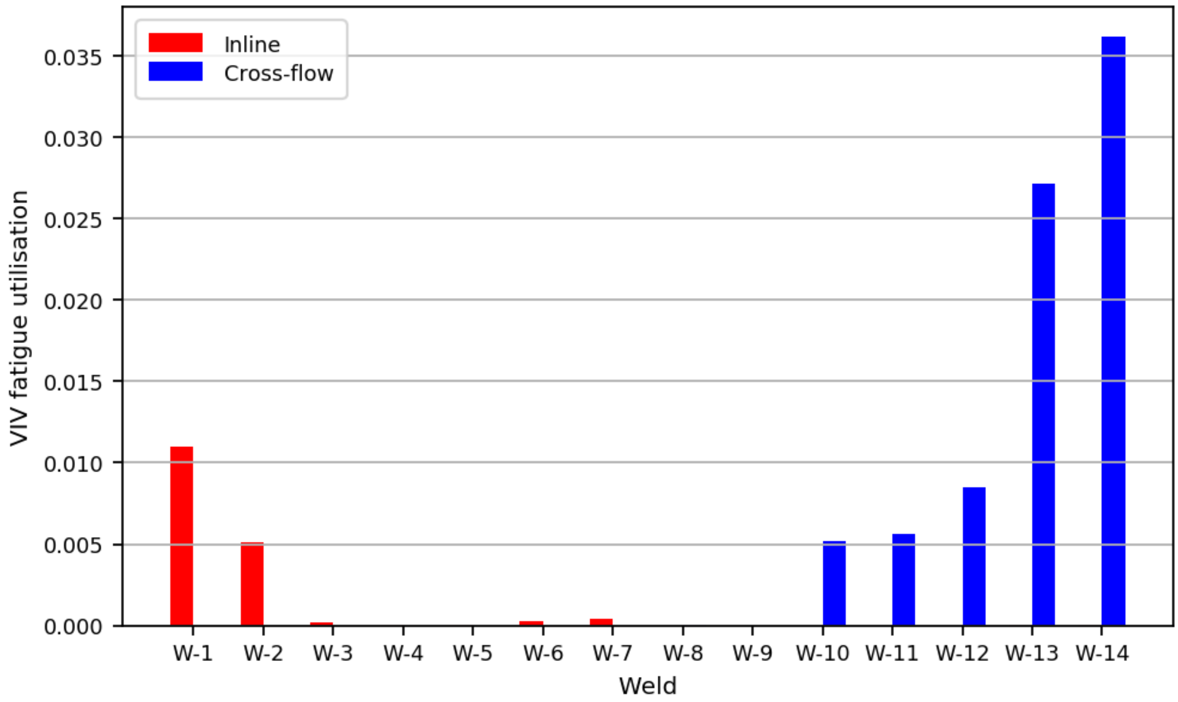
Figure 8.17 – Eigen-Modes of Most Utilised Load Case



The corresponding natural frequencies are presented within parenthesis in the figure legend, where the dominating mode type is denoted IL and / or CF.

The maximum VIV fatigue utilisation (all load cases) in each weld is shown in Figure 8.18.

Figure 8.18 – Maximum VIV Fatigue Utilisation at Each Weld



8.10 Support Loads

The maximum vertical support forces, from any of the analysed load cases, are presented in Table 8.6, for each subsequent load step.

Table 8.6 – Maximum Vertical Forces Acting on Supports and Seabed

Load Step	Vertical Force [kN]		
	SEABED	Support-1	Support-2
Docked	0.1	45.6	66.6
Tie-in 1st end	0.0	54.8	60.4
Tie-in 2nd end	6.6	58.6	62.1
Pressure test	6.7	58.7	62.1
Contraction	0.0	41.4	39.0
Expansion	0.0	40.0	42.4
Contraction/sett	9.2	43.6	35.9
Expansion/sett	10.5	42.0	37.3
Max	10.5	58.7	66.6

Note that the maximum loads are presented for any of the analysed load cases and do not necessarily occur concurrently.

9 CONFIGURATION MAX_L3

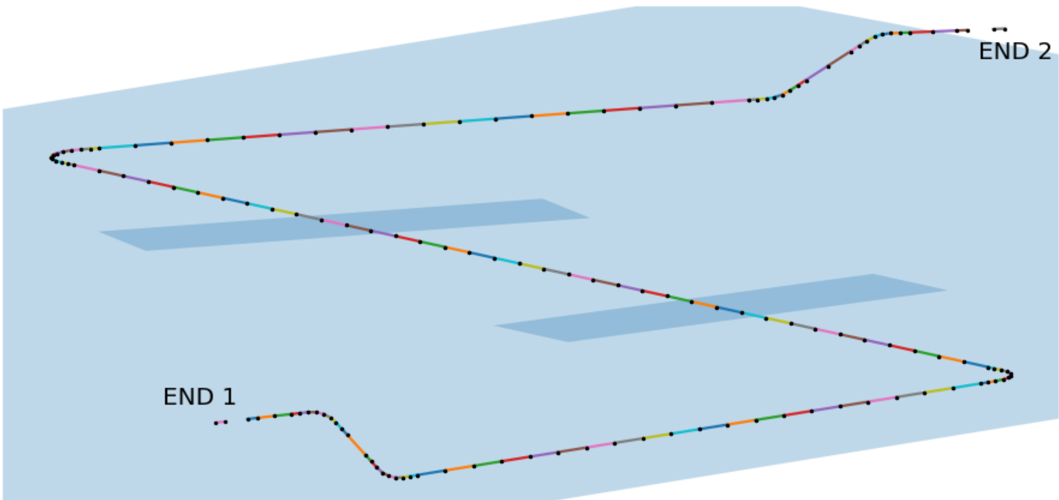
This section presents the following detailed results for configuration "max_L3".

- FE-model
- Spool geometry
- Load cases
- Load steps
- Spool CLC / ASD utilisation
- Spool ASME utilisation
- Spool HISC utilisation
- Spool end reaction loads
- Fatigue damage due to VIV
- Support loads

9.1 FE-MODEL

The FE-model consists of the spool and two connecting structures at each end. The mesh density used is shown in Figure 9.1.

Figure 9.1 – FE-Model Mesh



The beam / pipe elements are shown as lines and with the associated nodes are shown as black dots. The nodes belonging to the area elements are not shown.

The spool consists of three different cross-section types.

9.2 SPOOL GEOMETRY

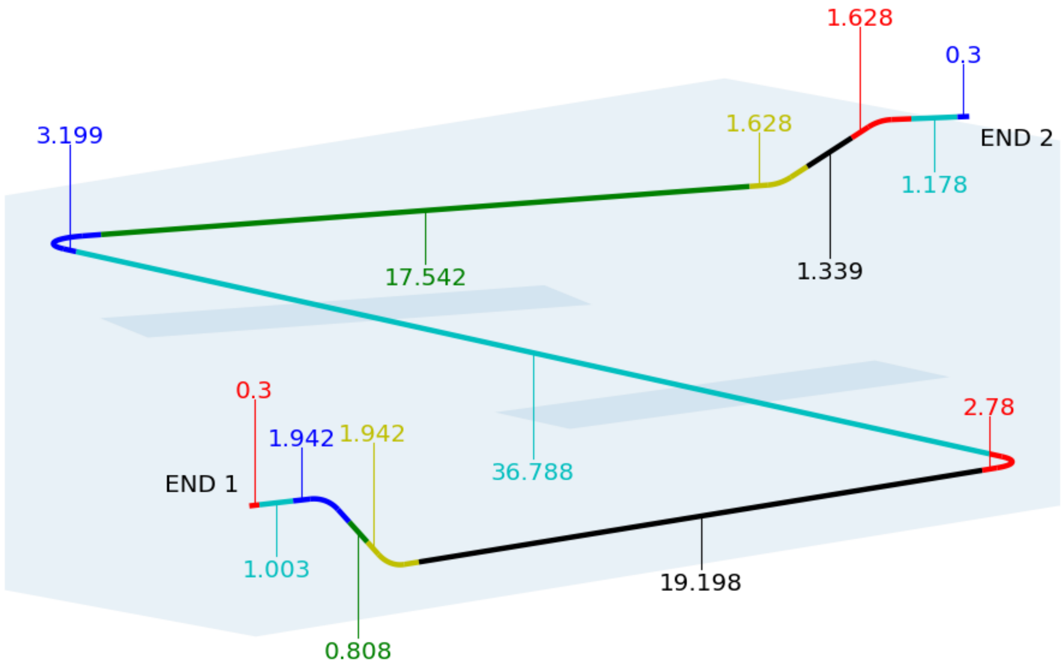
The coordinates at the spool ends and at the intersection points between the extended straight lines / sections, are presented in Table 9.1.

Table 9.1 – Coordinates at Ends and Intersection Points

Location	Coordinates [m]		
	X / Easting	Y / Northing	Z / Vertical
End 1	0.353	4.065	2.6
IP-1	0.405	4.36	2.6
IP-2	0.752	6.33	2.6
IP-3	0.926	8.311	0.626
IP-4	0.926	30.107	0.626
IP-5	-39.371	33.632	0.626
IP-6	-32.385	52.827	0.626
IP-7	-31.289	55.177	2.1
IP-8	-30.289	56.909	2.1
End 2	-30.139	57.169	2.1

An isometric view of the spool showing each section length (units in meter) is shown in Figure 9.2.

Figure 9.2 – Isometric View with Section Lengths



9.3 Load Cases

A set of 16 load case combinations has been analysed, as presented in Table 9.2. The prescribed end displacement / rotation values refer to uncertainties regarding make-up tolerances at each spool end.

Table 9.2 – Load Case Combinations

Load Case	END 1						END 2					
	Displacements [m]			Rotations [deg]			Displacements [m]			Rotations [deg]		
	ux	uy	uz	rx	ry	rz	ux	uy	uz	rx	ry	rz
1	0.09	0.09	0.1	Free	0.55	-0.7	0.09	0.09	0.1	Free	0.55	-0.7
2	0.09	0.09	0.1	Free	0.55	-0.7	0.09	0.09	-0.1	Free	-0.55	-0.7
3	0.09	0.09	-0.1	Free	-0.55	-0.7	0.09	0.09	0.1	Free	0.55	-0.7
4	0.09	0.09	-0.1	Free	-0.55	-0.7	0.09	0.09	-0.1	Free	-0.55	-0.7
5	0.09	-0.09	0.1	Free	0.55	0.7	0.09	-0.09	0.1	Free	0.55	0.7
6	0.09	-0.09	0.1	Free	0.55	0.7	0.09	-0.09	-0.1	Free	-0.55	0.7
7	0.09	-0.09	-0.1	Free	-0.55	0.7	0.09	-0.09	0.1	Free	0.55	0.7
8	0.09	-0.09	-0.1	Free	-0.55	0.7	0.09	-0.09	-0.1	Free	-0.55	0.7
9	-0.09	0.09	0.1	Free	0.55	-0.7	-0.09	0.09	0.1	Free	0.55	-0.7
10	-0.09	0.09	0.1	Free	0.55	-0.7	-0.09	0.09	-0.1	Free	-0.55	-0.7
11	-0.09	0.09	-0.1	Free	-0.55	-0.7	-0.09	0.09	0.1	Free	0.55	-0.7
12	-0.09	0.09	-0.1	Free	-0.55	-0.7	-0.09	0.09	-0.1	Free	-0.55	-0.7
13	-0.09	-0.09	0.1	Free	0.55	0.7	-0.09	-0.09	0.1	Free	0.55	0.7
14	-0.09	-0.09	0.1	Free	0.55	0.7	-0.09	-0.09	-0.1	Free	-0.55	0.7
15	-0.09	-0.09	-0.1	Free	-0.55	0.7	-0.09	-0.09	0.1	Free	0.55	0.7
16	-0.09	-0.09	-0.1	Free	-0.55	0.7	-0.09	-0.09	-0.1	Free	-0.55	0.7

The parameter "Free" indicates that no tolerances have been applied, i.e. as the termination unit is free to swivel around the pipe axis prior to and during tie-ins.

9.4 LOAD STEPS

The spool have been analysed for the subsequent load steps presented in Table 9.3.

Table 9.3 – Subsequent Load Steps

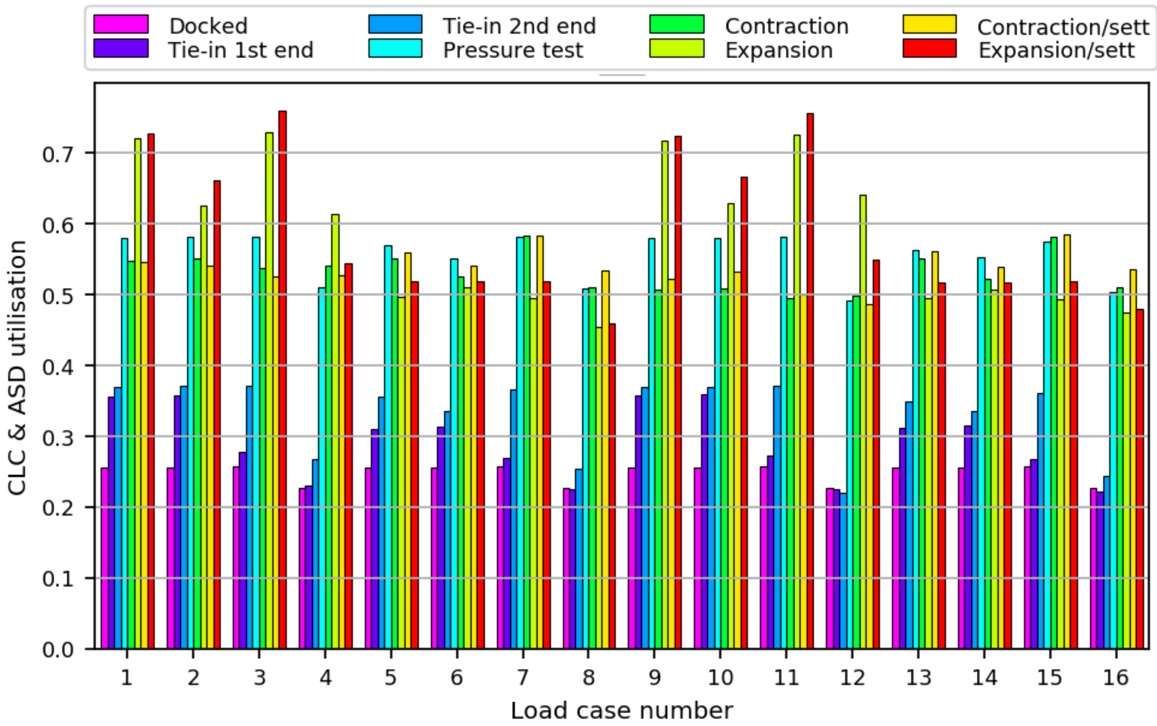
Load Step	Internal Pressure [bara]	Temperature [°C]	Content Density [kg/m3]	Axial Expansion - End 2 [m]
Docked	20	10	1150	0
Tie-in 1st end	20	10	1150	0
Tie-in 2nd end	20	10	1150	0
Pressure test	400	10	1150	0
Contraction	300	-20	250	-1.0
Expansion	300	100	250	3.0
Contraction/sett	300	-20	250	-1.0
Expansion/sett	300	100	250	3.0

Positive axial expansion is in the direction opposite to the tie-in stroking direction.

9.5 SPOOL CLC / ASD UTILISATION

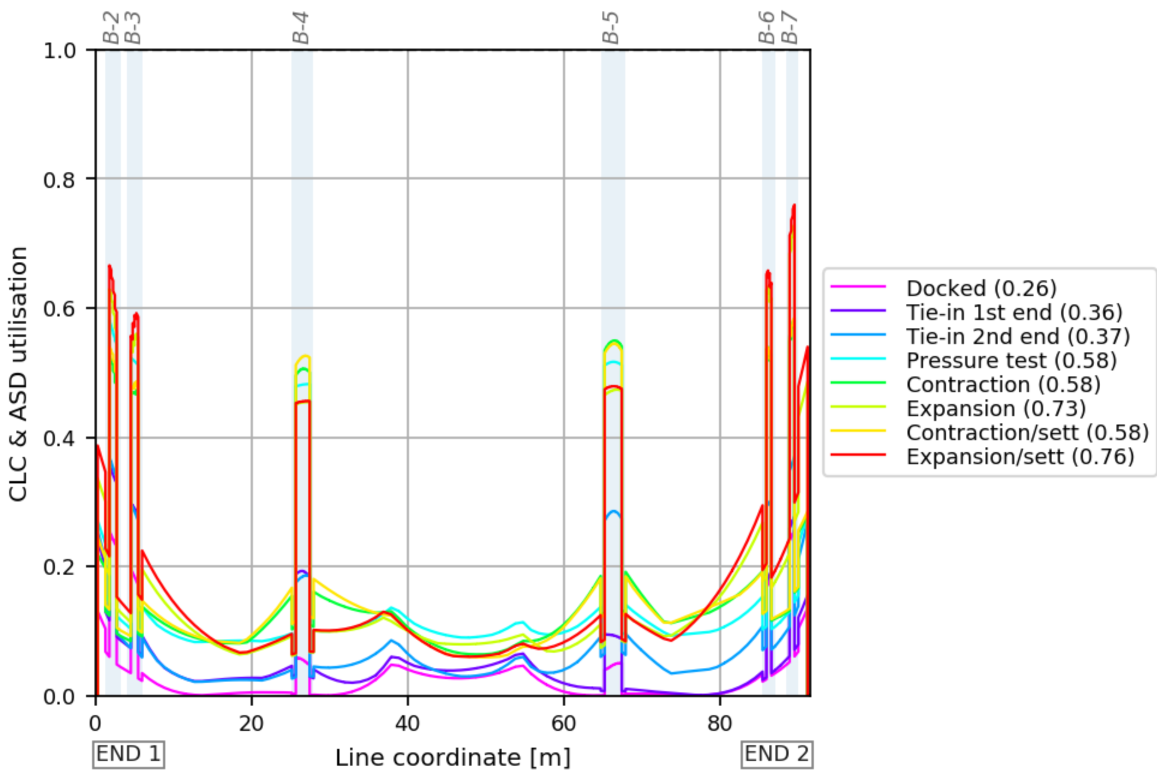
The maximum CLC / ASD utilisation along the spool, for each load case and load step, is shown in Figure 9.3.

Figure 9.3 – Maximum CLC / ASD Utilisation for Each Load Case and Load Step



A CLC / ASD utilisation envelope plot from all load cases and for each analysed subsequent load step is shown in Figure 9.4.

Figure 9.4 – Spool CLC / ASD Utilisation

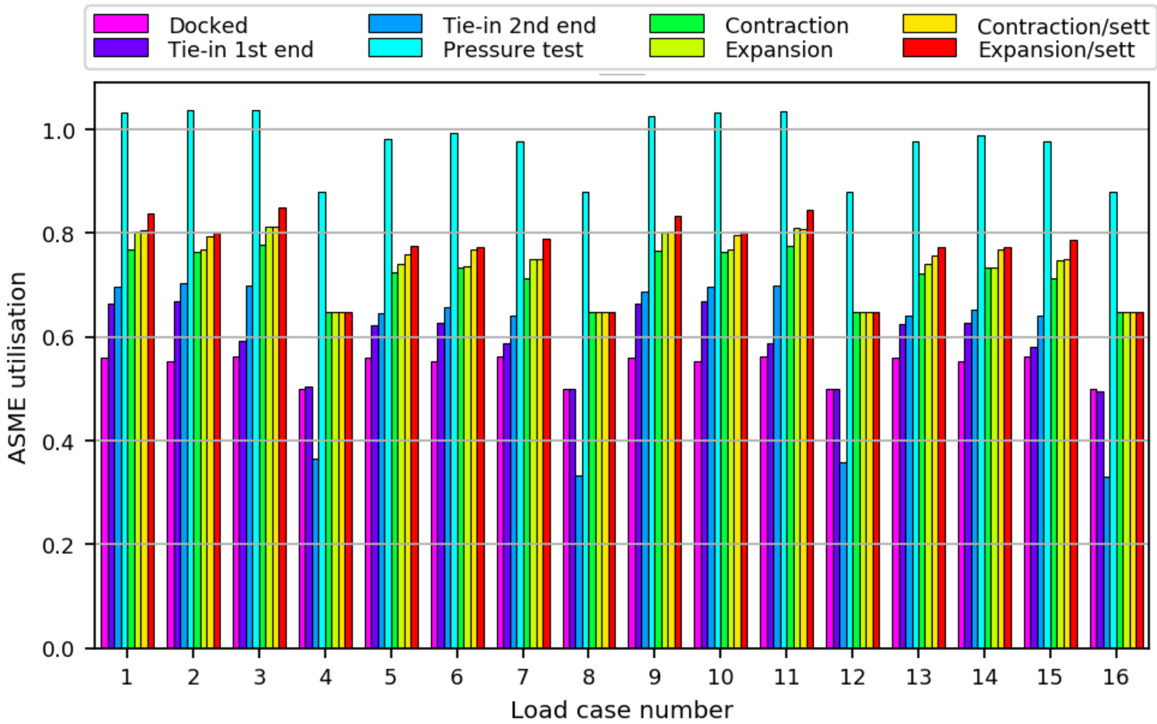


The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

9.6 SPOOL ASME UTILISATION

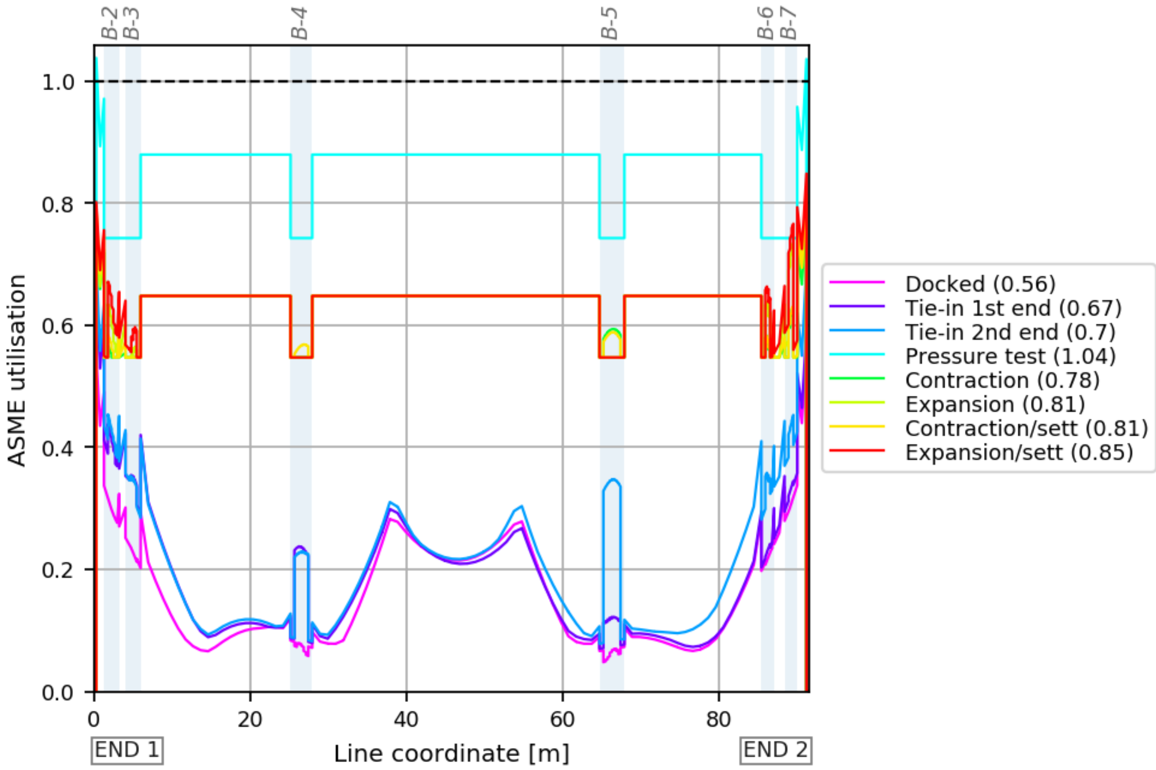
The maximum ASME utilisation along the spool, for each load case and load step, is shown in Figure 9.5.

Figure 9.5 – Maximum ASME Utilisation for Each Load Case and Load Step



An ASME utilisation envelope plot from all load cases and for each analysed subsequent load step is shown in Figure 9.6.

Figure 9.6 – Spool ASME Utilisation



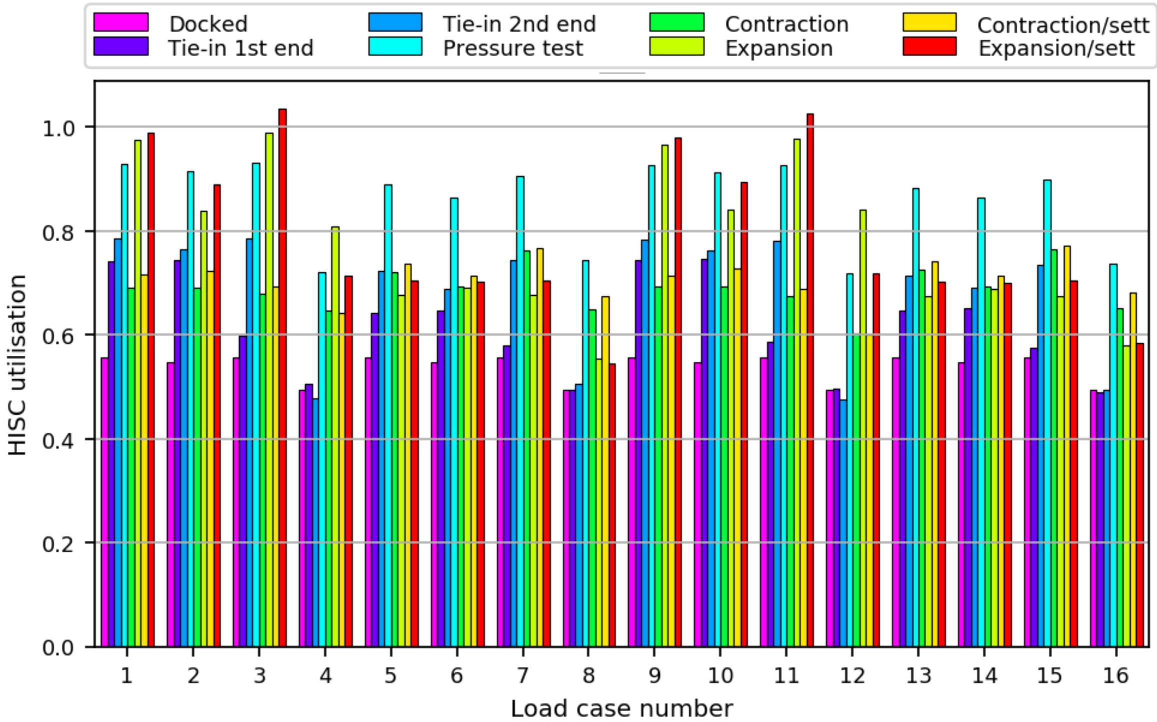
The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

Stress Intensification Factors, according to Ref. [ASME B31.8], have been accounted for when calculating utilisations in the bends and at welds.

9.7 Spool HISC Utilisation

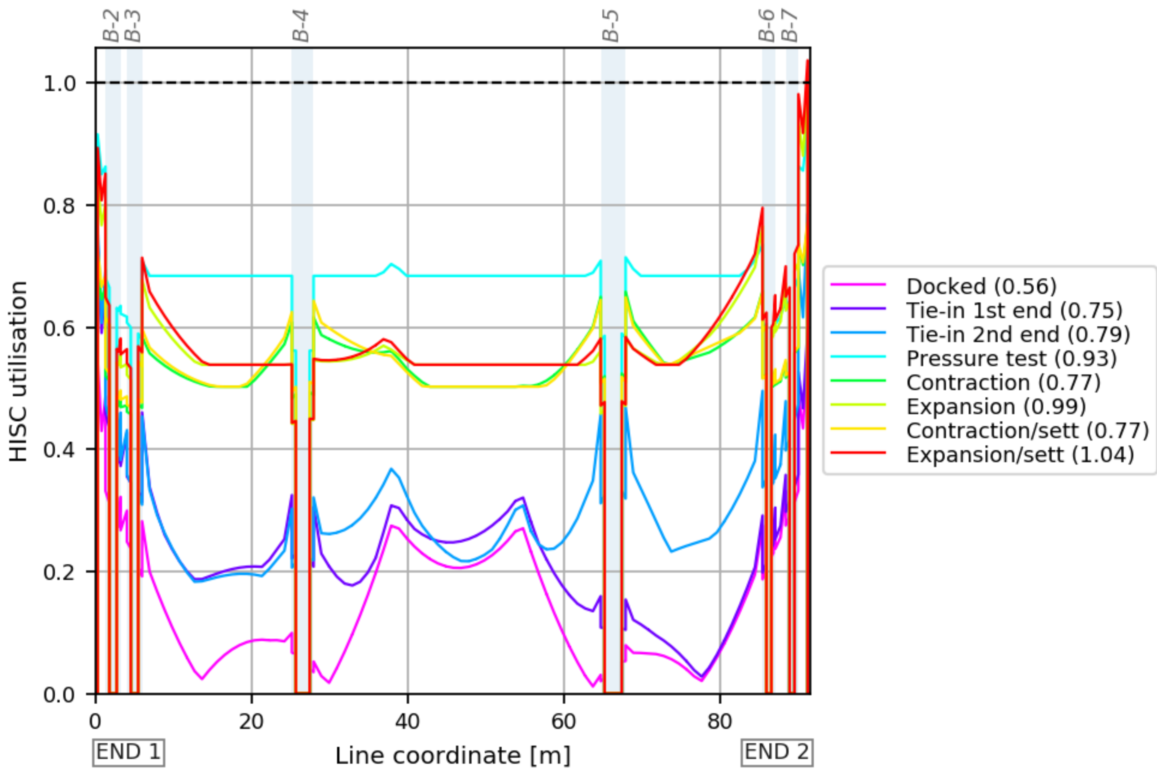
The maximum HISC utilisation along the spool, for each load case and load step, is shown in Figure 9.7.

Figure 9.7 – Maximum HISC Utilisation for Each Load Case and Load Step



A HISC utilisation envelope plot from all load cases and for each analysed subsequent load step is shown in Figure 9.8.

Figure 9.8 – Spool HISC Utilisation



The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

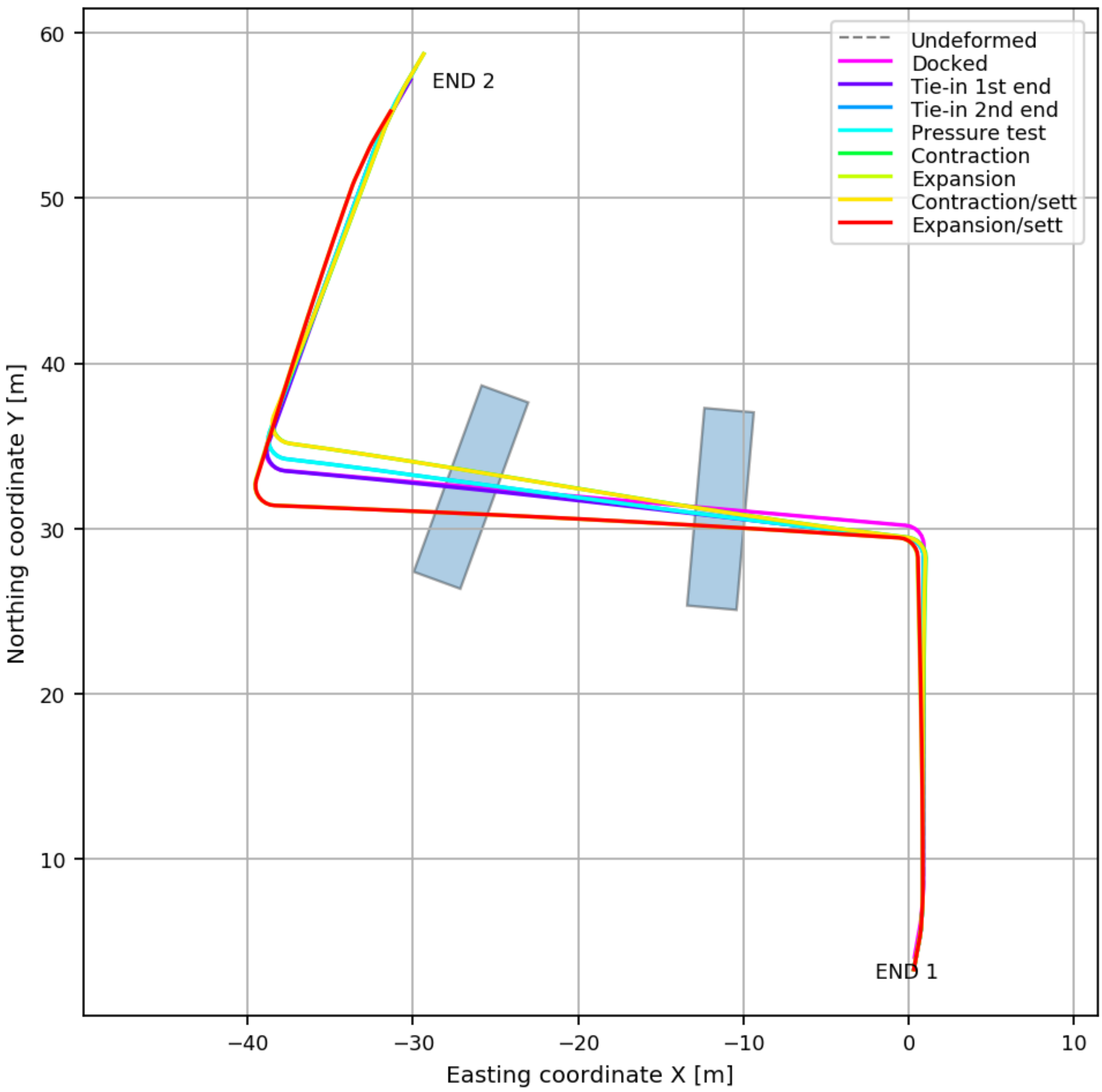
Longitudinal Stress Concentration Factors has been applied at each weld.

The spool bends (curved part) have not been assessed, since beam elements have been used in this assessment. HISC assessment in bends requires the use of either shell- or solid FE-models, in order to capture the ovalisation effects, which are causing high stress gradients across the wall thickness, as well as great stress variations around the circumference.

9.7.1 Most Utilised Load Case - Number 3

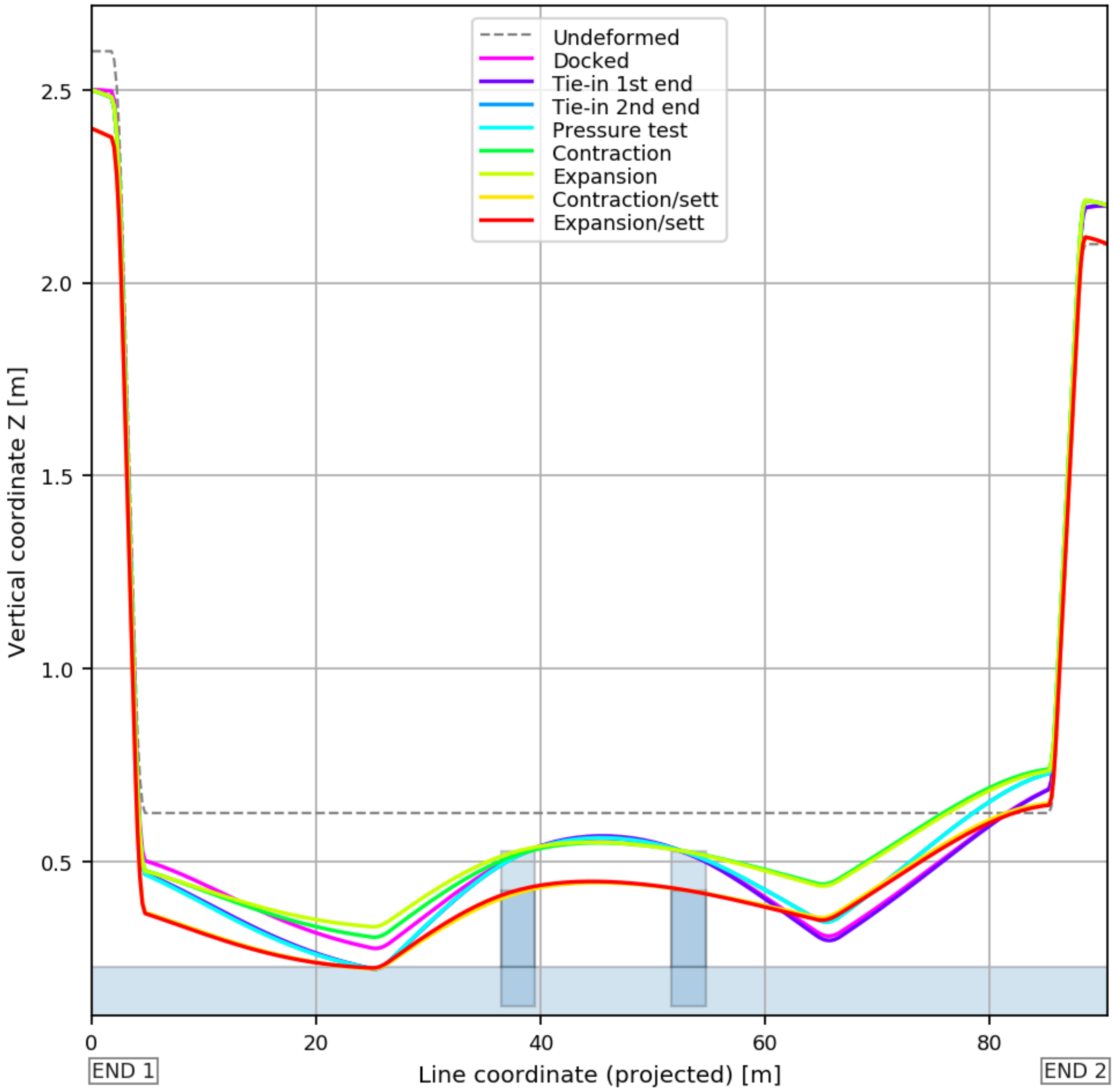
A top-view of the deformed shapes, for the most utilised load case (number 3), are shown for each load step in Figure 9.9.

Figure 9.9 – Top-View of Deformed Shapes of Critical Load Case



A profile view of the deformed shapes, for the most utilised load case (number 3), are shown for each load step in Figure 9.10.

Figure 9.10 – Profile View Deformed Shape of Critical Load Case



9.8 Spool End Reaction Loads

The weight of Termination Units has not been included in the assessment. This will primary affect the vertical reaction force RFz and secondary the reaction moment RMy.

9.8.1 End 1

The maximum magnitude reaction loads at End 1 of the spool, from any of the analysed load cases, are presented in Table 9.4 for each subsequent load step.

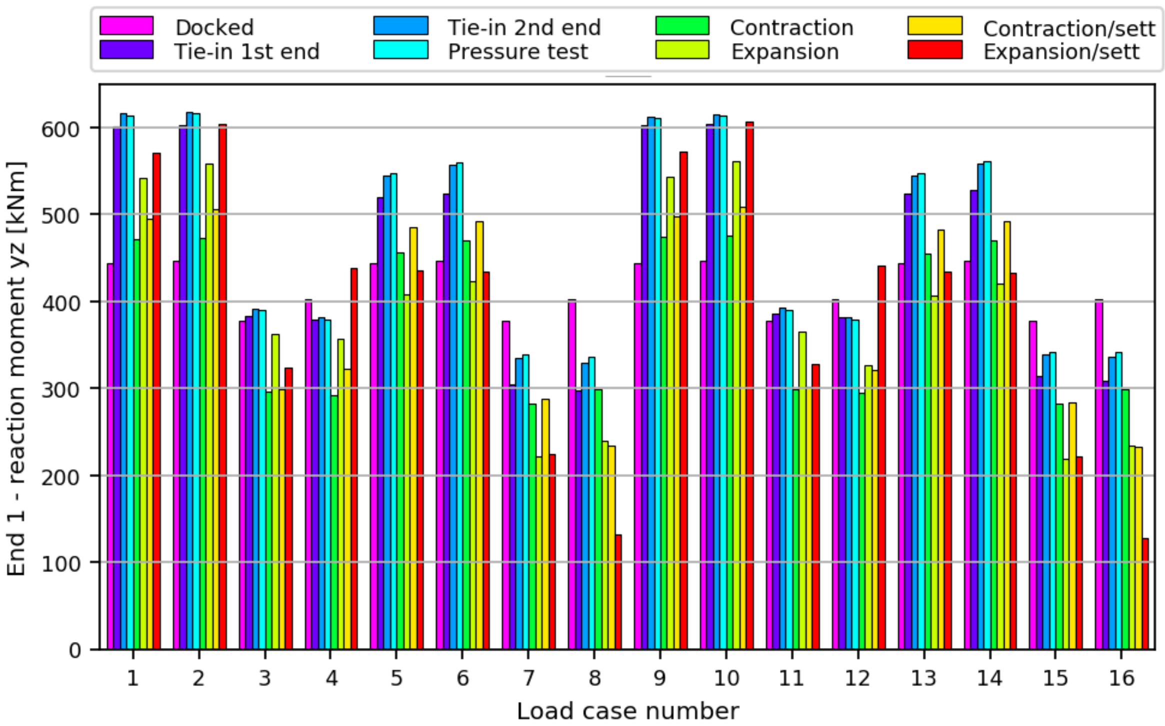
Table 9.4 – Maximum Magnitude Reaction Loads at End 1

Load Step	End Reaction Forces [kN]			End Reaction Moments [kNm]			
	RFx	RFy	RFz	RMx	RMy	RMz	RMb
Docked	3.1	1.5	88.2	-0.0	446.7	10.7	446.8
Tie-in 1st end	23.3	24.2	93.4	0.0	540.2	-274.4	604.0
Tie-in 2nd end	8.7	20.0	93.1	-9.0	565.3	-260.6	618.4
Pressure test	8.0	19.2	93.1	-10.1	566.6	-253.0	616.6
Contraction	13.0	26.7	76.2	-24.1	418.5	256.9	475.1
Expansion	8.8	-16.7	75.5	-45.9	421.5	-370.1	560.9
Contraction/sett	13.6	30.0	77.4	-32.0	442.5	-301.4	508.8
Expansion/sett	7.6	18.3	76.7	-50.6	447.6	-423.3	606.7
Max	23.3	30.0	93.4	-50.6	566.6	-423.3	618.4

The maximum loads are presented for any of the analysed load cases and do not necessarily occur concurrently.

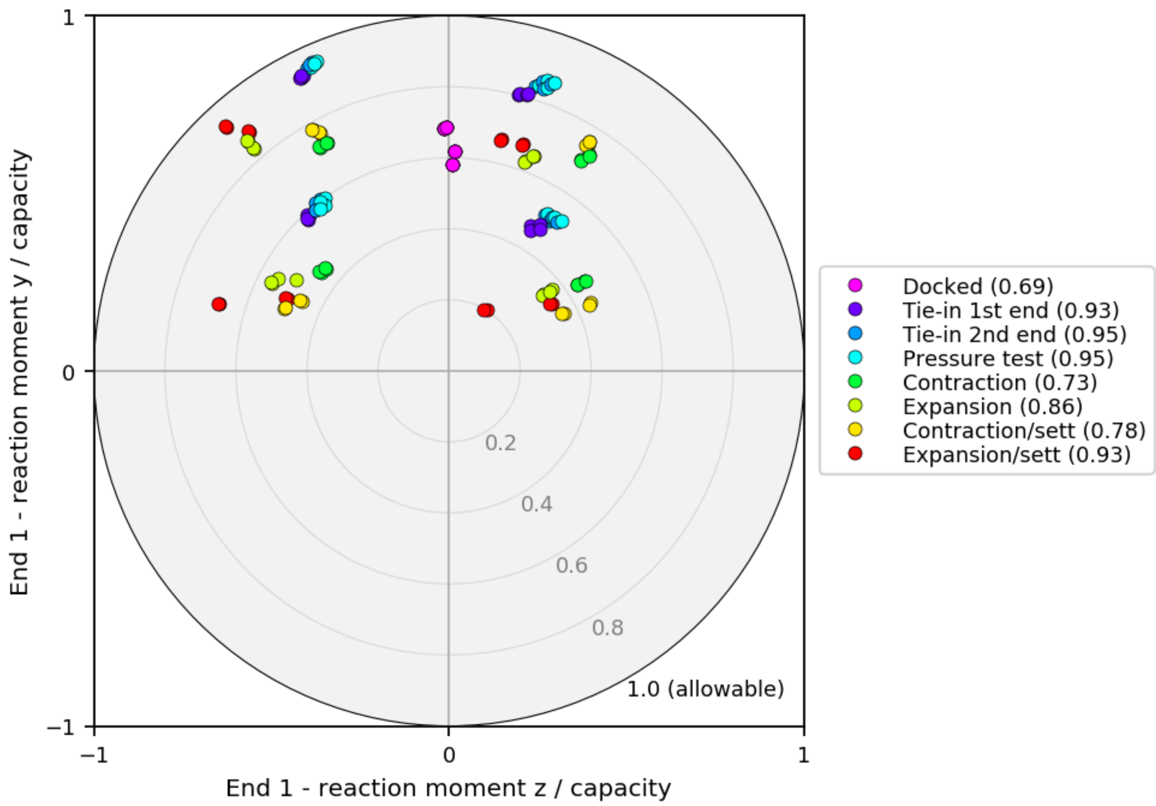
The maximum magnitude reaction bending moment at End 1, for each load case and load step, is shown in Figure 9.11.

Figure 9.11 – Maximum Magnitude Reaction Bending Moment at End 1



The connector / hub bending moment utilisations (RMy vs. RMz) at End 1, for all load cases and load steps, are shown in Figure 9.12.

Figure 9.12 – Reaction Bending Moment Components at End 1



The shaded circular area indicates the allowable. The maximum utilisation is presented for each load step within parenthesis in the figure legend.

9.8.2 End 2

The maximum magnitude reaction loads at End 2 of the spool, from any of the analysed load cases, are presented in Table 9.5 for each subsequent load step.

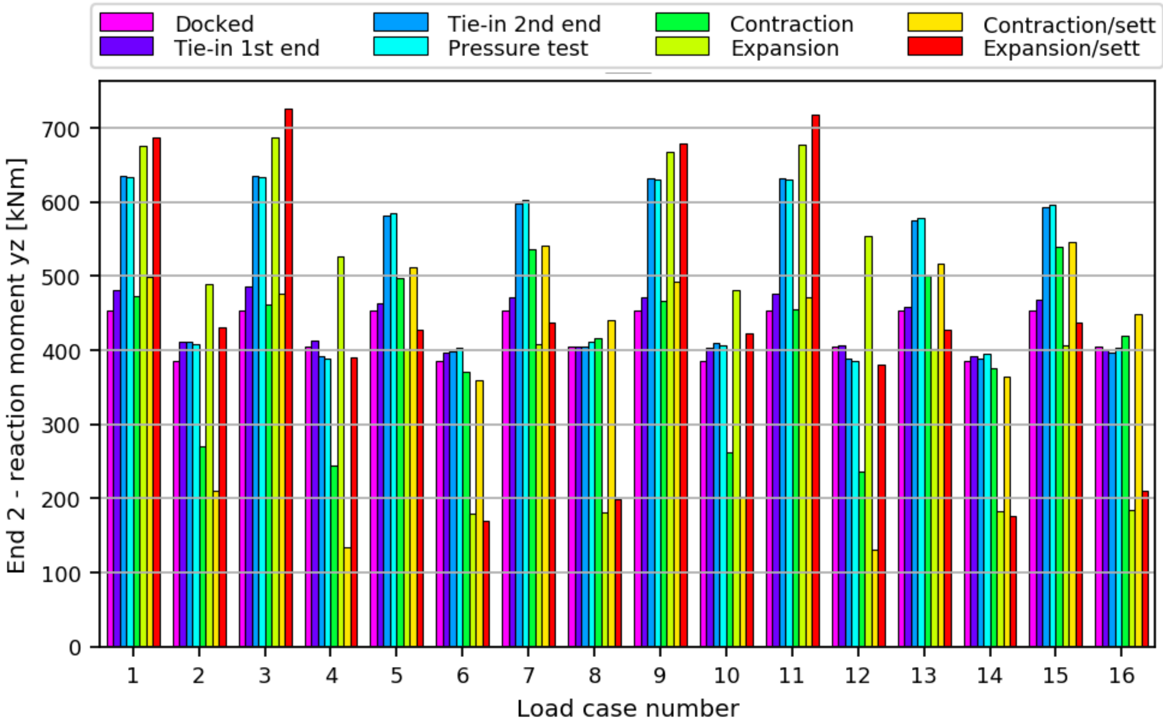
Table 9.5 – Maximum Magnitude Reaction Loads at End 2

Load Step	End Reaction Forces [kN]			End Reaction Moments [kNm]			
	RFx	RFy	RFz	RMx	RMy	RMz	RMb
Docked	2.3	1.2	86.9	-0.0	453.8	9.4	453.8
Tie-in 1st end	-15.6	7.6	87.4	0.0	476.7	-99.9	485.3
Tie-in 2nd end	22.0	31.7	92.8	-0.0	563.6	316.8	635.6
Pressure test	20.8	31.1	92.8	-1.2	564.1	323.7	633.2
Contraction	22.9	29.8	76.4	-17.4	428.4	397.5	539.8
Expansion	-22.0	-18.2	75.5	-25.8	457.2	-512.1	686.5
Contraction/sett	22.5	29.4	77.7	-27.5	454.3	442.6	546.5
Expansion/sett	-20.0	-23.0	76.8	-33.2	485.2	-541.0	726.7
Max	22.9	31.7	92.8	-33.2	564.1	-541.0	726.7

The maximum loads are presented for any of the analysed load cases and do not necessarily occur concurrently.

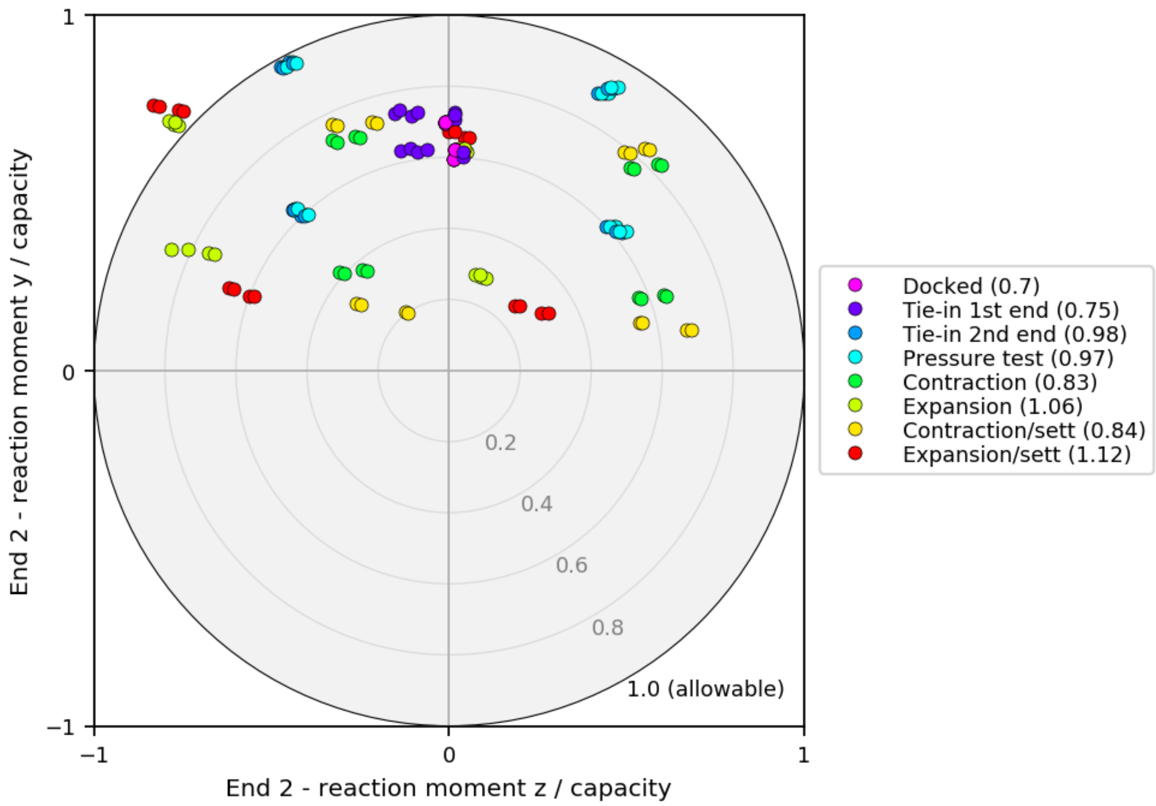
The maximum magnitude reaction bending moment at End 2, for each load case and load step, is shown in Figure 9.13.

Figure 9.13 – Maximum Magnitude Reaction Bending Moment at End 2



The connector / hub bending moment utilisations (RMy vs. RMz) at End 2, for all load cases and load steps, are shown in Figure 9.14.

Figure 9.14 – Reaction Bending Moment Components at End 2

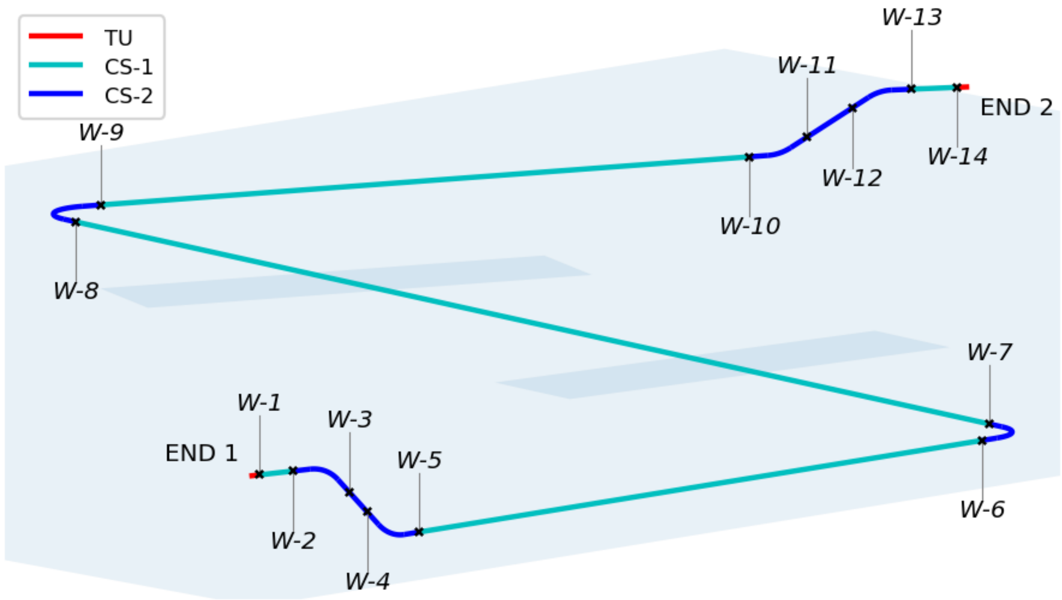


The shaded circular area indicates the allowable. The maximum utilisation is presented for each load step within parenthesis in the figure legend.

9.9 FATIGUE DAMAGE DUE TO VIV

The welds assessed for fatigue damage due to VIV are shown in Figure 9.15.

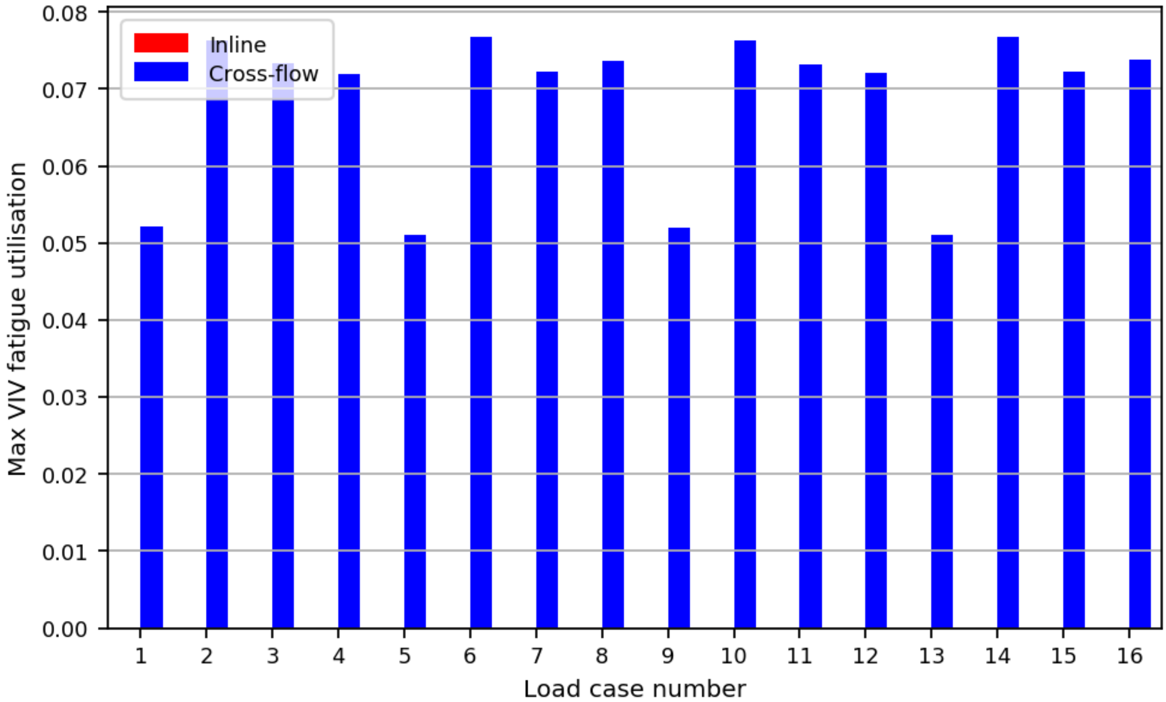
Figure 9.15 – Assessed Welds



Note that additional welds will be present where the pipe section exceeds the pipe joint length.

The maximum VIV fatigue utilisations for each load case are shown in Figure 9.16.

Figure 9.16 – Maximum VIV Fatigue Utilisation for Each Load Case

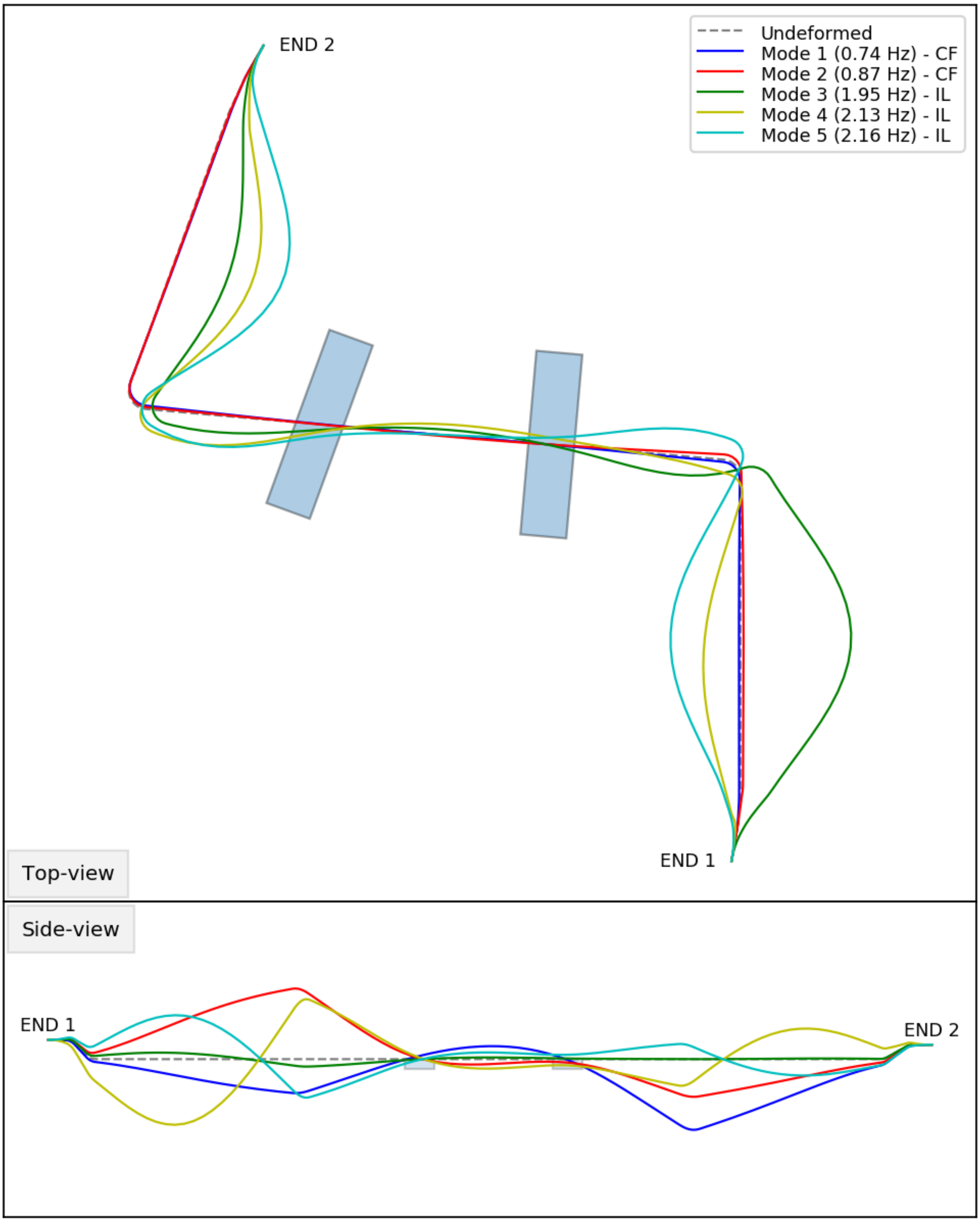


Inline and Cross-Flow utilisations are presented separately, and indicated that the damage has been accumulate at a specific location around the circumference.

It should be noted that both inline and cross-flow induced vibrations can potentially accrue damage at any location around the pipe circumference.

The Eigen-modes corresponding to the five lowest frequencies for load case number 14 (most critical in terms of fatigue damage) are shown in Figure 9.17.

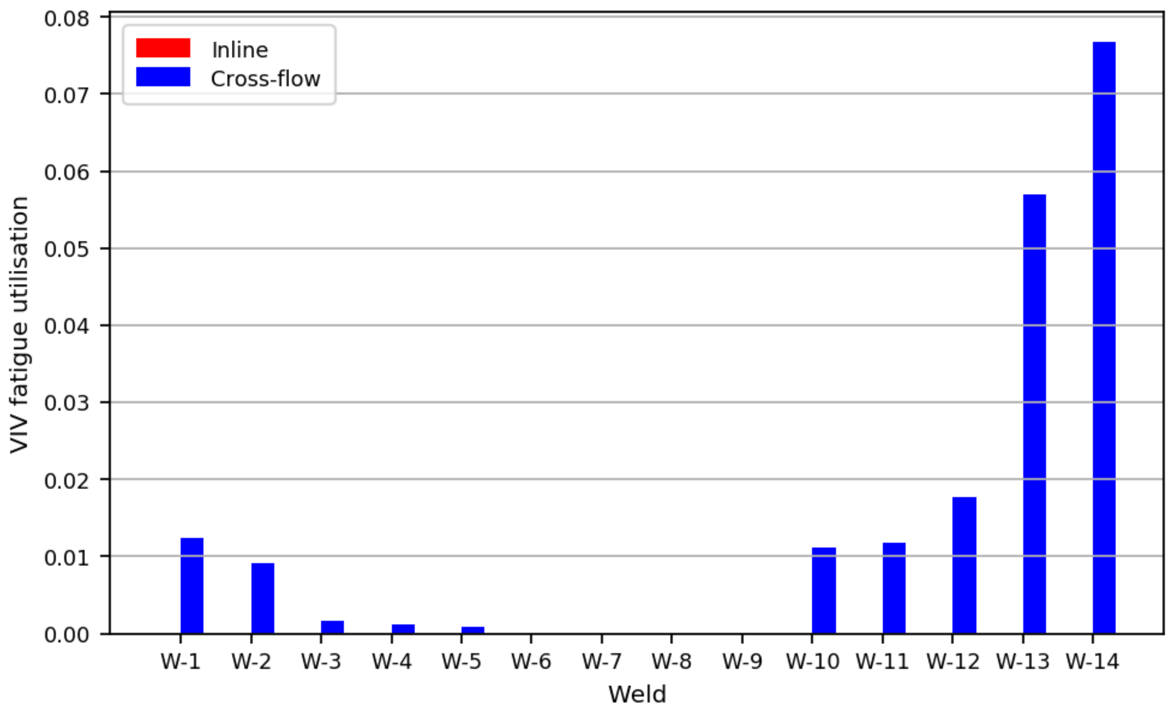
Figure 9.17 – Eigen-Modes of Most Utilised Load Case



The corresponding natural frequencies are presented within parenthesis in the figure legend, where the dominating mode type is denoted IL and / or CF.

The maximum VIV fatigue utilisation (all load cases) in each weld is shown in Figure 9.18.

Figure 9.18 – Maximum VIV Fatigue Utilisation at Each Weld



9.10 Support Loads

The maximum vertical support forces, from any of the analysed load cases, are presented in Table 9.6, for each subsequent load step.

Table 9.6 – Maximum Vertical Forces Acting on Supports and Seabed

Load Step	Vertical Force [kN]		
	SEABED	Support-1	Support-2
Docked	0.0	56.5	55.4
Tie-in 1st end	4.9	60.7	59.6
Tie-in 2nd end	12.2	65.3	63.6
Pressure test	12.4	65.3	63.6
Contraction	0.0	43.7	43.0
Expansion	0.0	42.3	45.1
Contraction/sett	16.3	44.2	42.3
Expansion/sett	14.2	49.4	43.3
Max	16.3	65.3	63.6

Note that the maximum loads are presented for any of the analysed load cases and do not necessarily occur concurrently.