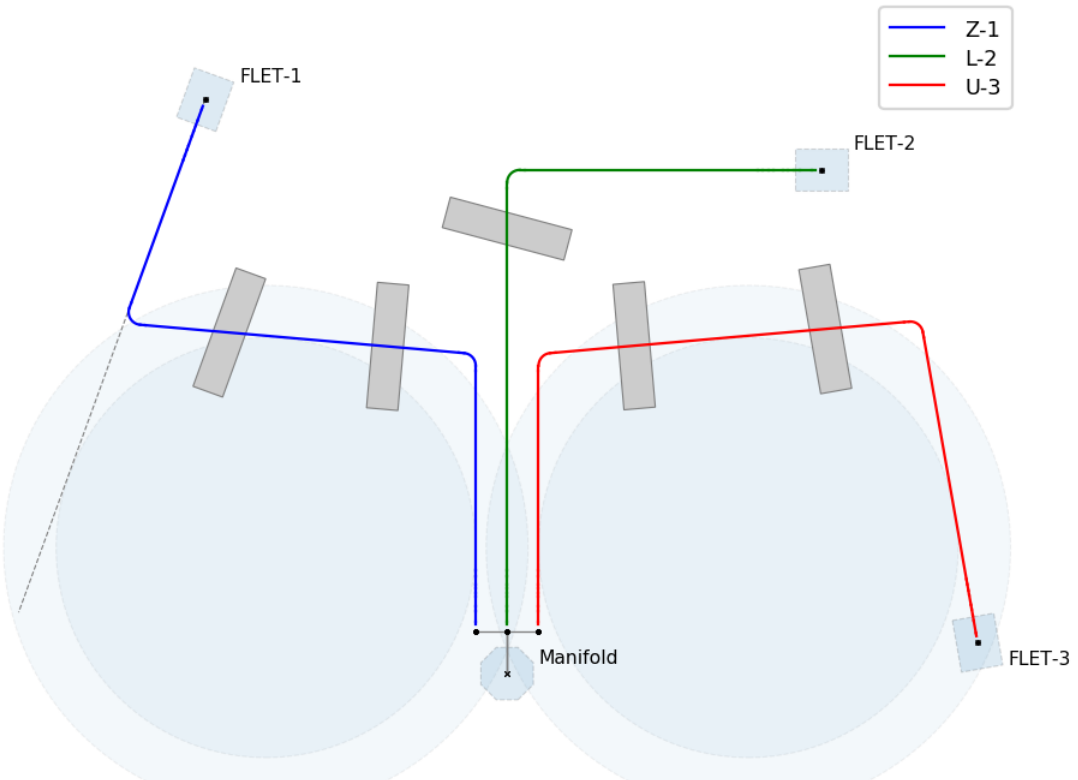
DETAILED RESULTS FOR SPOOL U-3



PROJECT	FIELD	SPOOL
Project Name	Ozean F-1	U-3

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 U-3, comprising of the following assessed configurations:

- min
- nom
- max
- min_L2
- min_L3
- min_L4
- max_L2
- max_L3
- max_L4

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

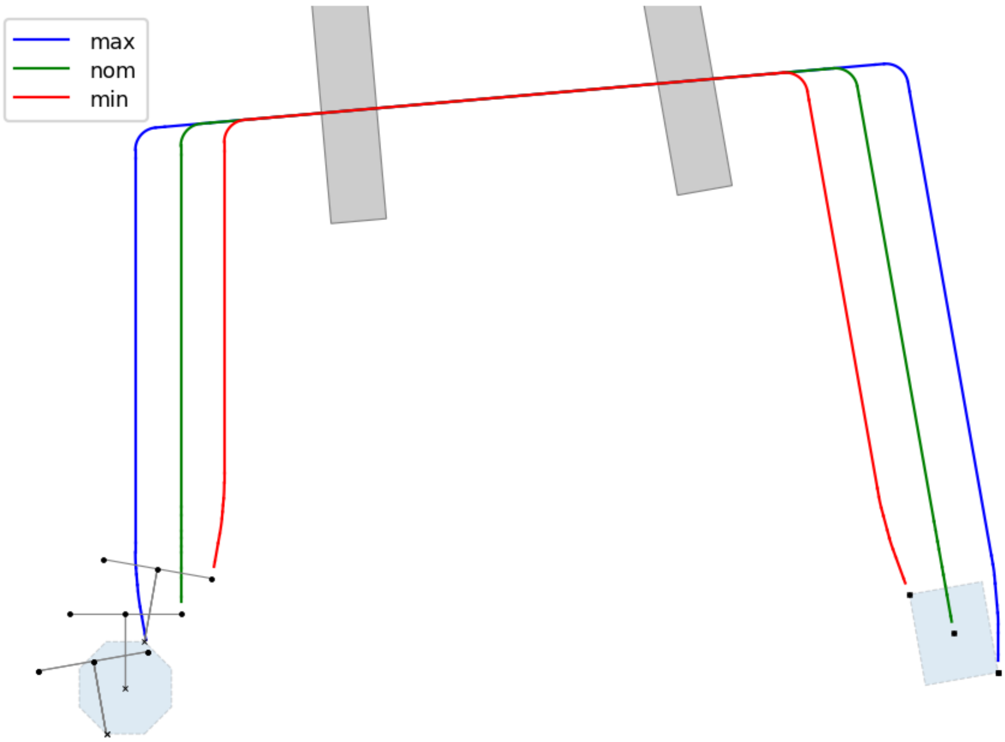
End 1	Manifold end of the spool
End 2	FLET-3 end of the spool
RFi	Reaction Force in i-direction, where i stands for either the x-, y-, or z-axis
RMi	Reaction Moment about i-axis, where i stands for either the x, y, or z
RMb	Reaction Moment bending
ui	Displacement in i-direction, where i stands for the 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.

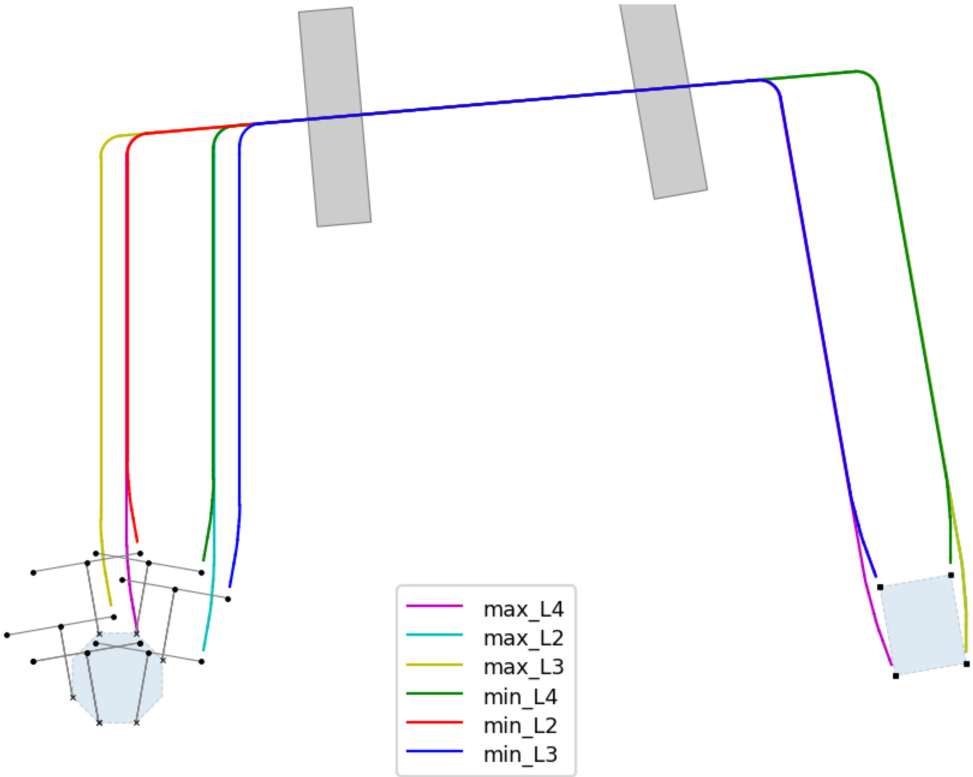
The minimum and maximum configurations refer to the total length of the spools, and are presented in Figure 1.1.

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.

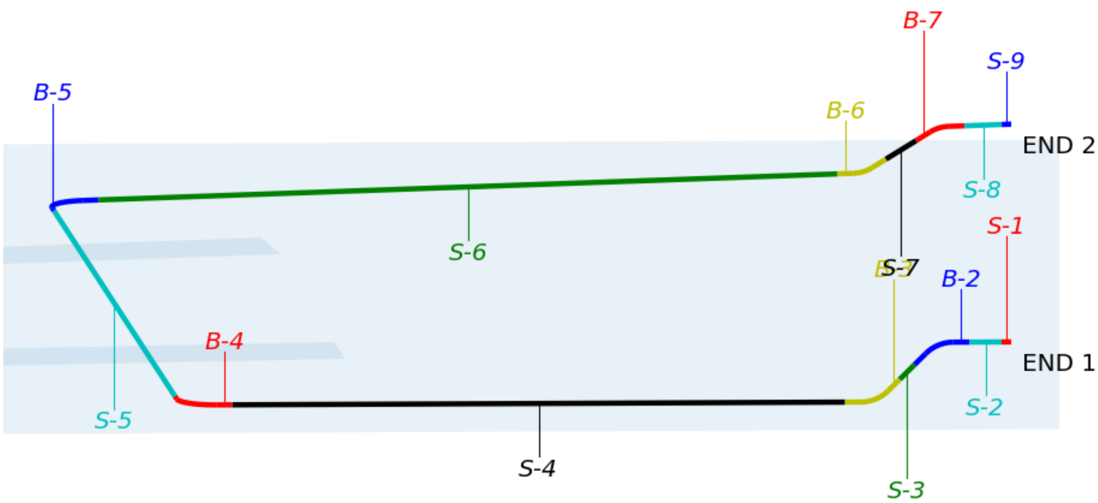
Figure 1.2 – Analysed Configurations - Min / Max Individual Legs



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.

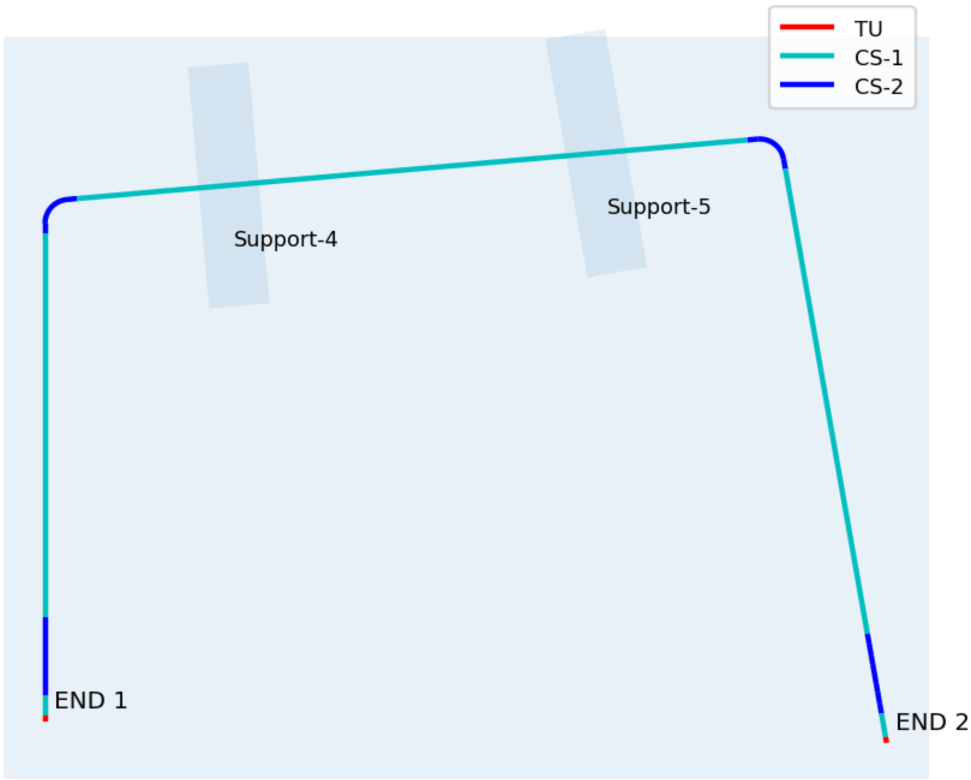
Figure 1.4 – End Coordinate Systems

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	0.76	0.9	0.9	1.21	N/A	0.0	1.33	0.92
nom	0.5	0.76	0.98	1.0	N/A	274.52	1.07	0.93
max	0.38	0.68	1.05	0.92	N/A	0.99	0.93	0.95
min_L2	0.76	0.9	0.97	1.22	N/A	0.0	1.34	0.92
min_L3	0.65	0.85	0.88	1.13	N/A	0.0	1.23	0.94
min_L4	0.49	0.74	1.0	0.99	N/A	0.04	0.95	1.05
max_L2	0.4	0.68	1.05	0.94	N/A	0.73	0.8	0.99
max_L3	0.39	0.68	1.05	0.91	N/A	1.03	0.97	0.95
max_L4	0.51	0.77	1.01	1.01	N/A	0.42	1.08	0.81
Max	0.76	0.9	1.05	1.22	N/A	274.52	1.34	1.05

The maximum allowable utilisation is exceeded by 27352%.

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	85.0	37.4
nom	94.0	41.8
max	103.5	46.2
min_L2	88.4	41.2
min_L3	85.1	36.0
min_L4	90.0	41.6
max_L2	100.1	42.5
max_L3	103.4	47.7
max_L4	98.5	42.0

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	33.383	-6.598	6.689
B-5	CS-2	2.78	-	-
S-6	CS-1	23.417	-2.898	2.929
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	85.0	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	39.443	33.638	0.626
IP-6	43.929	8.192	0.626
IP-7	44.343	5.849	2.0
IP-8	44.69	3.879	2.0
End 2	44.742	3.584	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-3	44.855	2.944	100.0
Support-4	12.111	31.247	-85.0
Support-5	30.332	32.841	-80.0

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	91.055
CS-2	350.0	30.0	14.85
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	2

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	31.3	40.6	26.3
nom	33.7	44.0	28.3
max	36.2	47.5	30.3
min_L2	32.2	41.9	27.1
min_L3	31.4	40.7	26.4
min_L4	32.6	42.5	27.4
max_L2	35.3	46.2	29.6
max_L3	36.1	47.5	30.3
max_L4	34.9	45.6	29.2

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	10.4	-2.1	88.3	-0.0	477.7	-22.0	477.7
Tie-in 1st end	30.7	-23.1	93.2	-0.0	567.1	269.3	627.3
Tie-in 2nd end	24.3	-14.9	93.2	29.5	574.4	257.3	607.2
Pressure test	19.9	-13.4	93.1	30.2	575.8	-262.7	605.7
Contraction	-10.5	-19.5	75.5	48.8	450.1	486.1	611.8
Expansion	31.9	27.9	75.7	61.3	439.6	-845.8	866.6
Contraction/sett	-12.7	-19.0	76.5	57.4	471.0	472.6	631.6
Expansion/sett	31.2	25.0	76.9	60.1	466.4	-790.7	869.3
Max	31.9	27.9	93.2	61.3	575.8	-845.8	869.3

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.

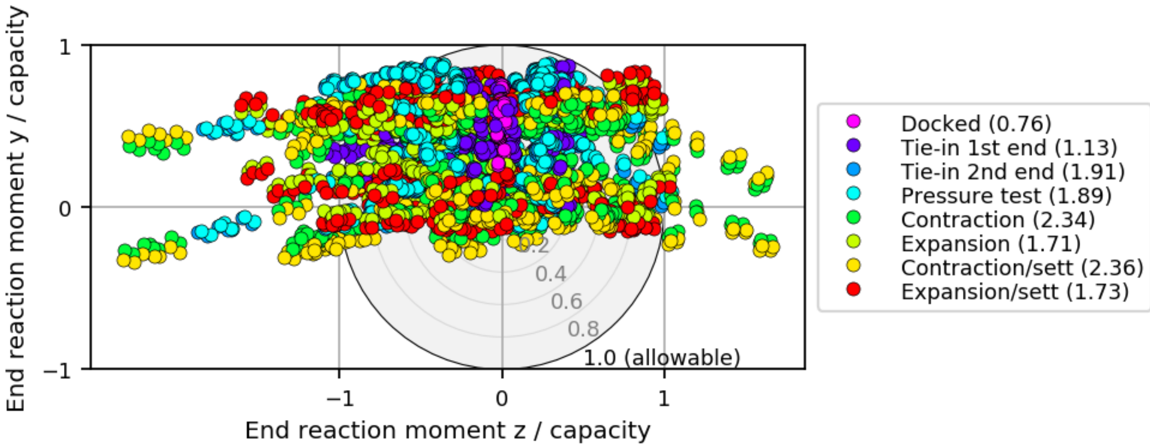
Table 2.11 – Maximum Magnitude Reaction Loads - End 2

Load Step	End Reaction Forces [kN]			End Reaction Moments [kNm]			
	RFx	RFy	RFz	RMx	RMy	RMz	RMb
Docked	8.9	1.3	90.9	0.0	496.5	11.8	496.5
Tie-in 1st end	19.6	-6.5	91.3	-0.0	493.3	-110.6	495.6
Tie-in 2nd end	30.8	23.1	94.6	-0.0	576.0	-463.2	657.4
Pressure test	26.6	22.1	94.6	7.8	577.6	-454.9	653.3
Contraction	32.2	24.7	75.4	-21.1	414.7	-438.7	525.0
Expansion	-43.1	-28.1	74.7	-60.0	449.8	-512.5	667.6
Contraction/sett	32.7	25.2	76.3	-24.1	439.4	-466.8	550.0
Expansion/sett	-43.5	-32.9	75.7	-66.0	476.3	-510.7	683.8
Max	-43.5	-32.9	94.6	-66.0	577.6	-512.5	683.8

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-4	Support-5
Docked	5.7	60.3	71.0
Tie-in 1st end	13.9	65.5	141.9
Tie-in 2nd end	21.3	66.4	73.5
Pressure test	21.6	66.5	73.5
Contraction	0.0	78.9	57.1
Expansion	0.0	47.6	51.7
Contraction/sett	21.4	47.4	53.7
Expansion/sett	23.0	51.8	49.7
Max	23.0	78.9	141.9

3 CONFIGURATION MIN

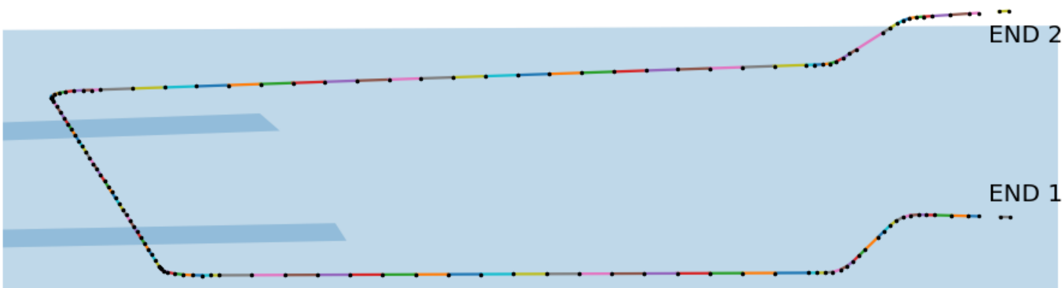
This section presents the following detailed results for configuration "min".

- 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

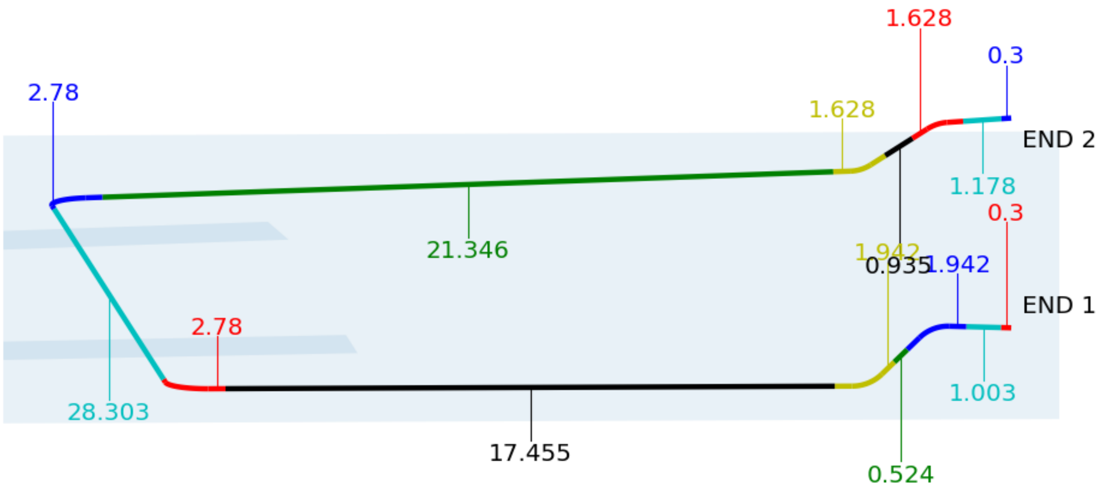
The coordinates at the spool ends and at the intersection points between the extended straight lines / sections, are presented in Table 3.1.

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	36.735	33.401	0.626
IP-6	40.862	9.995	0.626
IP-7	41.442	7.83	1.9
IP-8	42.126	5.951	1.9
End 2	42.229	5.669	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 32 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
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.

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

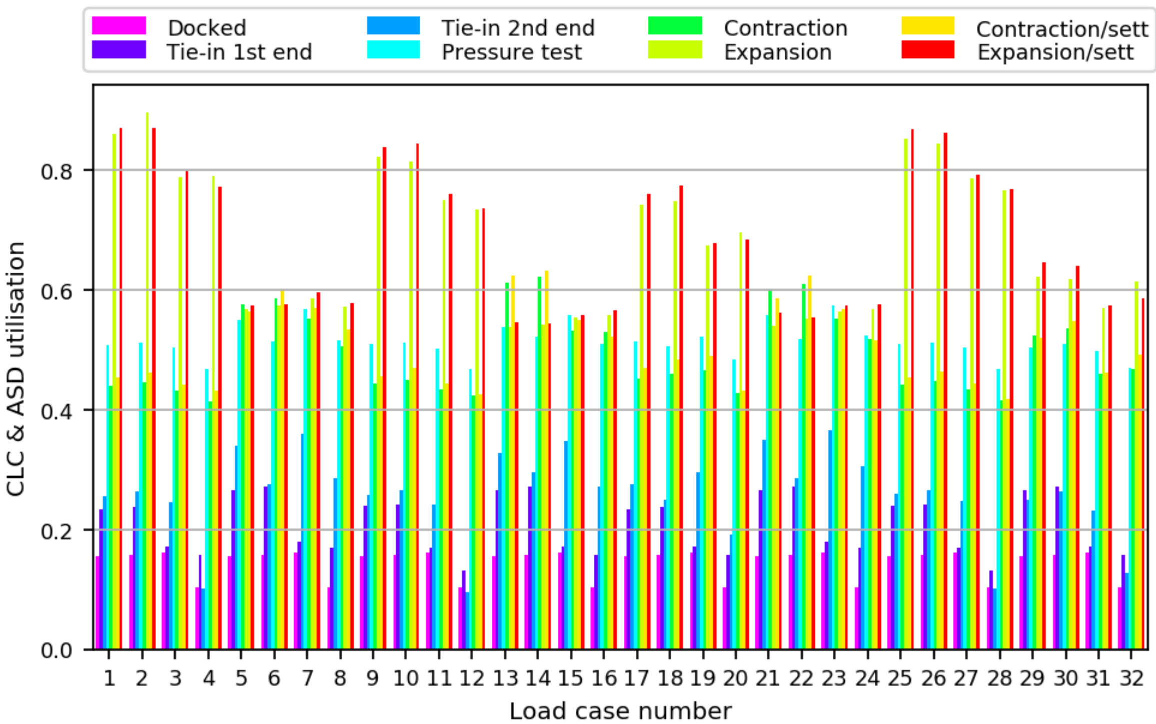
Load Step	Internal Pressure [bara]	Temperature [°C]	Content Density [kg/m3]	Axial Expansion - End 2 [m]
Docked	20	10	1150	0
Tie-in 1st end	20	10	1150	0
Tie-in 2nd end	20	10	1150	0
Pressure test	400	10	1150	0
Contraction	300	-20	250	-1.0
Expansion	300	100	250	3.0
Contraction/sett	300	-20	250	-1.0
Expansion/sett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

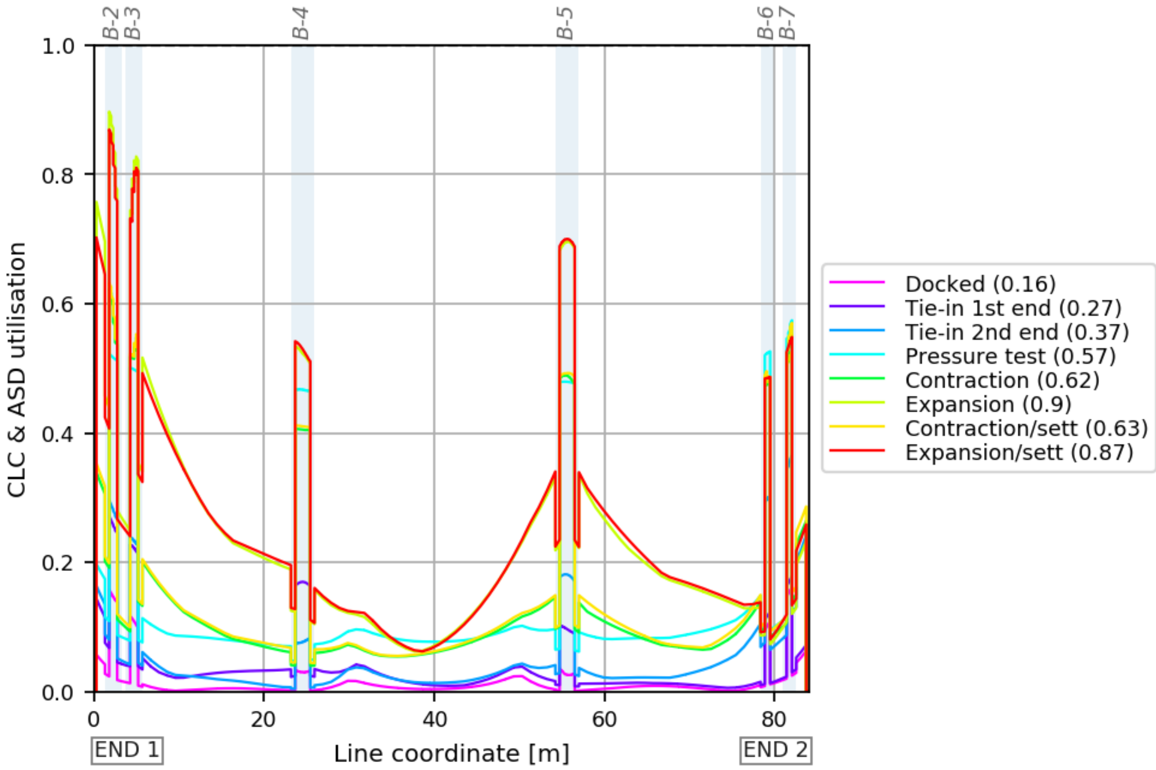
The maximum CLC / ASD utilisation along the spool, for each load case and load step, is shown in Figure 3.3.

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

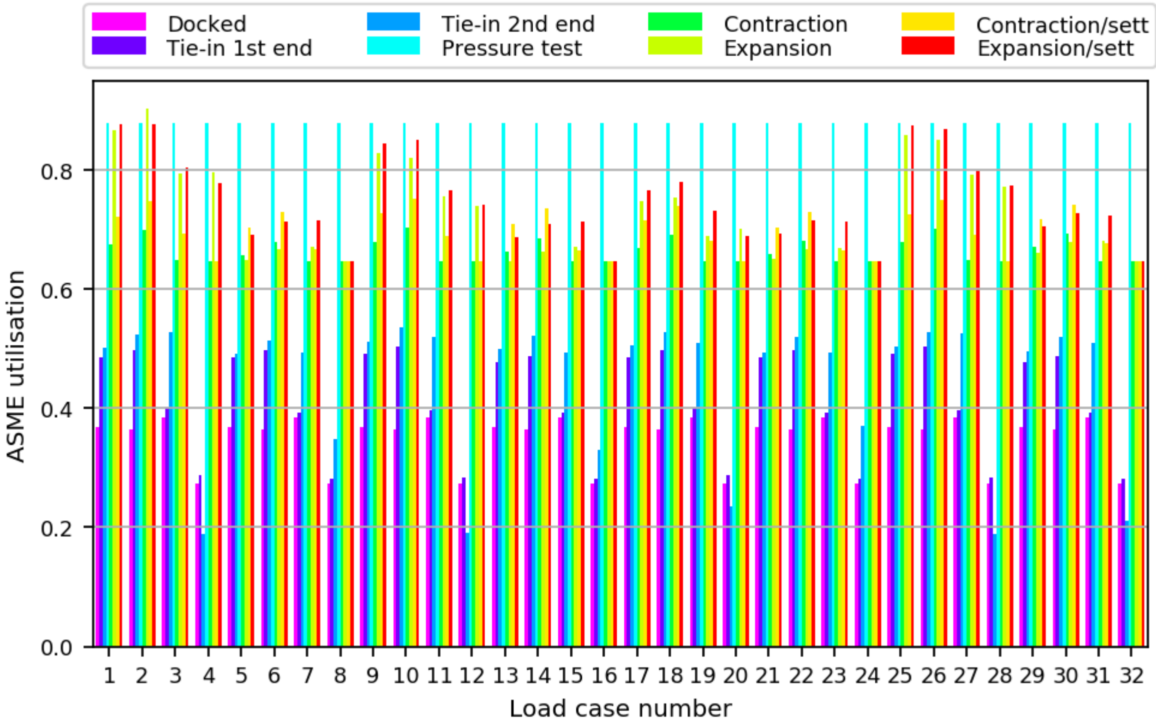


The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

3.6 Spool ASME Utilisation

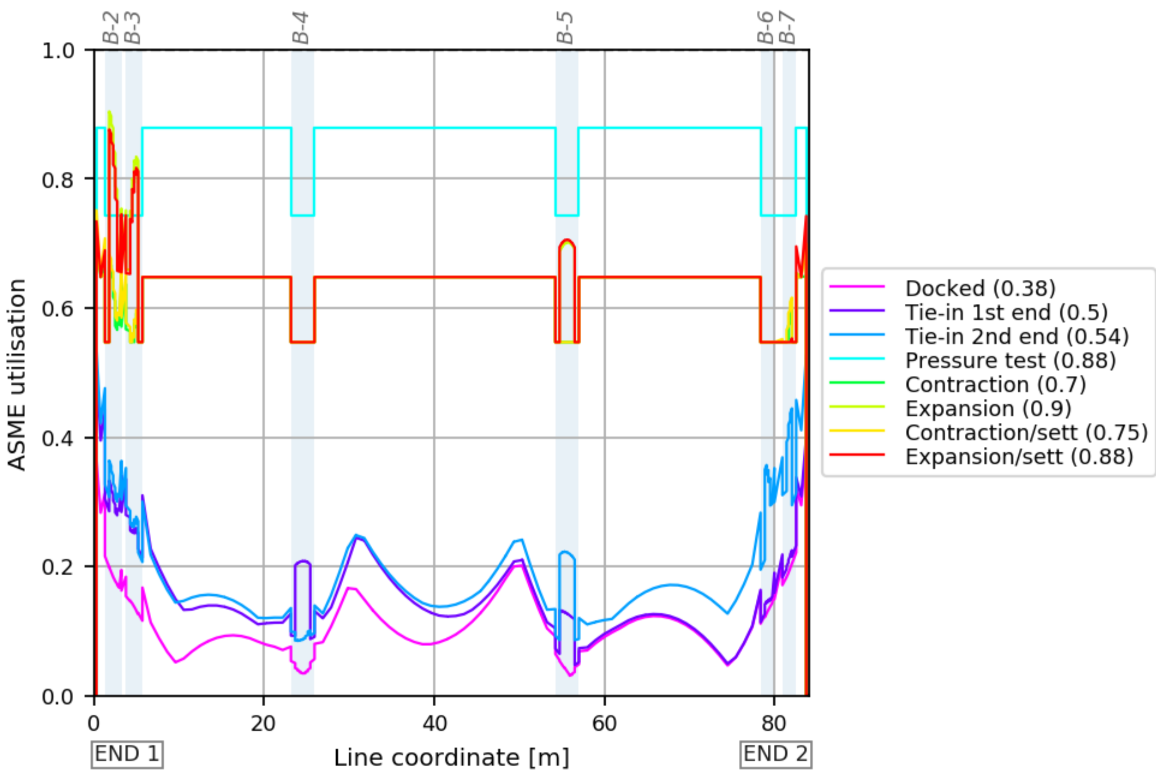
The maximum ASME utilisation along the spool, for each load case and load step, is shown in Figure 3.5.

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



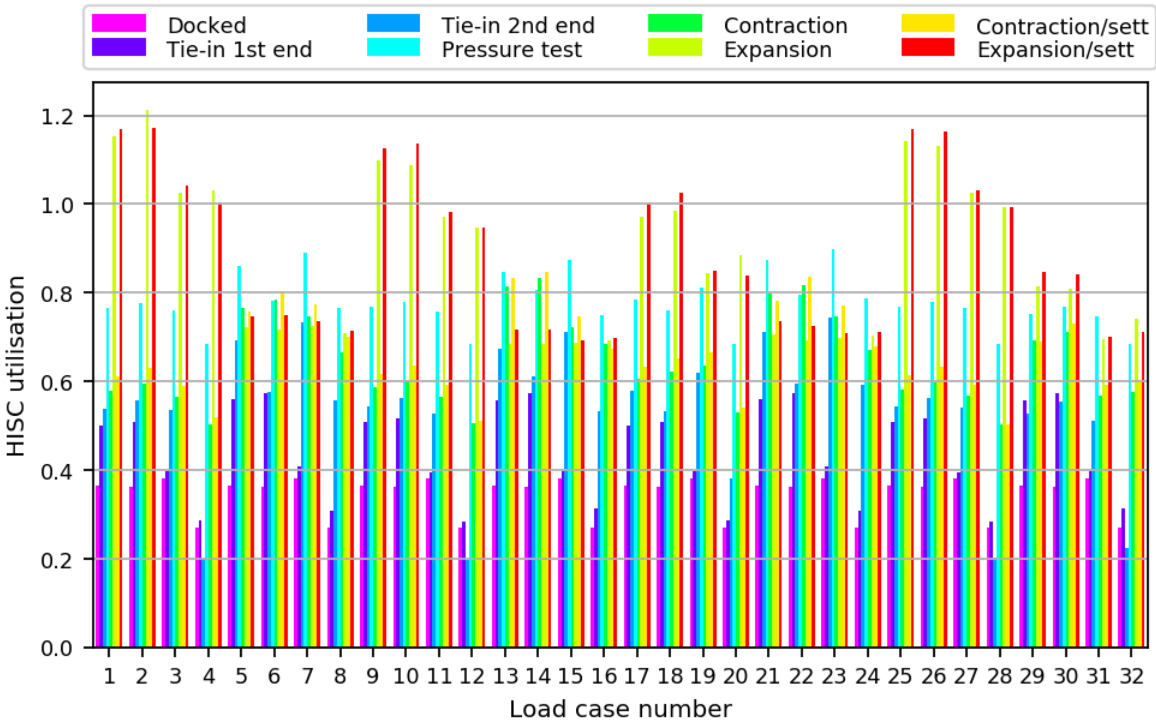
The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

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

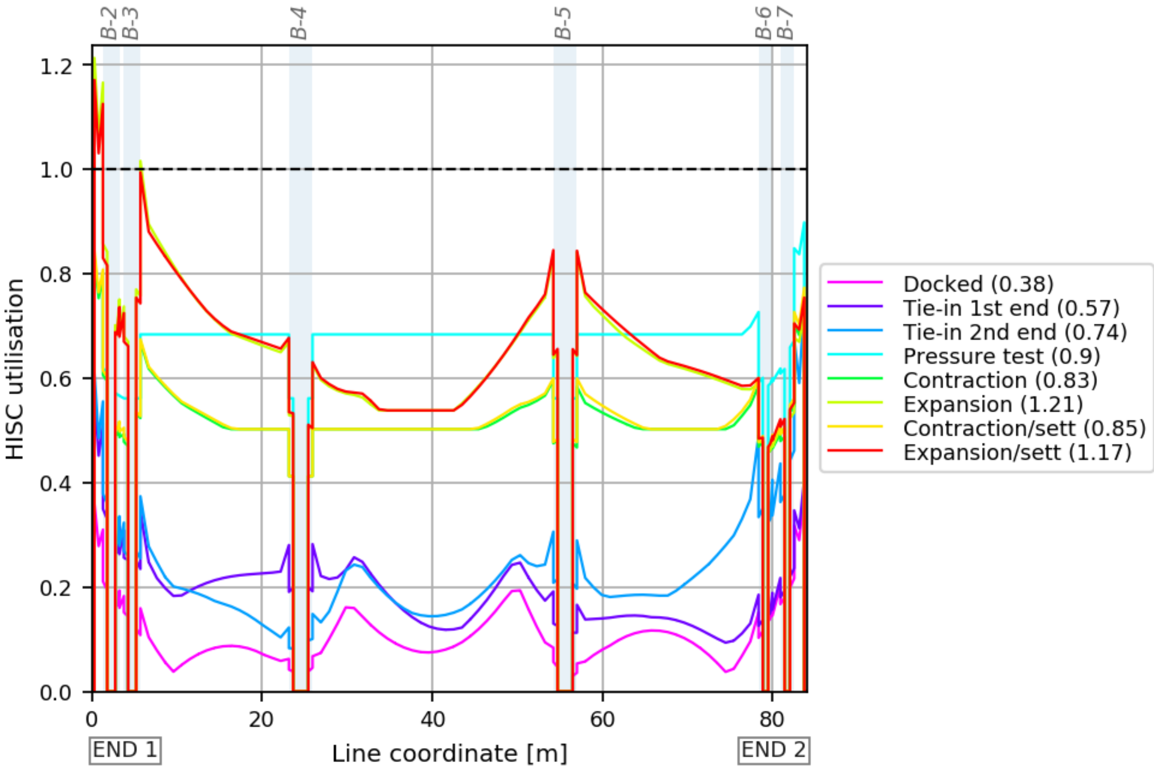
The maximum HISC utilisation along the spool, for each load case and load step, is shown in Figure 3.7.

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.

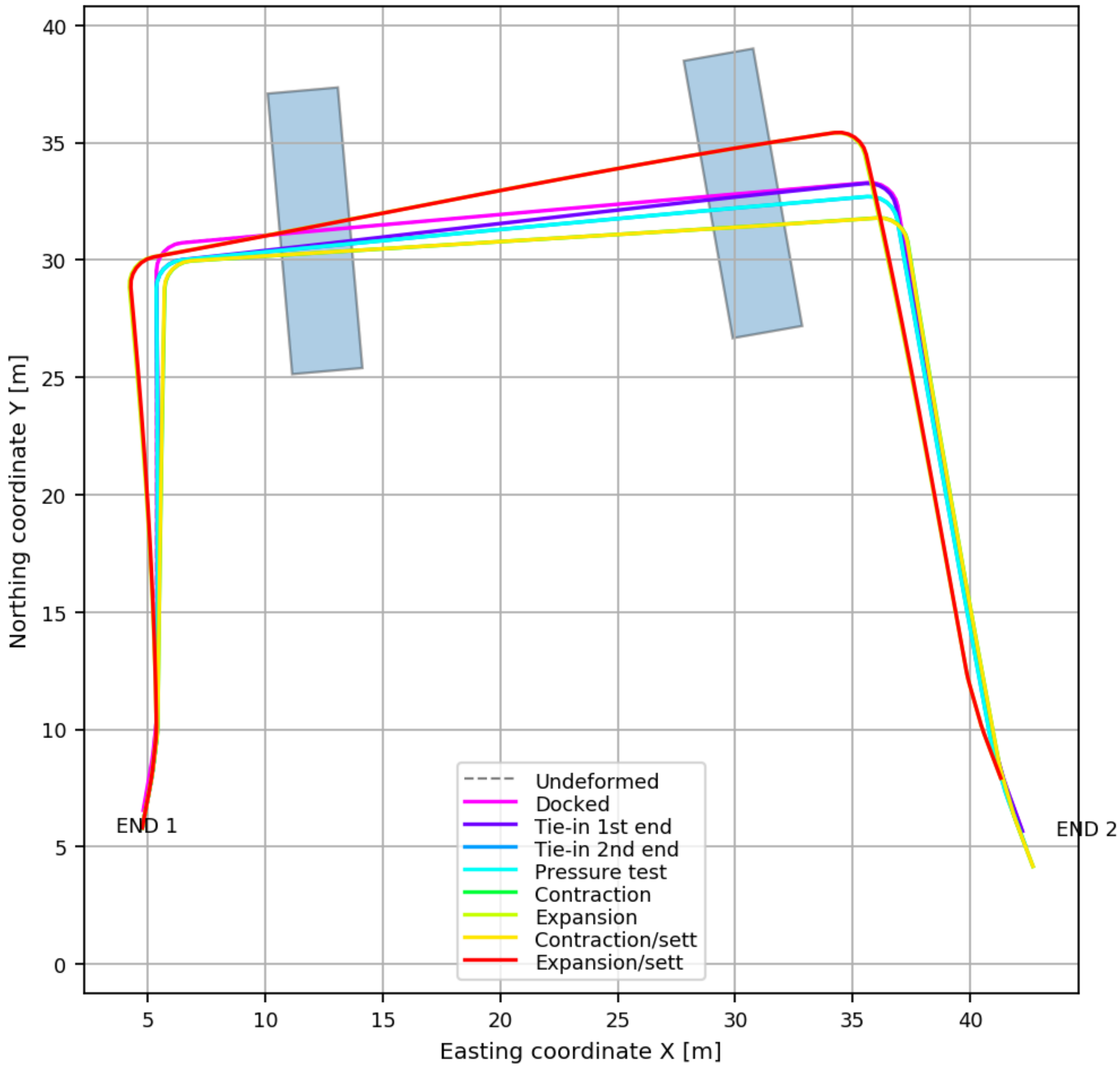
Longitudinal Stress Concentration Factors has been applied at each weld.

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 2

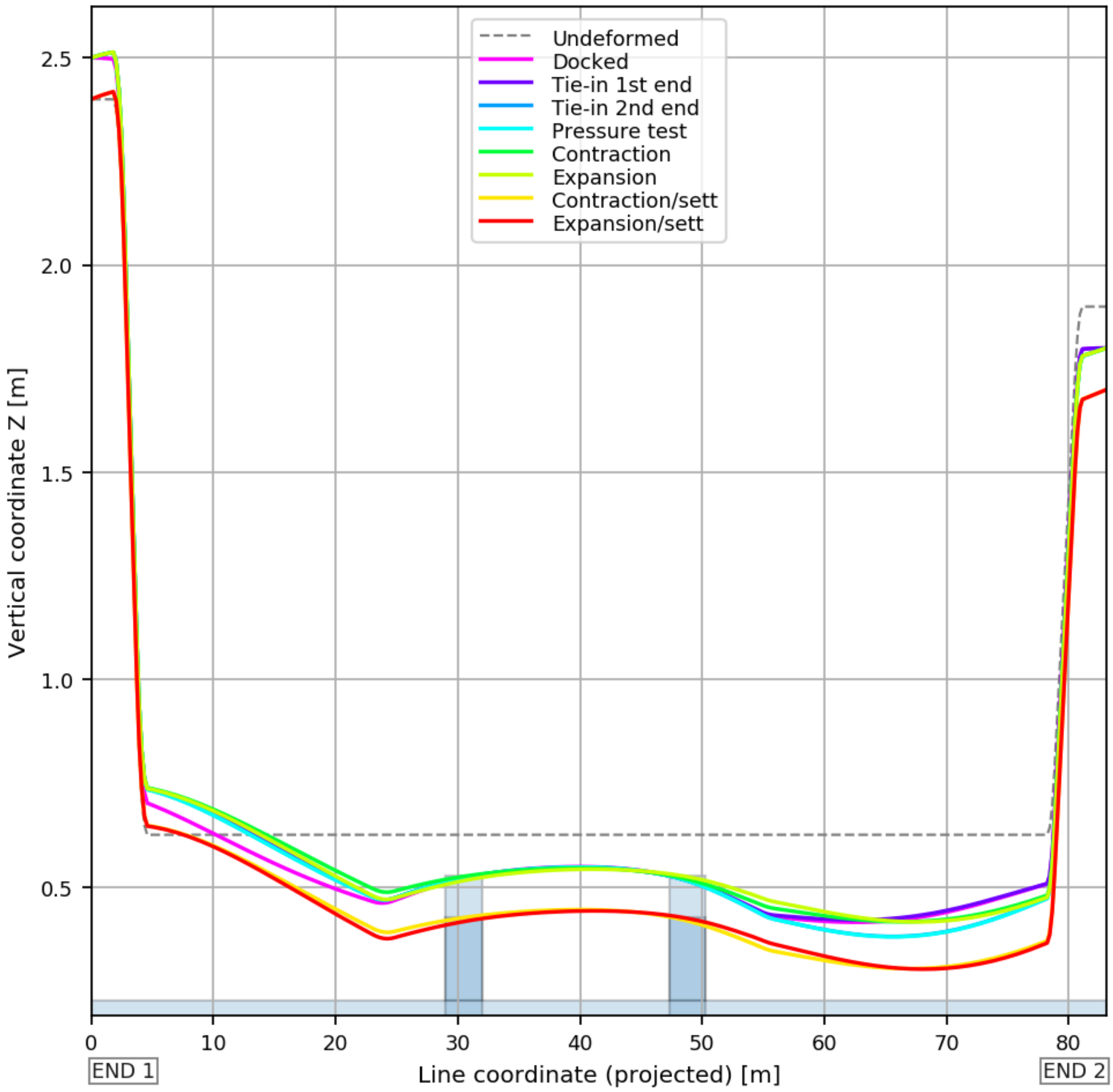
A top-view of the deformed shapes, for the most utilised load case (number 2), are shown for each load step in Figure 3.9.

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 2), 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.

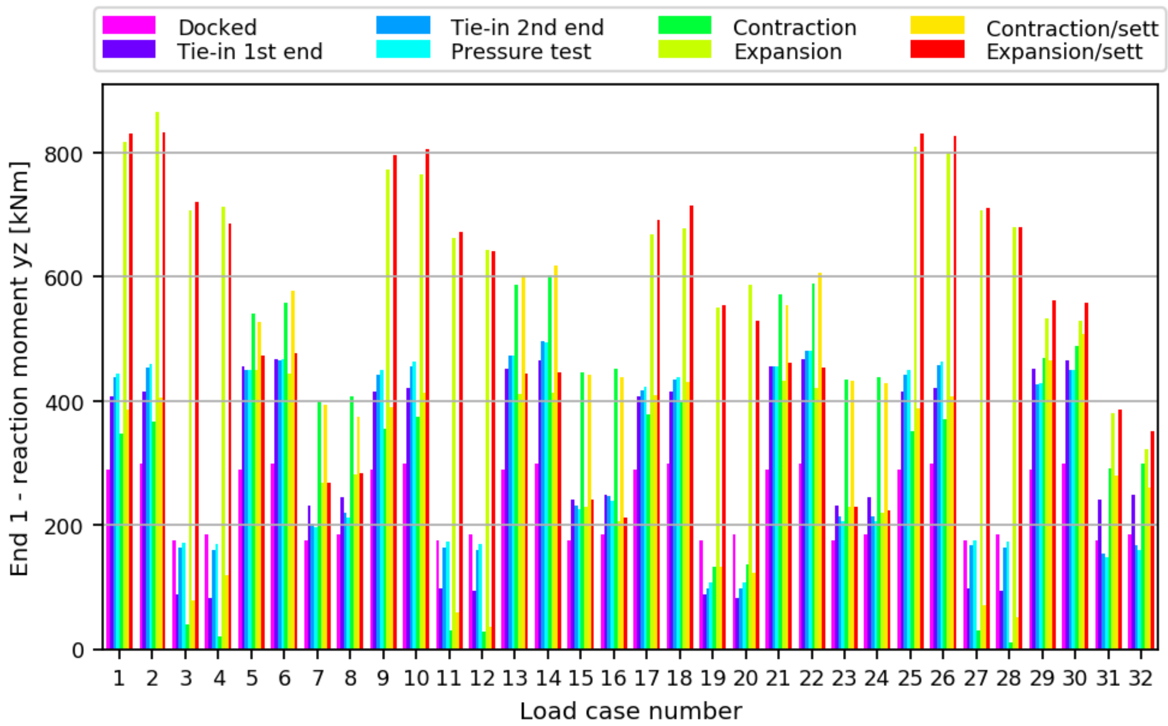
Table 3.4 – Maximum Magnitude Reaction Loads at End 1

Load Step	End Reaction Forces [kN]			End Reaction Moments [kNm]			
	RFx	RFy	RFz	RMx	RMy	RMz	RMb
Docked	6.3	1.1	80.3	-0.0	298.7	-15.4	299.1
Tie-in 1st end	29.3	-16.1	86.2	-0.0	409.5	246.4	466.3
Tie-in 2nd end	18.0	-11.3	86.5	29.5	433.2	257.3	495.4
Pressure test	13.6	-10.9	86.4	30.2	437.1	248.9	494.4
Contraction	-8.1	-19.5	72.0	41.1	370.6	486.1	603.3
Expansion	26.6	26.4	73.2	61.3	358.2	-789.1	866.6
Contraction/sett	-10.2	-19.0	73.7	48.6	408.9	472.6	617.4
Expansion/sett	25.8	24.5	75.0	55.4	390.5	-745.7	833.0
Max	29.3	26.4	86.5	61.3	437.1	-789.1	866.6

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

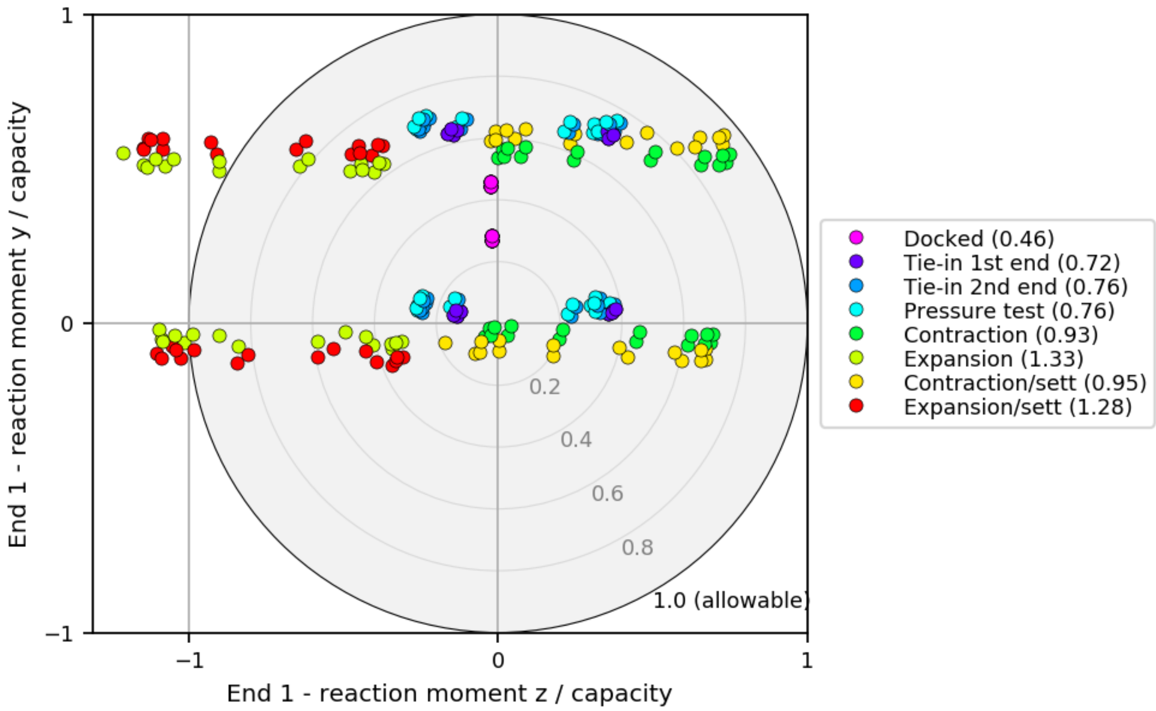
The maximum magnitude reaction bending moment at End 1, for each load case and load step, is shown in Figure 3.11.

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.

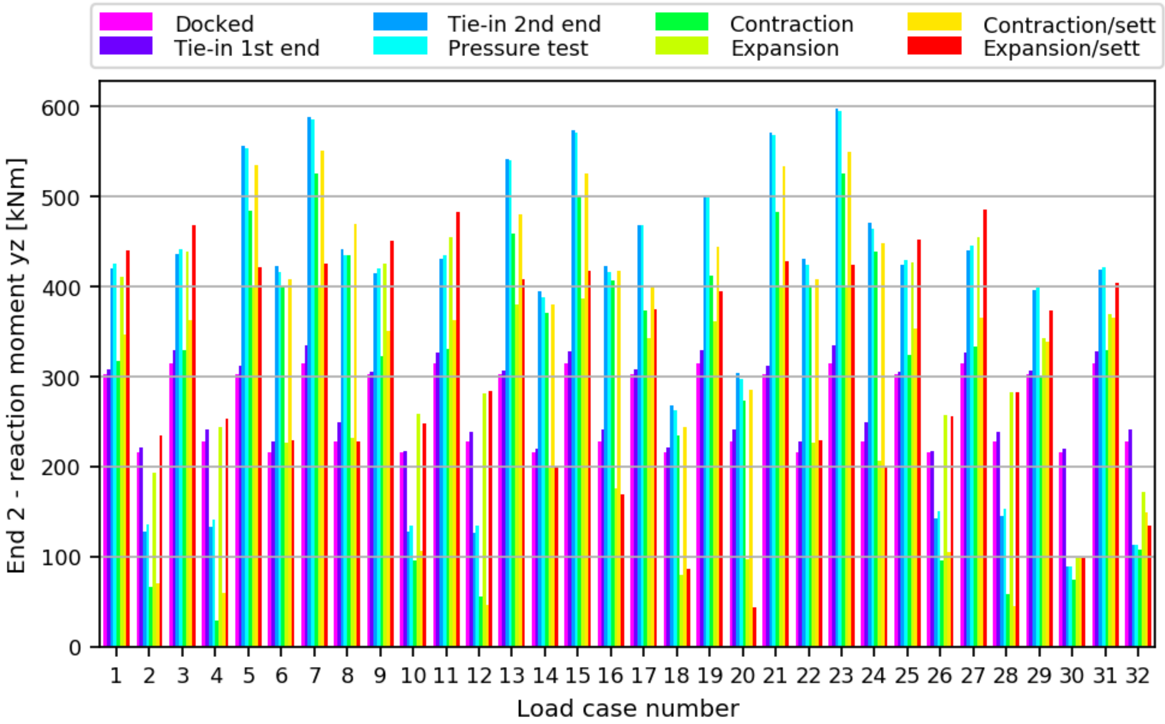
Table 3.5 – Maximum Magnitude Reaction Loads at End 2

Load Step	End Reaction Forces [kN]			End Reaction Moments [kNm]			
	RFx	RFy	RFz	RMx	RMy	RMz	RMb
Docked	6.3	-0.8	81.8	0.0	314.4	8.0	314.5
Tie-in 1st end	6.6	-6.4	82.3	-0.0	327.1	-92.6	334.2
Tie-in 2nd end	30.8	21.3	86.7	-0.0	428.0	-463.2	597.7
Pressure test	26.6	21.1	86.6	-0.4	431.4	-454.9	594.5
Contraction	30.4	24.5	71.0	-15.7	327.0	-438.2	525.0
Expansion	-42.9	-25.2	69.8	-57.7	366.3	278.3	454.8
Contraction/sett	32.7	25.2	72.4	-17.8	361.1	-466.8	550.0
Expansion/sett	-43.5	-25.2	71.2	-60.4	400.9	282.3	484.4
Max	-43.5	-25.2	86.7	-60.4	431.4	-466.8	597.7

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

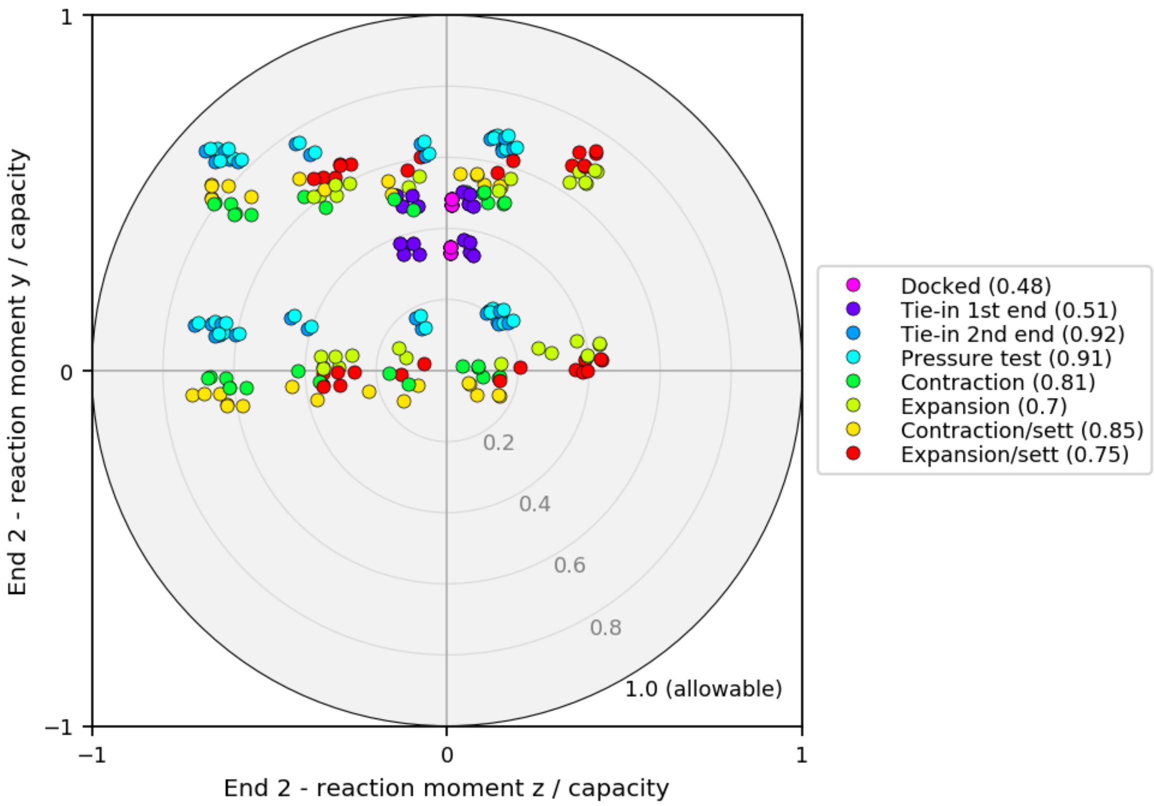
The maximum magnitude reaction bending moment at End 2, for each load case and load step, is shown in Figure 3.13.

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

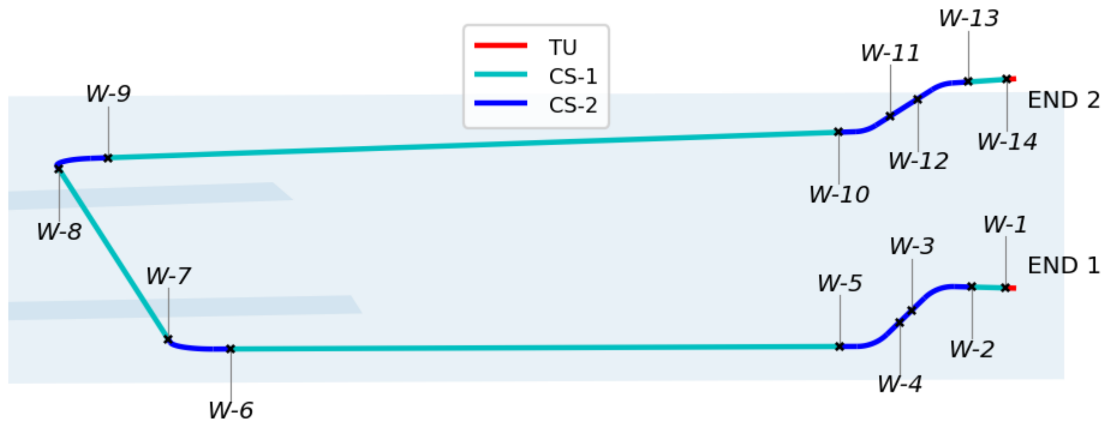


The shaded circular area indicates the allowable. The maximum utilisation is presented for each load step within parenthesis in the figure legend.

3.9 Fatigue Damage due to VIV

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

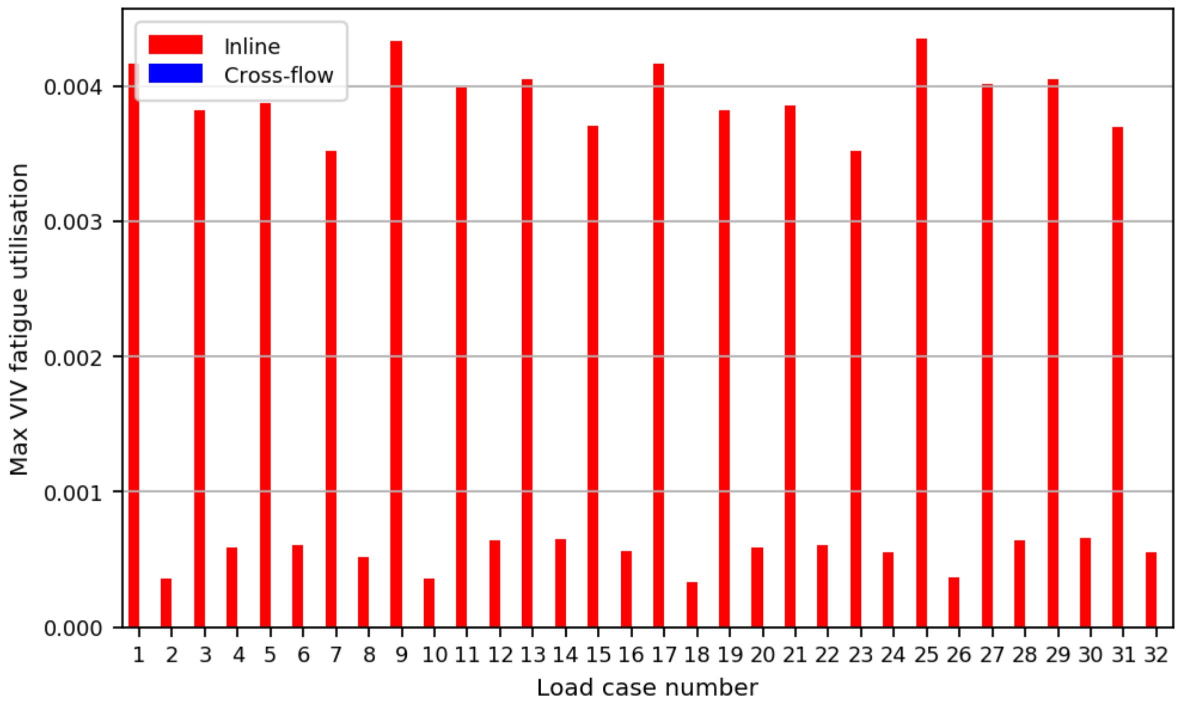
Figure 3.15 – Assessed Welds



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

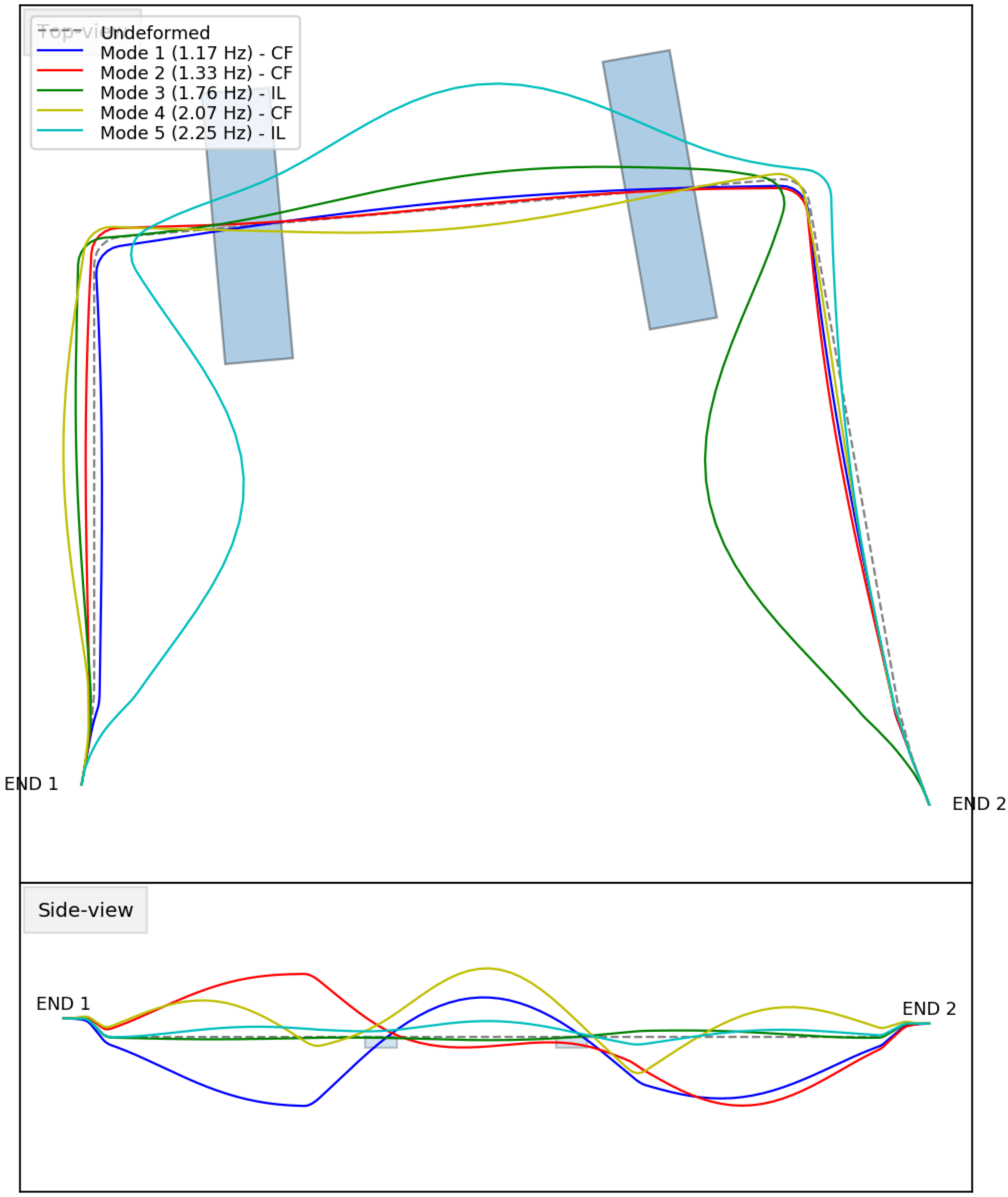


Inline and Cross-Flow utilisations are presented separately, and indicated that the damage has been accumulate at a specific location around the circumference.

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 25 (most critical in terms of fatigue damage) are shown in Figure 3.17.

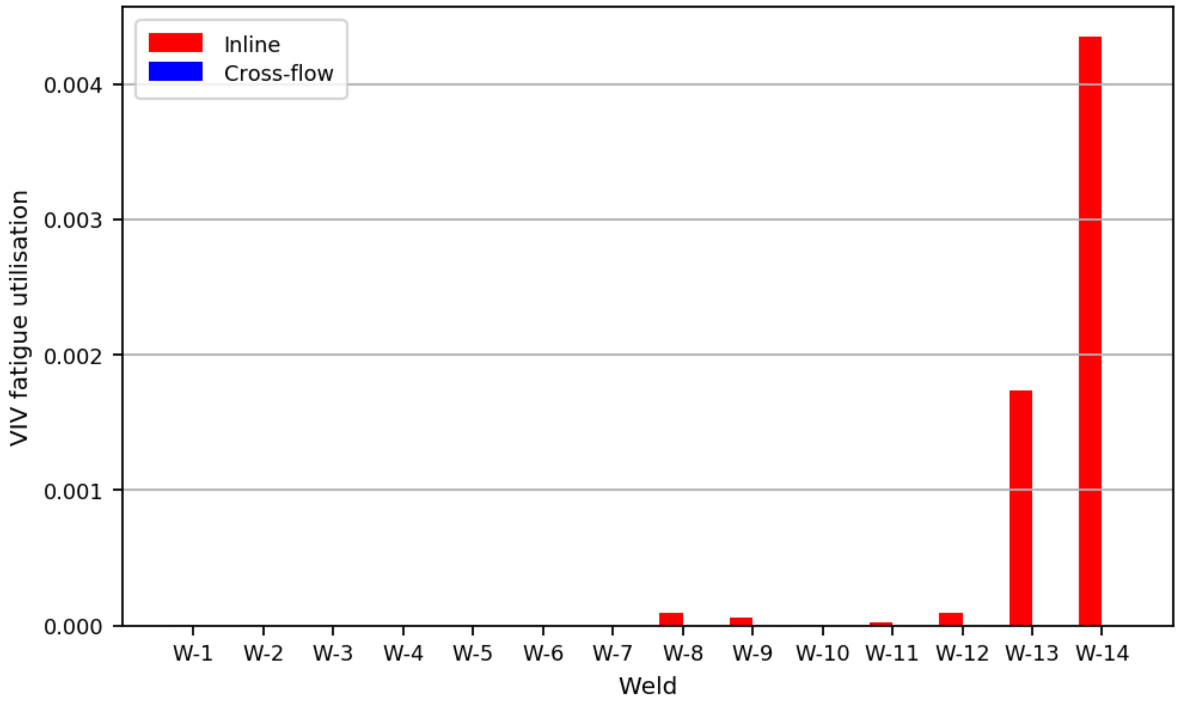
Figure 3.17 – Eigen-Modes of Most Utilised Load Case



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-4	Support-5
Docked	0.0	51.4	59.7
Tie-in 1st end	0.0	61.3	60.6
Tie-in 2nd end	0.0	61.5	66.6
Pressure test	0.0	61.6	66.6
Contraction	0.0	42.6	44.2
Expansion	0.0	43.7	43.6
Contraction/sett	0.0	45.2	46.2
Expansion/sett	0.0	46.2	45.7
Max	0.0	61.6	66.6

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

4 CONFIGURATION NOM

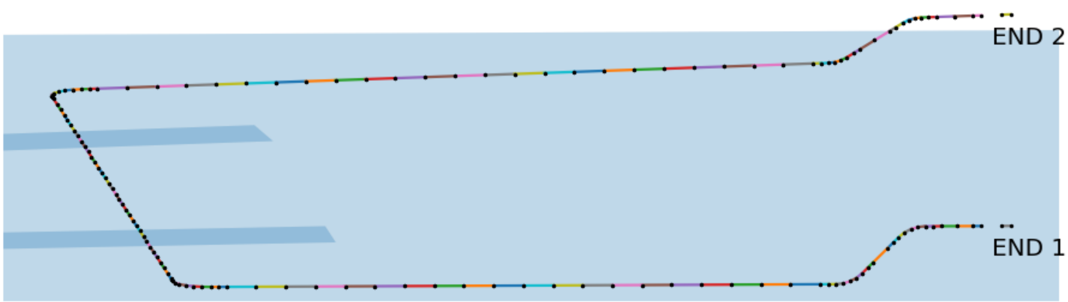
This section presents the following detailed results for configuration "nom".

- 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

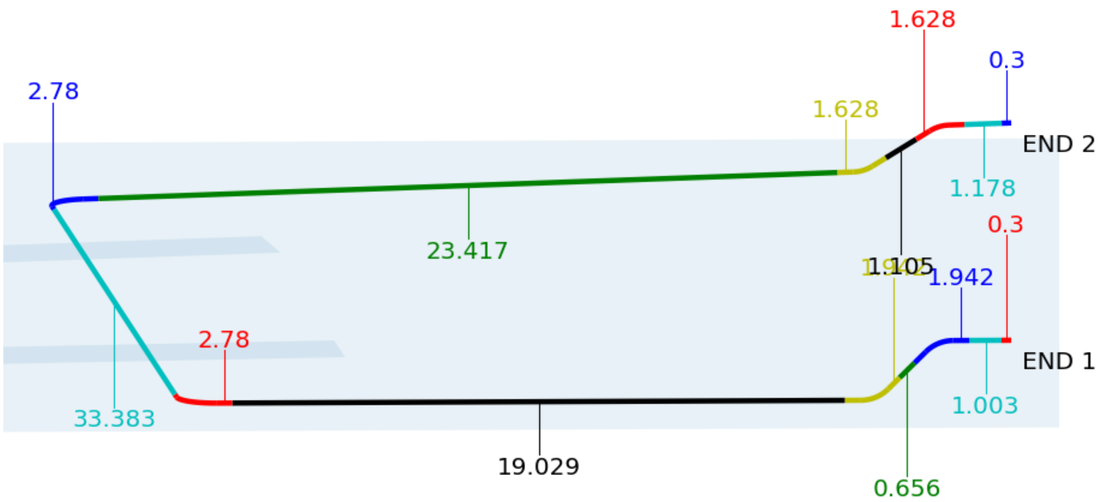
The coordinates at the spool ends and at the intersection points between the extended straight lines / sections, are presented in Table 4.1.

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	39.443	33.638	0.626
IP-6	43.929	8.192	0.626
IP-7	44.343	5.849	2.0
IP-8	44.69	3.879	2.0
End 2	44.742	3.584	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

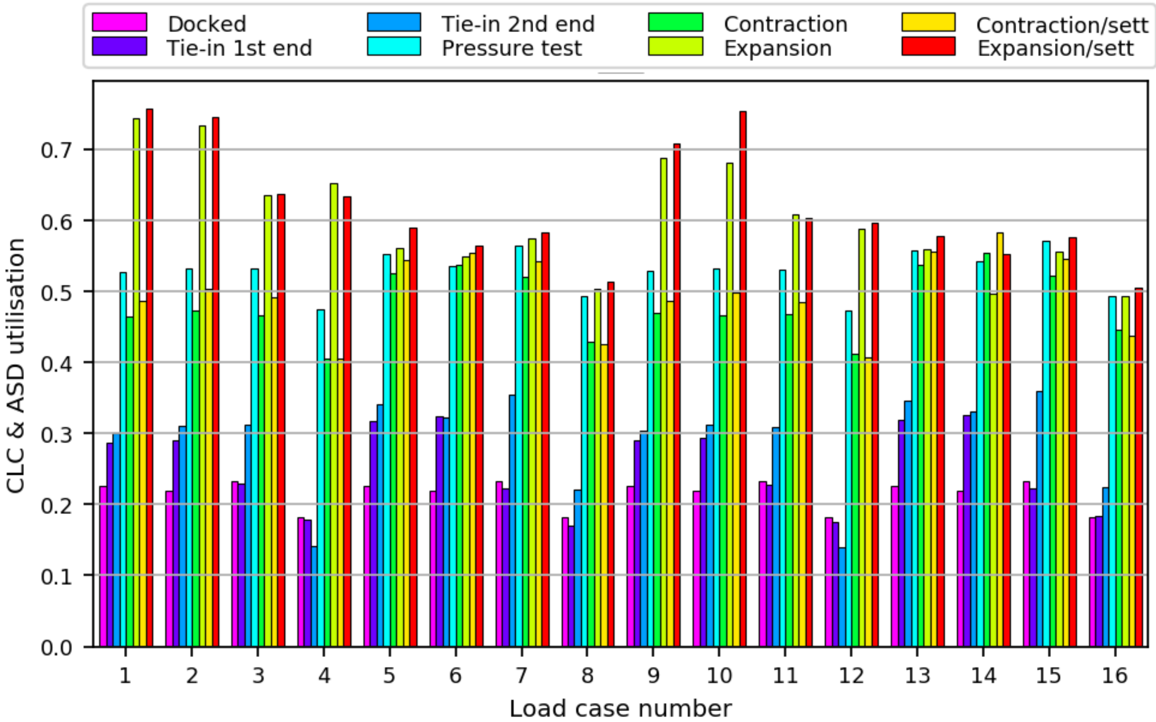
Load Step	Internal Pressure [bara]	Temperature [°C]	Content Density [kg/m3]	Axial Expansion - End 2 [m]
Docked	20	10	1150	0
Tie-in 1st end	20	10	1150	0
Tie-in 2nd end	20	10	1150	0
Pressure test	400	10	1150	0
Contraction	300	-20	250	-1.0
Expansion	300	100	250	3.0
Contraction/sett	300	-20	250	-1.0
Expansion/sett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

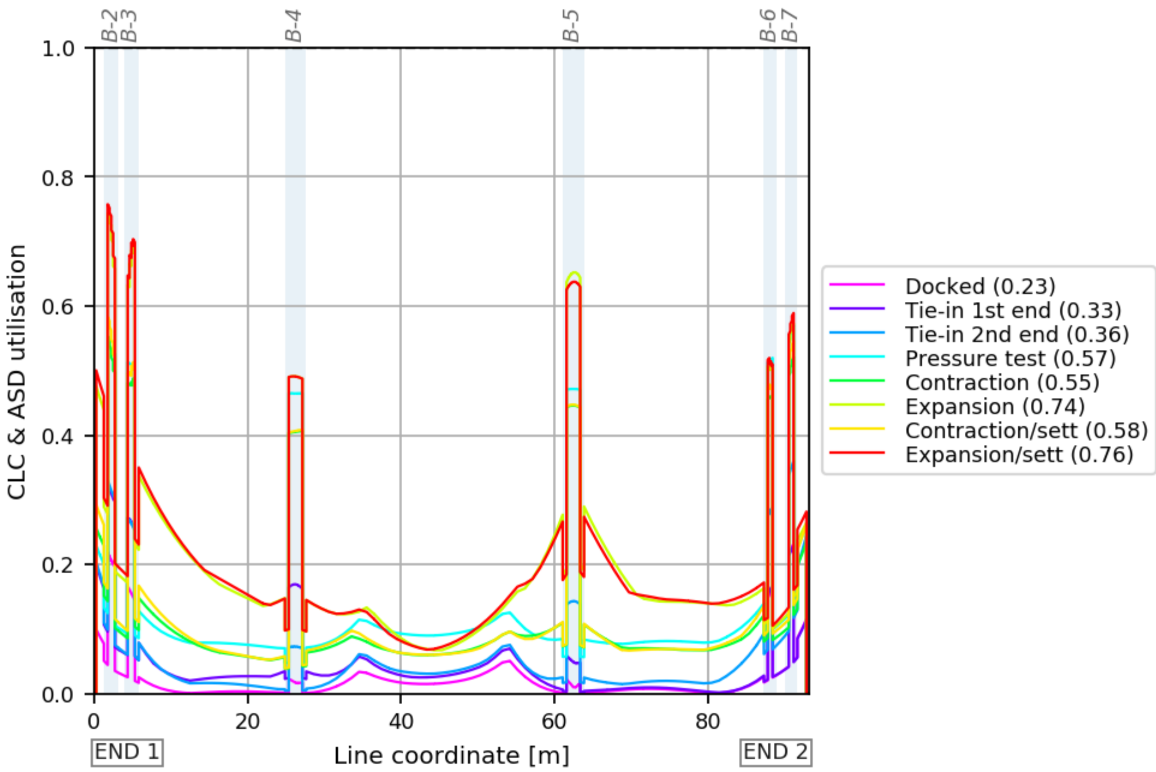
The maximum CLC / ASD utilisation along the spool, for each load case and load step, is shown in Figure 4.3.

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

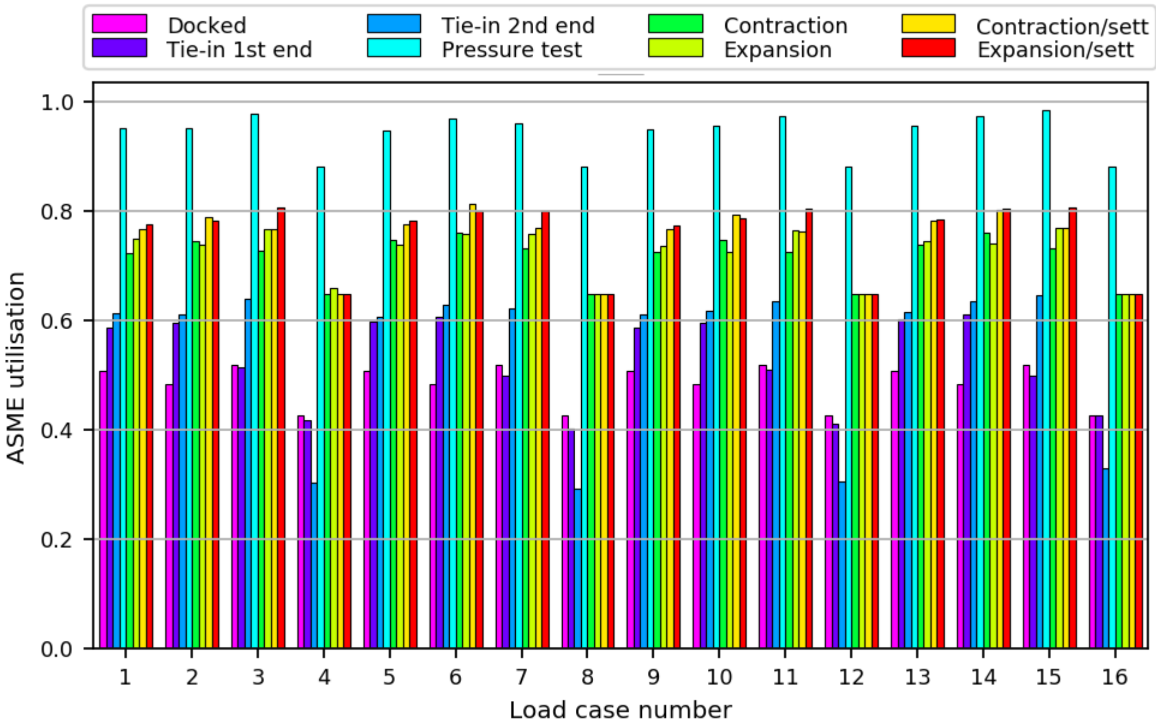


The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

4.6 Spool ASME Utilisation

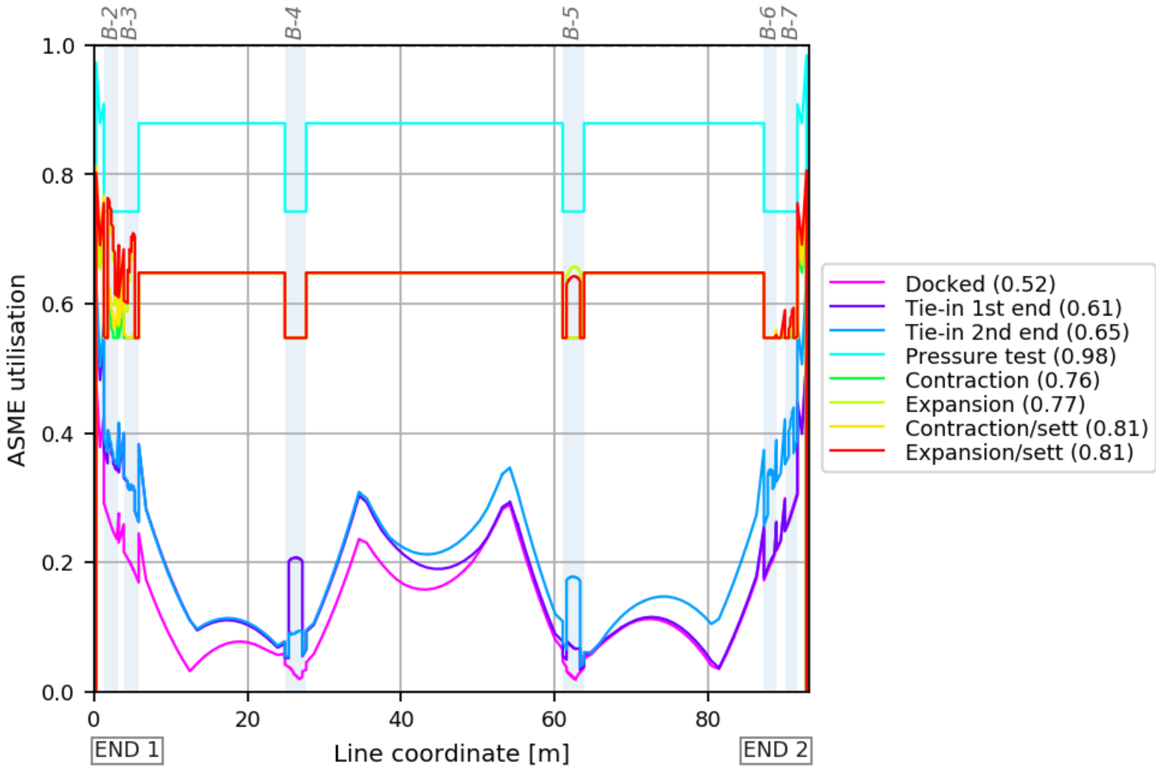
The maximum ASME utilisation along the spool, for each load case and load step, is shown in Figure 4.5.

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



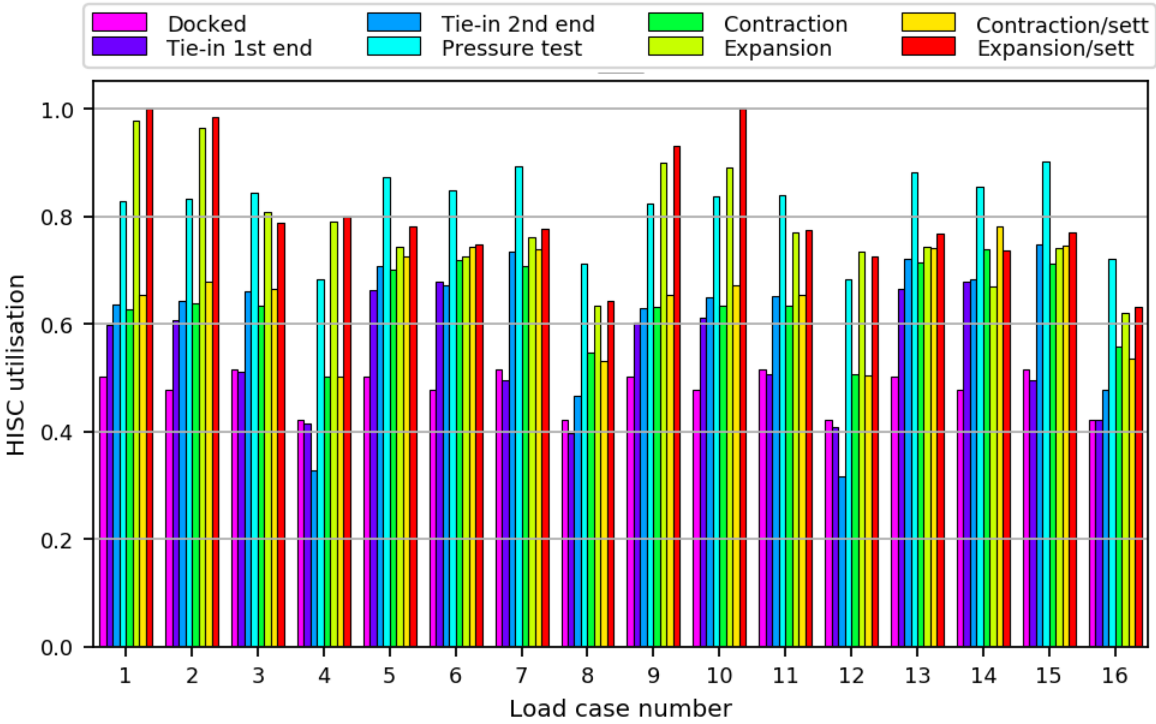
The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

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

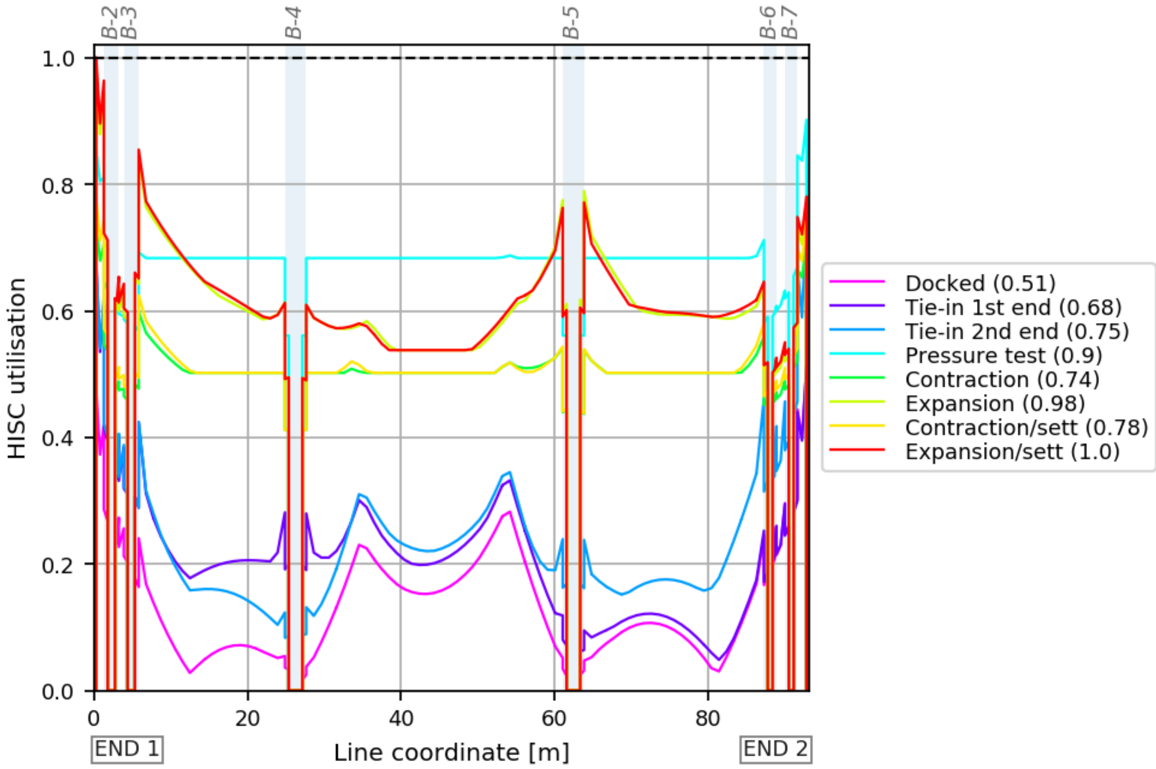
The maximum HISC utilisation along the spool, for each load case and load step, is shown in Figure 4.7.

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.

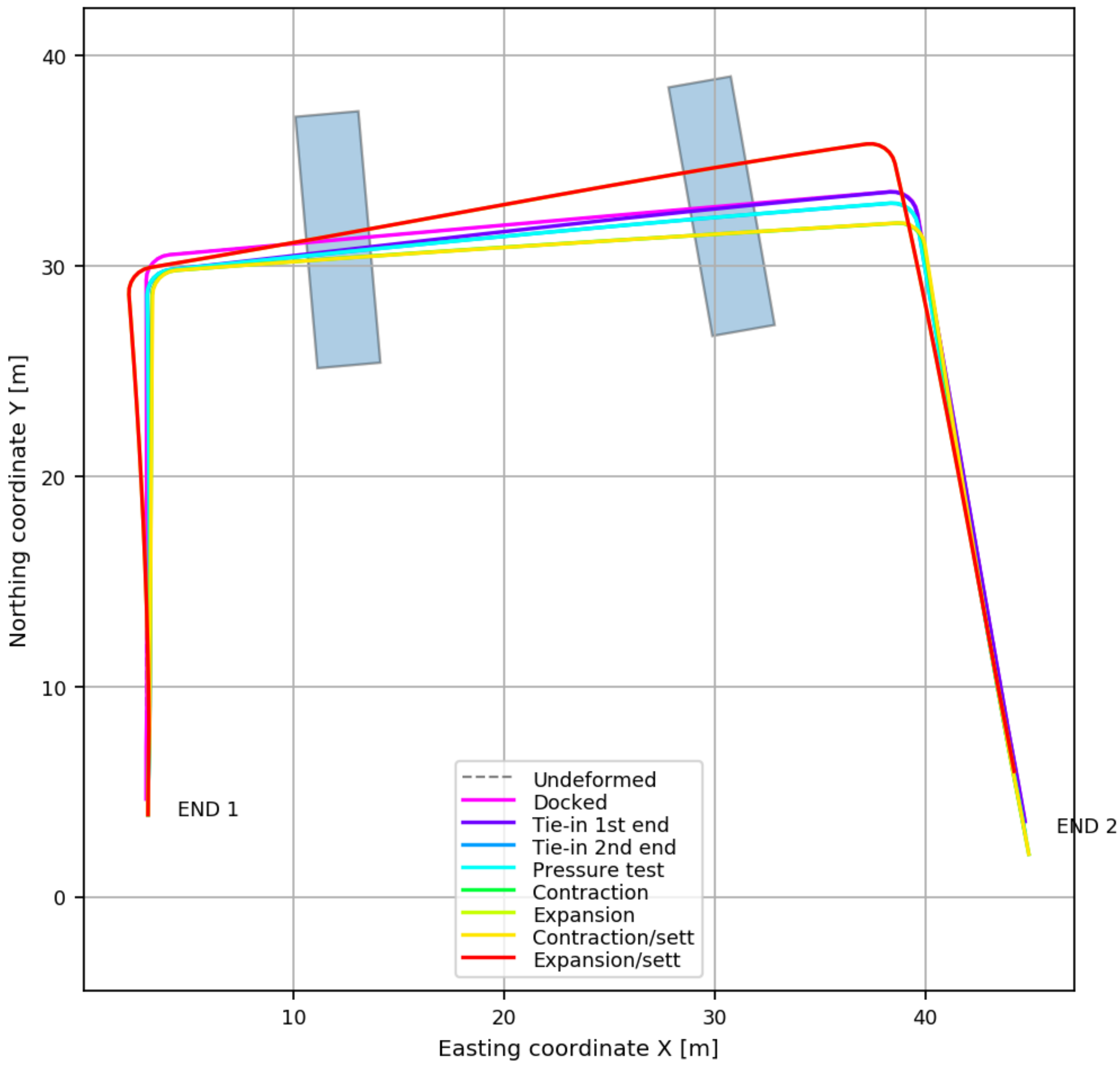
Longitudinal Stress Concentration Factors has been applied at each weld.

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 1

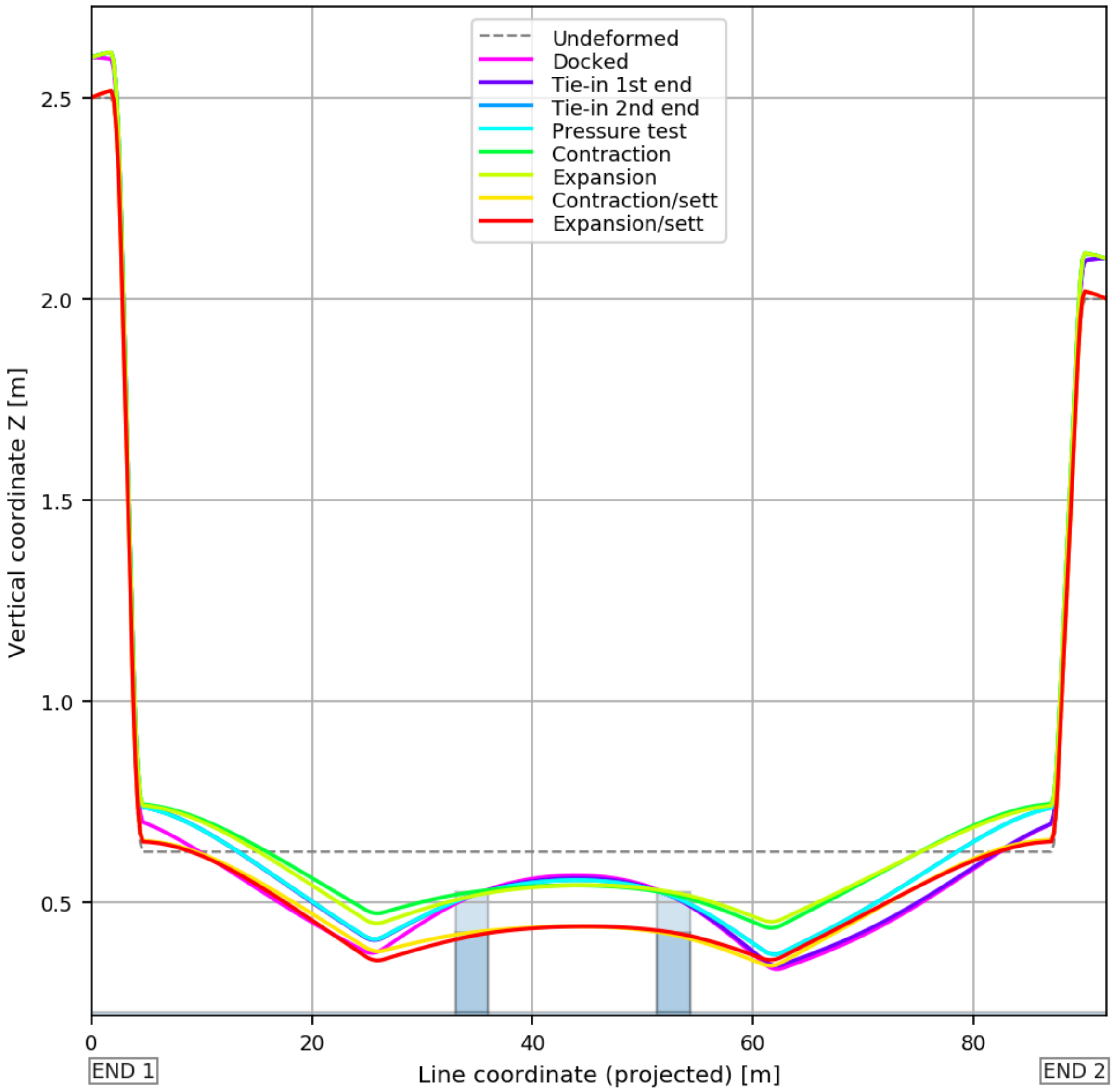
A top-view of the deformed shapes, for the most utilised load case (number 1), are shown for each load step in Figure 4.9.

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 1), 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.

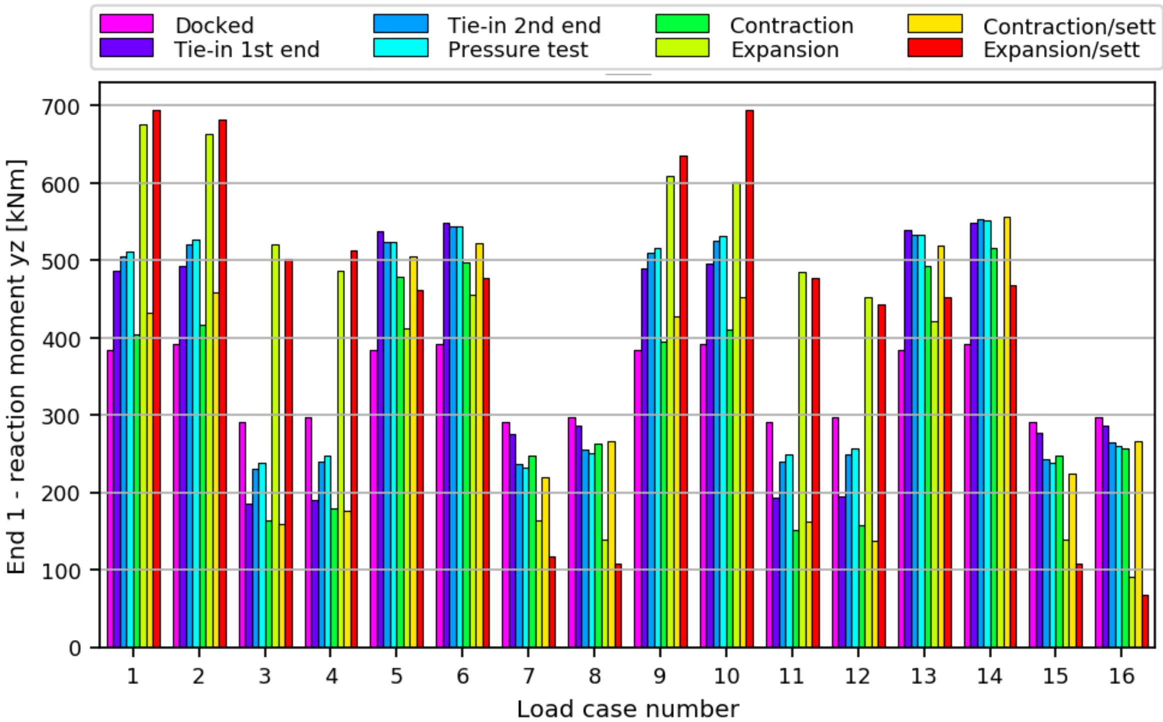
Table 4.4 – Maximum Magnitude Reaction Loads at End 1

Load Step	End Reaction Forces [kN]			End Reaction Moments [kNm]			
	RFx	RFy	RFz	RMx	RMy	RMz	RMb
Docked	2.5	1.1	84.5	0.0	390.8	-22.0	391.1
Tie-in 1st end	26.1	-18.9	90.2	-0.0	493.8	247.4	549.2
Tie-in 2nd end	19.9	-11.4	90.4	14.7	512.6	206.0	552.4
Pressure test	17.6	-10.6	90.4	16.0	515.1	197.0	551.5
Contraction	-3.2	11.7	73.8	48.8	414.1	308.2	516.2
Expansion	17.2	13.1	75.1	48.8	410.0	-557.3	675.7
Contraction/sett	-5.5	12.8	75.5	47.7	456.0	331.3	556.7
Expansion/sett	17.6	14.6	76.5	51.7	446.3	-558.5	695.0
Max	26.1	-18.9	90.4	51.7	515.1	-558.5	695.0

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

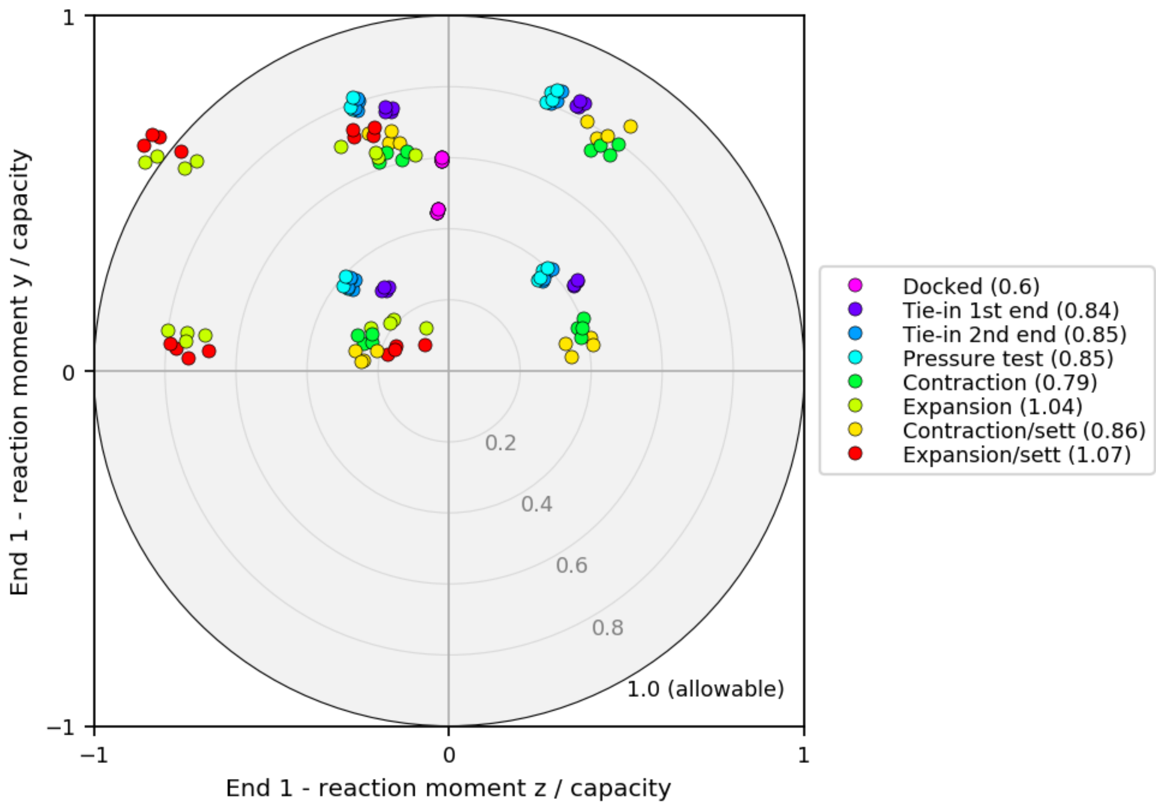
The maximum magnitude reaction bending moment at End 1, for each load case and load step, is shown in Figure 4.11.

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.

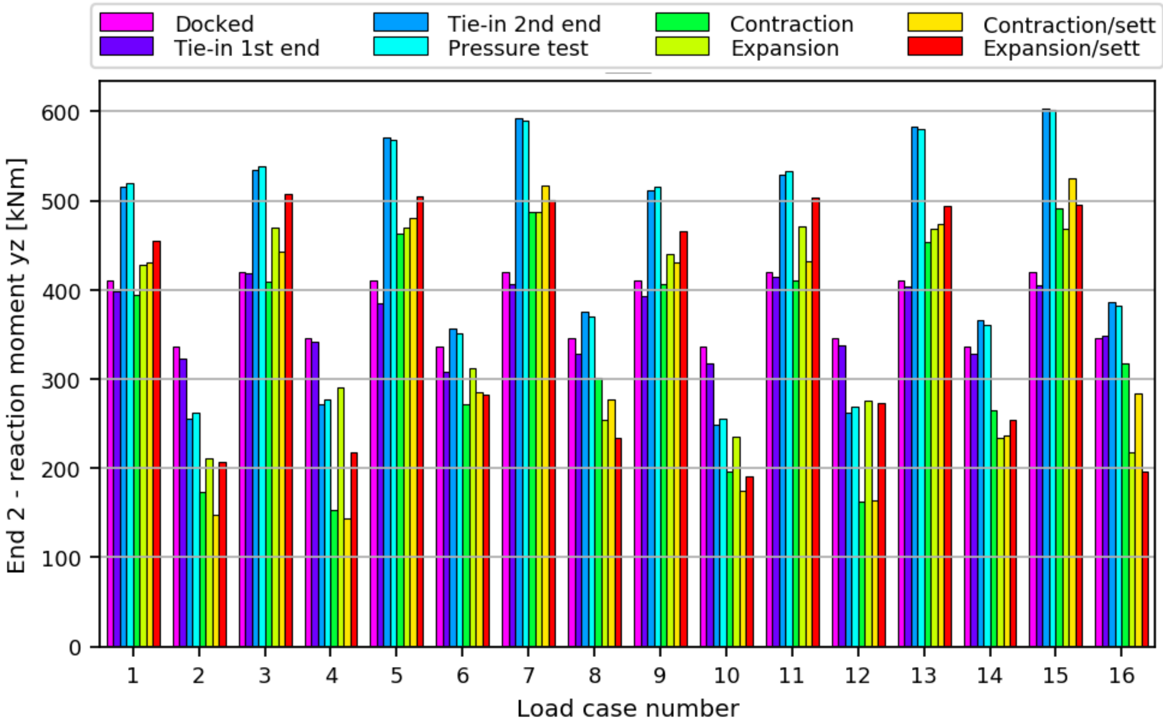
Table 4.5 – Maximum Magnitude Reaction Loads at End 2

Load Step	End Reaction Forces [kN]			End Reaction Moments [kNm]			
	RFx	RFy	RFz	RMx	RMy	RMz	RMb
Docked	2.4	-0.4	86.7	-0.0	420.4	11.8	420.5
Tie-in 1st end	16.1	-3.3	87.1	-0.0	416.8	35.7	418.1
Tie-in 2nd end	24.6	17.0	91.0	-0.0	521.7	-314.5	603.9
Pressure test	22.2	16.3	90.9	-0.9	523.8	-306.0	601.7
Contraction	23.8	20.0	73.8	-19.6	391.2	-298.7	491.5
Expansion	-37.8	-26.1	72.4	-54.3	420.3	-290.7	487.2
Contraction/sett	20.7	20.6	74.9	-22.8	421.4	-315.8	525.4
Expansion/sett	-32.5	-24.8	73.6	-53.8	450.6	-269.5	507.5
Max	-37.8	-26.1	91.0	-54.3	523.8	-315.8	603.9

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

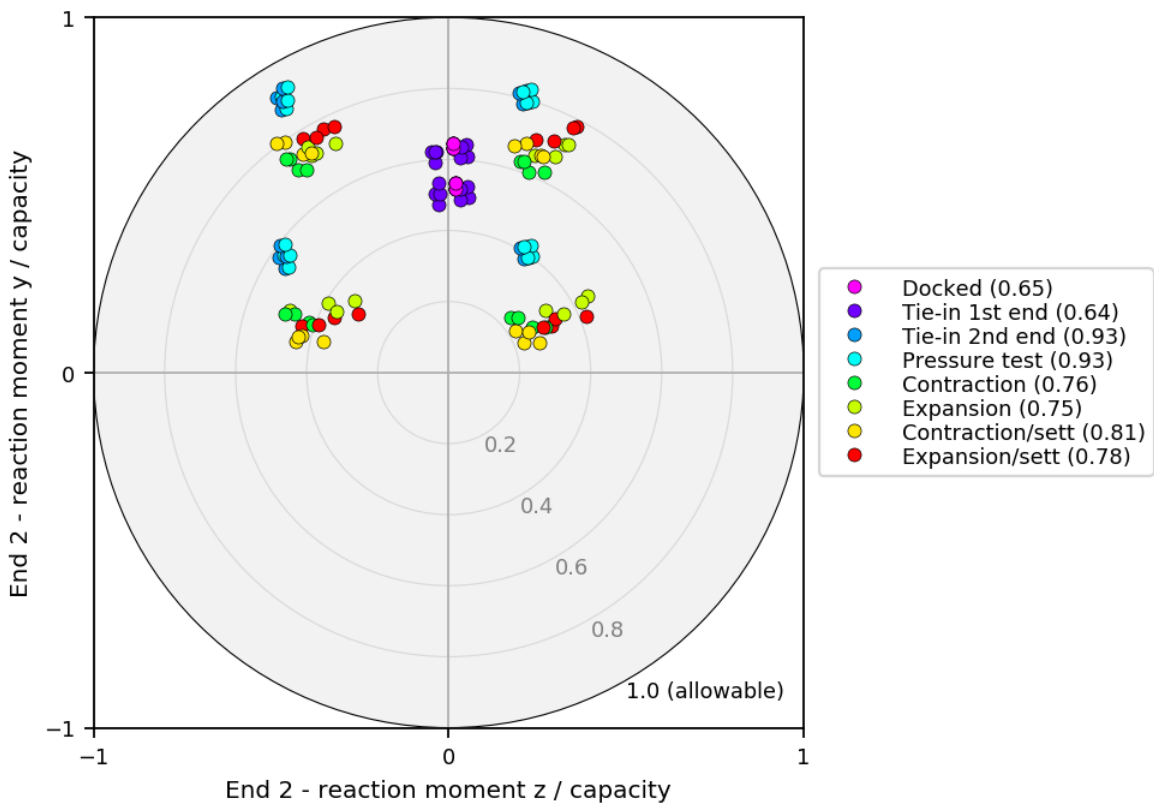
The maximum magnitude reaction bending moment at End 2, for each load case and load step, is shown in Figure 4.13.

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

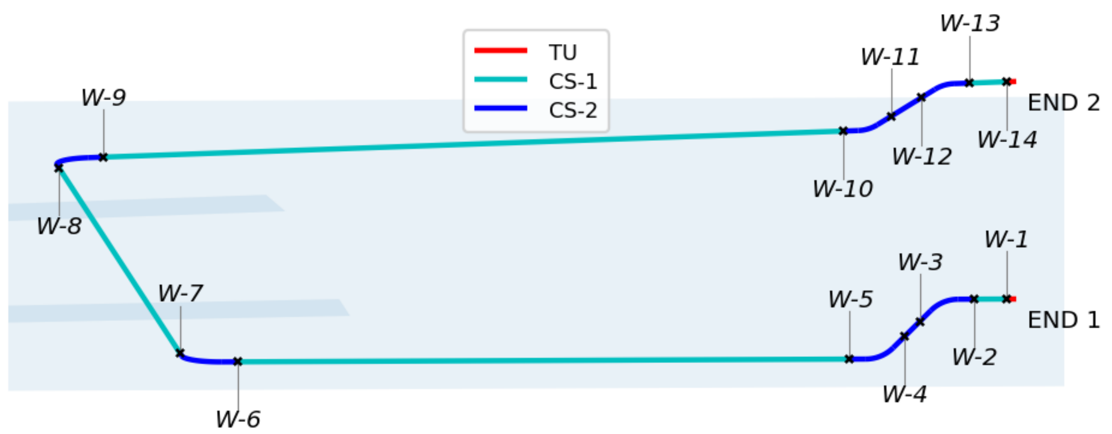


The shaded circular area indicates the allowable. The maximum utilisation is presented for each load step within parenthesis in the figure legend.

4.9 FATIGUE DAMAGE DUE TO VIV

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

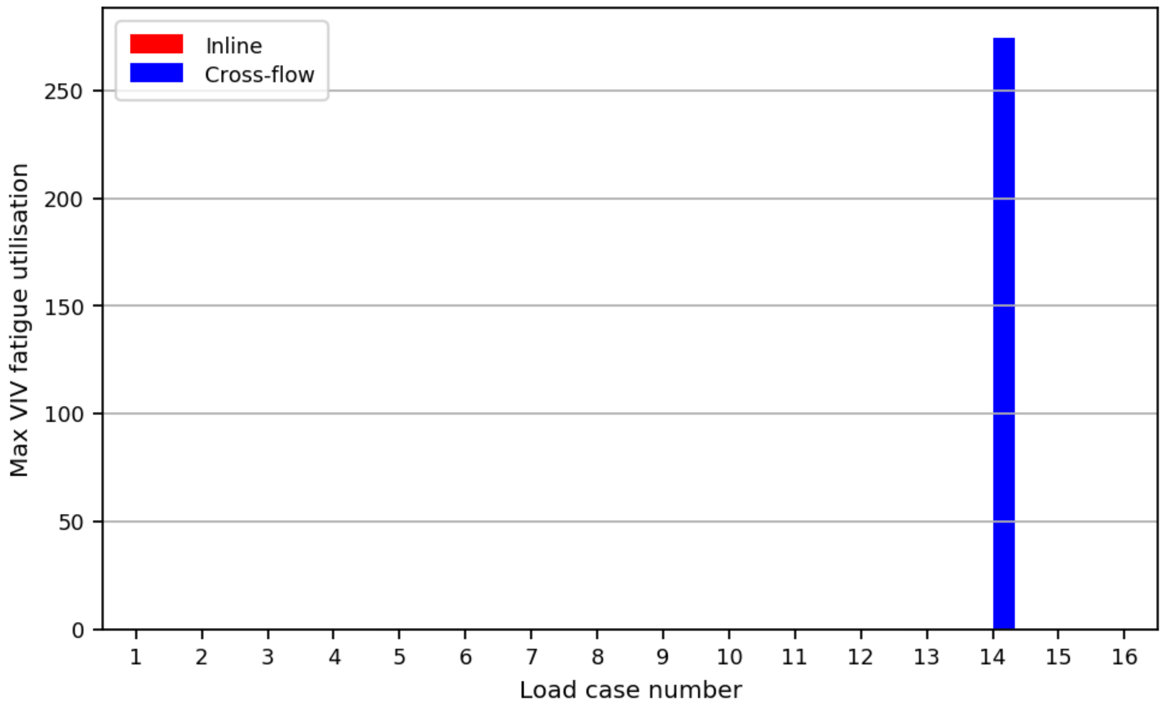
Figure 4.15 – Assessed Welds



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

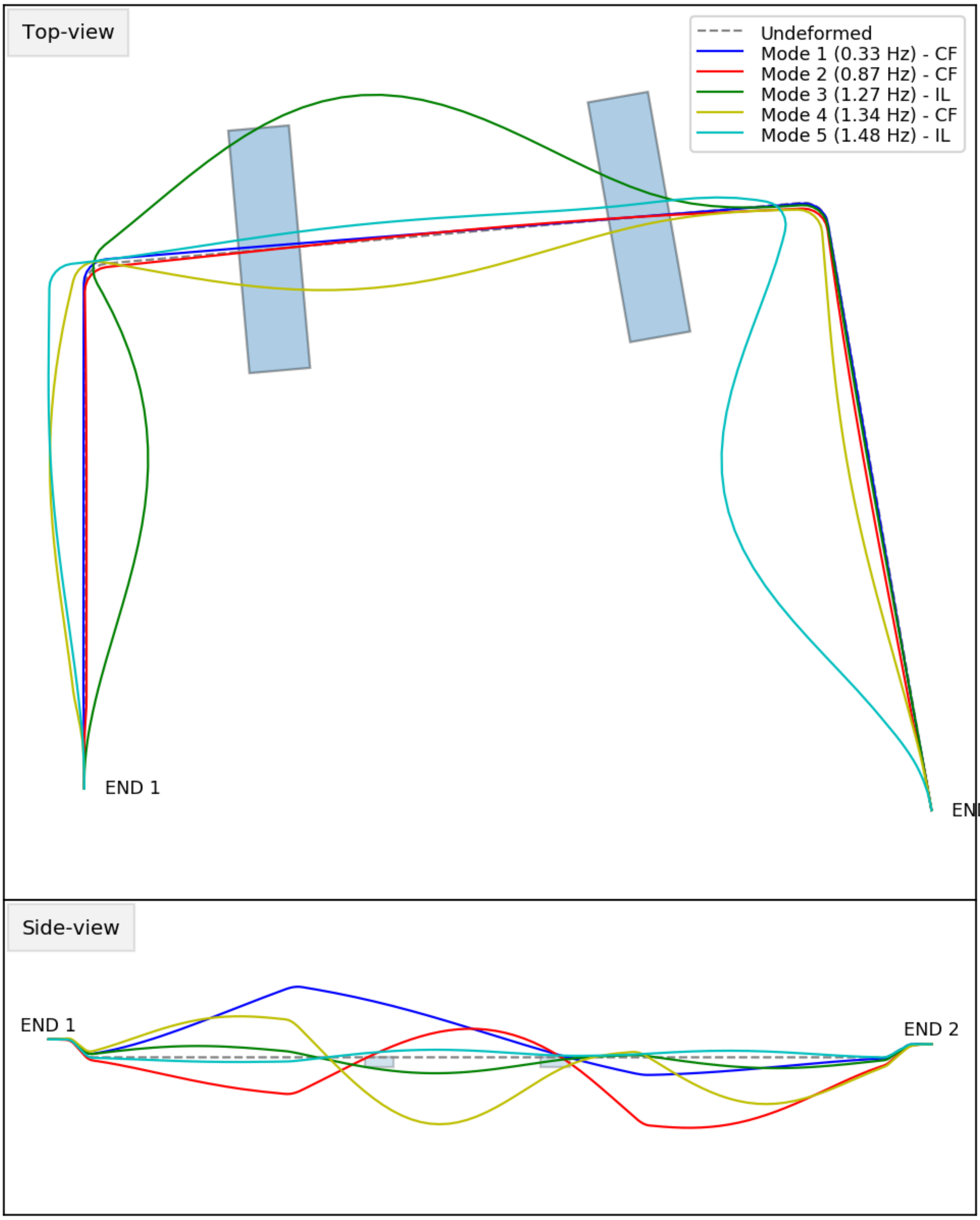


Inline and Cross-Flow utilisations are presented separately, and indicated that the damage has been accumulate at a specific location around the circumference.

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 14 (most critical in terms of fatigue damage) are shown in Figure 4.17.

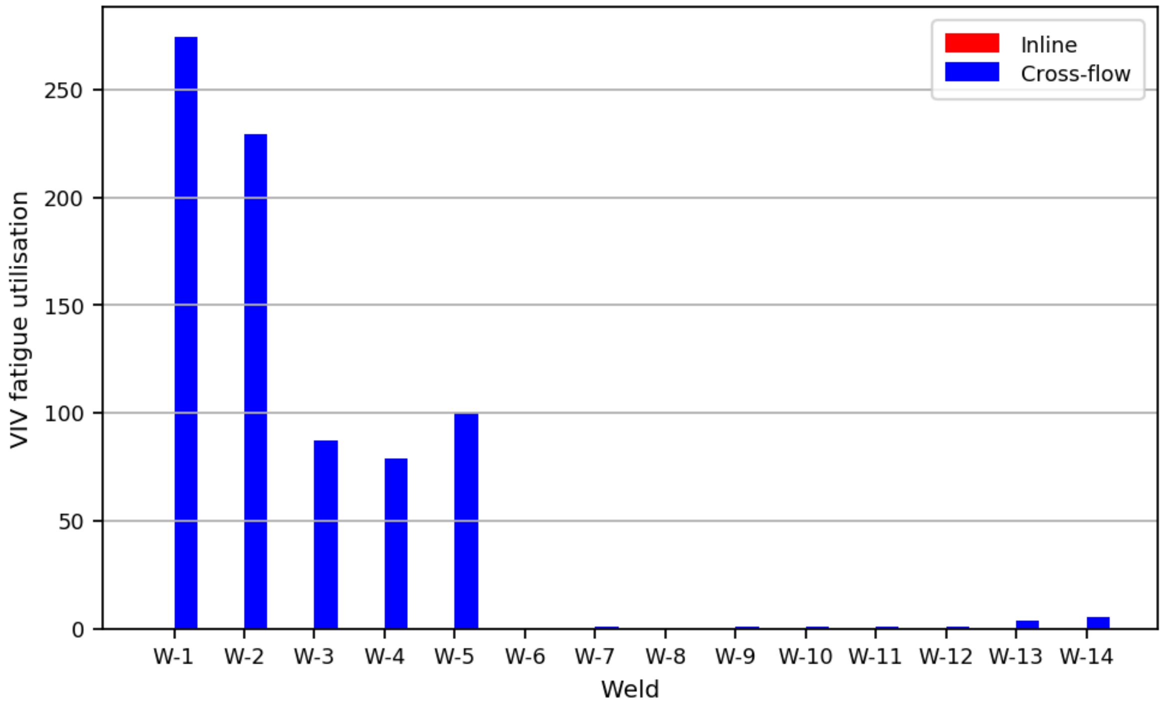
Figure 4.17 – Eigen-Modes of Most Utilised Load Case



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-4	Support-5
Docked	0.0	54.2	65.6
Tie-in 1st end	0.0	63.5	141.9
Tie-in 2nd end	0.0	65.0	73.5
Pressure test	0.0	65.0	73.5
Contraction	0.0	42.9	48.8
Expansion	0.0	44.1	47.9
Contraction/sett	6.8	45.4	53.7
Expansion/sett	6.9	51.8	49.7
Max	6.9	65.0	141.9

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

5 CONFIGURATION MAX

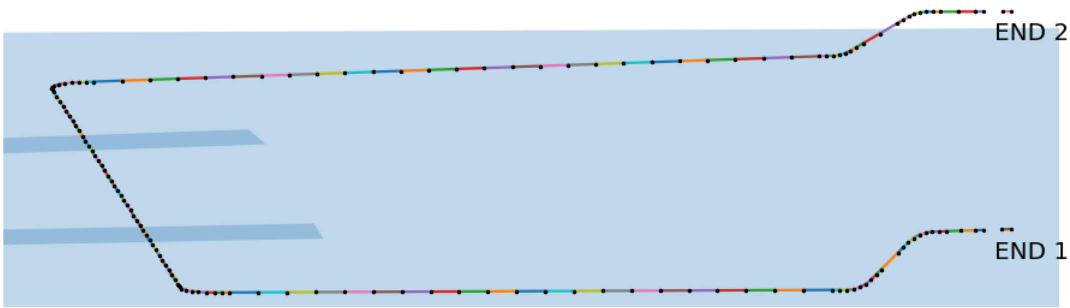
This section presents the following detailed results for configuration "max".

- 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

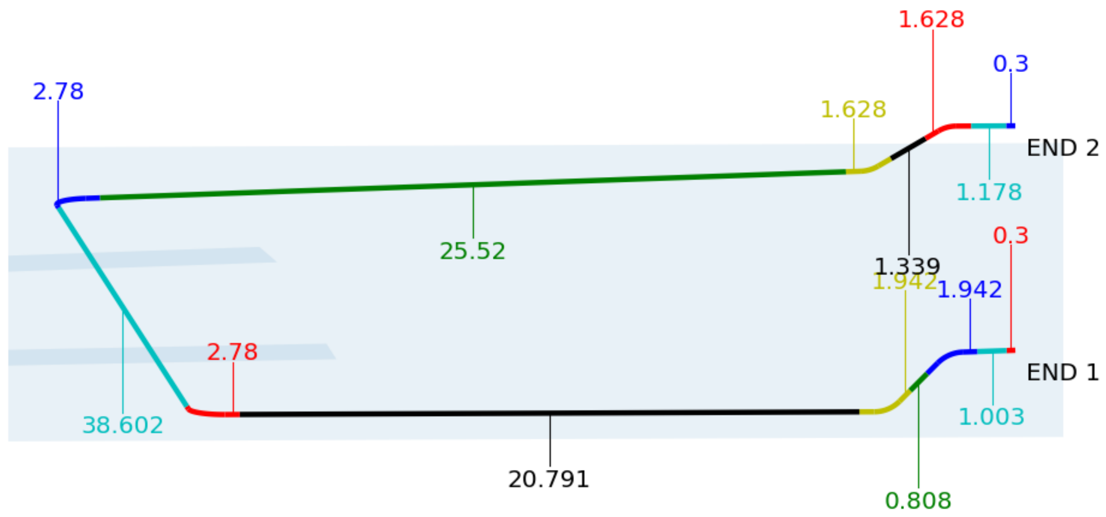
The coordinates at the spool ends and at the intersection points between the extended straight lines / sections, are presented in Table 5.1.

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	42.181	33.878	0.626
IP-6	47.033	6.362	0.626
IP-7	47.259	3.779	2.1
IP-8	47.259	1.779	2.1
End 2	47.259	1.479	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

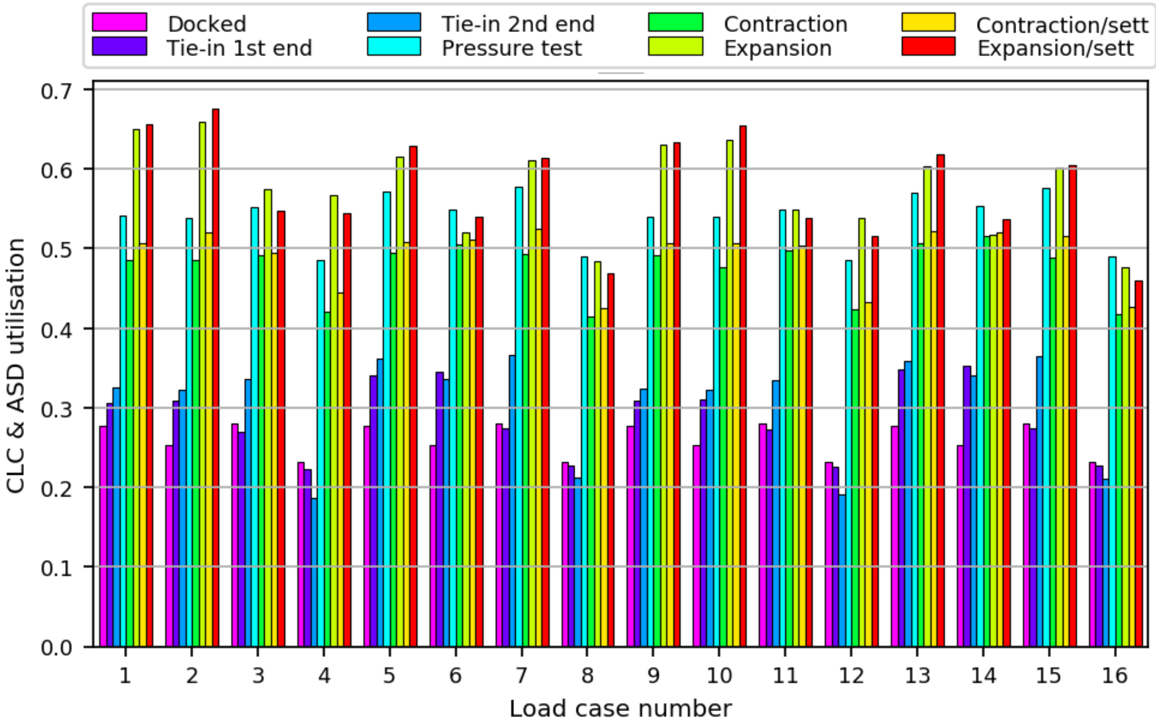
Load Step	Internal Pressure [bara]	Temperature [°C]	Content Density [kg/m3]	Axial Expansion - End 2 [m]
Docked	20	10	1150	0
Tie-in 1st end	20	10	1150	0
Tie-in 2nd end	20	10	1150	0
Pressure test	400	10	1150	0
Contraction	300	-20	250	-1.0
Expansion	300	100	250	3.0
Contraction/sett	300	-20	250	-1.0
Expansion/sett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

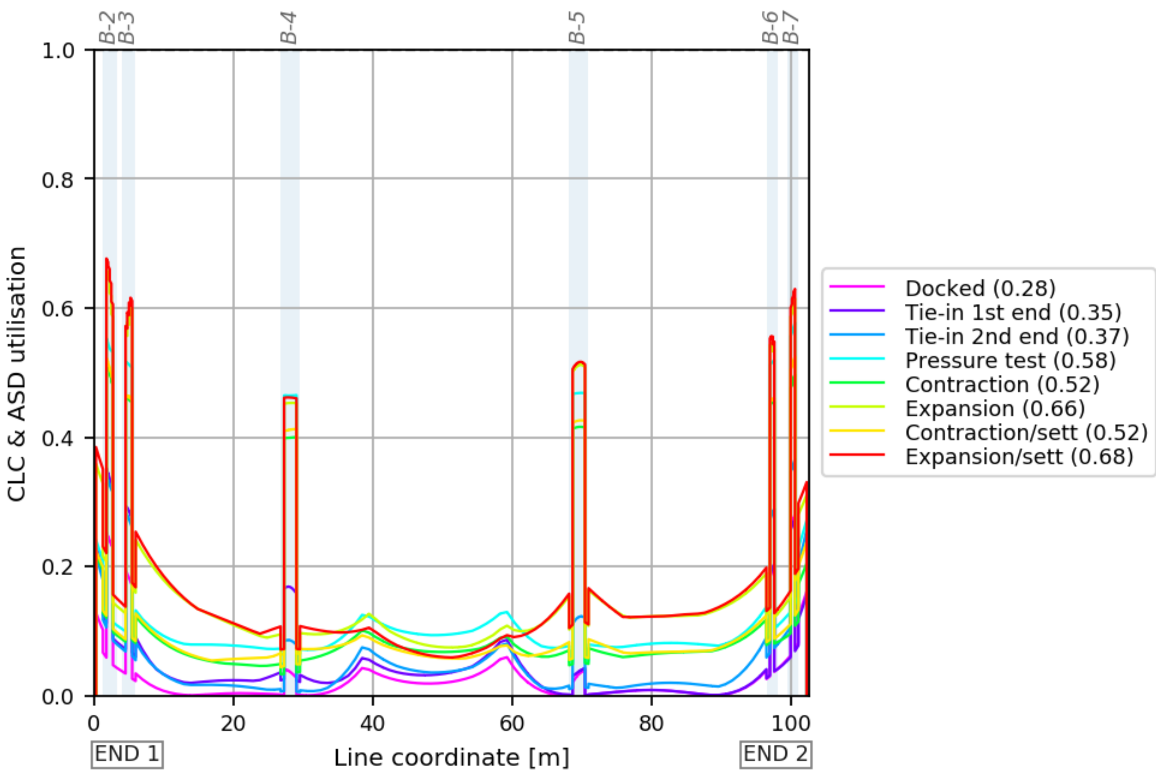
The maximum CLC / ASD utilisation along the spool, for each load case and load step, is shown in Figure 5.3.

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

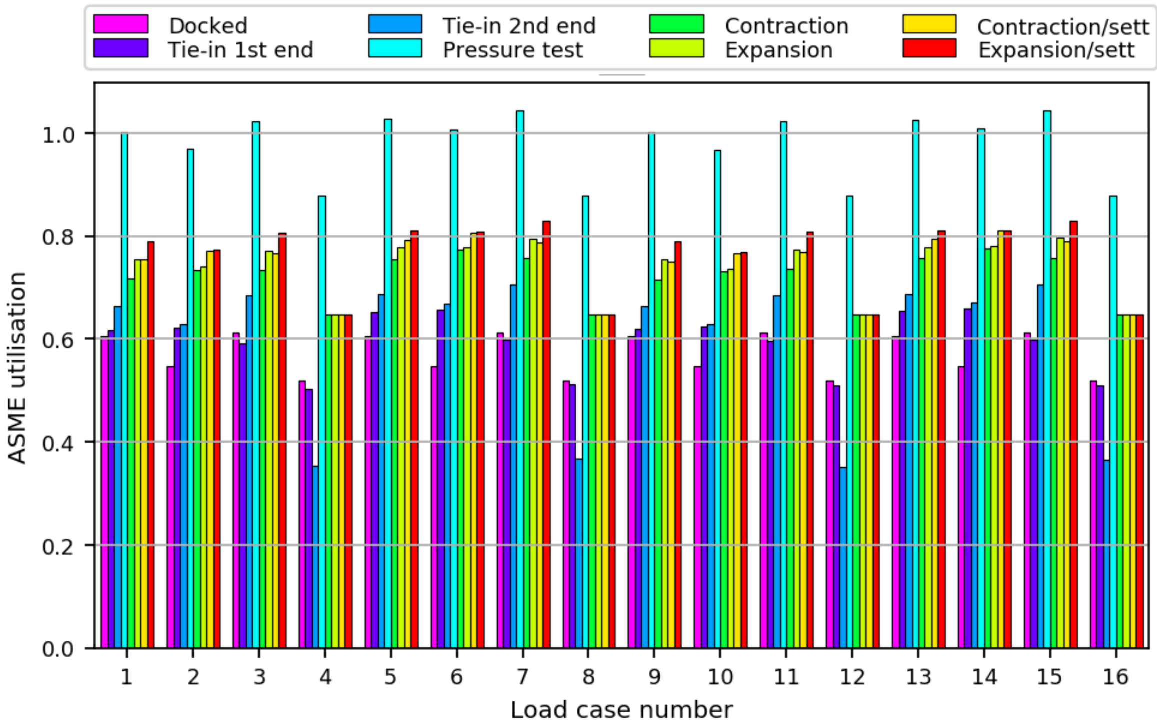


The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

5.6 SPOOL ASME UTILISATION

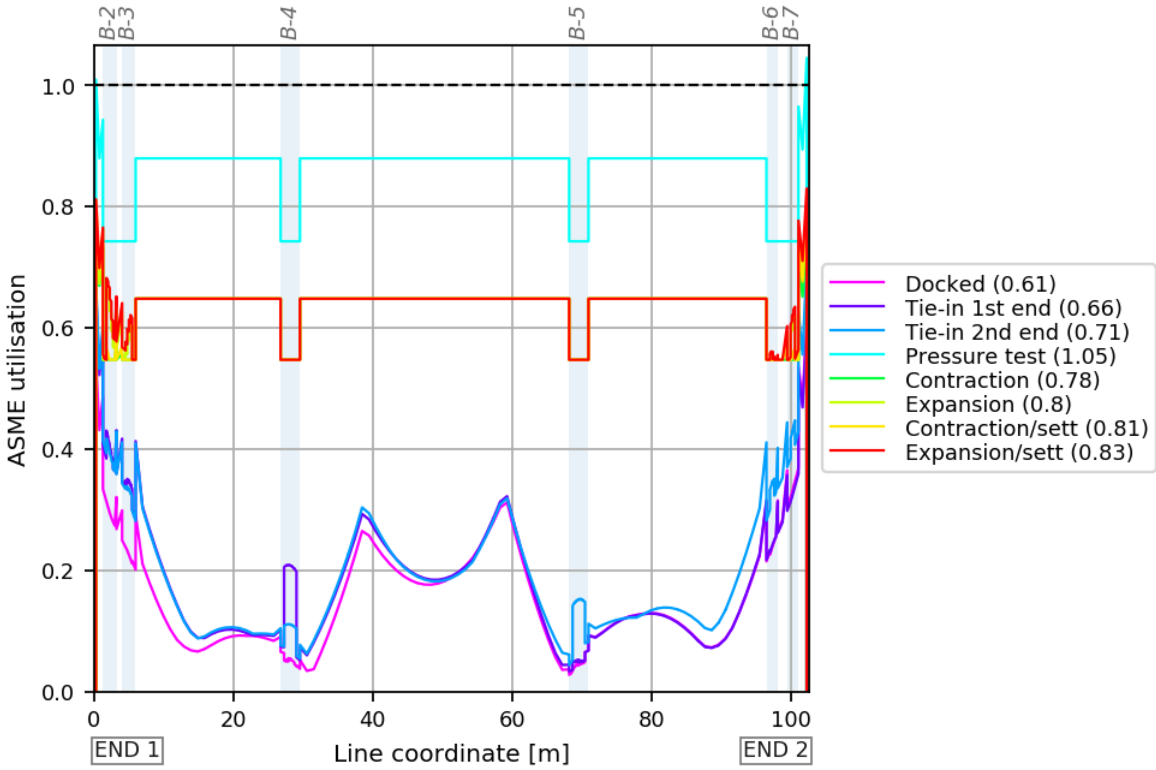
The maximum ASME utilisation along the spool, for each load case and load step, is shown in Figure 5.5.

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



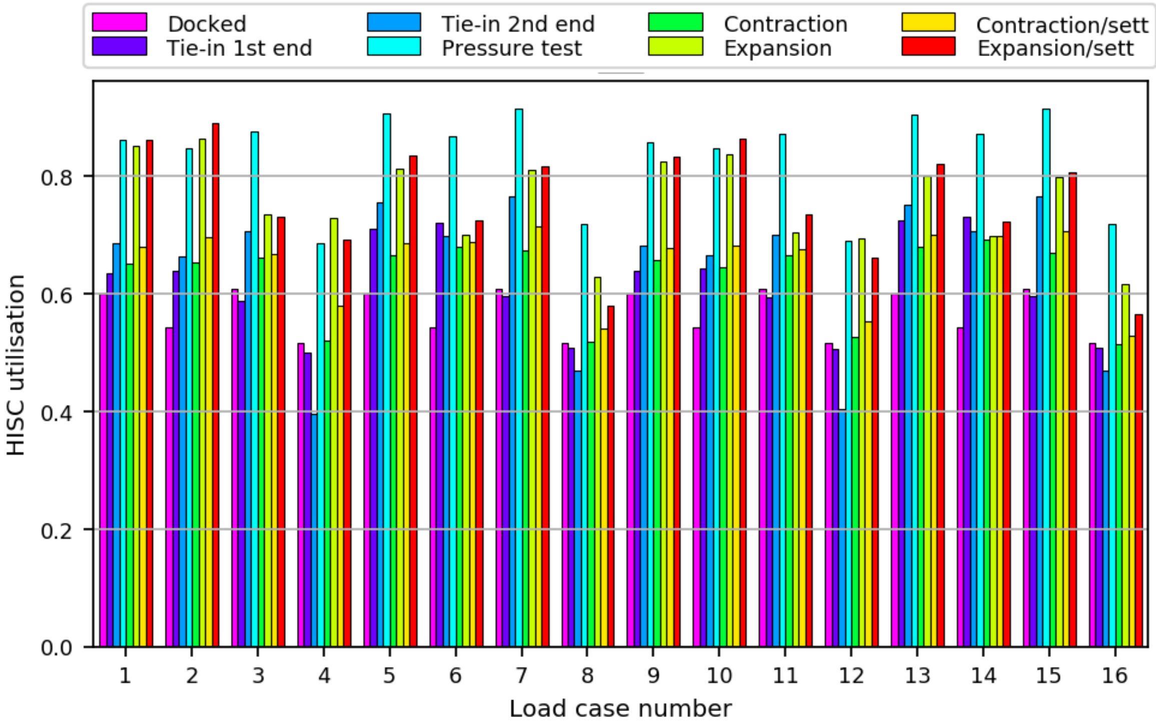
The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

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

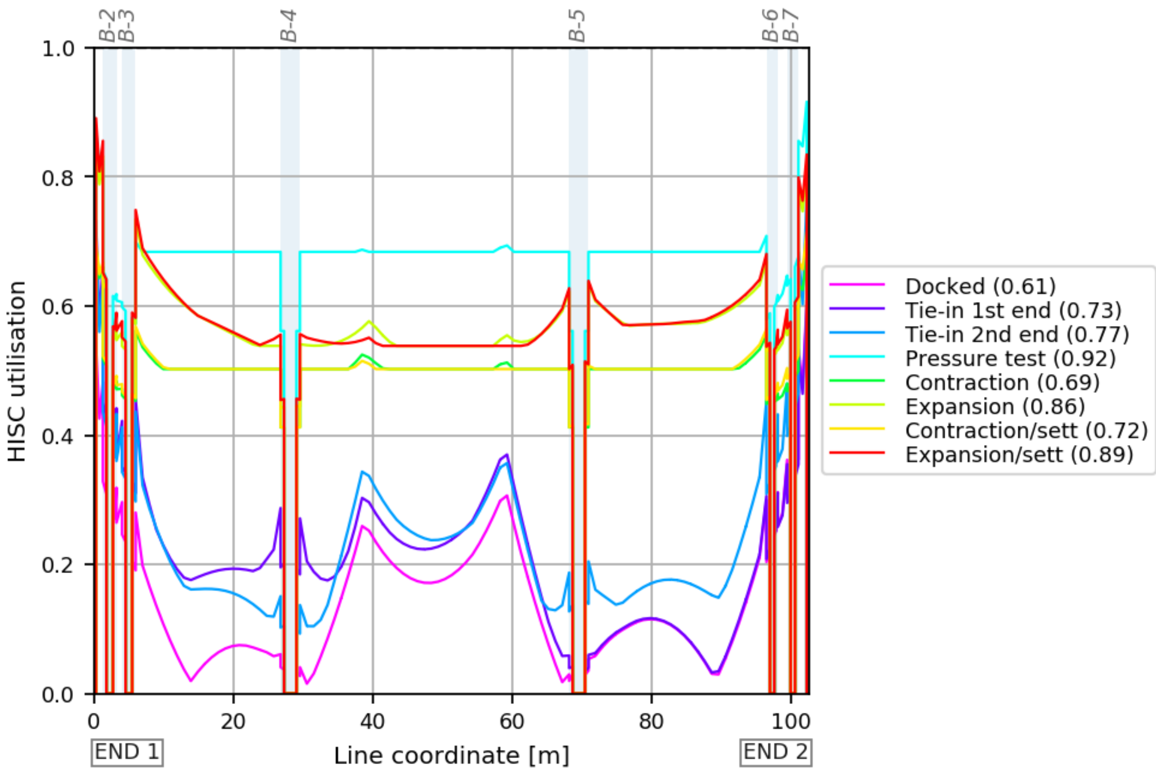
The maximum HISC utilisation along the spool, for each load case and load step, is shown in Figure 5.7.

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.

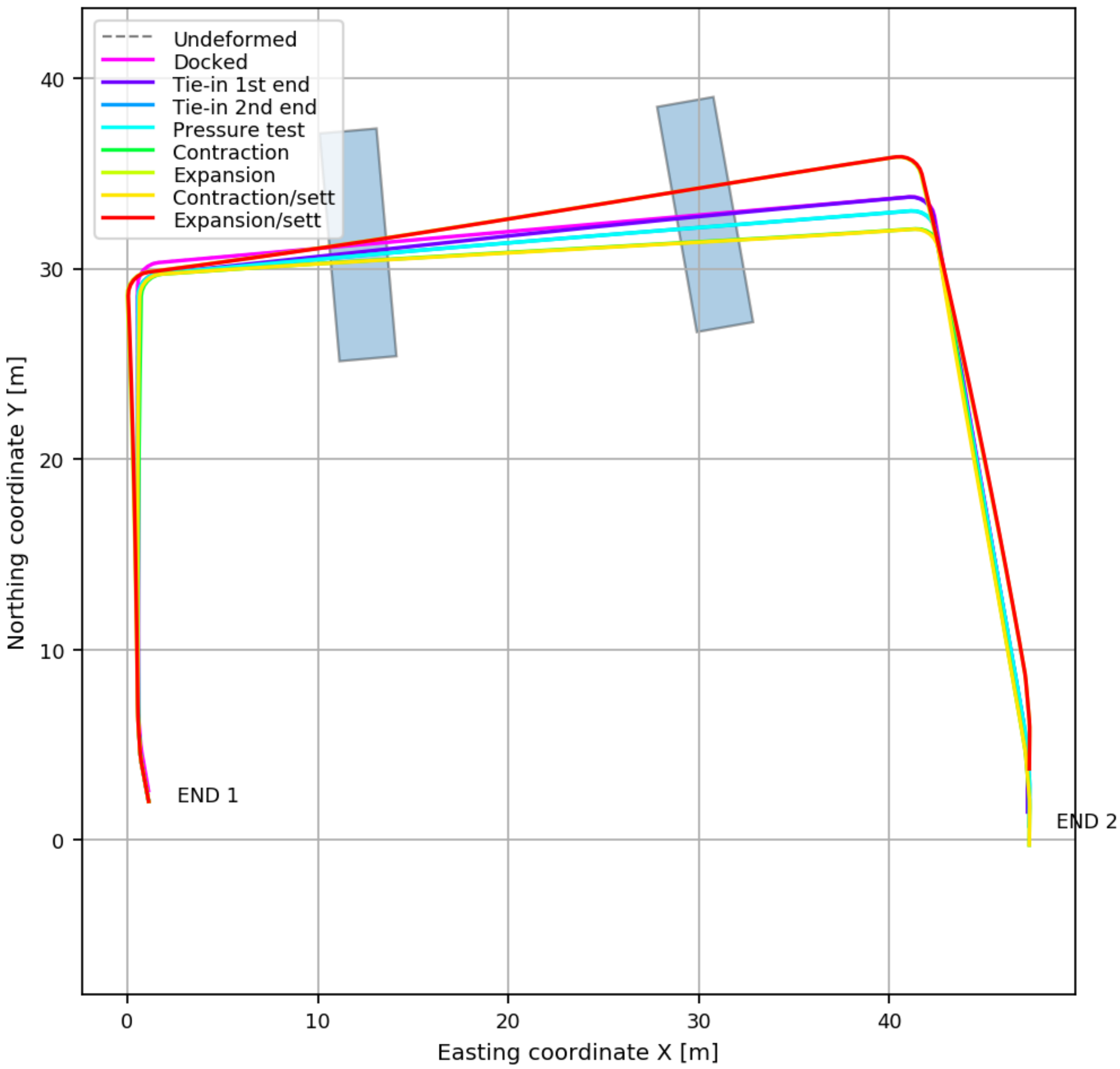
Longitudinal Stress Concentration Factors has been applied at each weld.

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 15

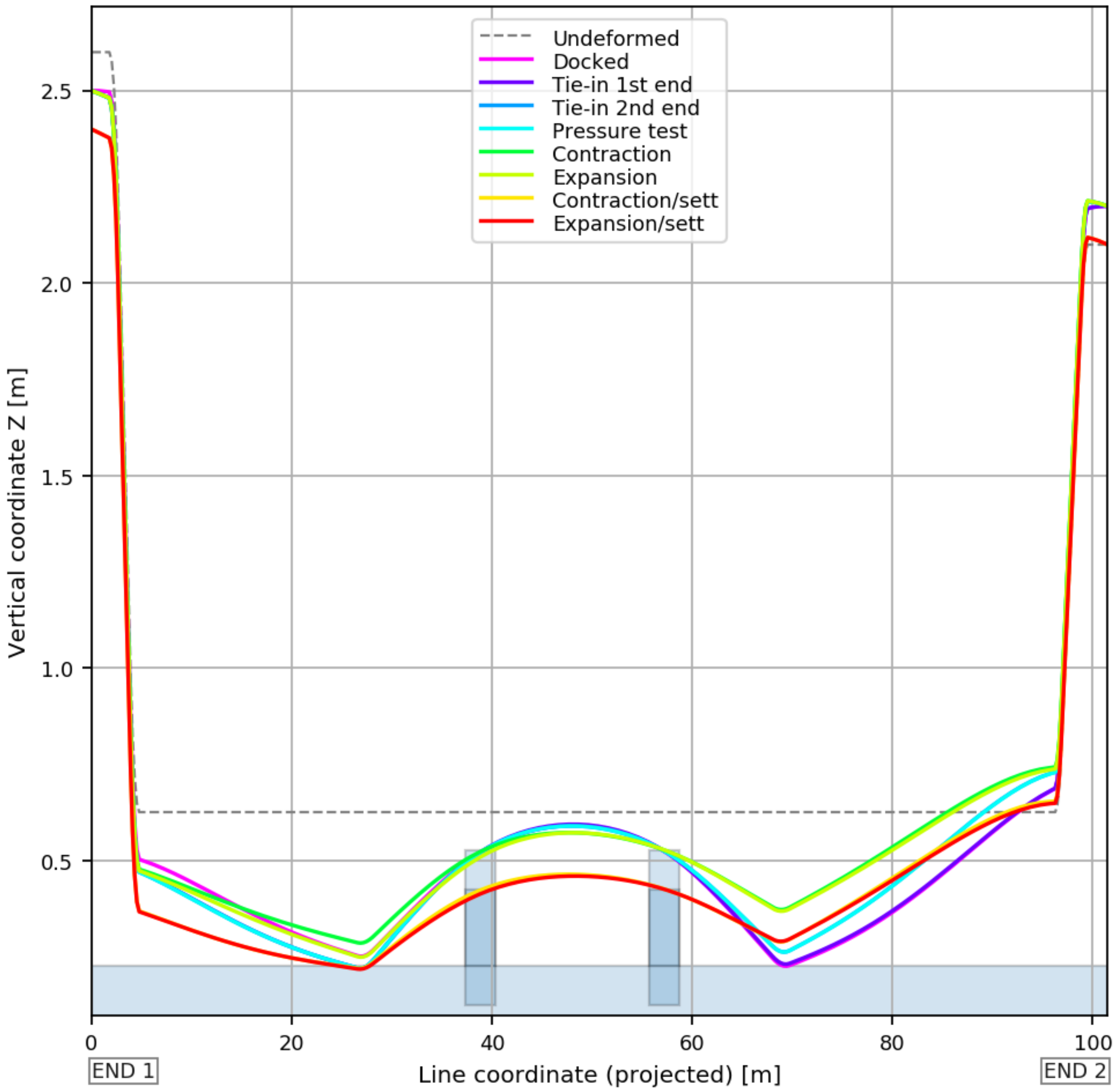
A top-view of the deformed shapes, for the most utilised load case (number 15), are shown for each load step in Figure 5.9.

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 15), 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.

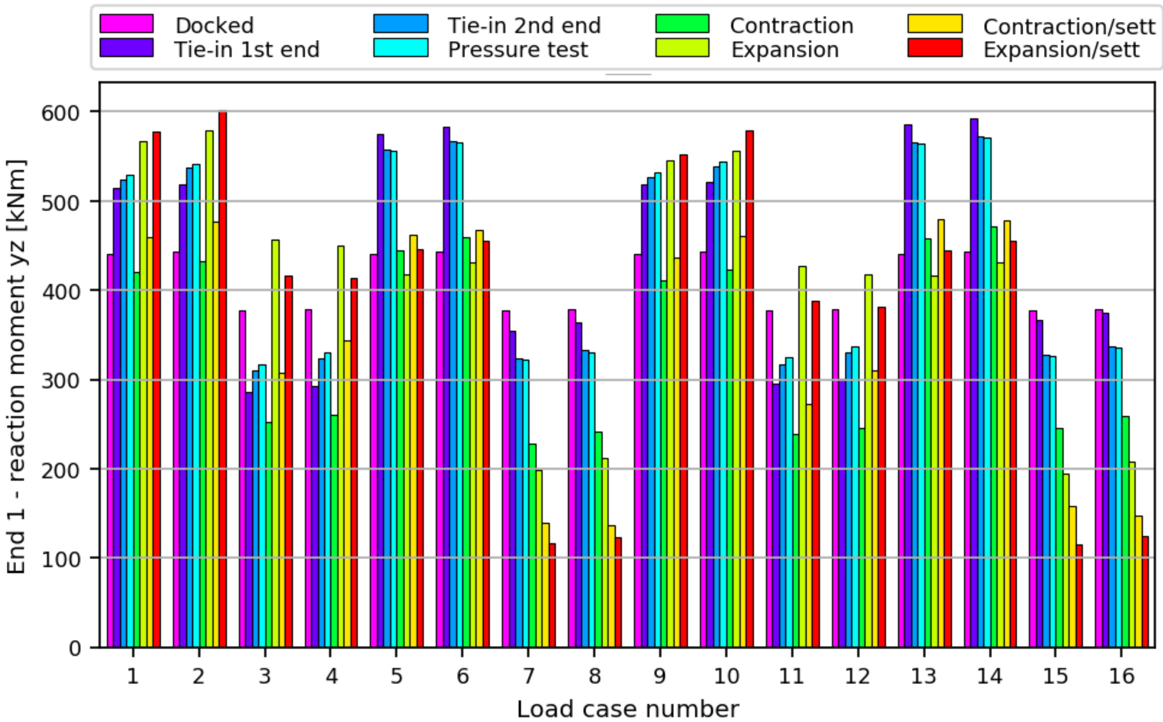
Table 5.4 – Maximum Magnitude Reaction Loads at End 1

Load Step	End Reaction Forces [kN]			End Reaction Moments [kNm]			
	RFx	RFy	RFz	RMx	RMy	RMz	RMb
Docked	2.8	-1.2	87.3	0.0	442.6	-9.3	442.6
Tie-in 1st end	23.7	-21.3	92.1	0.0	532.8	258.9	592.4
Tie-in 2nd end	21.4	-14.0	92.1	16.9	541.5	-196.6	572.4
Pressure test	19.2	-12.8	92.1	18.7	543.4	-205.6	571.3
Contraction	7.7	10.6	74.6	38.3	426.2	-207.0	472.0
Expansion	8.6	7.9	75.1	35.7	430.0	-427.4	579.5
Contraction/sett	-4.0	18.5	75.6	56.9	451.8	-322.9	479.1
Expansion/sett	7.2	-10.1	76.1	43.6	454.0	-429.5	602.6
Max	23.7	-21.3	92.1	56.9	543.4	-429.5	602.6

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

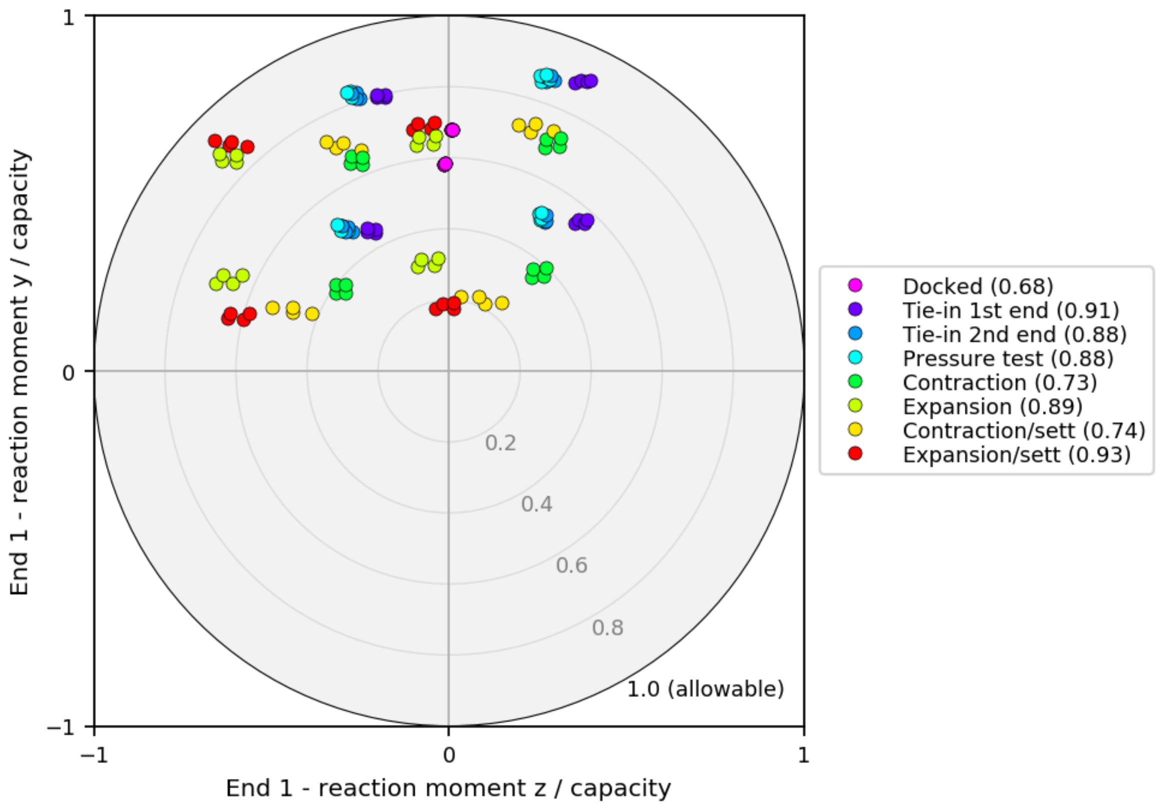
The maximum magnitude reaction bending moment at End 1, for each load case and load step, is shown in Figure 5.11.

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.

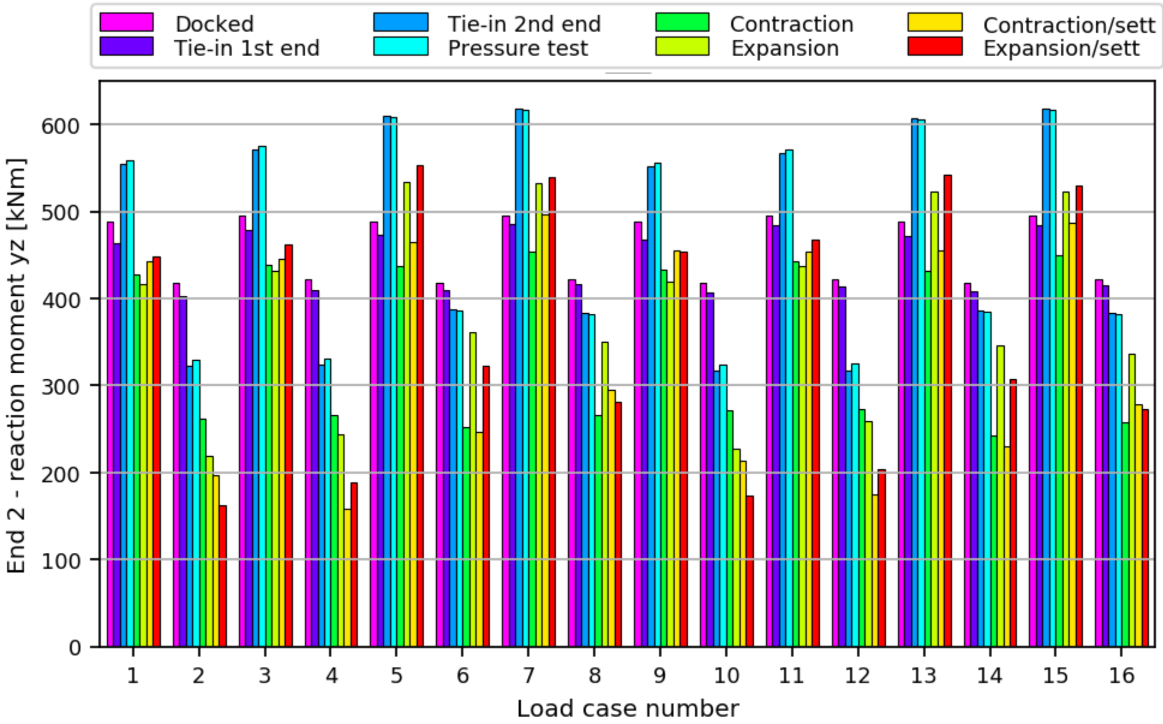
Table 5.5 – Maximum Magnitude Reaction Loads at End 2

Load Step	End Reaction Forces [kN]			End Reaction Moments [kNm]			
	RFx	RFy	RFz	RMx	RMy	RMz	RMb
Docked	5.1	1.1	90.5	-0.0	494.7	-5.4	494.8
Tie-in 1st end	19.6	4.3	90.7	-0.0	485.3	-24.7	485.5
Tie-in 2nd end	22.4	16.7	93.7	-0.0	570.2	-251.8	618.9
Pressure test	18.2	15.4	93.7	-1.7	571.7	-244.0	617.3
Contraction	17.6	14.6	74.6	-14.8	412.9	216.8	454.4
Expansion	-21.8	-18.7	73.9	-29.6	444.0	-317.2	534.2
Contraction/sett	16.9	18.9	75.5	-19.6	436.9	-270.3	496.3
Expansion/sett	-28.7	-19.8	74.9	-39.4	469.7	-314.8	553.5
Max	-28.7	-19.8	93.7	-39.4	571.7	-317.2	618.9

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

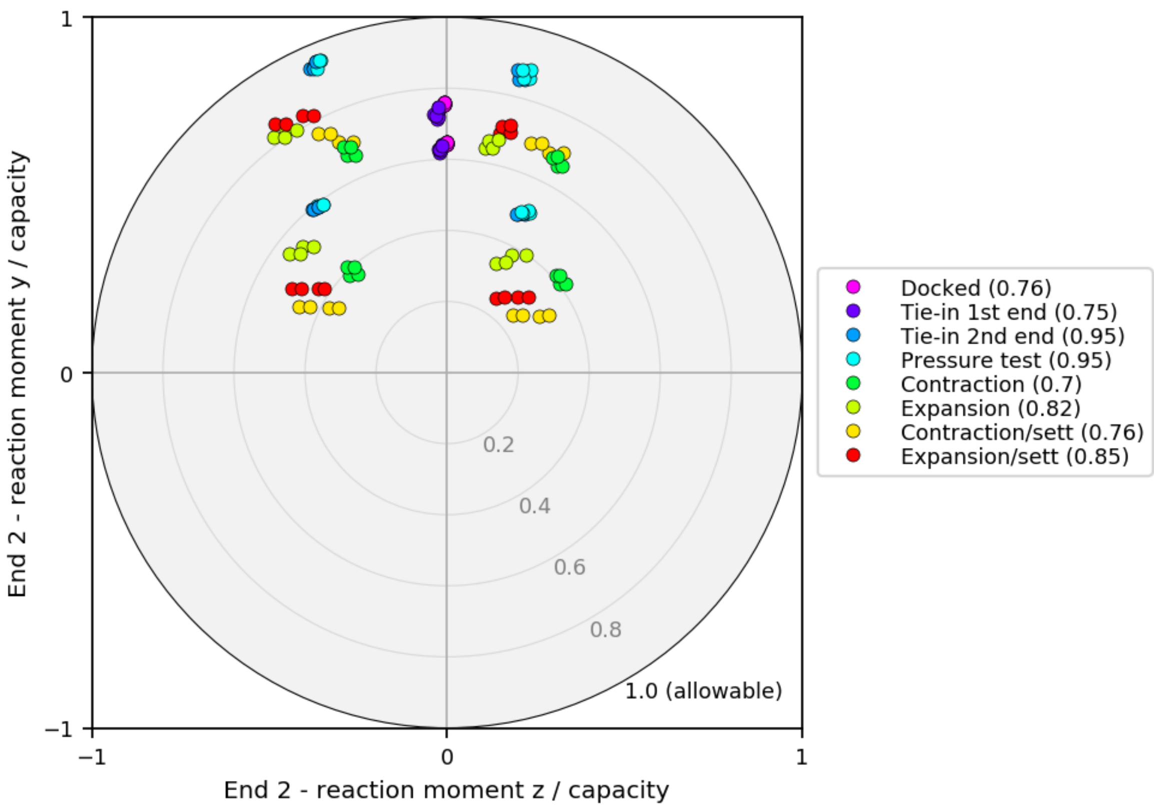
The maximum magnitude reaction bending moment at End 2, for each load case and load step, is shown in Figure 5.13.

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

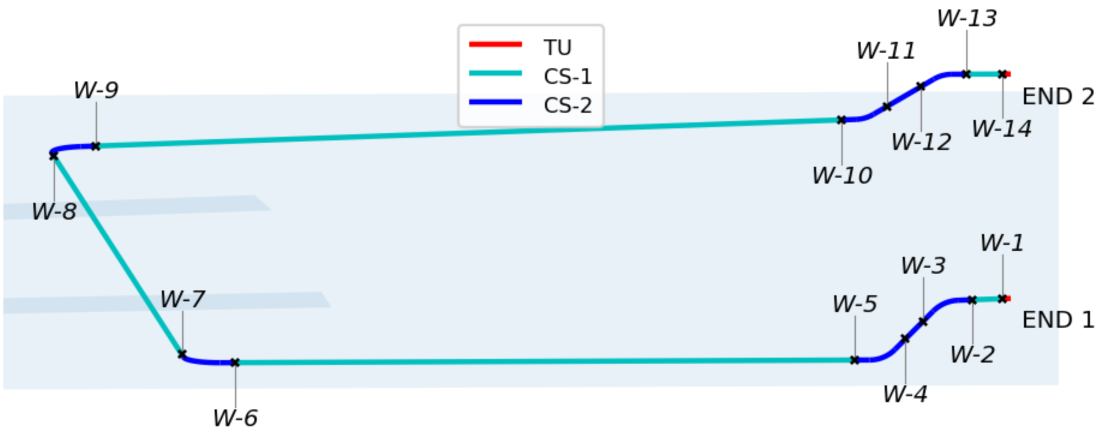


The shaded circular area indicates the allowable. The maximum utilisation is presented for each load step within parenthesis in the figure legend.

5.9 Fatigue Damage due to VIV

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

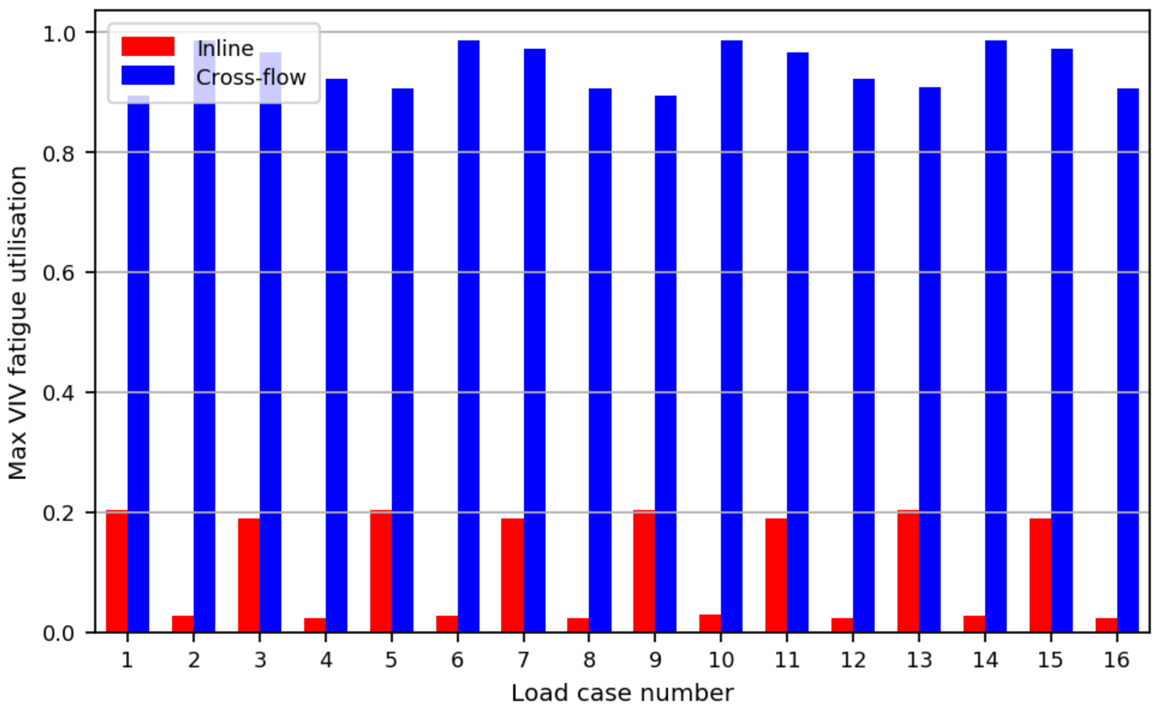
Figure 5.15 – Assessed Welds



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

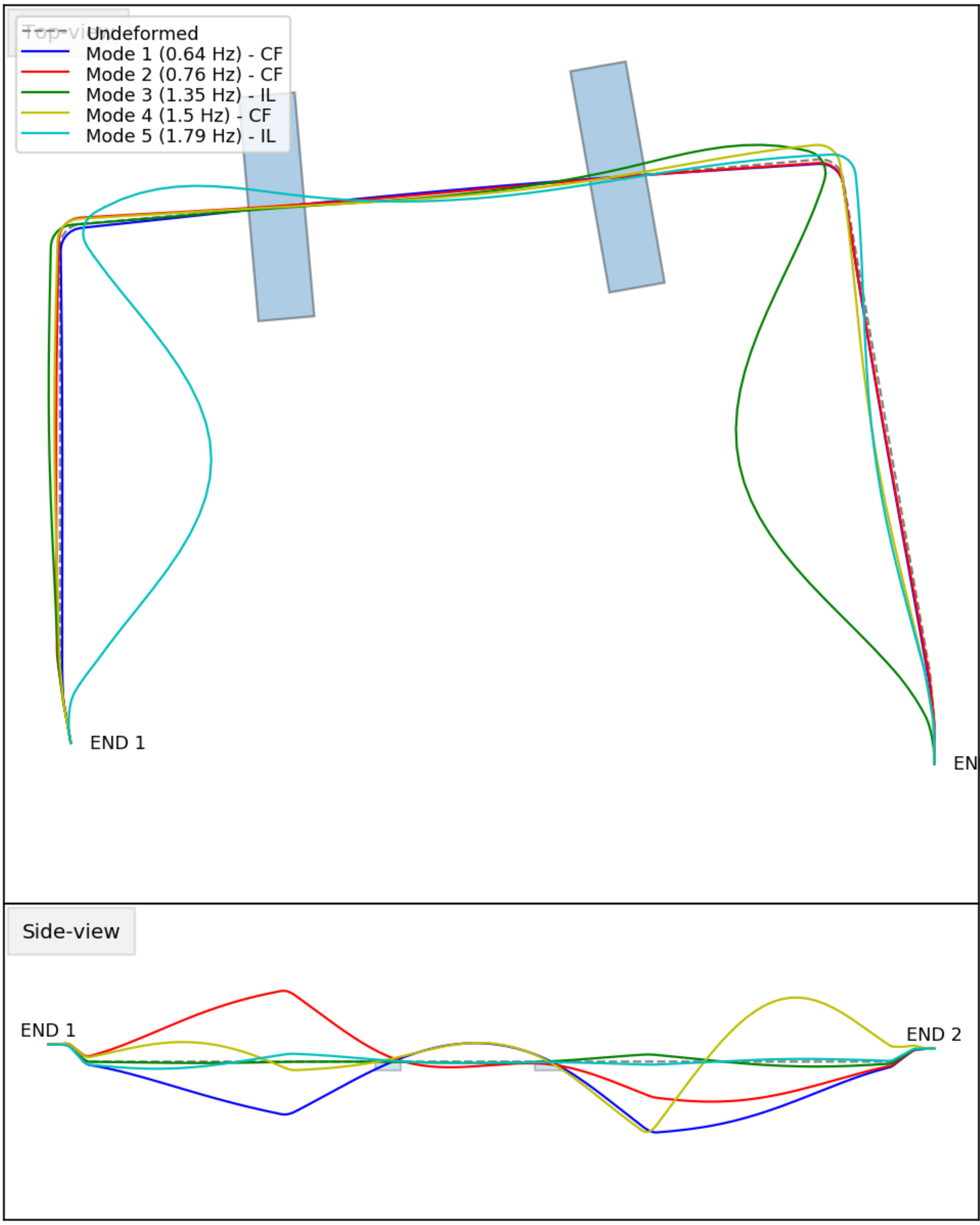


Inline and Cross-Flow utilisations are presented separately, and indicated that the damage has been accumulate at a specific location around the circumference.

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 2 (most critical in terms of fatigue damage) are shown in Figure 5.17.

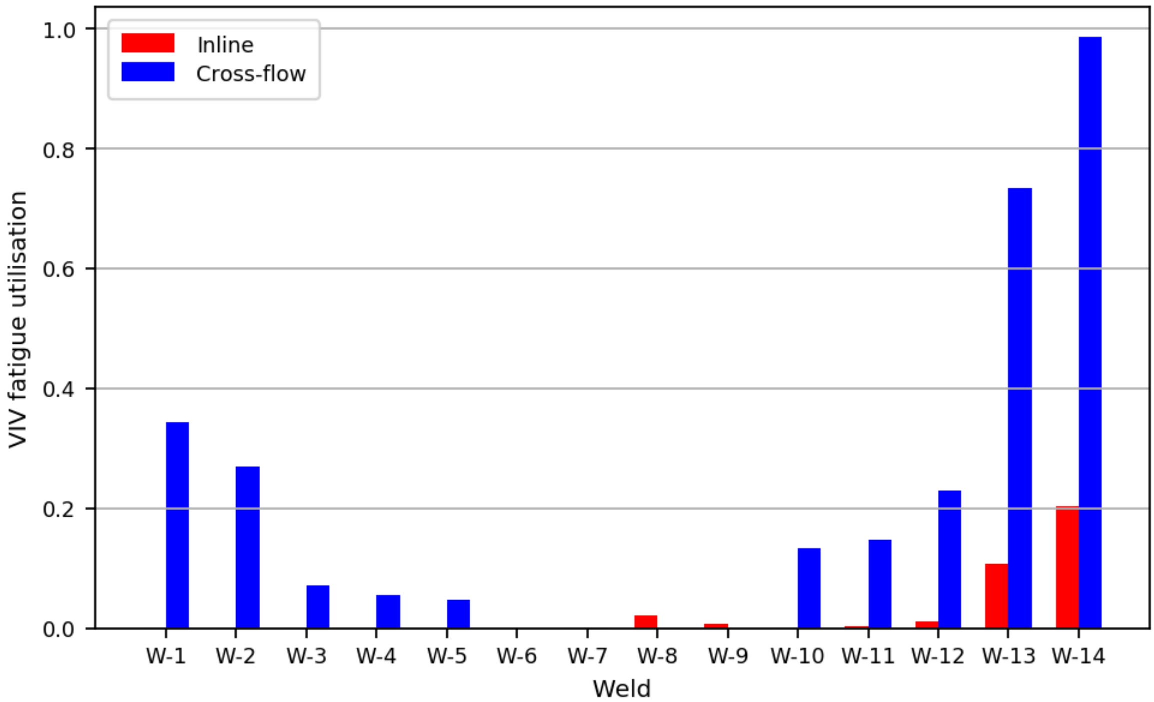
Figure 5.17 – Eigen-Modes of Most Utilised Load Case



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-4	Support-5
Docked	3.0	57.9	69.3
Tie-in 1st end	7.8	60.7	71.9
Tie-in 2nd end	15.4	64.1	70.1
Pressure test	15.6	64.1	70.0
Contraction	0.0	43.5	50.8
Expansion	0.0	44.0	50.9
Contraction/sett	17.7	41.3	45.7
Expansion/sett	22.2	36.9	44.9
Max	22.2	64.1	71.9

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

6 CONFIGURATION MIN_L2

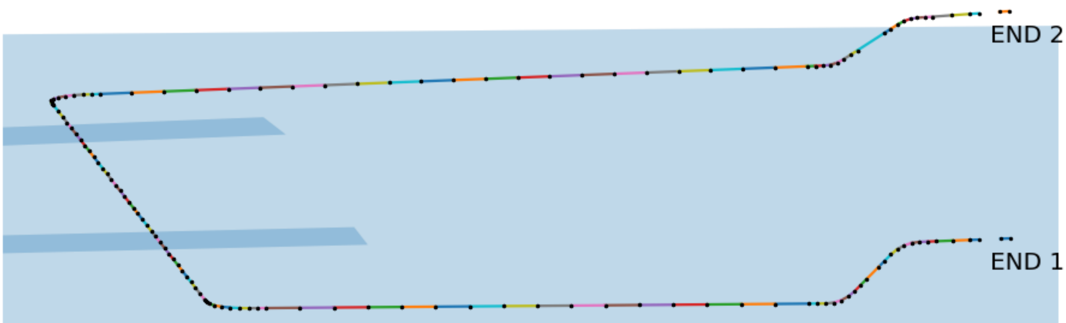
This section presents the following detailed results for configuration "min_L2".

- 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

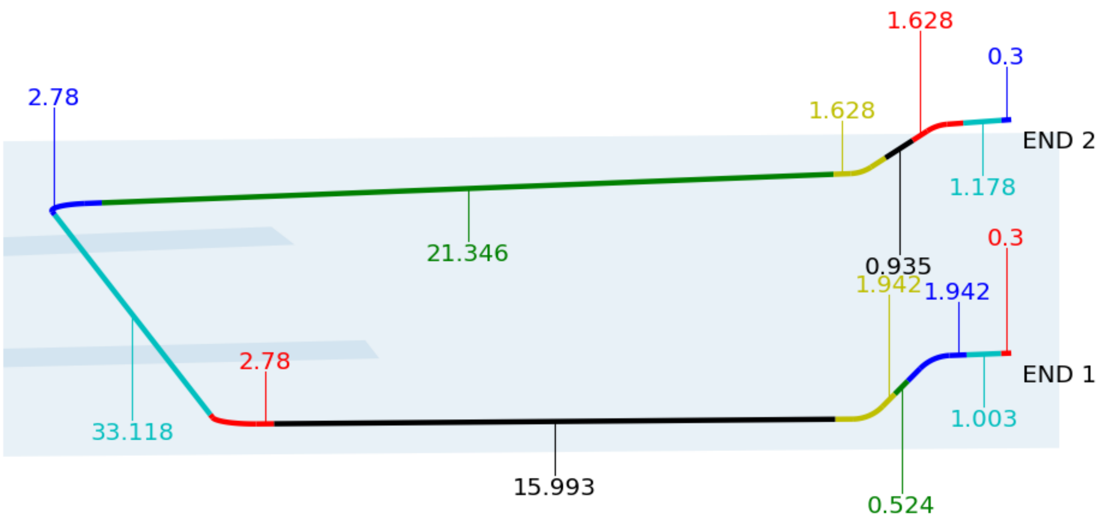
The coordinates at the spool ends and at the intersection points between the extended straight lines / sections, are presented in Table 6.1.

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	36.735	33.401	0.626
IP-6	40.862	9.995	0.626
IP-7	41.442	7.83	1.9
IP-8	42.126	5.951	1.9
End 2	42.229	5.669	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

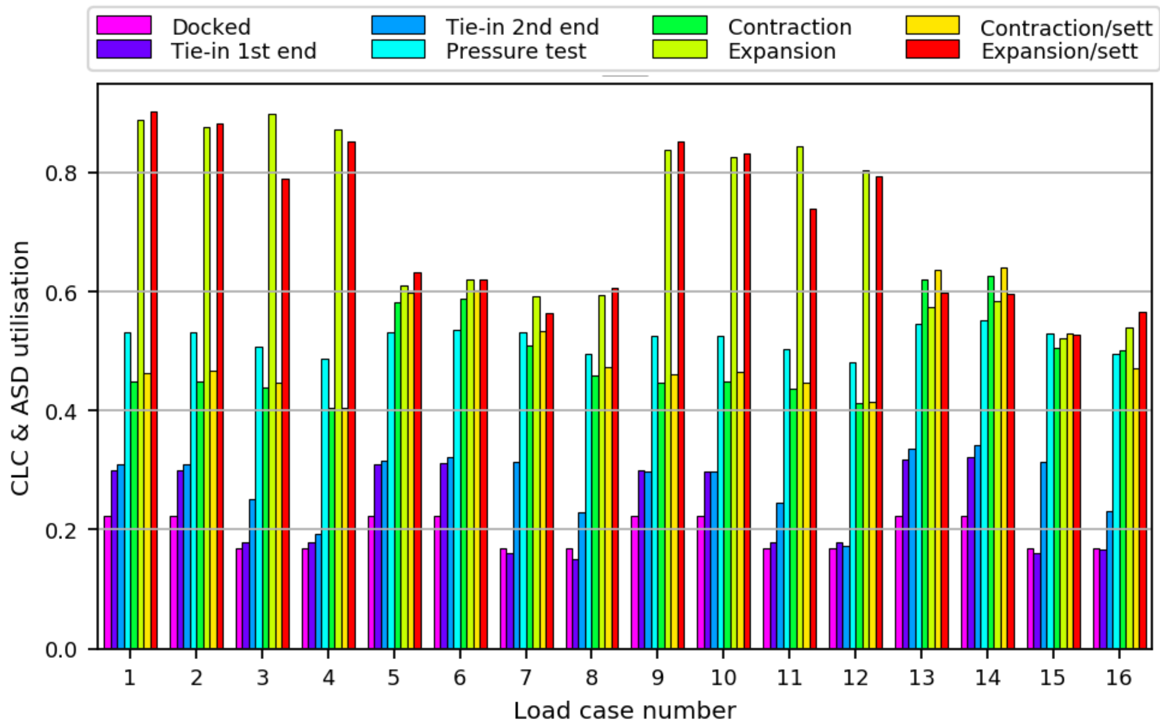
Load Step	Internal Pressure [bara]	Temperature [°C]	Content Density [kg/m3]	Axial Expansion - End 2 [m]
Docked	20	10	1150	0
Tie-in 1st end	20	10	1150	0
Tie-in 2nd end	20	10	1150	0
Pressure test	400	10	1150	0
Contraction	300	-20	250	-1.0
Expansion	300	100	250	3.0
Contraction/sett	300	-20	250	-1.0
Expansion/sett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

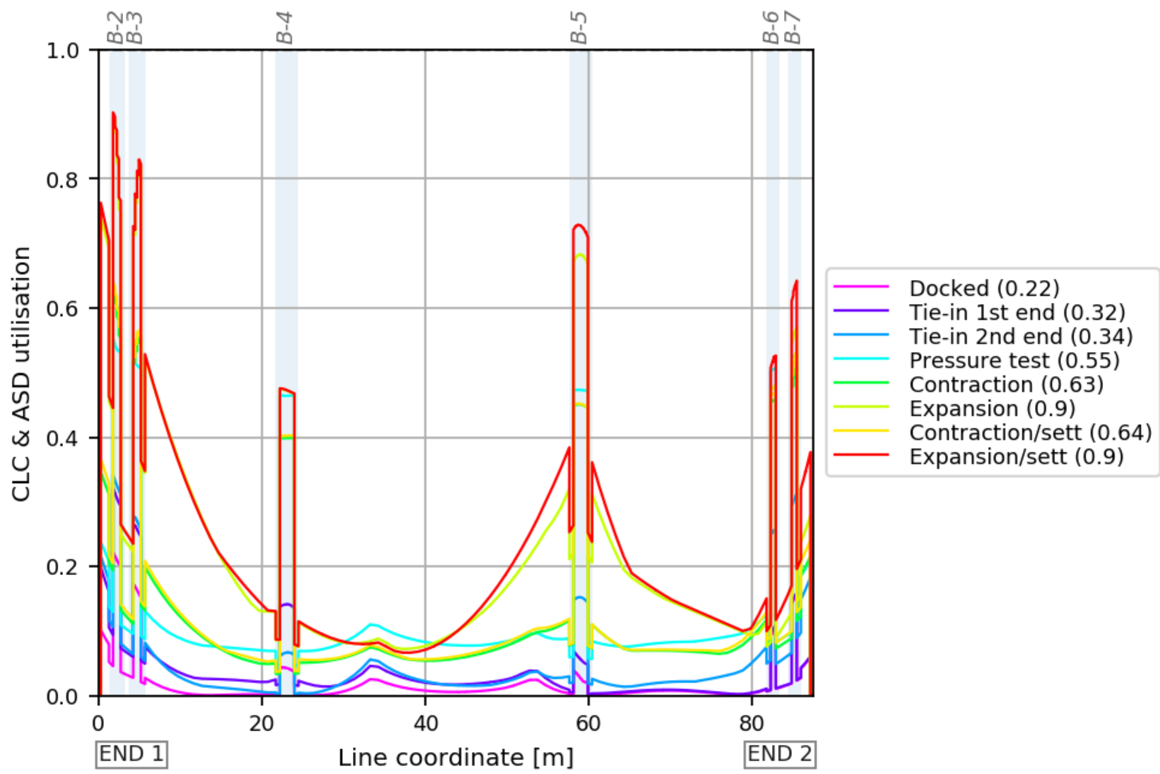
The maximum CLC / ASD utilisation along the spool, for each load case and load step, is shown in Figure 6.3.

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

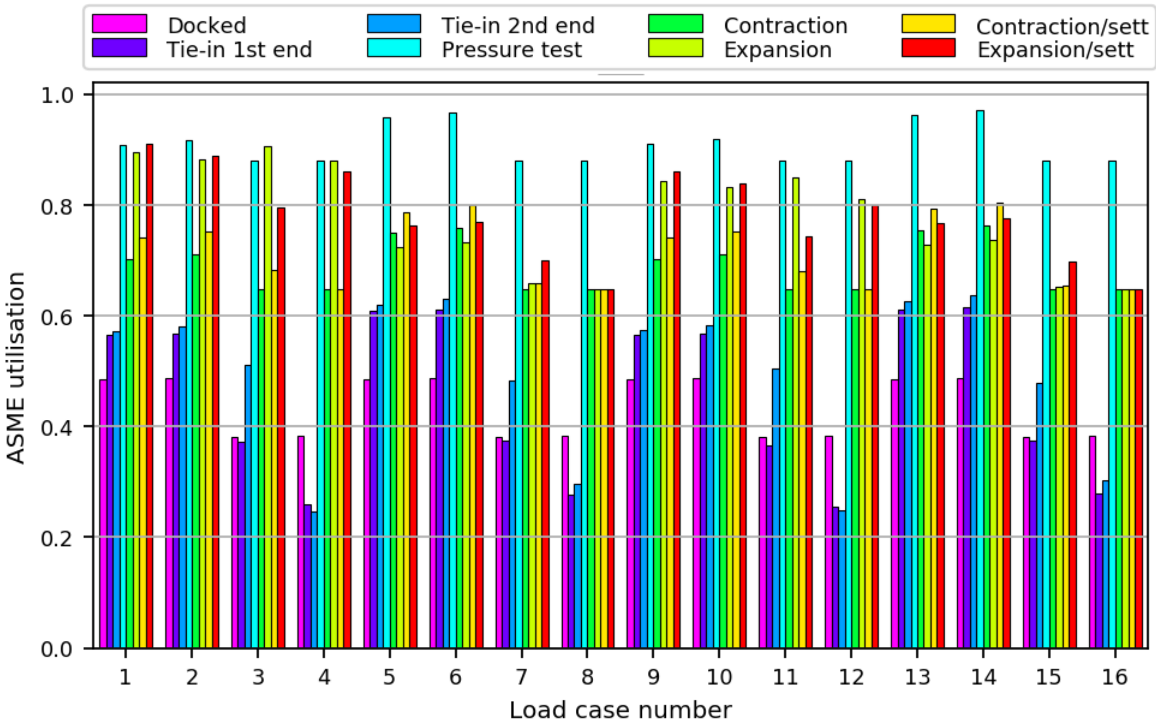


The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

6.6 SPOOL ASME UTILISATION

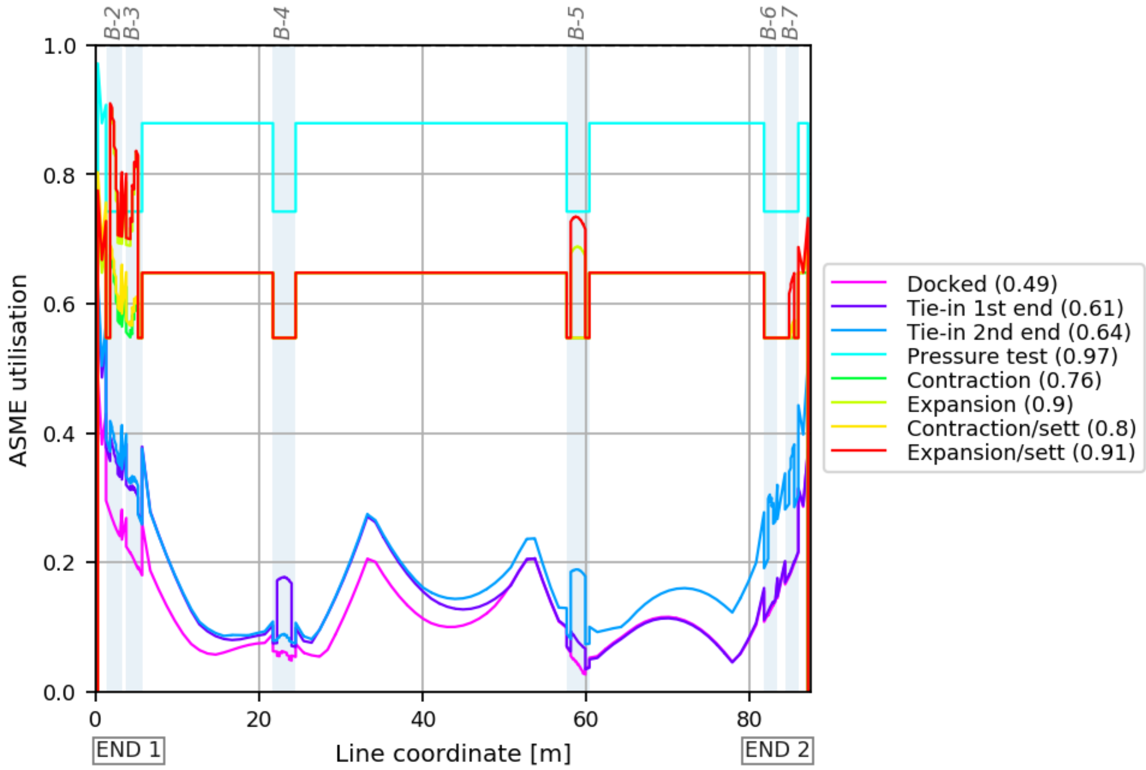
The maximum ASME utilisation along the spool, for each load case and load step, is shown in Figure 6.5.

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



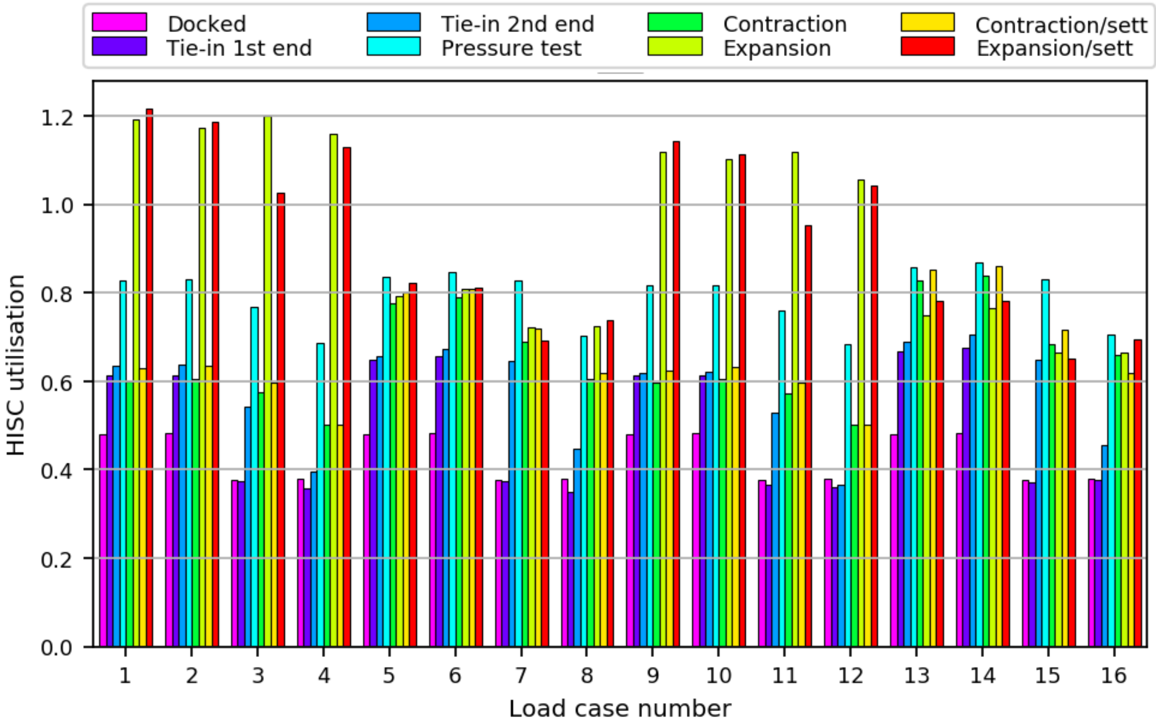
The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

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

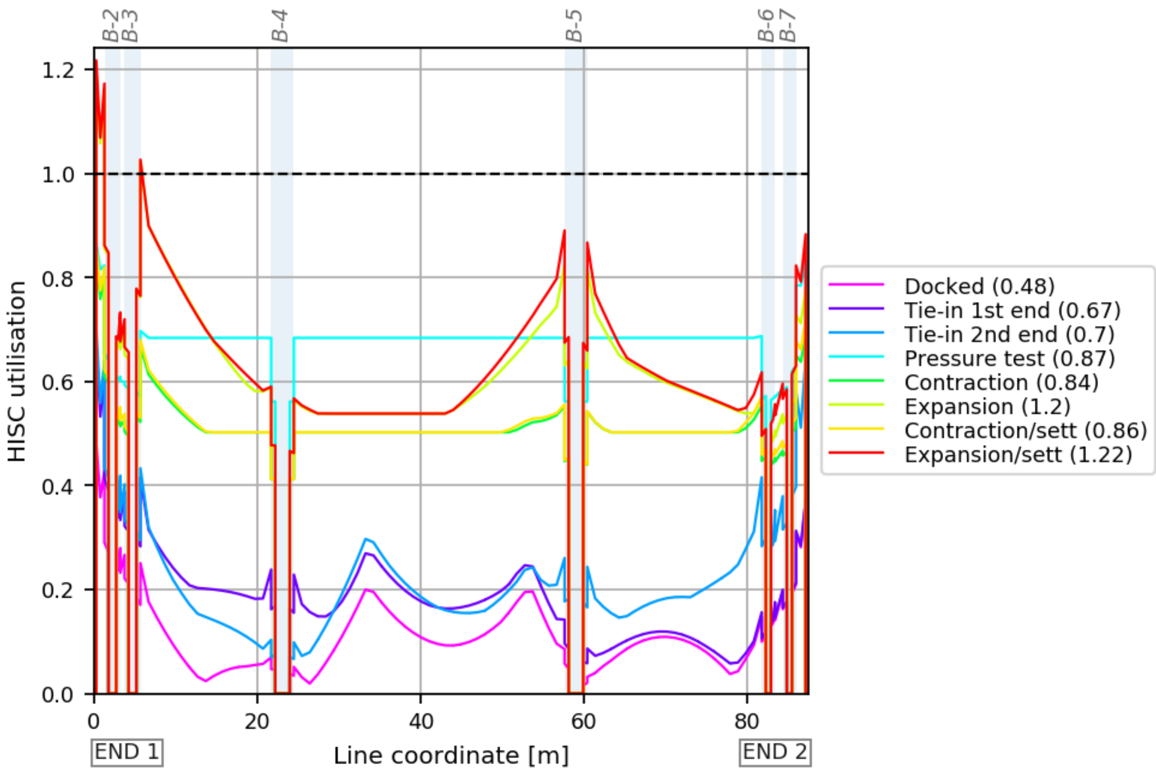
The maximum HISC utilisation along the spool, for each load case and load step, is shown in Figure 6.7.

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.

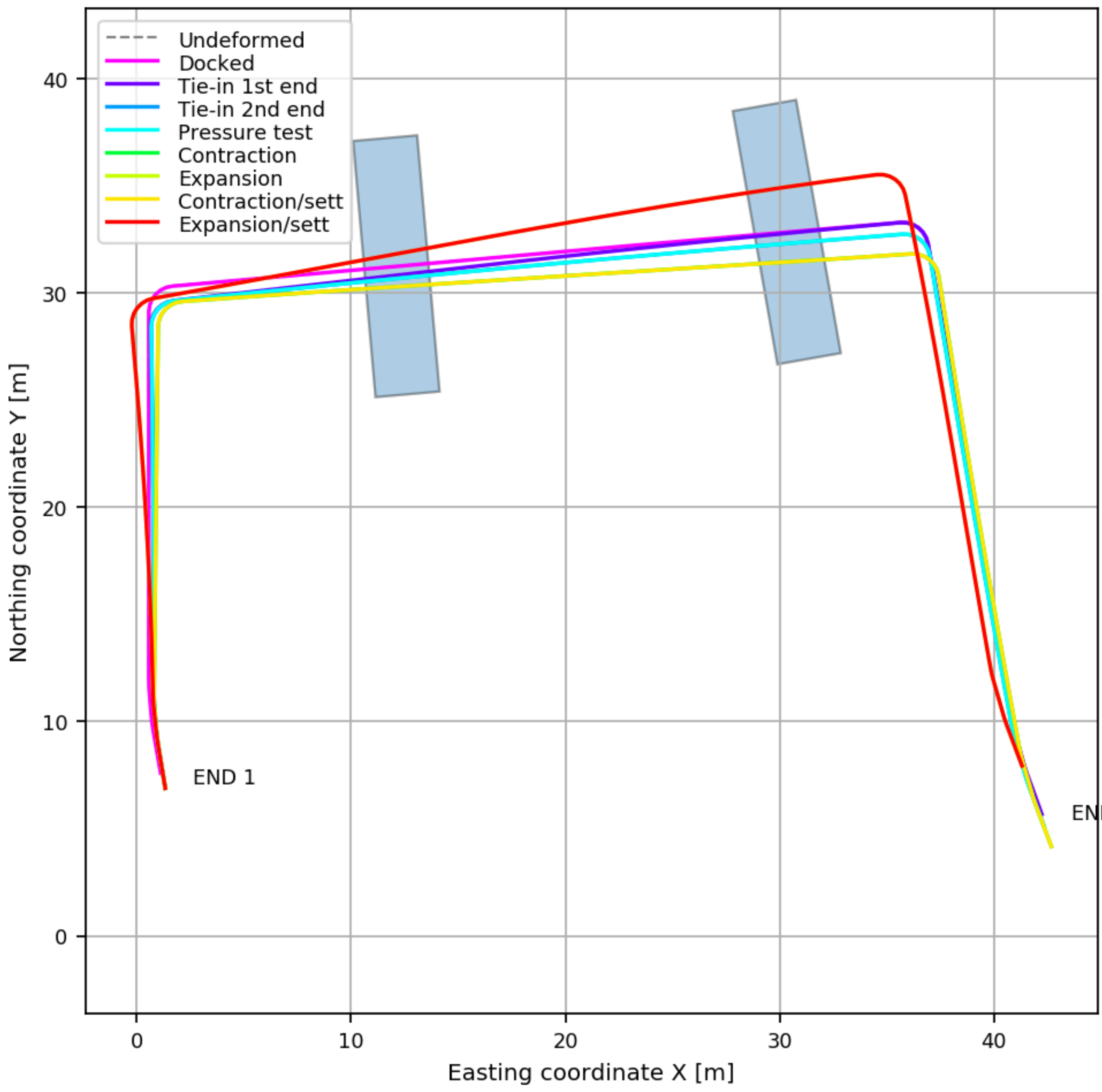
Longitudinal Stress Concentration Factors has been applied at each weld.

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 1

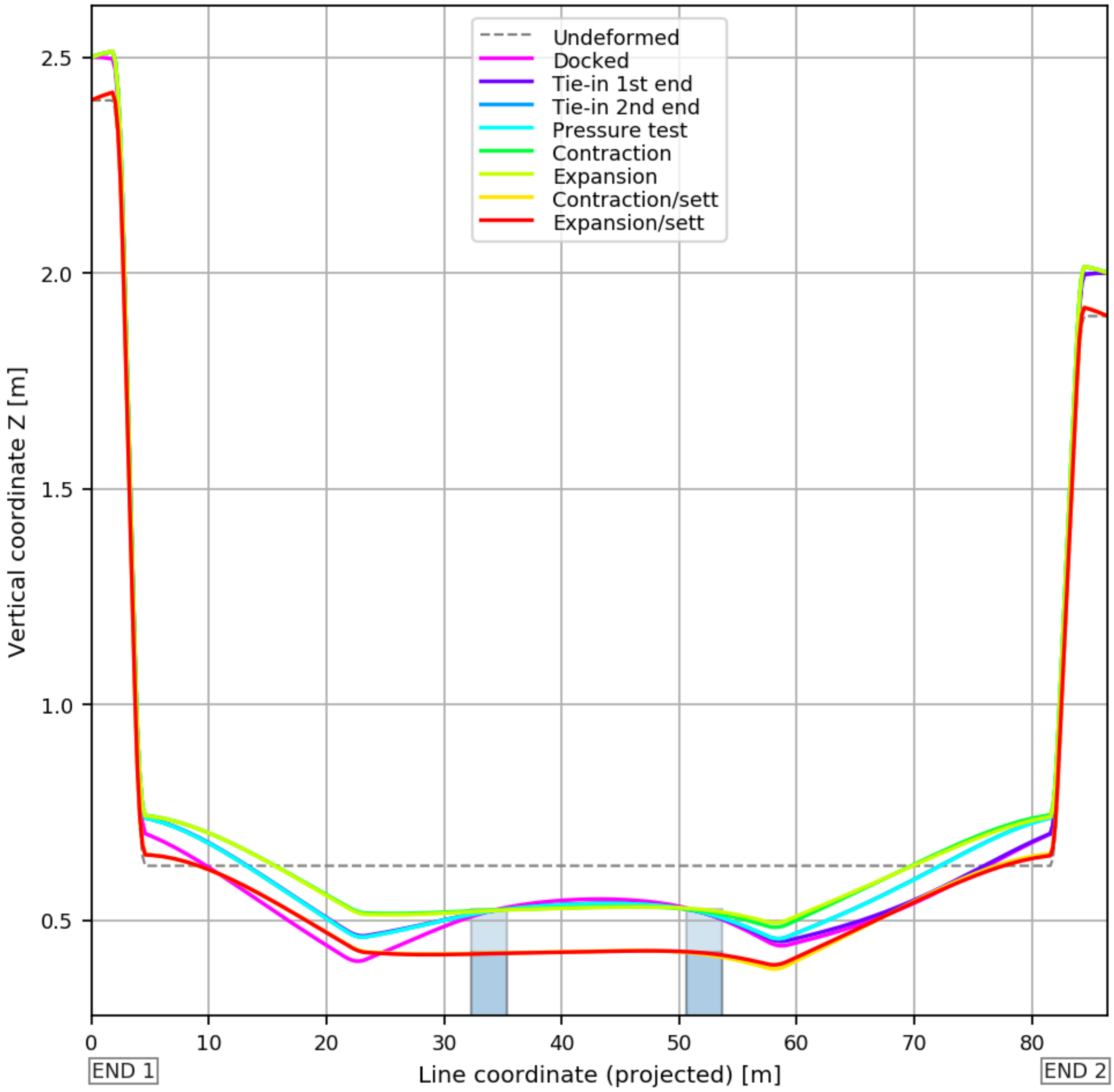
A top-view of the deformed shapes, for the most utilised load case (number 1), are shown for each load step in Figure 6.9.

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 1), 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.

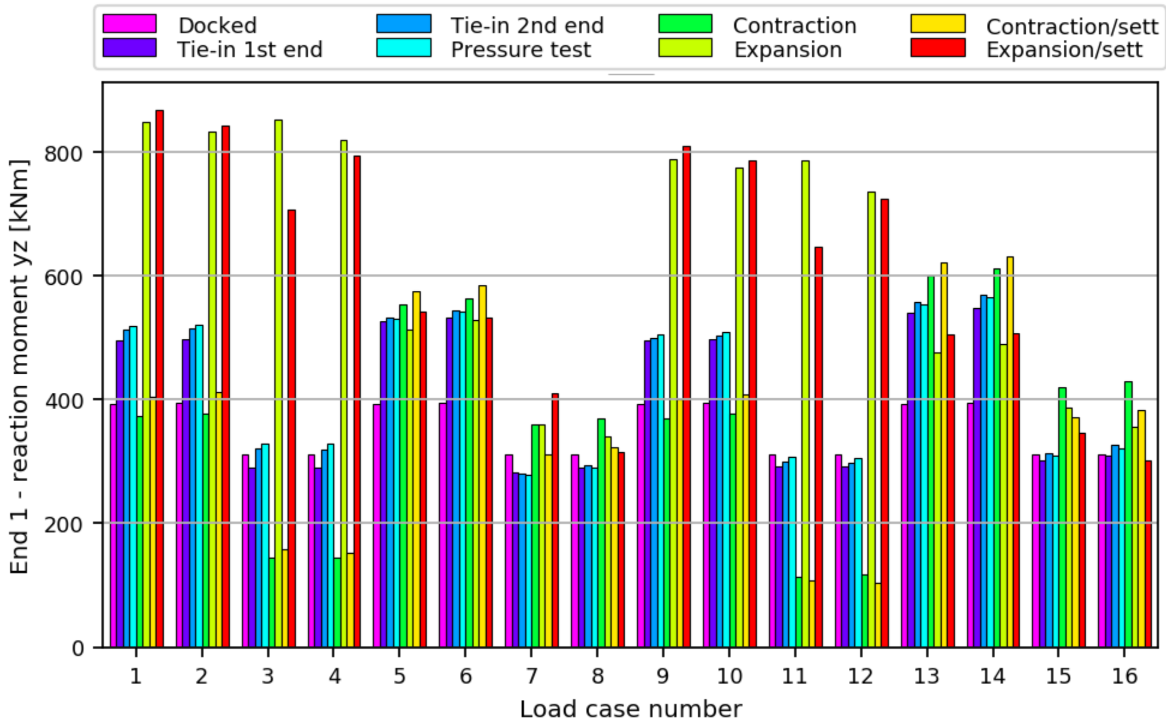
Table 6.4 – Maximum Magnitude Reaction Loads at End 1

Load Step	End Reaction Forces [kN]			End Reaction Moments [kNm]			
	RFx	RFy	RFz	RMx	RMy	RMz	RMb
Docked	3.1	-2.1	84.2	-0.0	394.5	14.0	394.8
Tie-in 1st end	21.4	-20.8	89.9	-0.0	497.0	229.3	547.3
Tie-in 2nd end	16.0	-13.7	90.1	13.0	512.8	-253.0	569.2
Pressure test	14.5	-12.5	90.1	14.7	514.3	-262.7	566.1
Contraction	-7.2	-17.3	74.6	20.6	417.9	446.9	611.8
Expansion	20.6	27.9	75.3	57.1	392.6	-845.8	852.1
Contraction/sett	-8.8	-16.8	76.1	27.3	450.3	442.9	631.6
Expansion/sett	20.6	25.0	76.9	60.1	423.3	-790.7	869.3
Max	21.4	27.9	90.1	60.1	514.3	-845.8	869.3

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

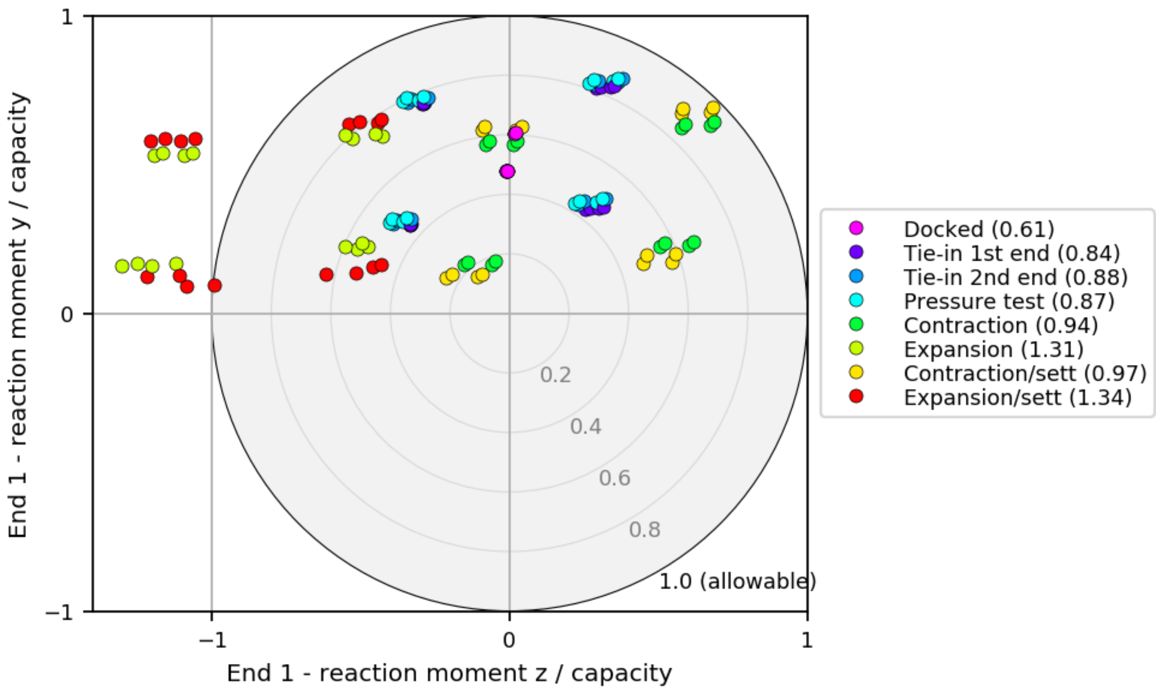
The maximum magnitude reaction bending moment at End 1, for each load case and load step, is shown in Figure 6.11.

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.

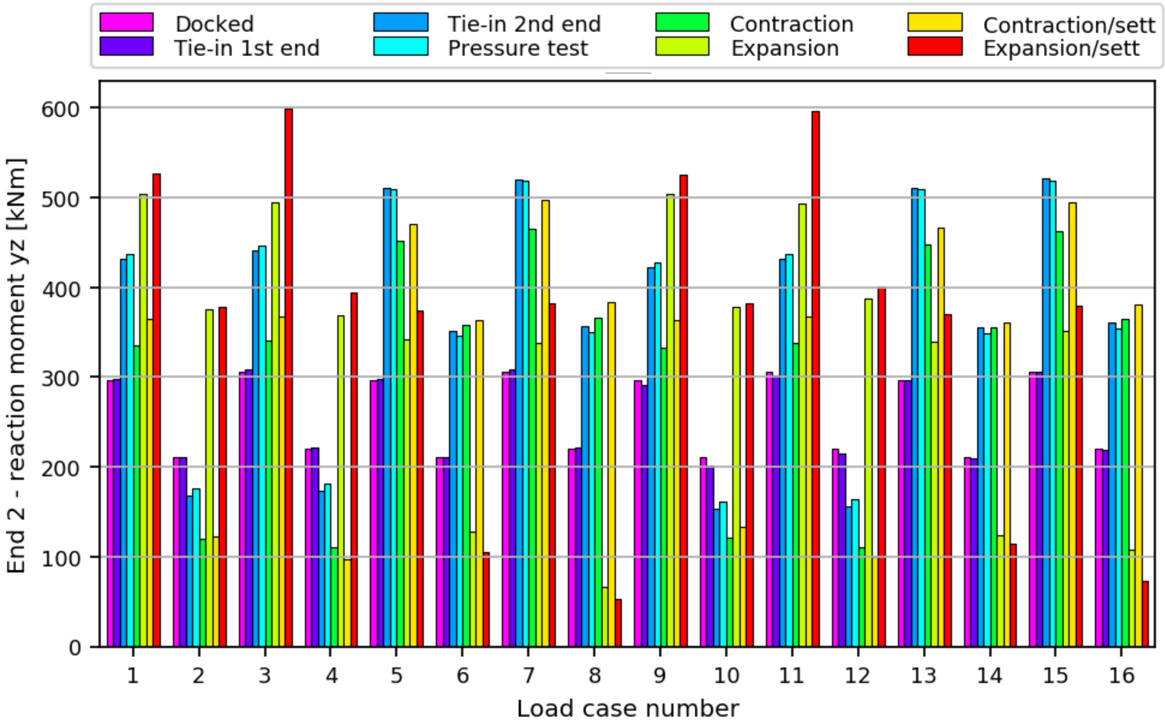
Table 6.5 – Maximum Magnitude Reaction Loads at End 2

Load Step	End Reaction Forces [kN]			End Reaction Moments [kNm]			
	RFx	RFy	RFz	RMx	RMy	RMz	RMb
Docked	6.3	-0.9	80.8	0.0	305.3	9.6	305.5
Tie-in 1st end	18.9	-6.3	81.1	-0.0	306.9	52.6	308.9
Tie-in 2nd end	29.4	16.1	85.3	0.0	414.6	-353.3	521.8
Pressure test	25.2	16.0	85.3	-0.4	417.9	-345.9	519.4
Contraction	27.6	20.4	69.8	-16.5	319.6	-366.0	465.6
Expansion	-39.4	-28.1	68.7	-60.0	351.1	385.5	504.6
Contraction/sett	27.2	21.3	71.1	-19.6	353.0	-380.7	497.5
Expansion/sett	-42.1	-32.9	69.9	-63.9	391.6	454.2	599.7
Max	-42.1	-32.9	85.3	-63.9	417.9	454.2	599.7

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

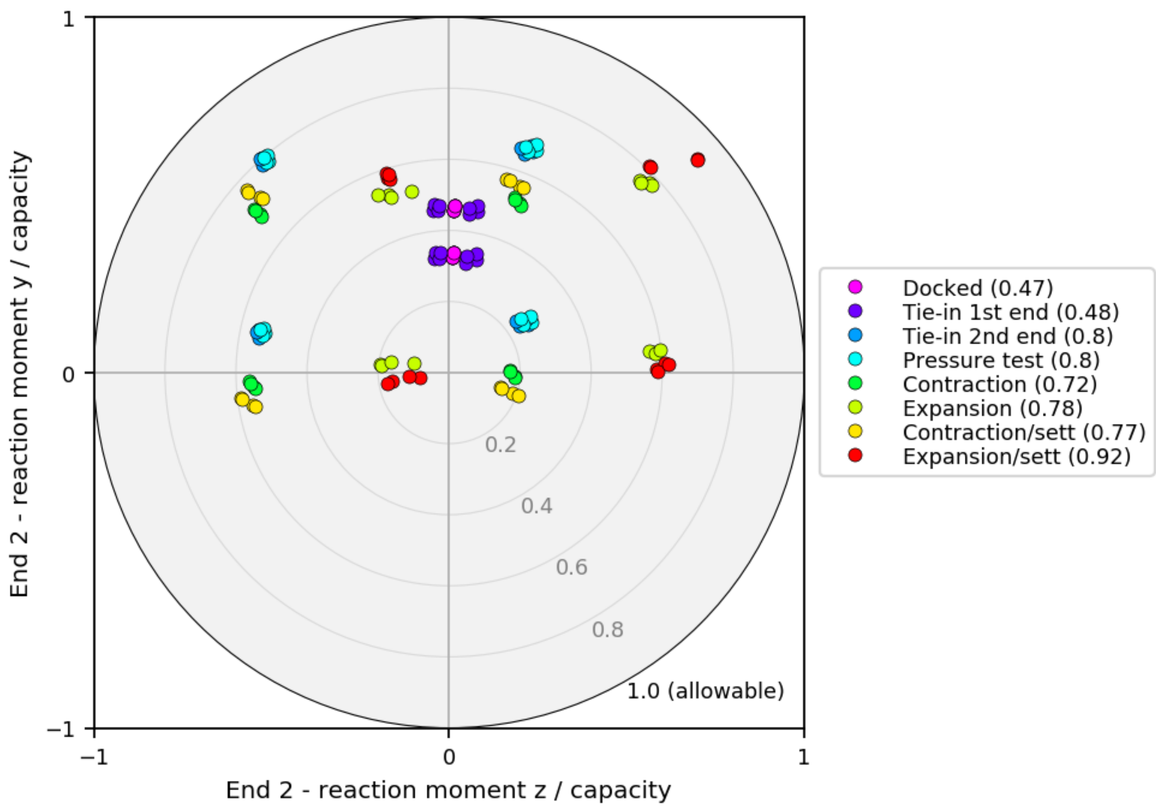
The maximum magnitude reaction bending moment at End 2, for each load case and load step, is shown in Figure 6.13.

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

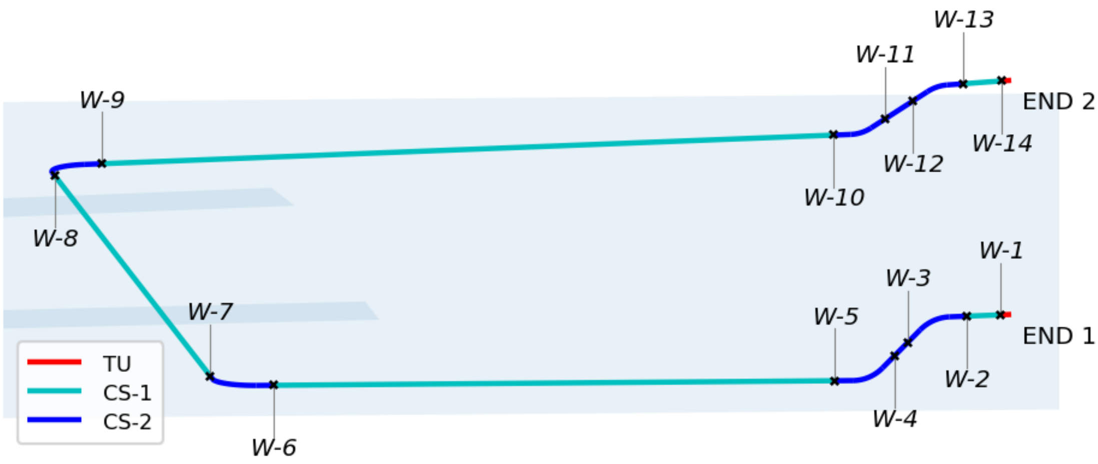


The shaded circular area indicates the allowable. The maximum utilisation is presented for each load step within parenthesis in the figure legend.

6.9 Fatigue Damage due to VIV

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

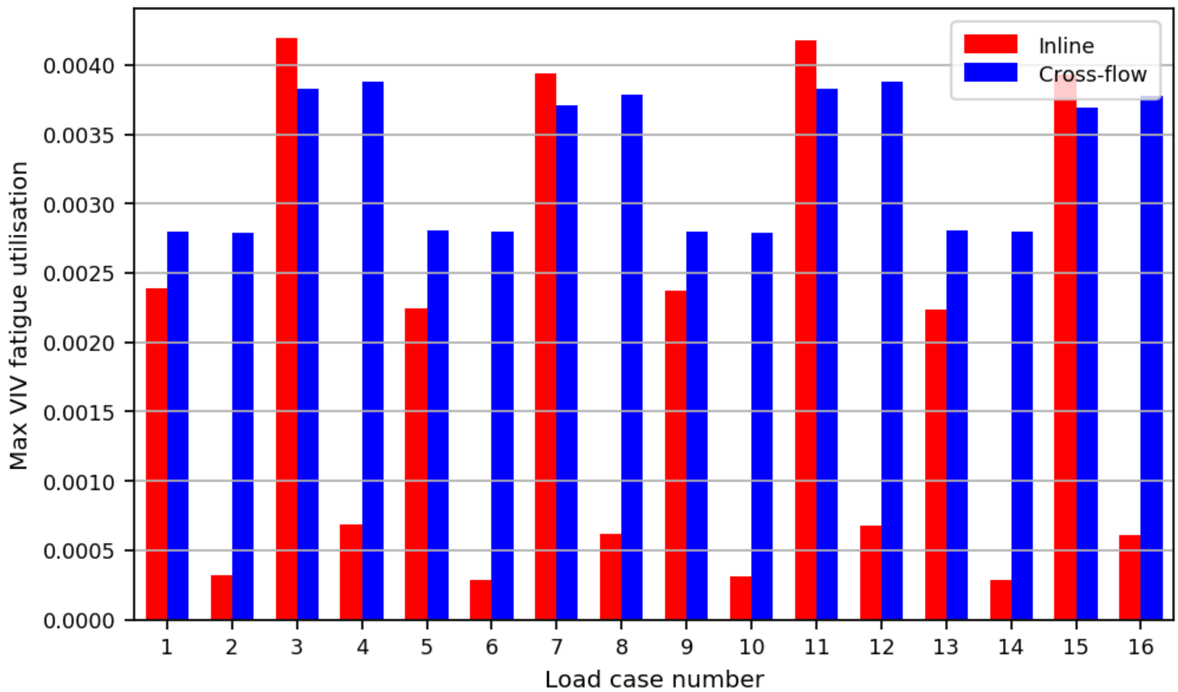
Figure 6.15 – Assessed Welds



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

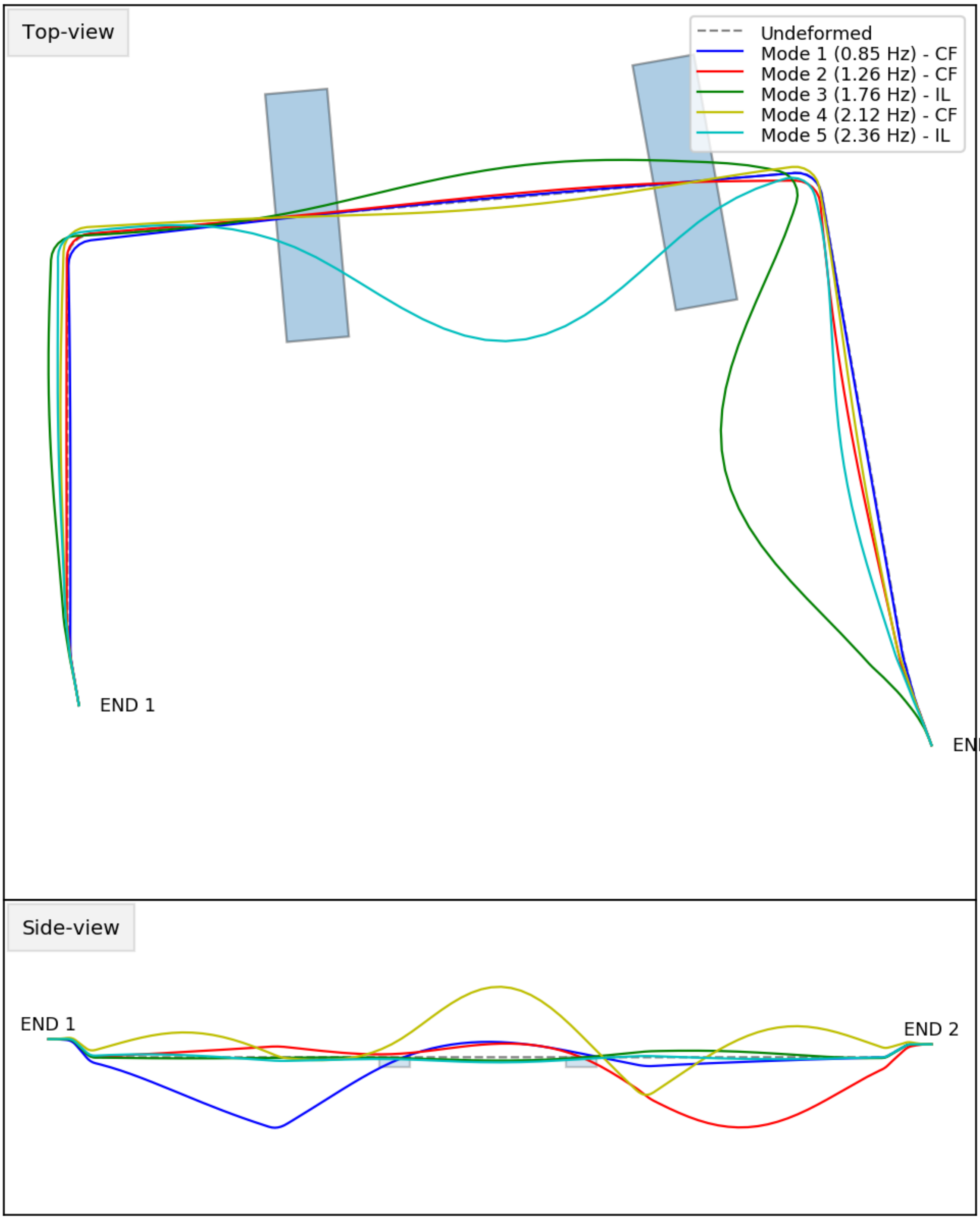


Inline and Cross-Flow utilisations are presented separately, and indicated that the damage has been accumulate at a specific location around the circumference.

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.

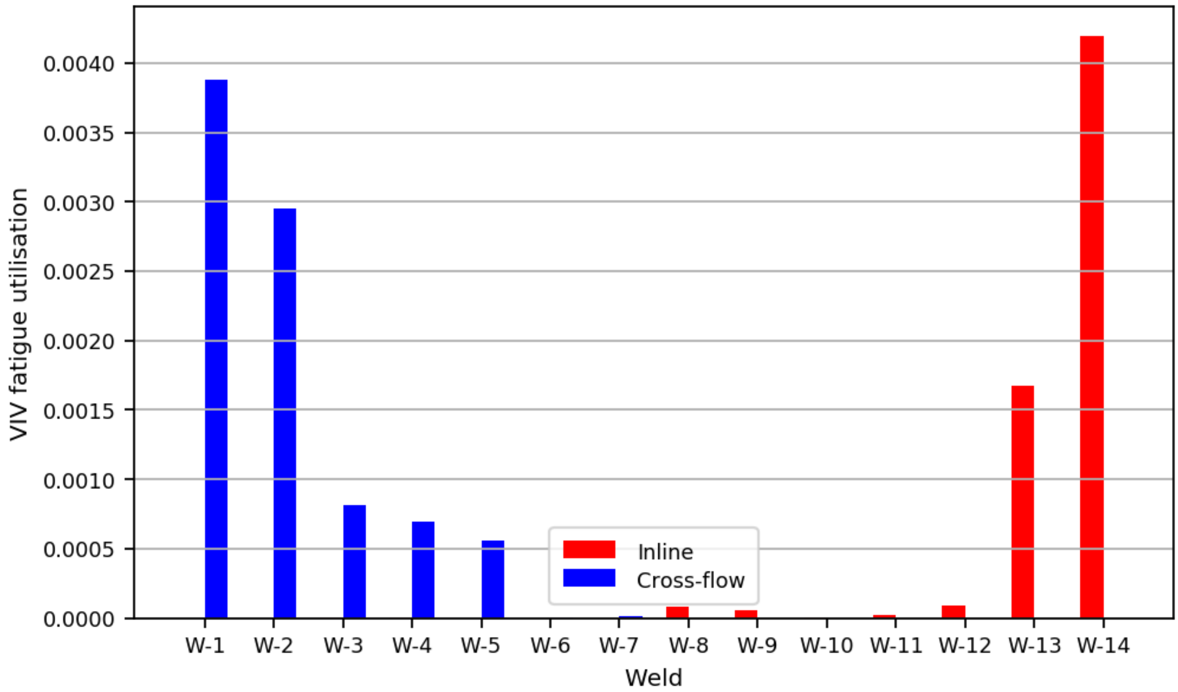
Figure 6.17 – Eigen-Modes of Most Utilised Load Case



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-4	Support-5
Docked	0.0	54.4	60.3
Tie-in 1st end	0.0	61.0	62.9
Tie-in 2nd end	0.0	62.4	69.2
Pressure test	0.0	62.5	69.2
Contraction	0.0	40.1	48.2
Expansion	0.0	40.4	47.4
Contraction/sett	2.2	42.8	50.5
Expansion/sett	5.6	44.8	49.6
Max	5.6	62.5	69.2

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

7 CONFIGURATION MIN_L3

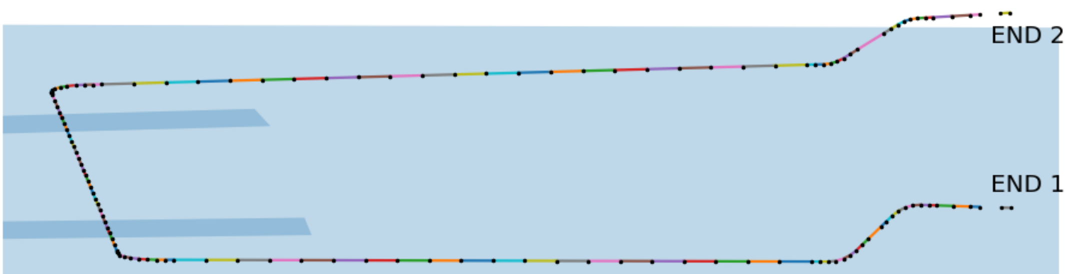
This section presents the following detailed results for configuration "min_L3".

- 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

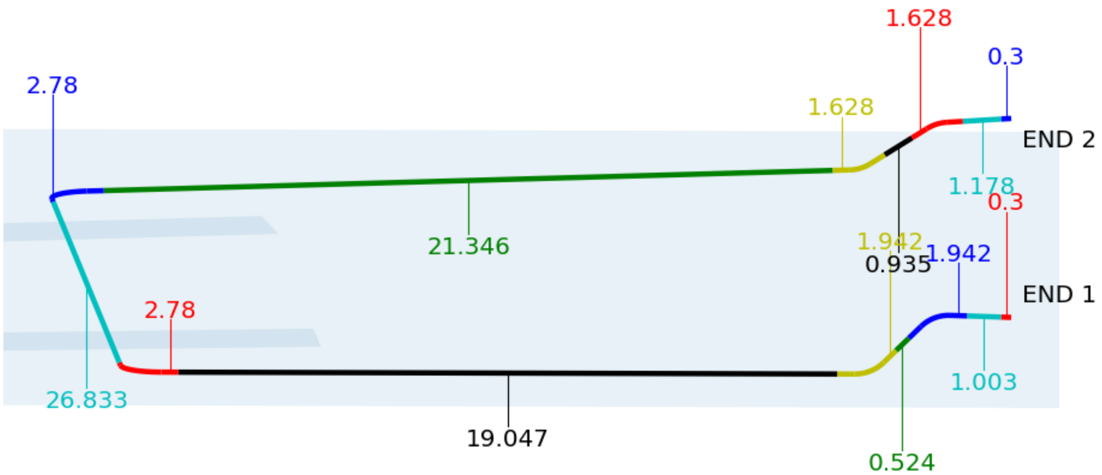
The coordinates at the spool ends and at the intersection points between the extended straight lines / sections, are presented in Table 7.1.

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	36.735	33.401	0.626
IP-6	40.862	9.995	0.626
IP-7	41.442	7.83	1.9
IP-8	42.126	5.951	1.9
End 2	42.229	5.669	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 32 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
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.

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

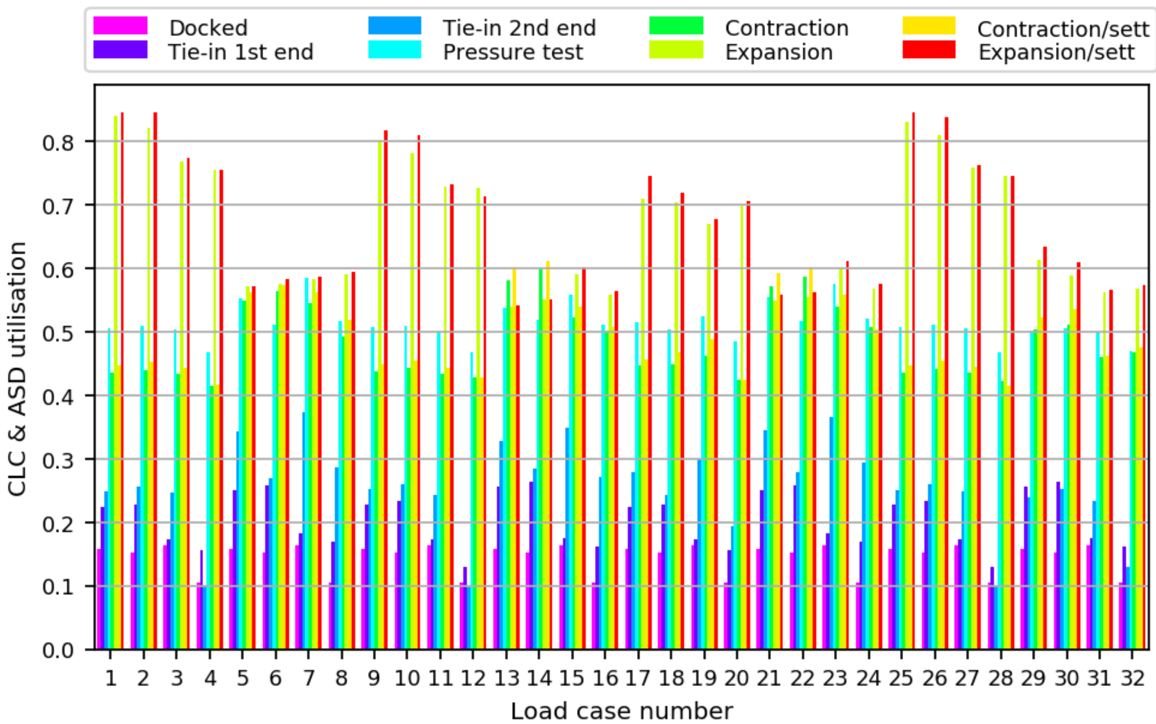
Load Step	Internal Pressure [bara]	Temperature [°C]	Content Density [kg/m3]	Axial Expansion - End 2 [m]
Docked	20	10	1150	0
Tie-in 1st end	20	10	1150	0
Tie-in 2nd end	20	10	1150	0
Pressure test	400	10	1150	0
Contraction	300	-20	250	-1.0
Expansion	300	100	250	3.0
Contraction/sett	300	-20	250	-1.0
Expansion/sett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

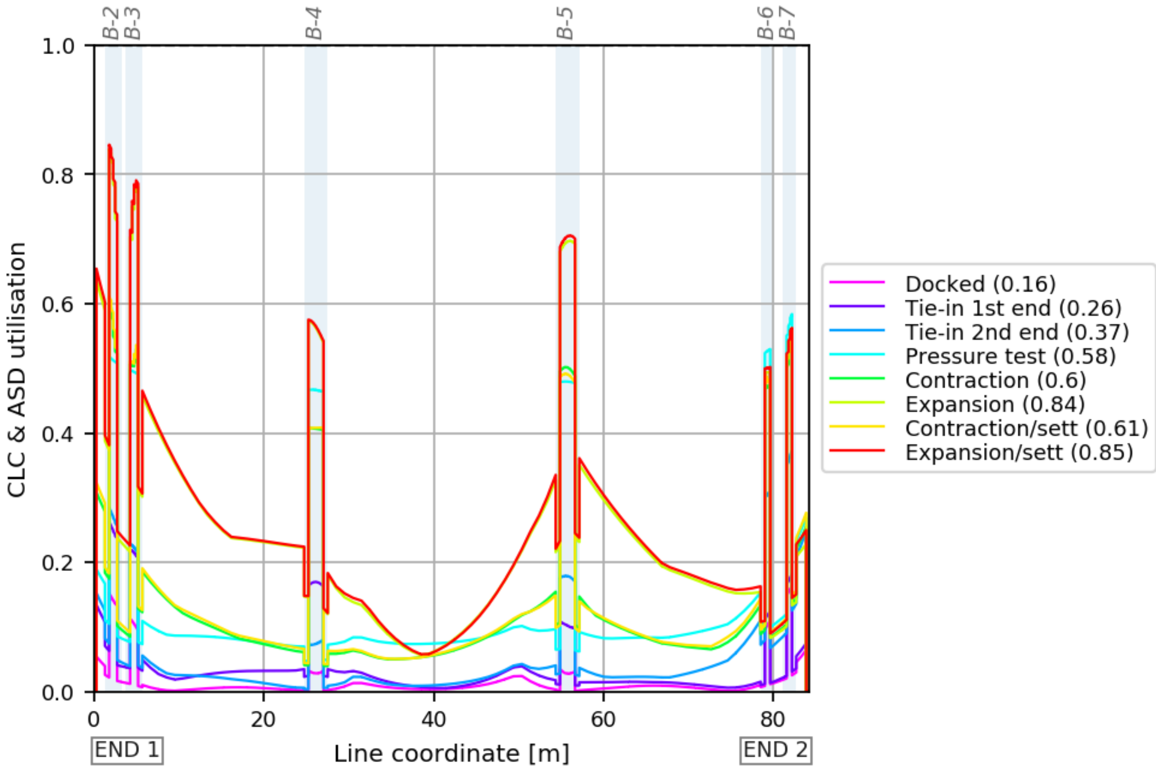
The maximum CLC / ASD utilisation along the spool, for each load case and load step, is shown in Figure 7.3.

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

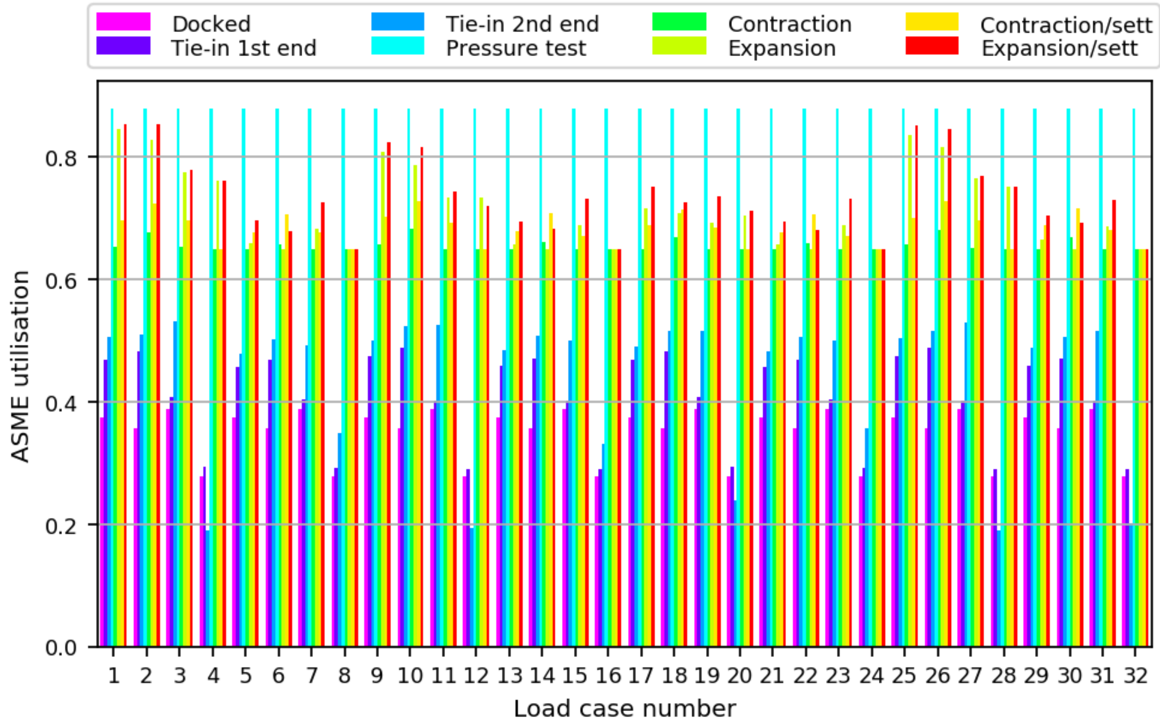


The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

7.6 SPOOL ASME UTILISATION

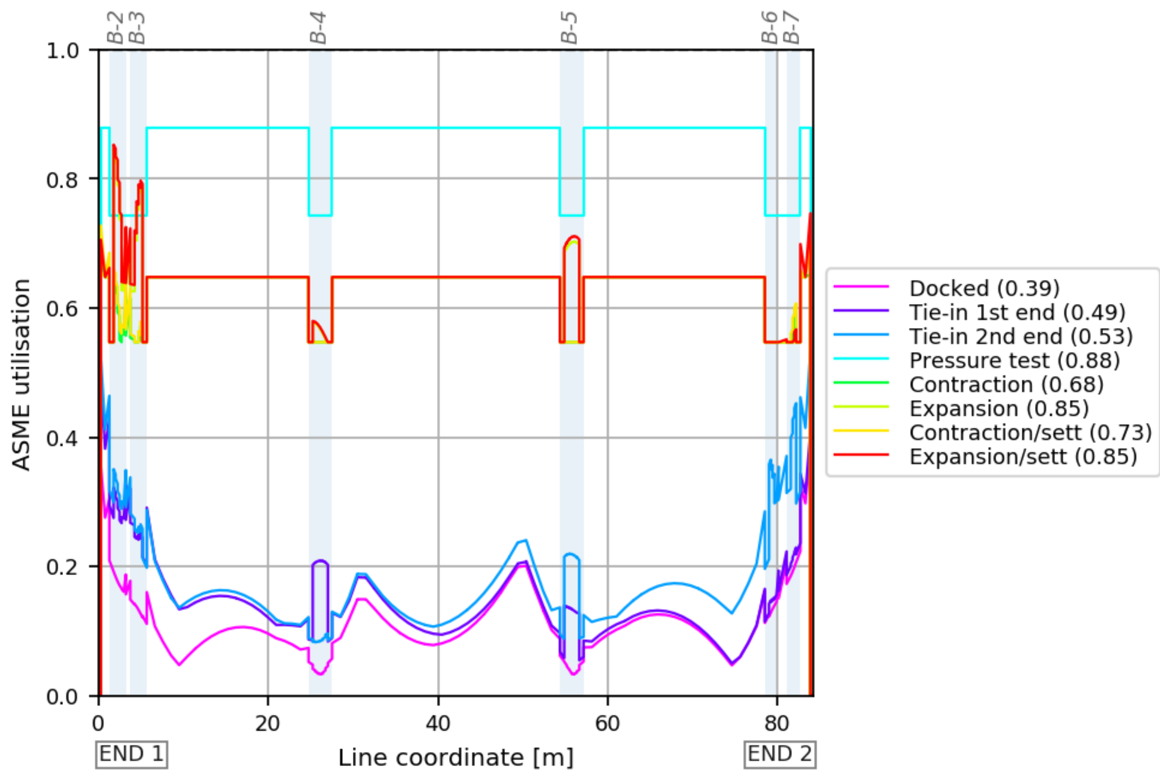
The maximum ASME utilisation along the spool, for each load case and load step, is shown in Figure 7.5.

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



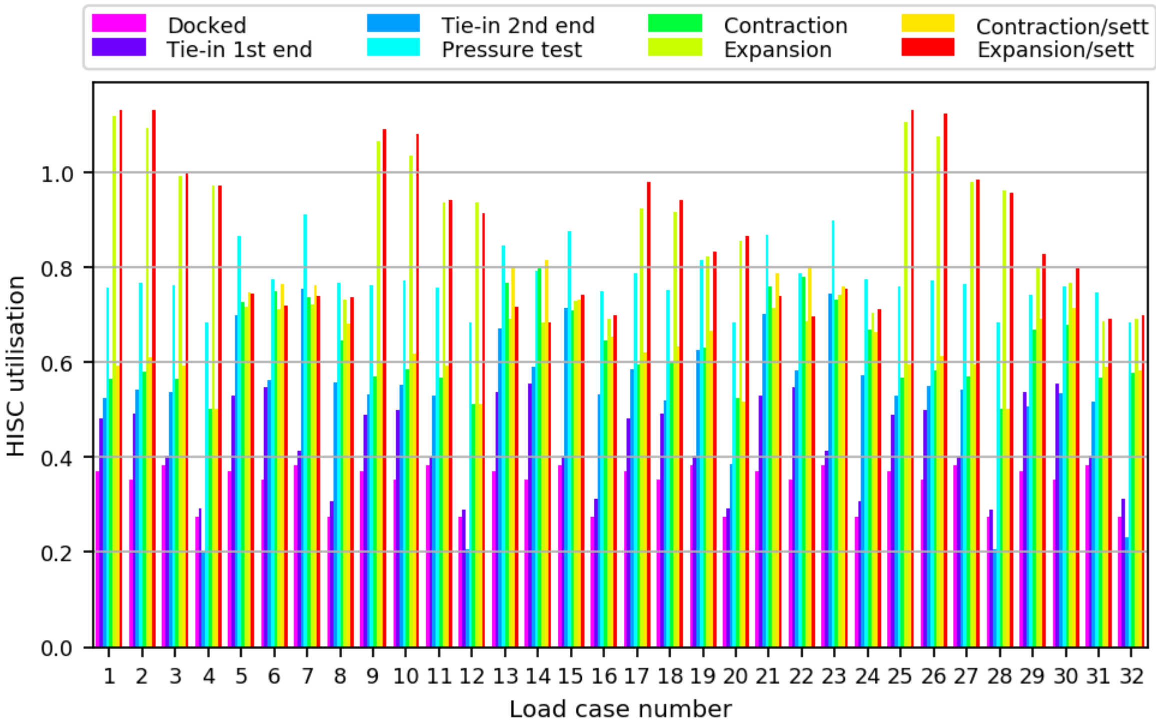
The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

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

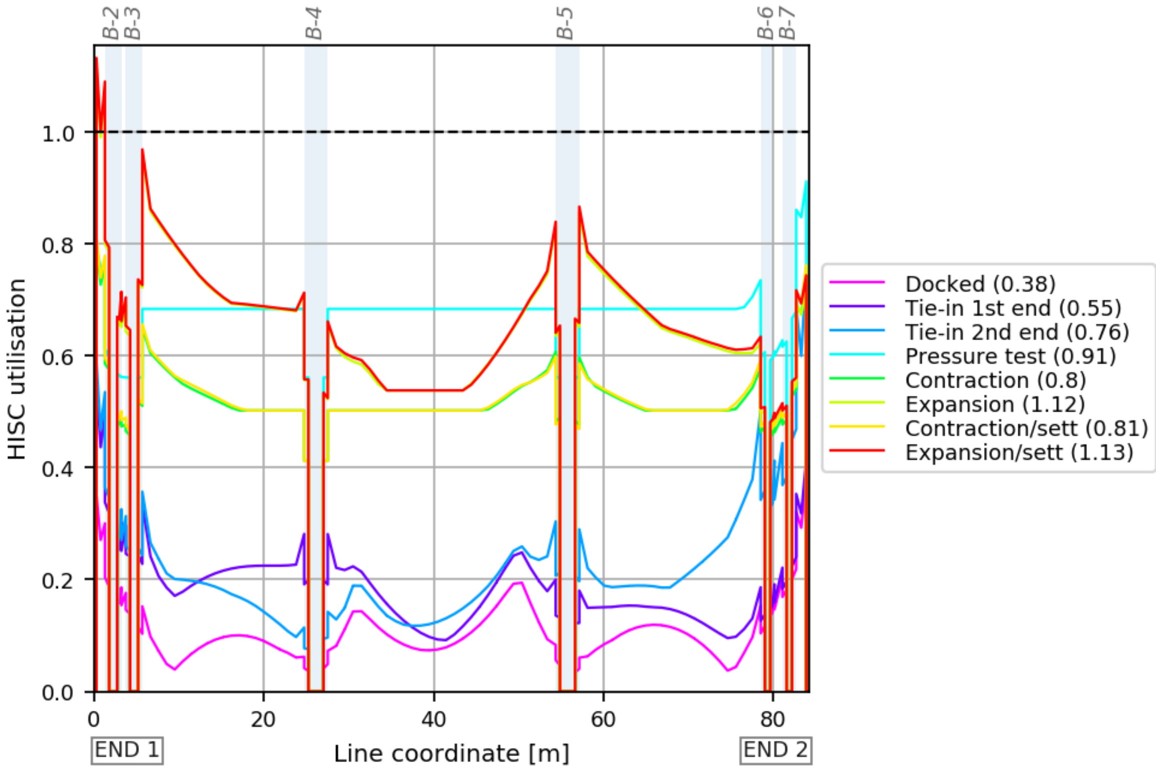
The maximum HISC utilisation along the spool, for each load case and load step, is shown in Figure 7.7.

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.

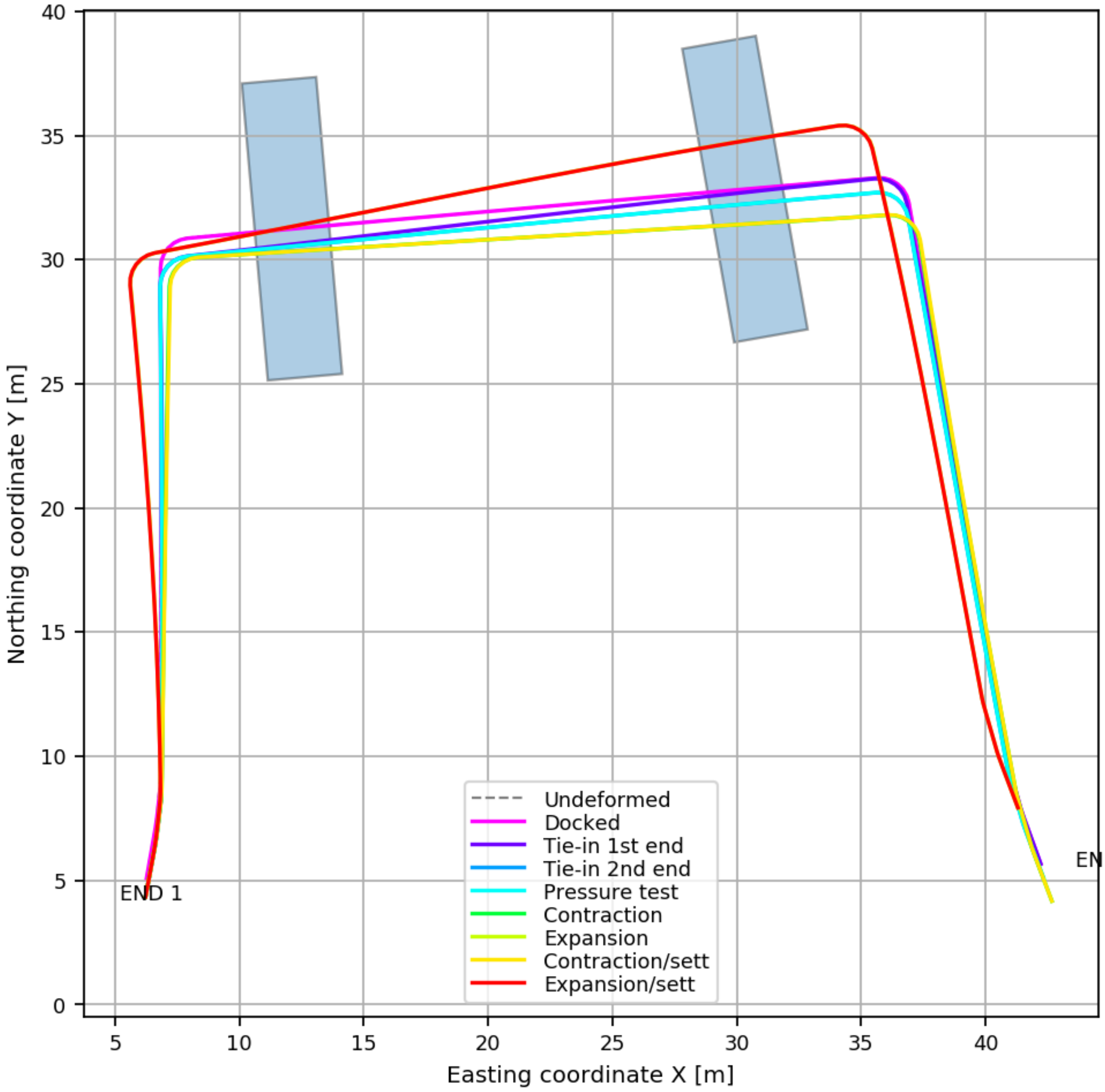
Longitudinal Stress Concentration Factors has been applied at each weld.

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 2

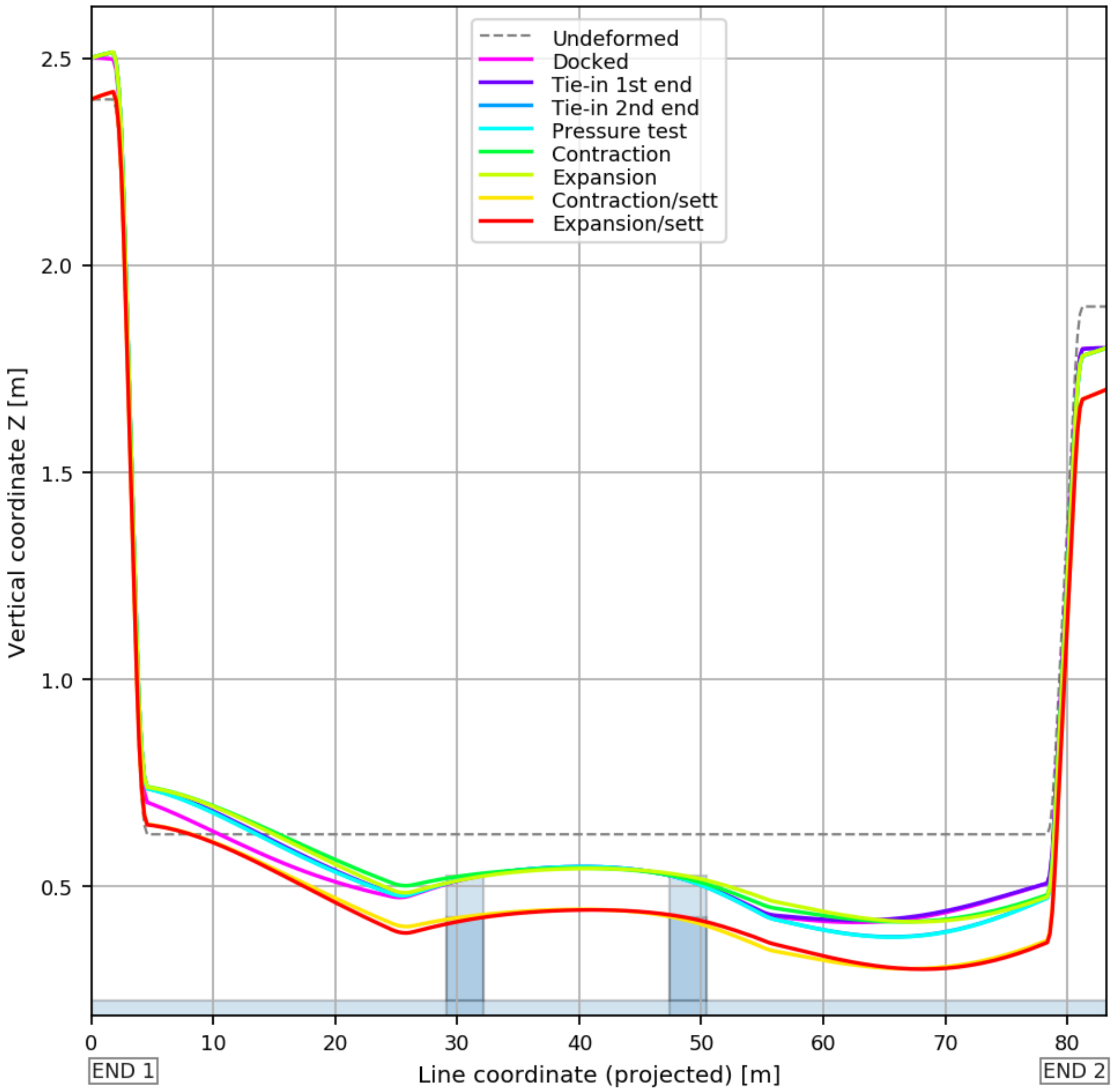
A top-view of the deformed shapes, for the most utilised load case (number 2), are shown for each load step in Figure 7.9.

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 2), 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.

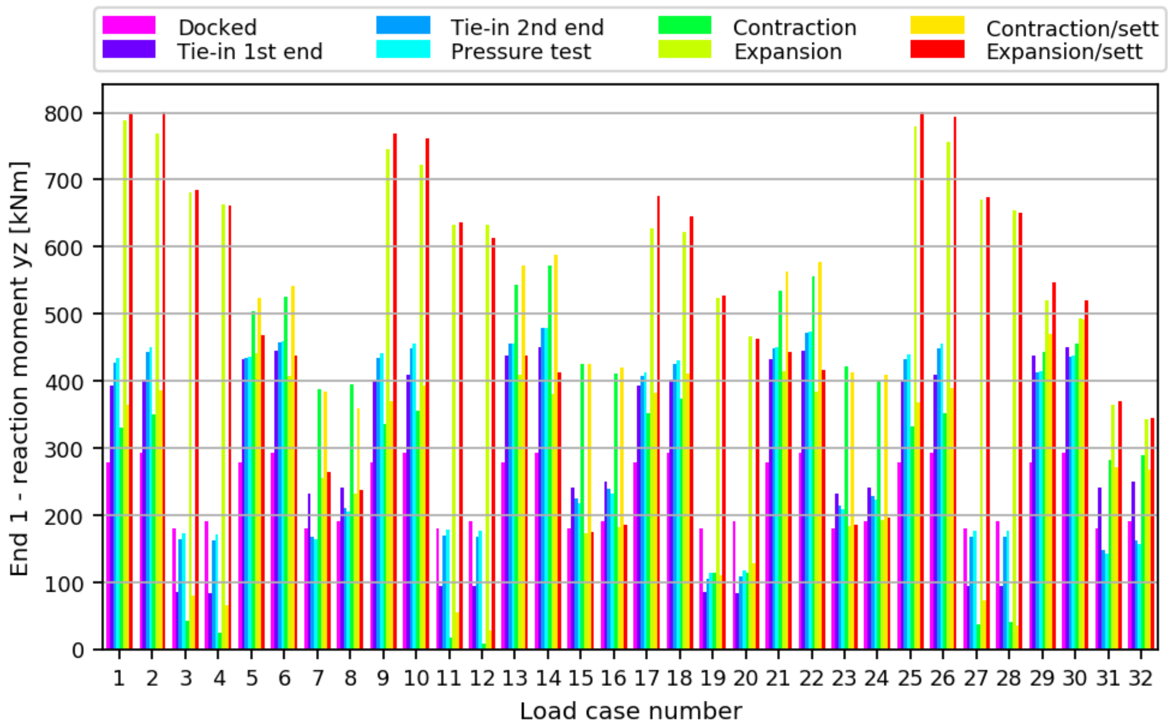
Table 7.4 – Maximum Magnitude Reaction Loads at End 1

Load Step	End Reaction Forces [kN]			End Reaction Moments [kNm]			
	RFx	RFy	RFz	RMx	RMy	RMz	RMb
Docked	10.4	1.2	80.8	-0.0	292.2	-11.4	292.4
Tie-in 1st end	29.6	-14.6	86.1	-0.0	397.6	247.6	450.6
Tie-in 2nd end	17.2	-10.4	86.4	17.3	423.8	243.6	478.9
Pressure test	12.2	-10.1	86.3	17.8	428.5	236.0	479.2
Contraction	-10.5	-17.5	71.0	32.7	353.9	461.4	571.2
Expansion	31.9	22.1	72.4	54.0	328.9	-724.9	789.2
Contraction/sett	-12.7	-17.2	72.6	38.1	390.1	452.3	587.4
Expansion/sett	31.2	22.5	74.0	52.5	368.7	-721.3	801.7
Max	31.9	22.5	86.4	54.0	428.5	-724.9	801.7

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

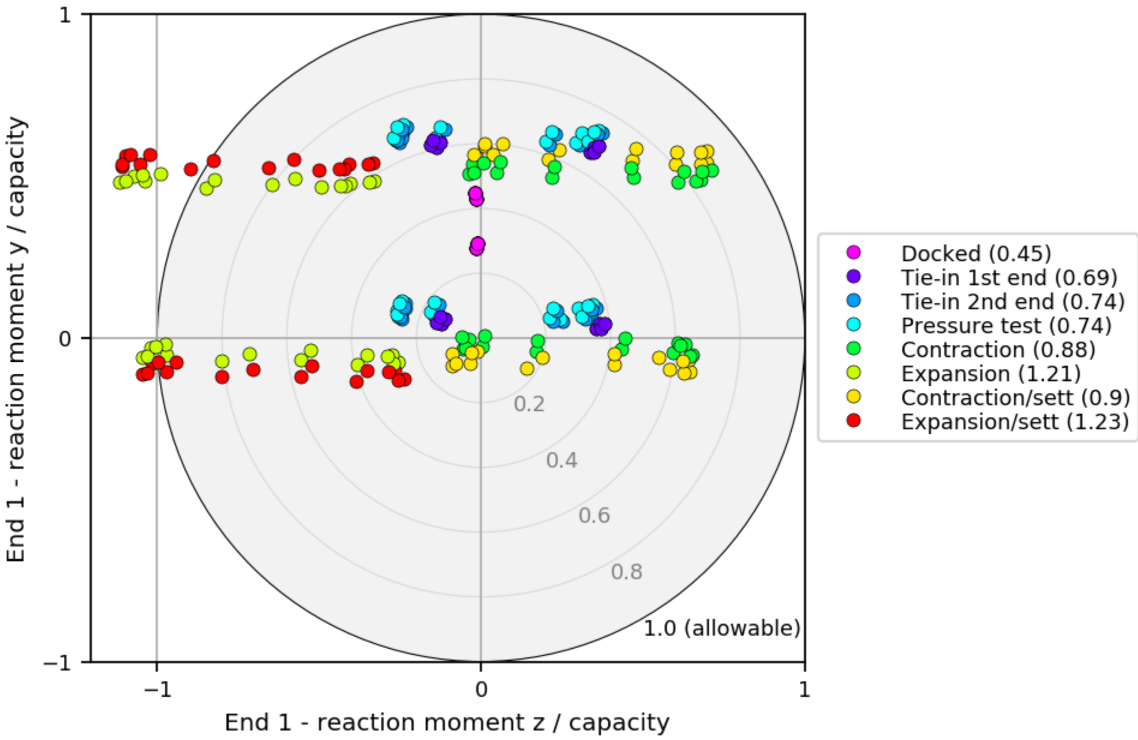
The maximum magnitude reaction bending moment at End 1, for each load case and load step, is shown in Figure 7.11.

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.

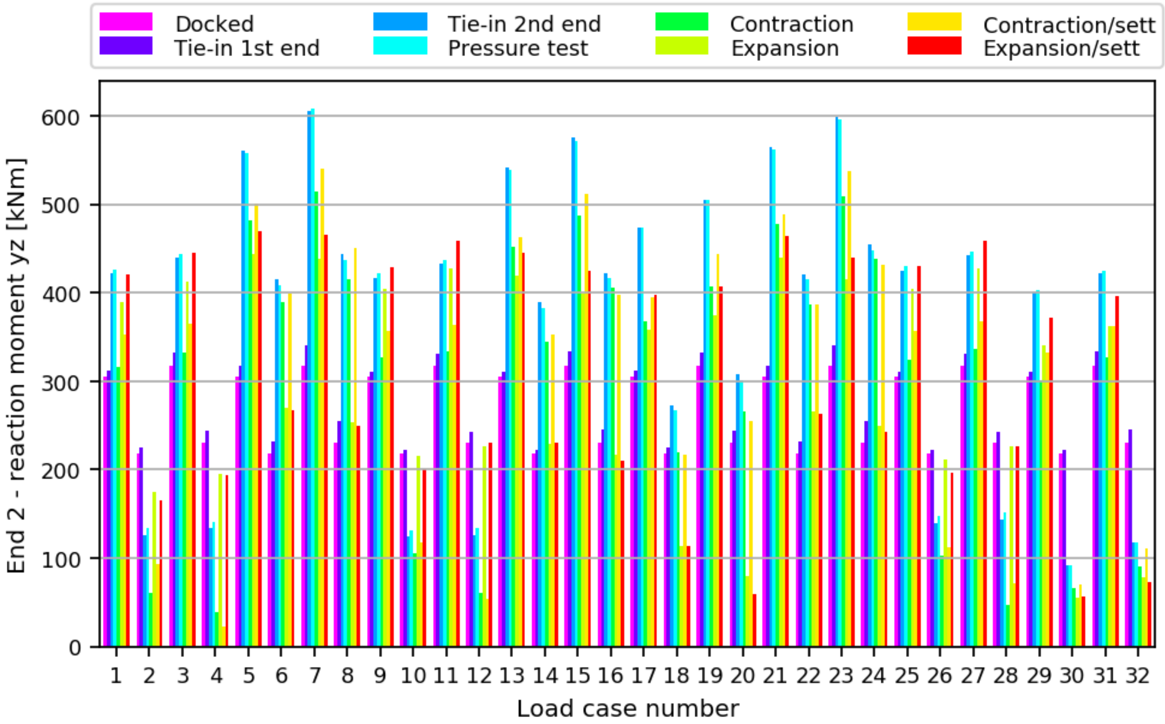
Table 7.5 – Maximum Magnitude Reaction Loads at End 2

Load Step	End Reaction Forces [kN]			End Reaction Moments [kNm]			
	RFx	RFy	RFz	RMx	RMy	RMz	RMb
Docked	6.4	-0.8	82.1	-0.0	317.5	7.8	317.6
Tie-in 1st end	4.0	-6.5	82.6	0.0	331.8	-88.3	340.3
Tie-in 2nd end	30.1	20.4	87.1	-0.0	431.8	-454.5	605.9
Pressure test	25.9	20.2	87.0	7.8	435.2	-444.0	608.6
Contraction	32.2	24.7	71.4	-16.7	329.6	-438.7	514.9
Expansion	-43.1	-22.6	70.1	-56.4	370.1	-293.4	443.9
Contraction/sett	29.9	24.5	72.8	-19.5	363.7	-448.0	539.5
Expansion/sett	-42.5	-22.8	71.5	-59.5	404.7	-296.7	469.1
Max	-43.1	24.7	87.1	-59.5	435.2	-454.5	608.6

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

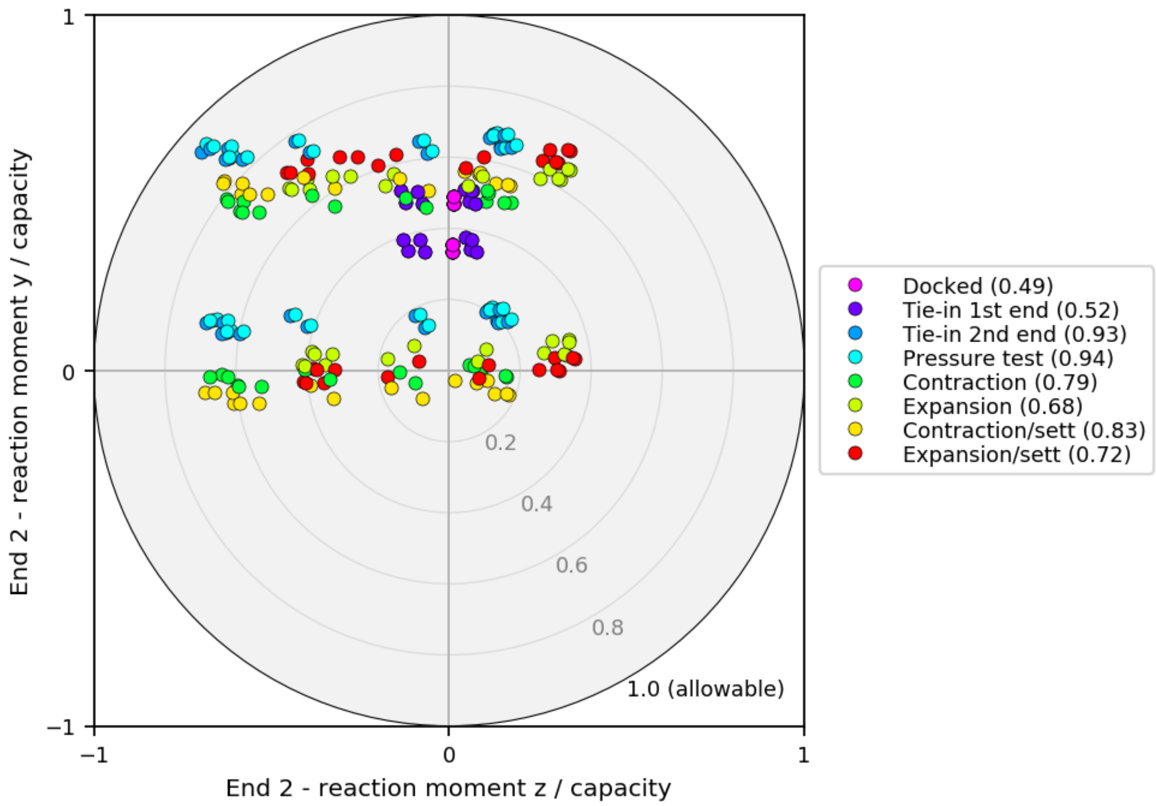
The maximum magnitude reaction bending moment at End 2, for each load case and load step, is shown in Figure 7.13.

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

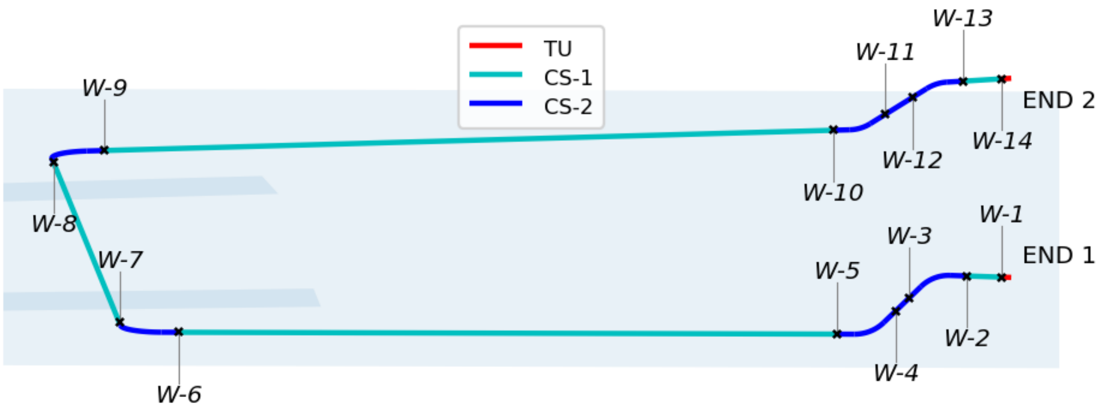


The shaded circular area indicates the allowable. The maximum utilisation is presented for each load step within parenthesis in the figure legend.

7.9 Fatigue Damage due to VIV

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

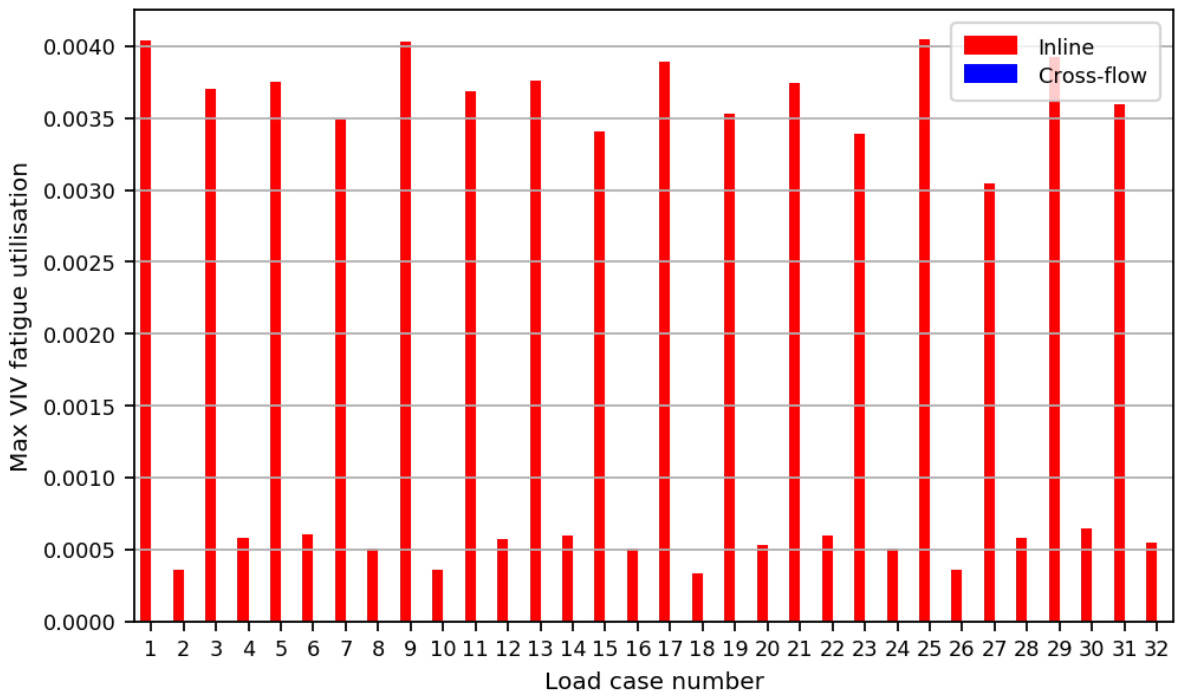
Figure 7.15 – Assessed Welds



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

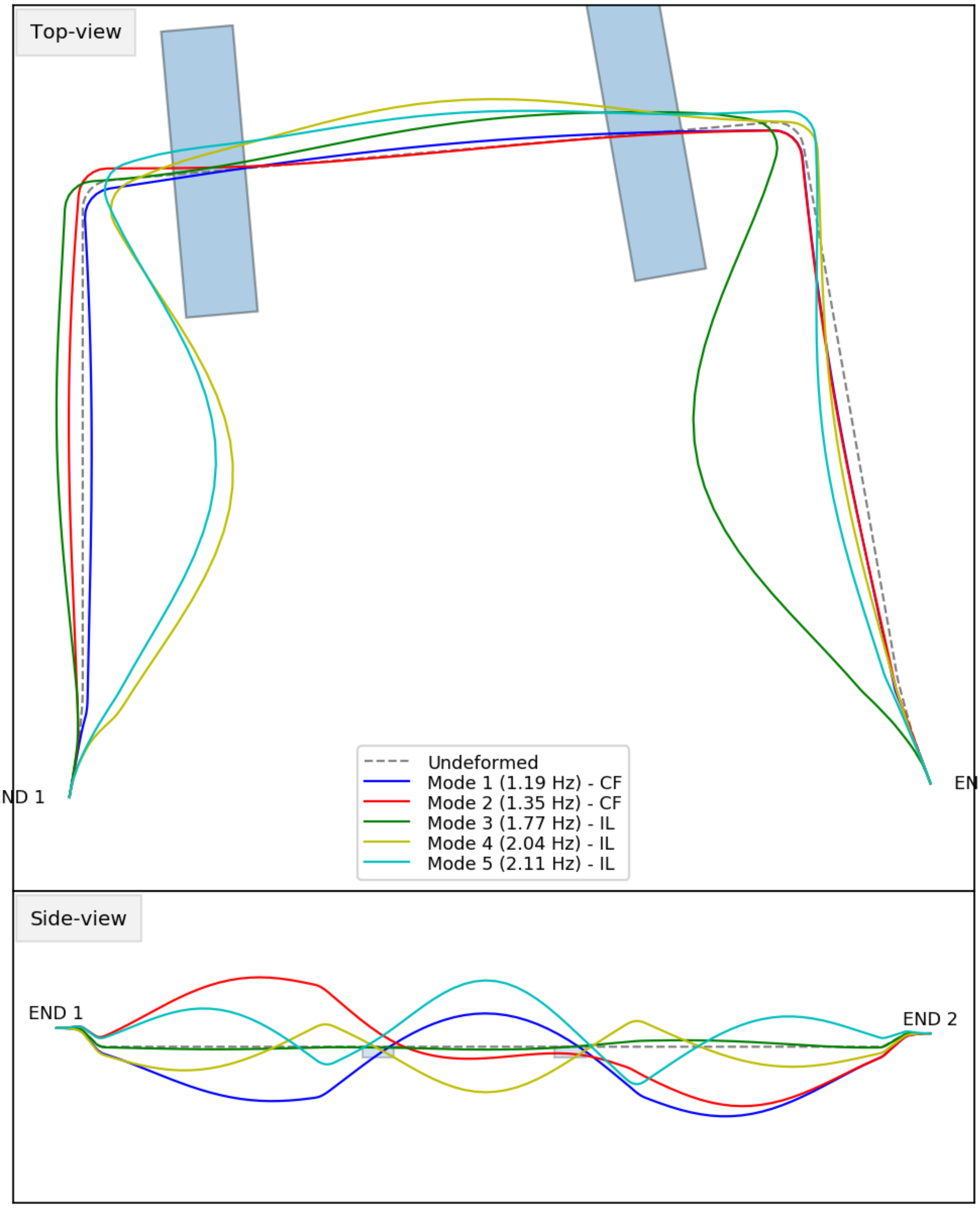


Inline and Cross-Flow utilisations are presented separately, and indicated that the damage has been accumulate at a specific location around the circumference.

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 25 (most critical in terms of fatigue damage) are shown in Figure 7.17.

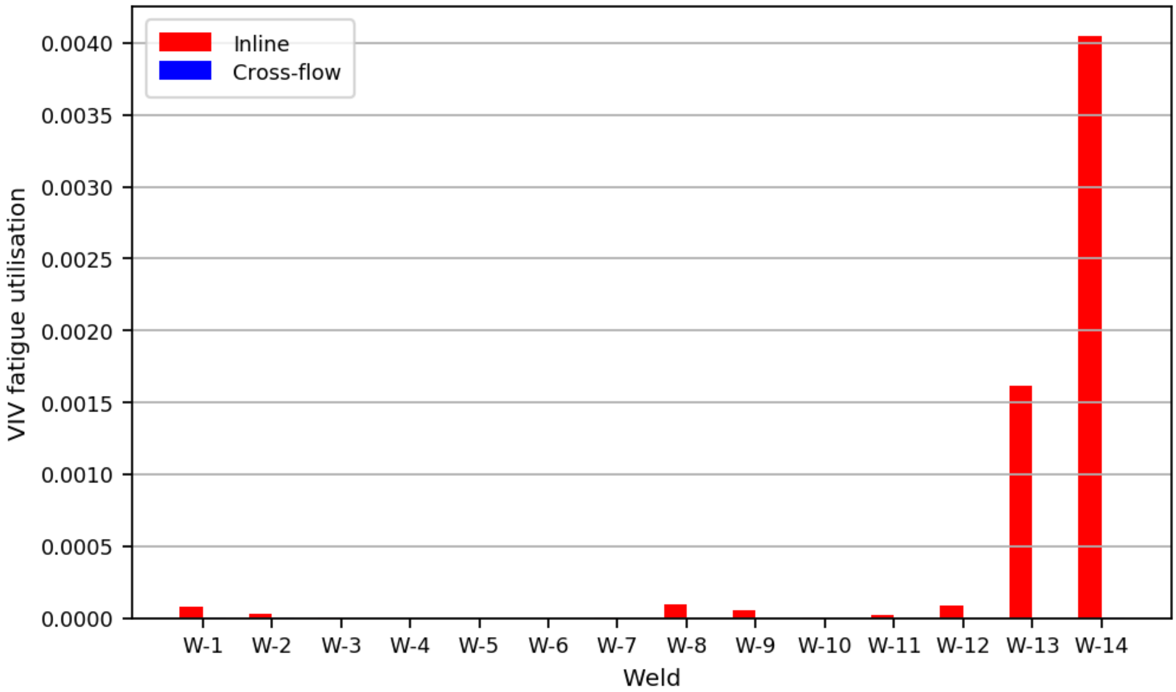
Figure 7.17 – Eigen-Modes of Most Utilised Load Case



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-4	Support-5
Docked	0.0	49.9	59.4
Tie-in 1st end	0.0	57.0	60.1
Tie-in 2nd end	0.0	59.4	66.0
Pressure test	0.0	58.4	66.1
Contraction	0.0	78.9	44.2
Expansion	0.0	40.8	42.9
Contraction/sett	0.0	42.1	46.1
Expansion/sett	0.0	43.0	45.0
Max	0.0	78.9	66.1

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

8 CONFIGURATION MIN_L4

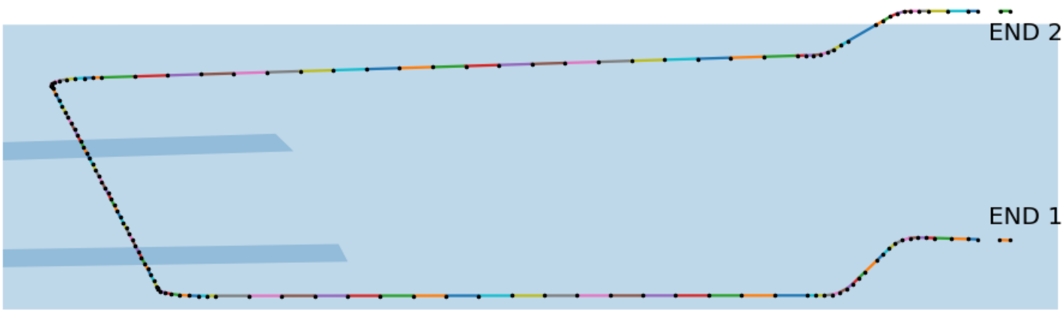
This section presents the following detailed results for configuration "min_L4".

- 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

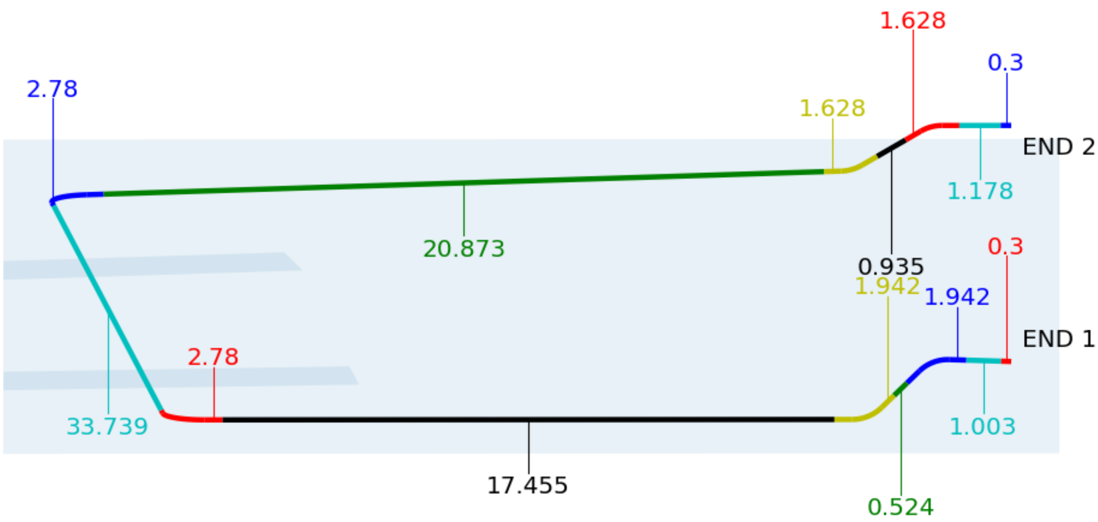
The coordinates at the spool ends and at the intersection points between the extended straight lines / sections, are presented in Table 8.1.

Table 8.1 – Coordinates at Ends and Intersection Points

Location	Coordinates [m]		
	X / Easting	Y / Northing	Z / Vertical
End 1	4.797	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	42.15	33.875	0.626
IP-6	46.195	10.935	0.626
IP-7	46.39	8.703	1.9
IP-8	46.39	6.703	1.9
End 2	46.39	6.403	1.9

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 16 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

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

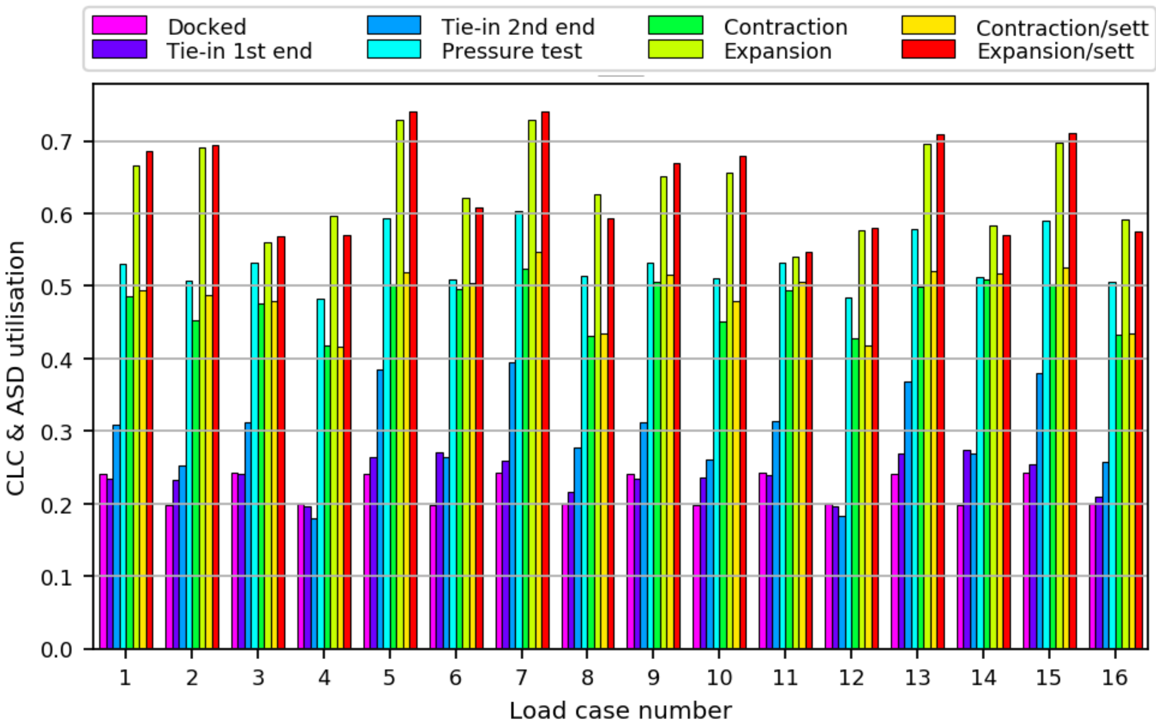
Load Step	Internal Pressure [bara]	Temperature [°C]	Content Density [kg/m3]	Axial Expansion - End 2 [m]
Docked	20	10	1150	0
Tie-in 1st end	20	10	1150	0
Tie-in 2nd end	20	10	1150	0
Pressure test	400	10	1150	0
Contraction	300	-20	250	-1.0
Expansion	300	100	250	3.0
Contraction/sett	300	-20	250	-1.0
Expansion/sett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

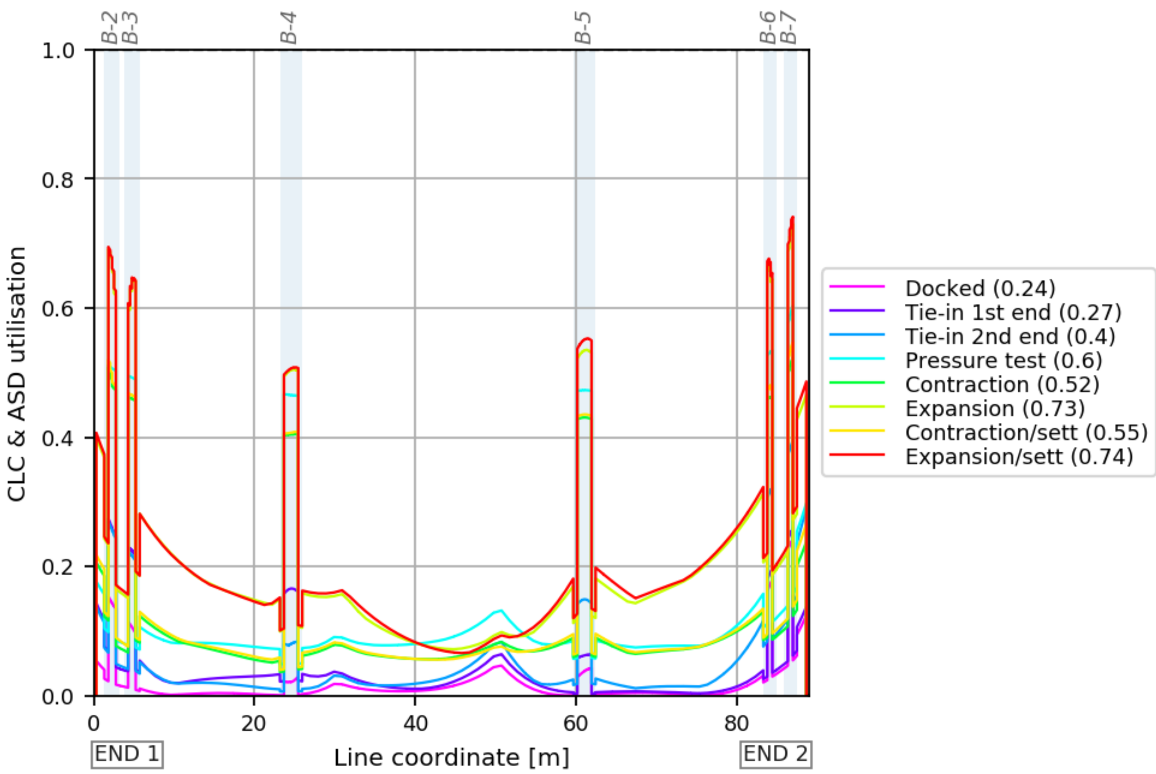
The maximum CLC / ASD utilisation along the spool, for each load case and load step, is shown in Figure 8.3.

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

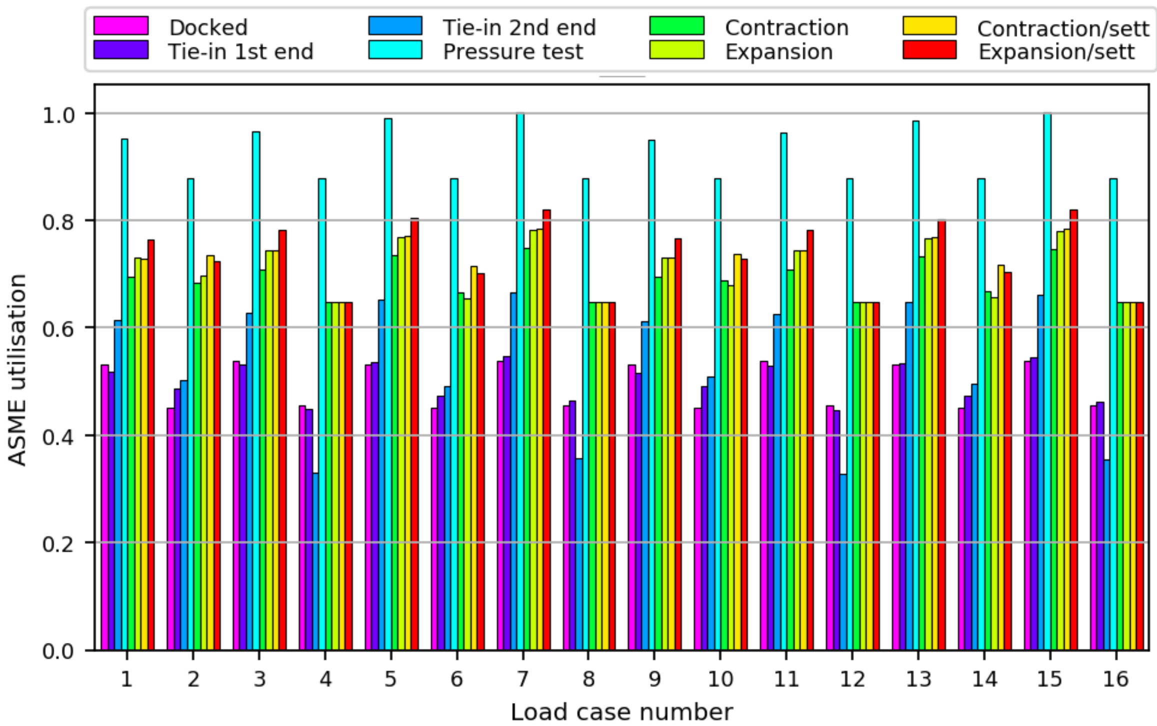


The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

8.6 SPOOL ASME UTILISATION

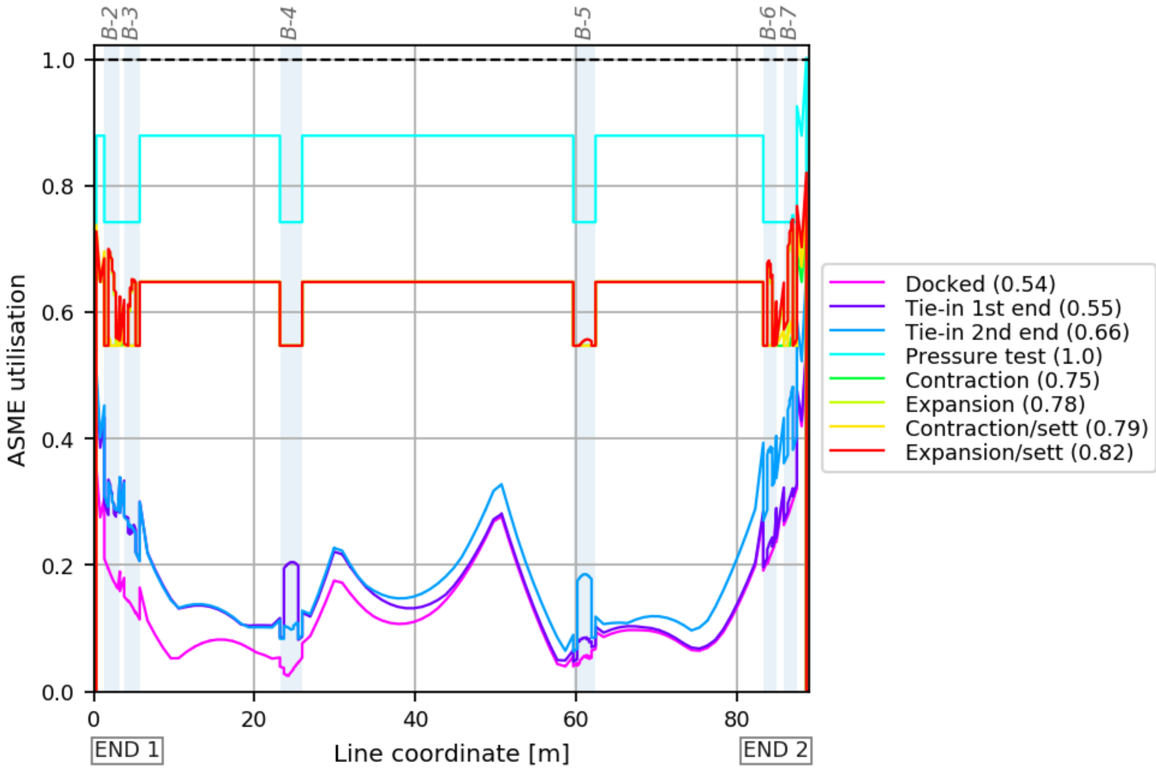
The maximum ASME utilisation along the spool, for each load case and load step, is shown in Figure 8.5.

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



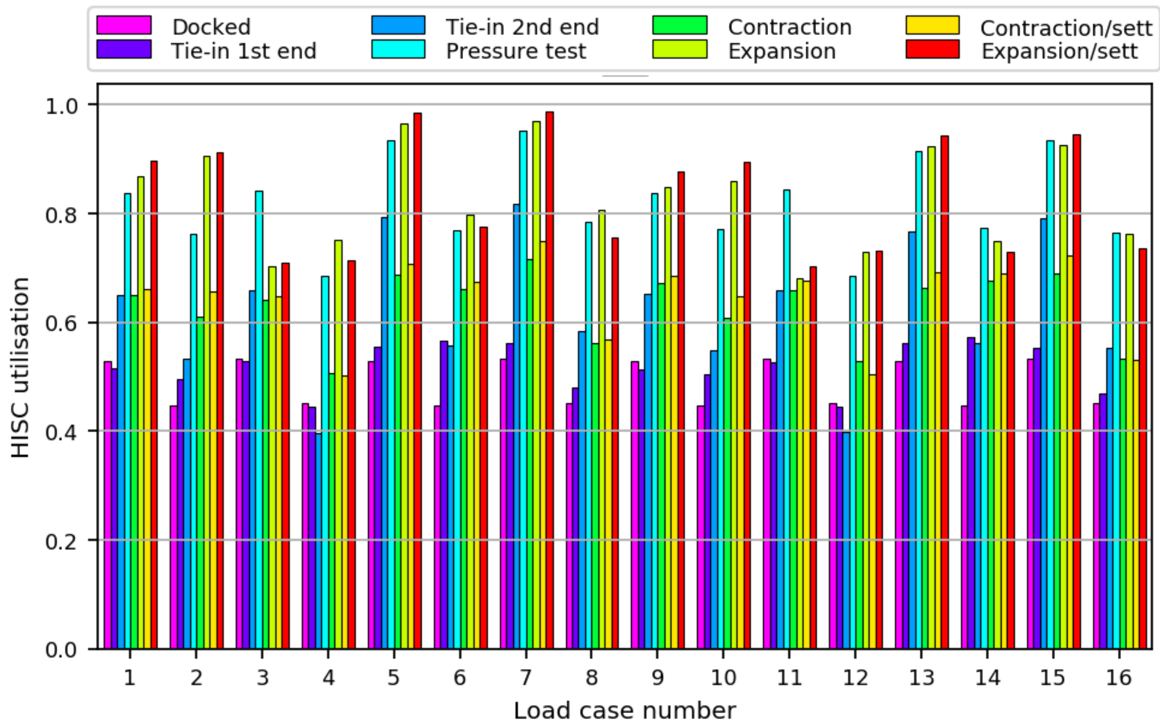
The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

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

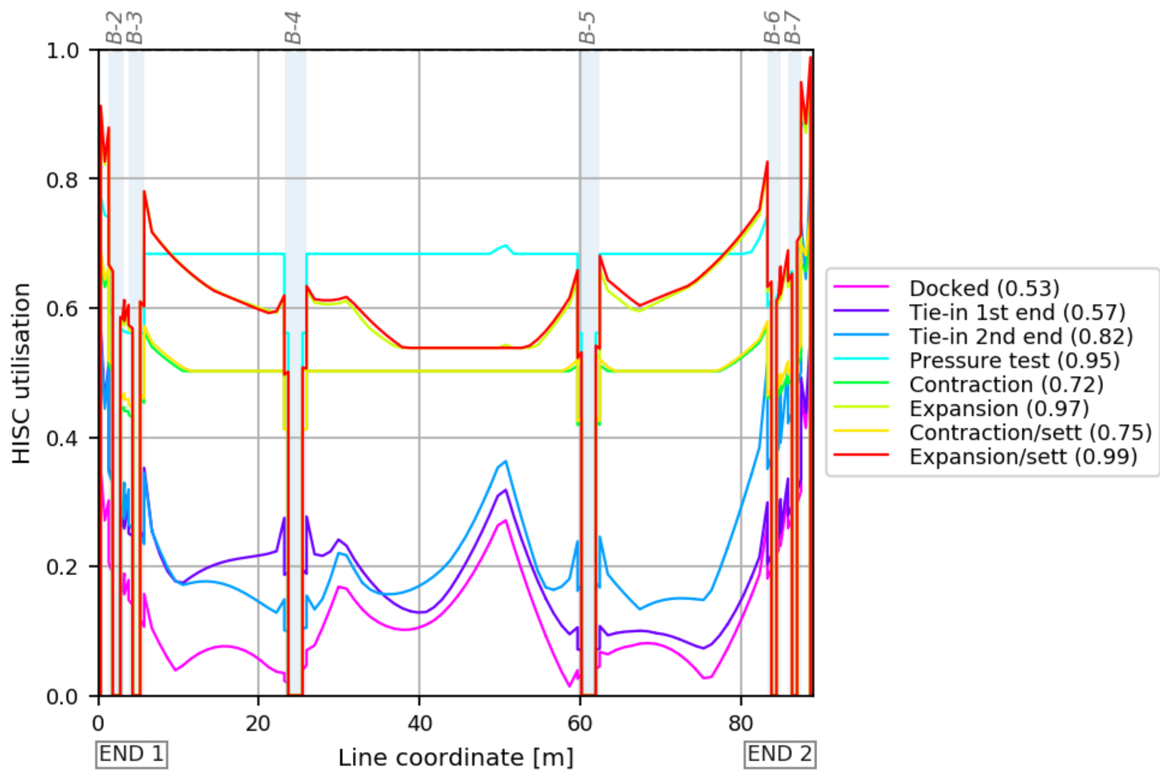
The maximum HISC utilisation along the spool, for each load case and load step, is shown in Figure 8.7.

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.

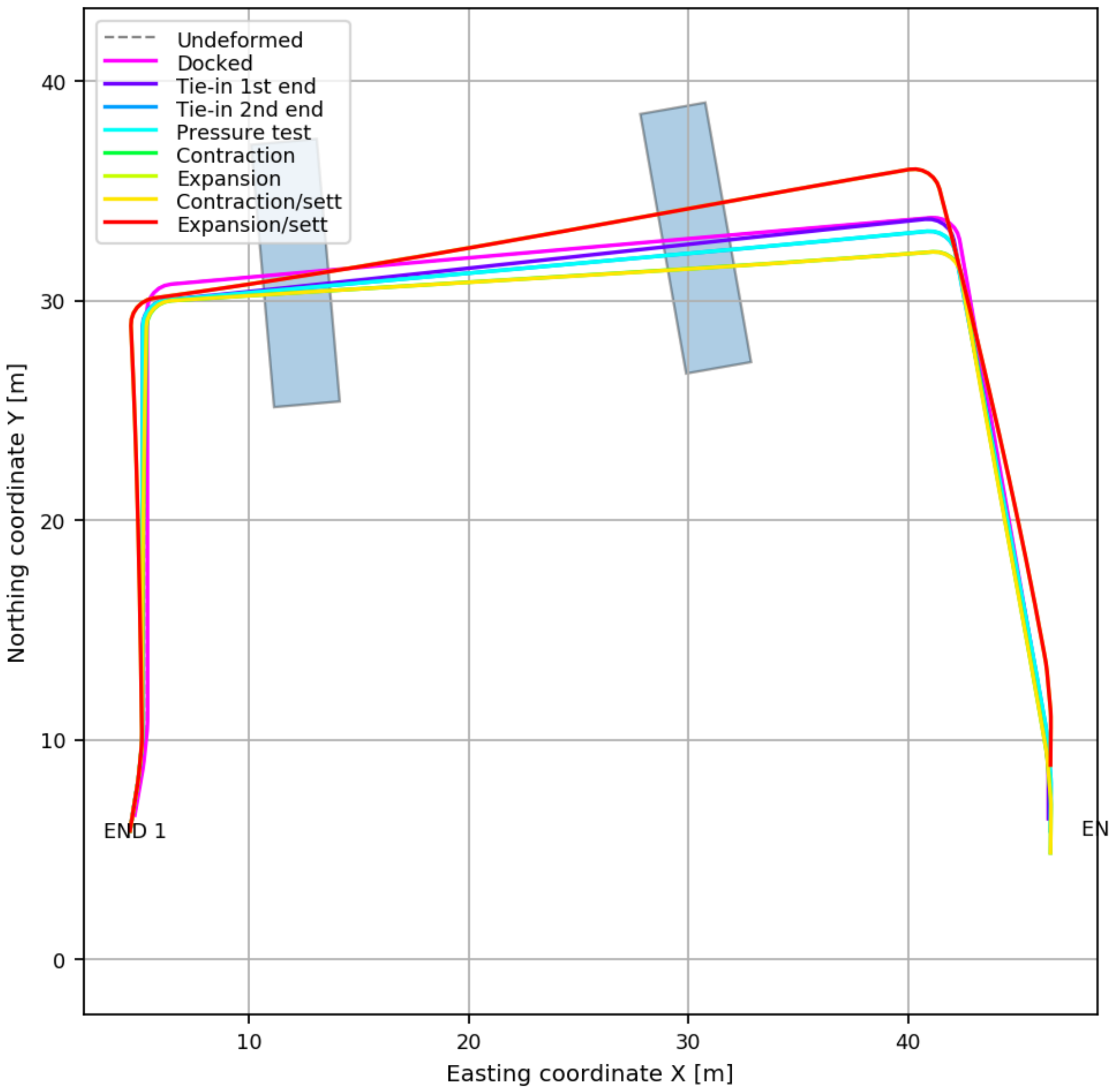
Longitudinal Stress Concentration Factors has been applied at each weld.

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 7

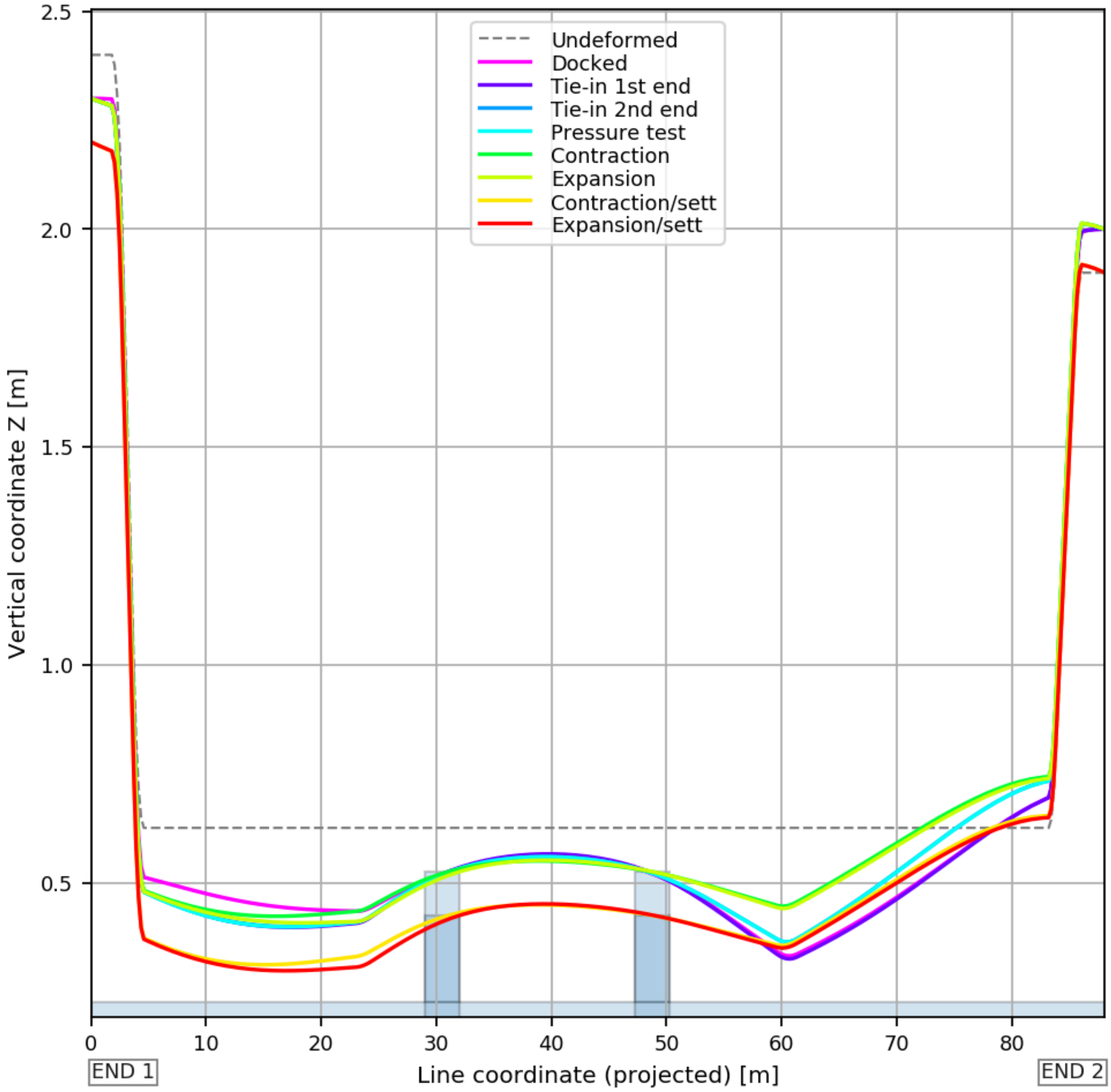
A top-view of the deformed shapes, for the most utilised load case (number 7), are shown for each load step in Figure 8.9.

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 7), 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.

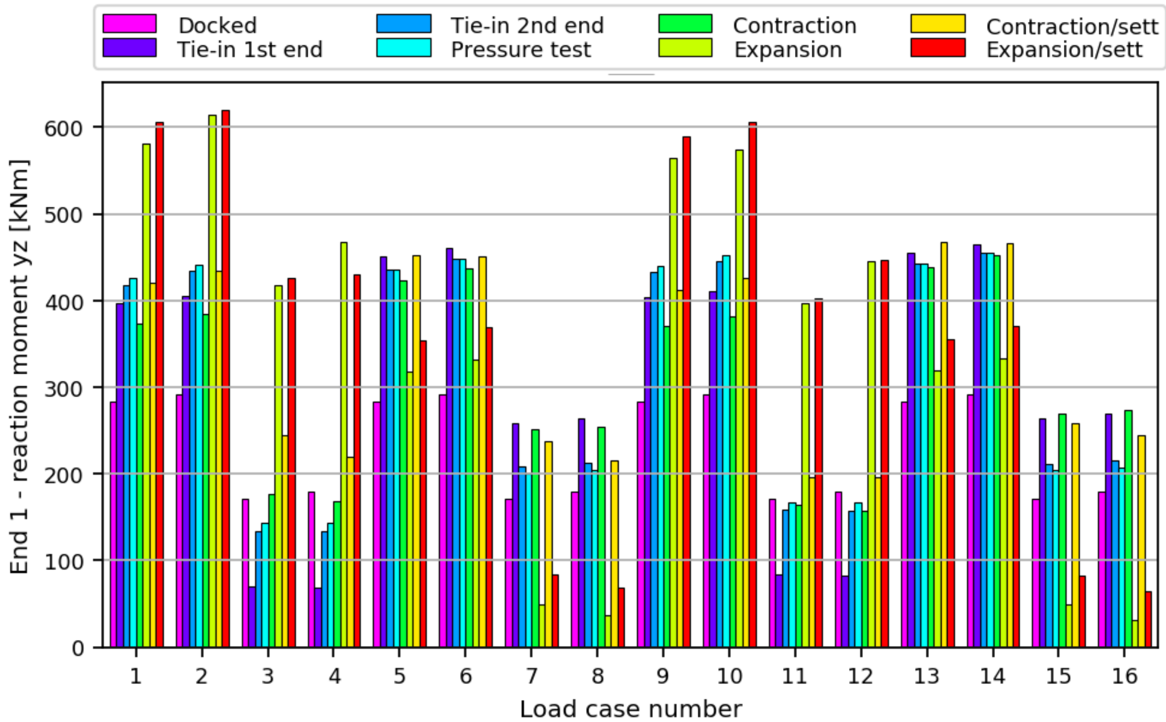
Table 8.4 – Maximum Magnitude Reaction Loads at End 1

Load Step	End Reaction Forces [kN]			End Reaction Moments [kNm]			
	RFx	RFy	RFz	RMx	RMy	RMz	RMb
Docked	6.0	1.4	78.9	-0.0	290.6	-19.3	291.2
Tie-in 1st end	29.2	-16.8	84.8	0.0	399.8	269.3	464.8
Tie-in 2nd end	22.5	-10.3	84.9	16.5	413.7	213.8	455.6
Pressure test	18.5	-9.9	84.8	17.3	417.6	205.4	455.3
Contraction	-3.4	13.0	70.6	46.7	357.1	296.8	452.8
Expansion	16.3	12.4	71.3	40.9	349.4	-505.9	614.1
Contraction/sett	-5.6	15.9	72.3	56.3	396.5	295.1	467.9
Expansion/sett	15.2	-13.7	73.0	40.0	388.0	-486.5	620.6
Max	29.2	-16.8	84.9	56.3	417.6	-505.9	620.6

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

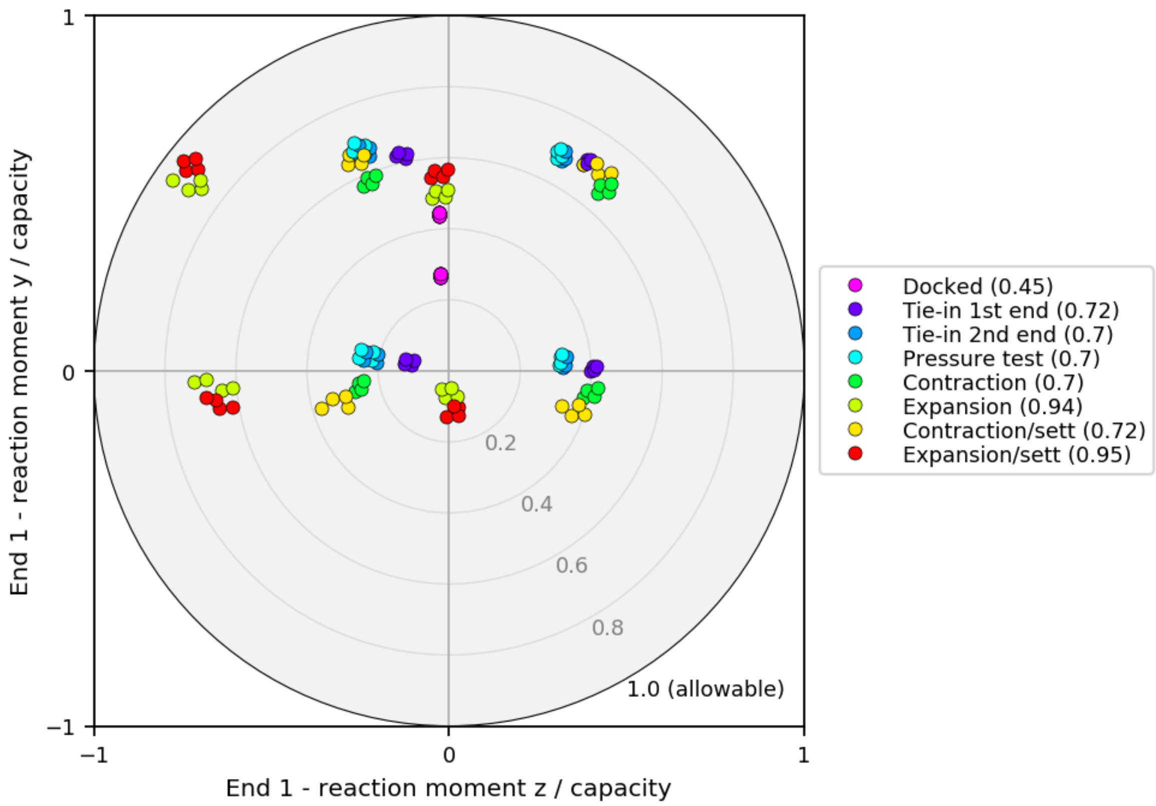
The maximum magnitude reaction bending moment at End 1, for each load case and load step, is shown in Figure 8.11.

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.

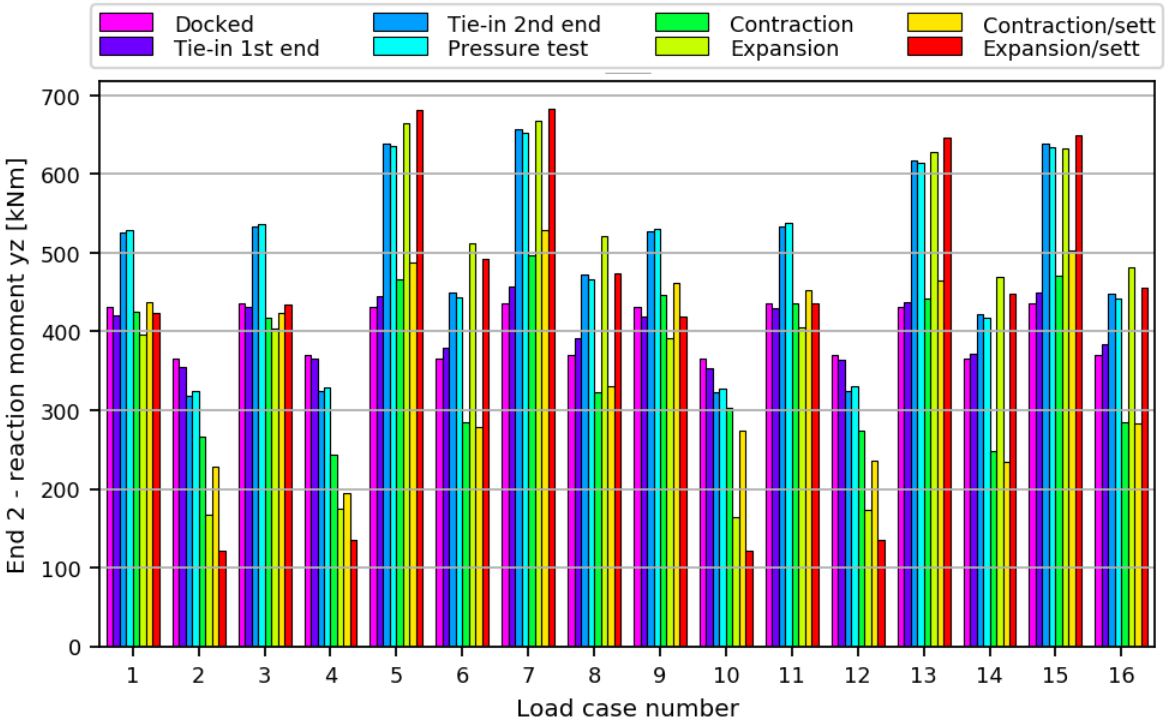
Table 8.5 – Maximum Magnitude Reaction Loads at End 2

Load Step	End Reaction Forces [kN]			End Reaction Moments [kNm]			
	RFx	RFy	RFz	RMx	RMy	RMz	RMb
Docked	2.2	1.1	86.3	0.0	435.1	-7.5	435.2
Tie-in 1st end	11.0	3.7	86.9	-0.0	443.4	-110.6	457.0
Tie-in 2nd end	18.6	23.1	91.0	-0.0	536.7	-379.6	657.4
Pressure test	16.7	22.1	91.0	-1.1	538.0	-370.6	653.3
Contraction	17.5	21.2	74.1	-15.2	405.3	-287.2	496.7
Expansion	-24.9	-17.9	73.4	-25.8	433.5	-512.5	667.6
Contraction/sett	17.5	23.2	75.3	-21.3	434.3	-307.8	529.1
Expansion/sett	-29.3	-20.3	74.6	-31.9	463.6	-510.7	683.8
Max	-29.3	23.2	91.0	-31.9	538.0	-512.5	683.8

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

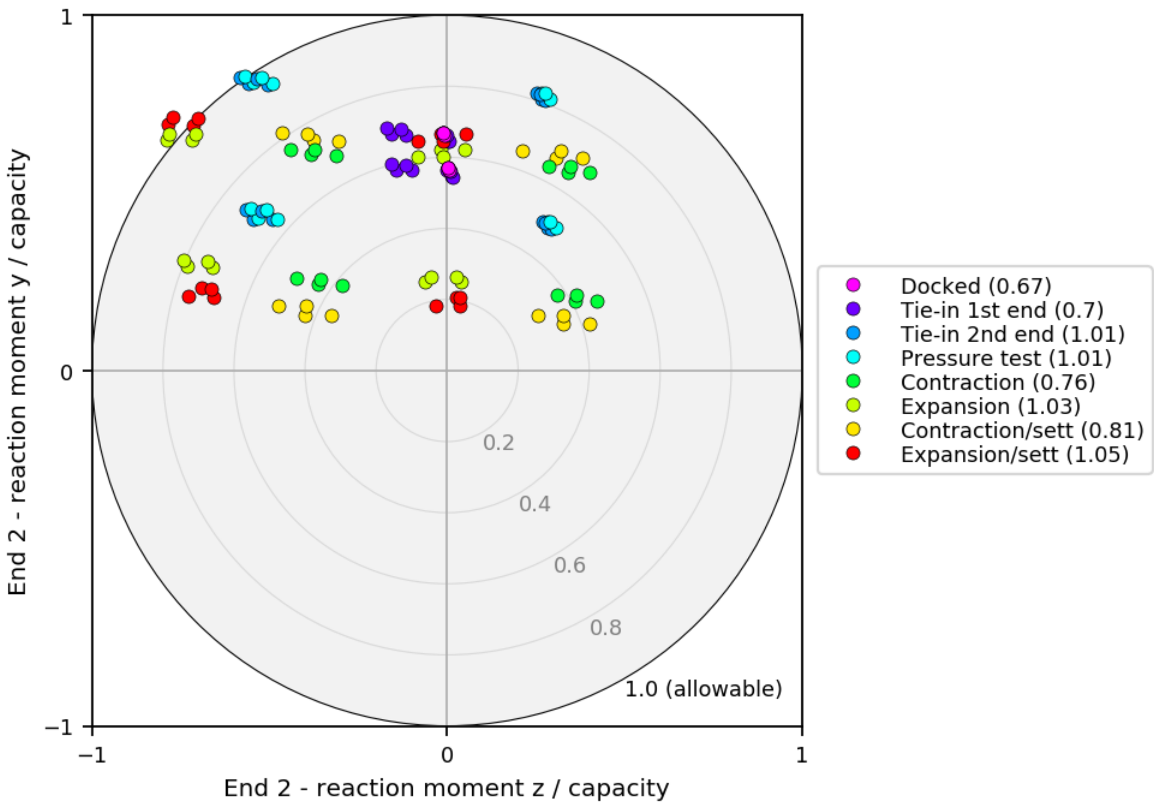
The maximum magnitude reaction bending moment at End 2, for each load case and load step, is shown in Figure 8.13.

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

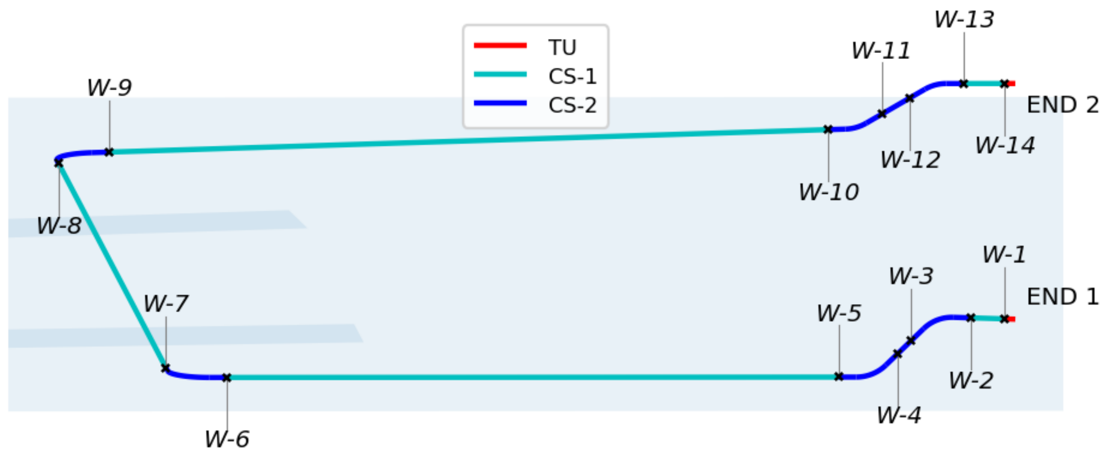


The shaded circular area indicates the allowable. The maximum utilisation is presented for each load step within parenthesis in the figure legend.

8.9 Fatigue Damage due to VIV

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

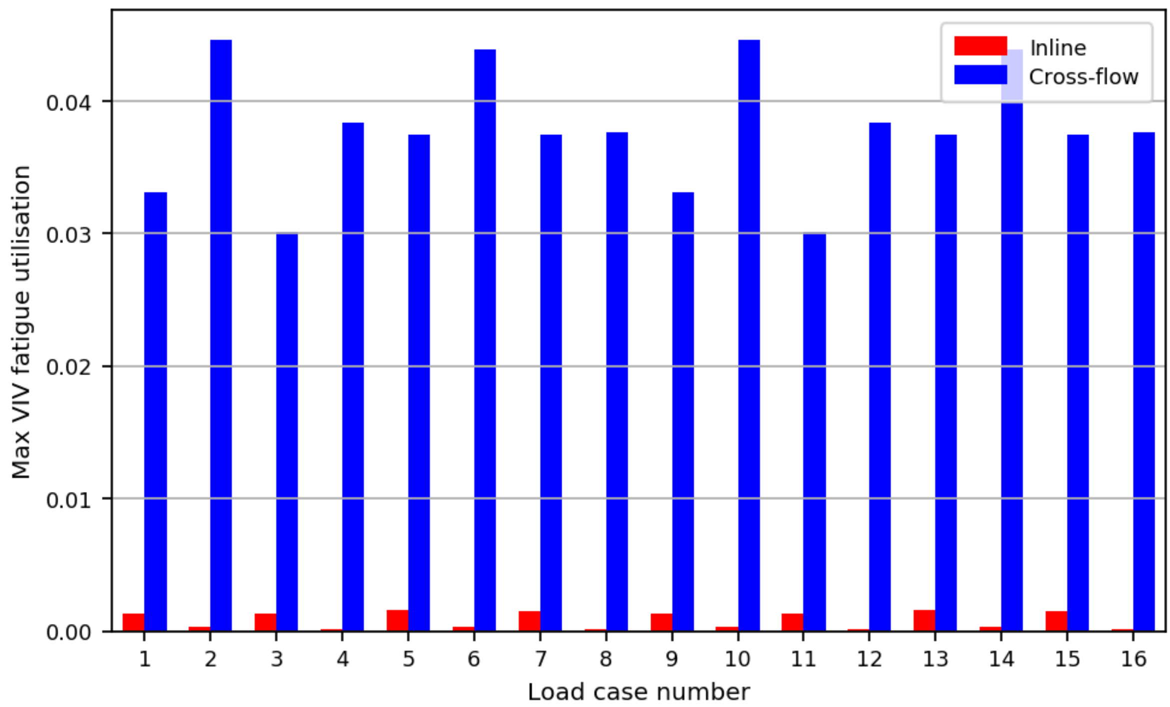
Figure 8.15 – Assessed Welds



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

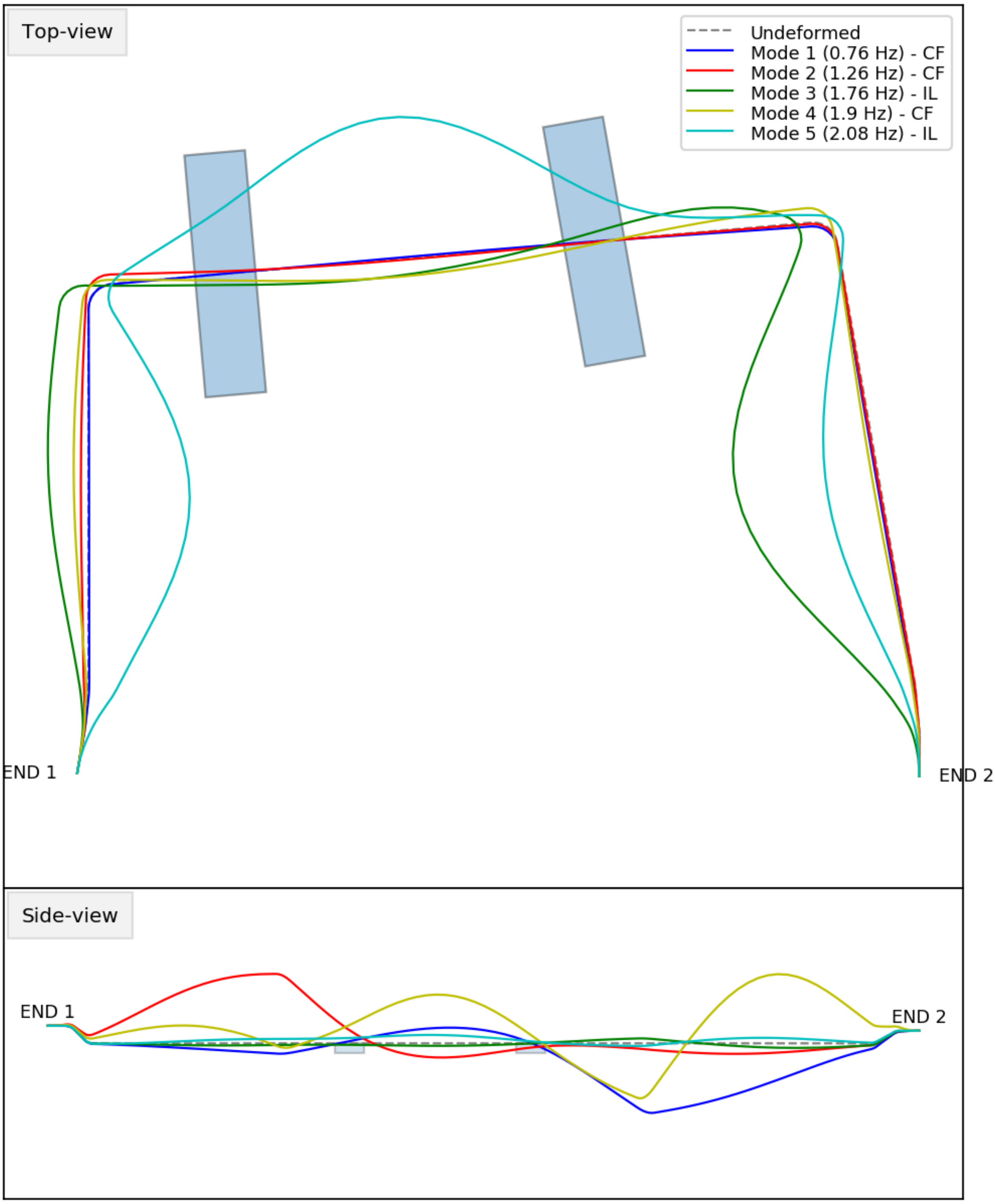


Inline and Cross-Flow utilisations are presented separately, and indicated that the damage has been accumulate at a specific location around the circumference.

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 2 (most critical in terms of fatigue damage) are shown in Figure 8.17.

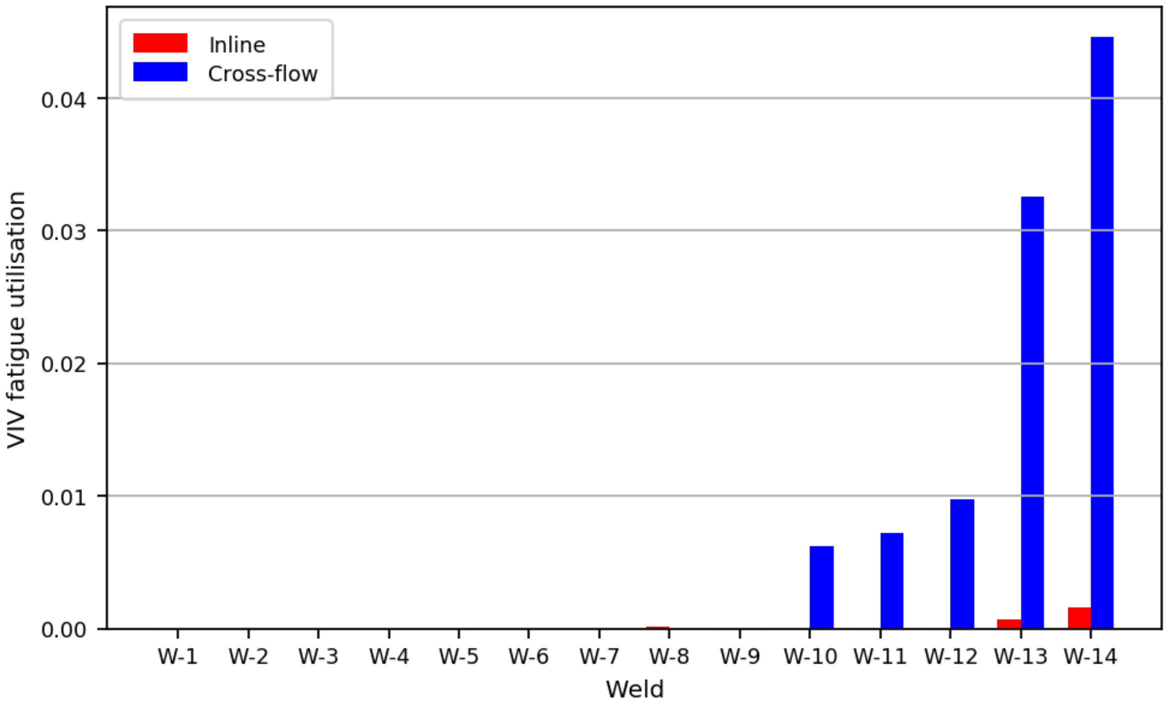
Figure 8.17 – Eigen-Modes of Most Utilised Load Case



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-4**	**Support-5**
Docked	0.0	51.0	66.6
Tie-in 1st end	0.0	59.2	67.7
Tie-in 2nd end	2.6	61.9	73.3
Pressure test	2.6	62.0	73.3
Contraction	0.0	44.7	46.1
Expansion	0.0	47.6	46.6
Contraction/sett	6.5	47.4	44.3
Expansion/sett	7.1	49.9	44.2
Max	7.1	62.0	73.3

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

9 CONFIGURATION MAX_L2

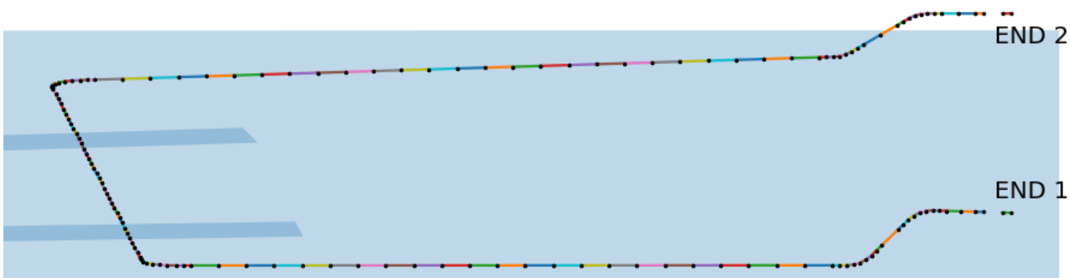
This section presents the following detailed results for configuration "max_L2".

- 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

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

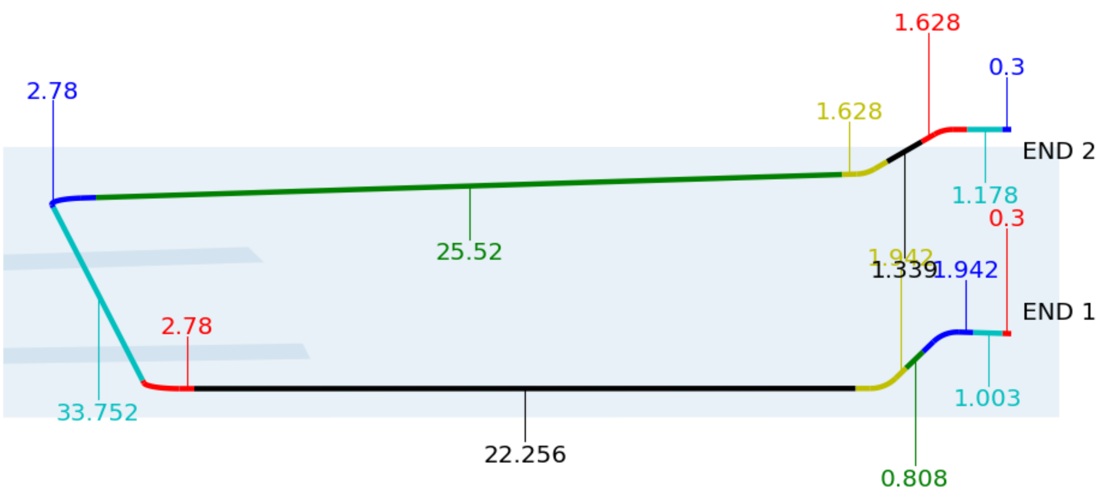
The coordinates at the spool ends and at the intersection points between the extended straight lines / sections, are presented in Table 9.1.

Table 9.1 – Coordinates at Ends and Intersection Points

Location	Coordinates [m]		
	X / Easting	Y / Northing	Z / Vertical
End 1	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	42.181	33.878	0.626
IP-6	47.033	6.362	0.626
IP-7	47.259	3.779	2.1
IP-8	47.259	1.779	2.1
End 2	47.259	1.479	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

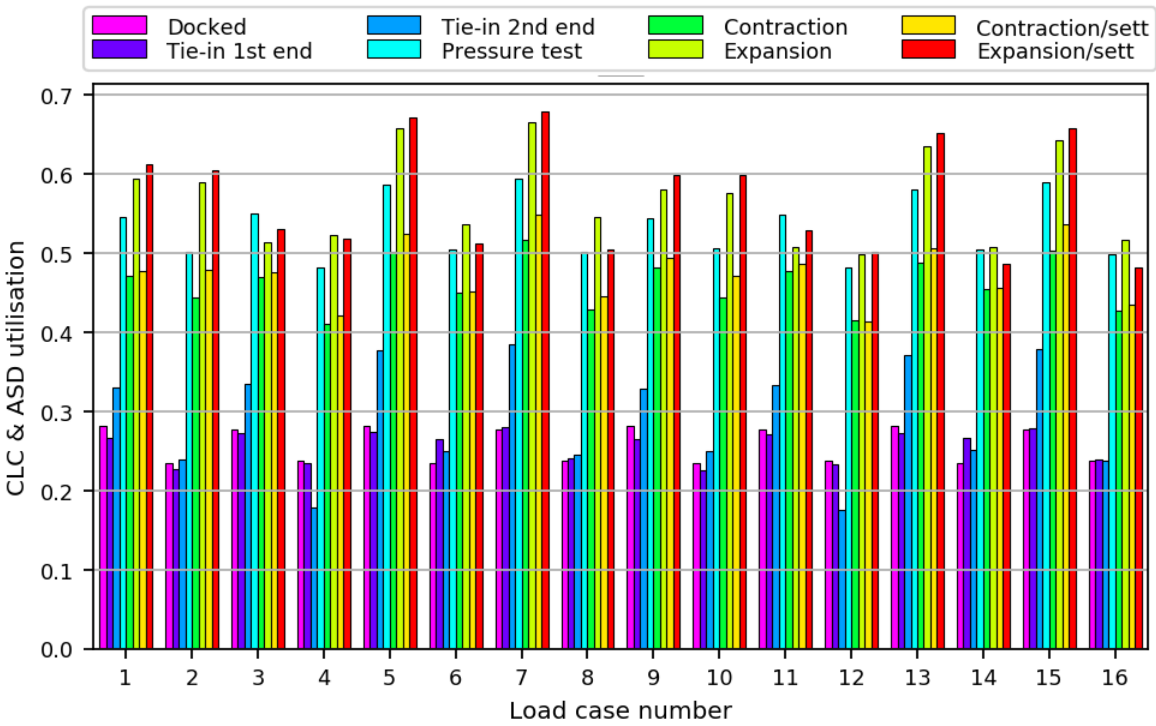
Load Step	Internal Pressure [bara]	Temperature [°C]	Content Density [kg/m3]	Axial Expansion - End 2 [m]
Docked	20	10	1150	0
Tie-in 1st end	20	10	1150	0
Tie-in 2nd end	20	10	1150	0
Pressure test	400	10	1150	0
Contraction	300	-20	250	-1.0
Expansion	300	100	250	3.0
Contraction/sett	300	-20	250	-1.0
Expansion/sett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

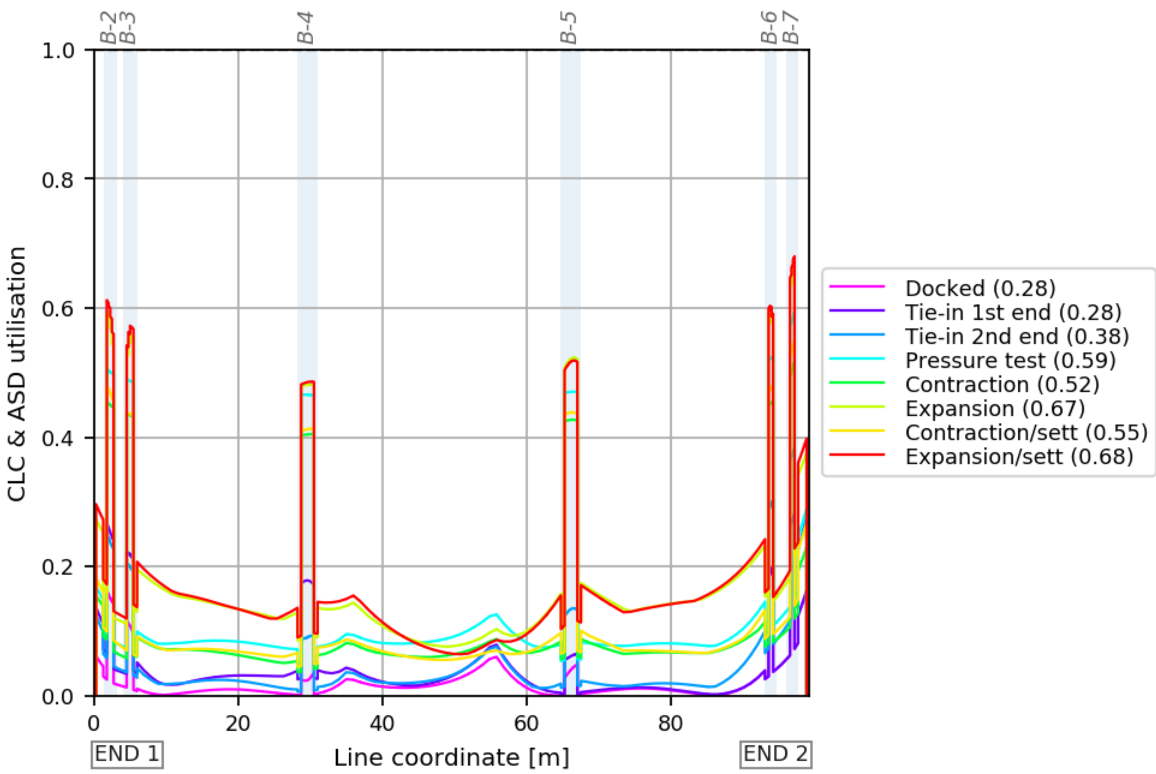
The maximum CLC / ASD utilisation along the spool, for each load case and load step, is shown in Figure 9.3.

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

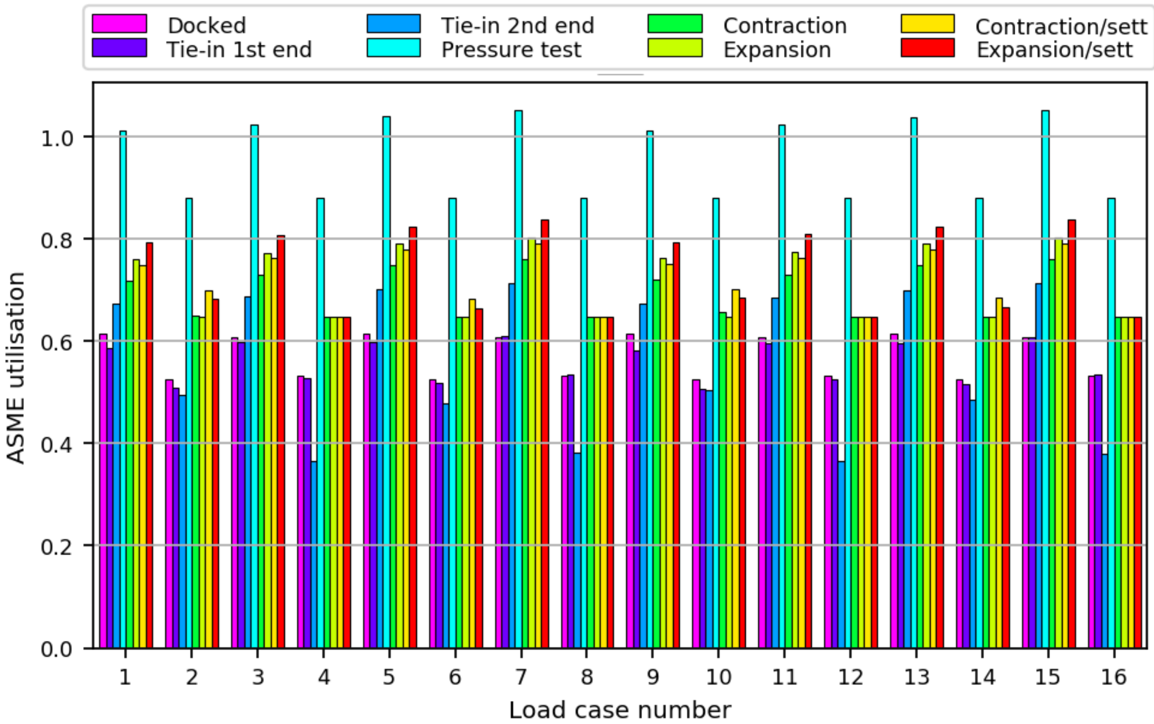


The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

9.6 SPOOL ASME UTILISATION

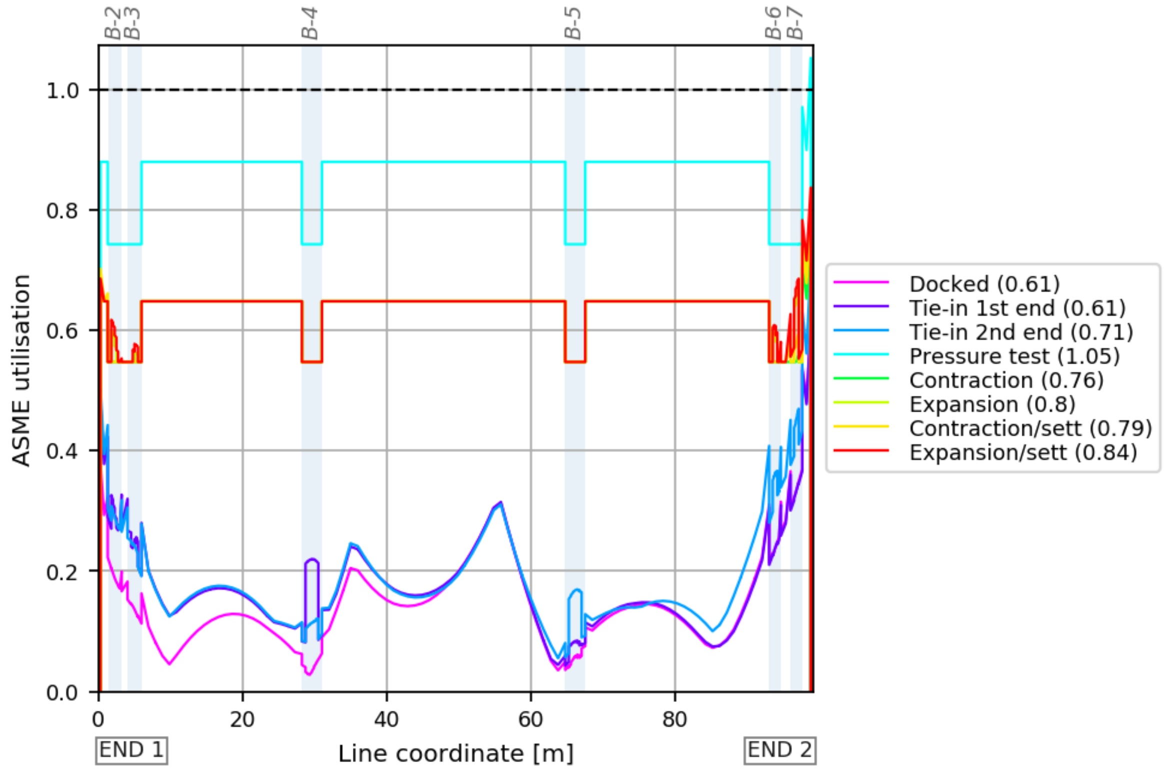
The maximum ASME utilisation along the spool, for each load case and load step, is shown in Figure 9.5.

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



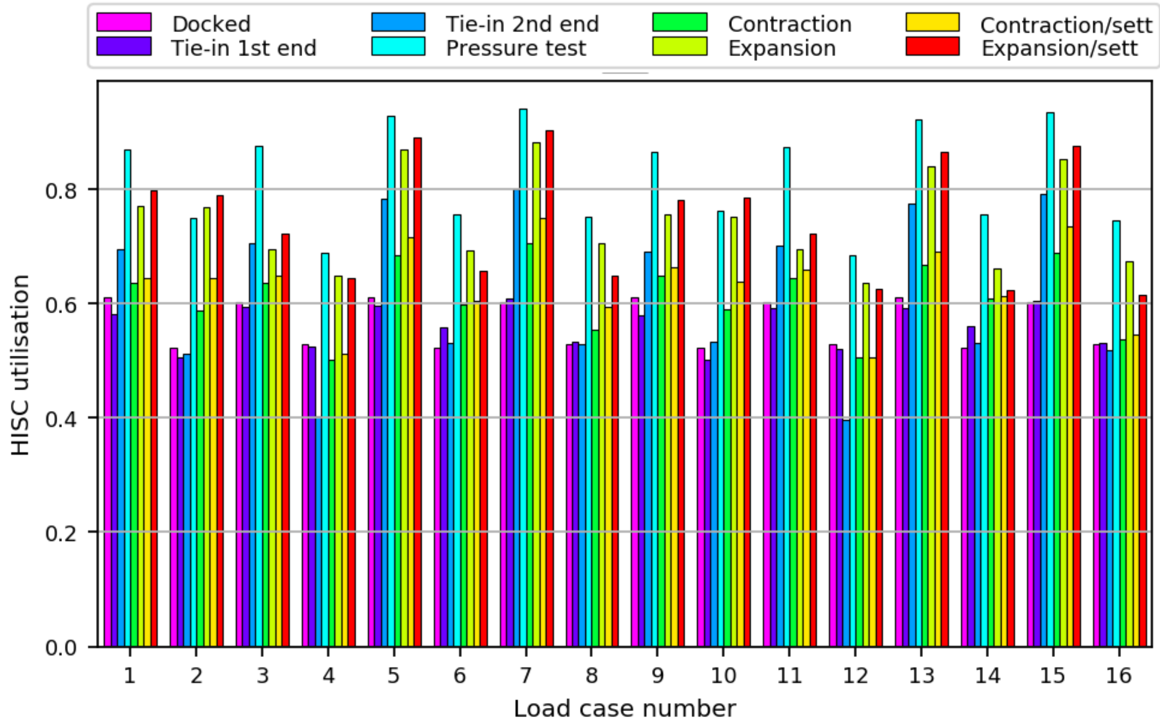
The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

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

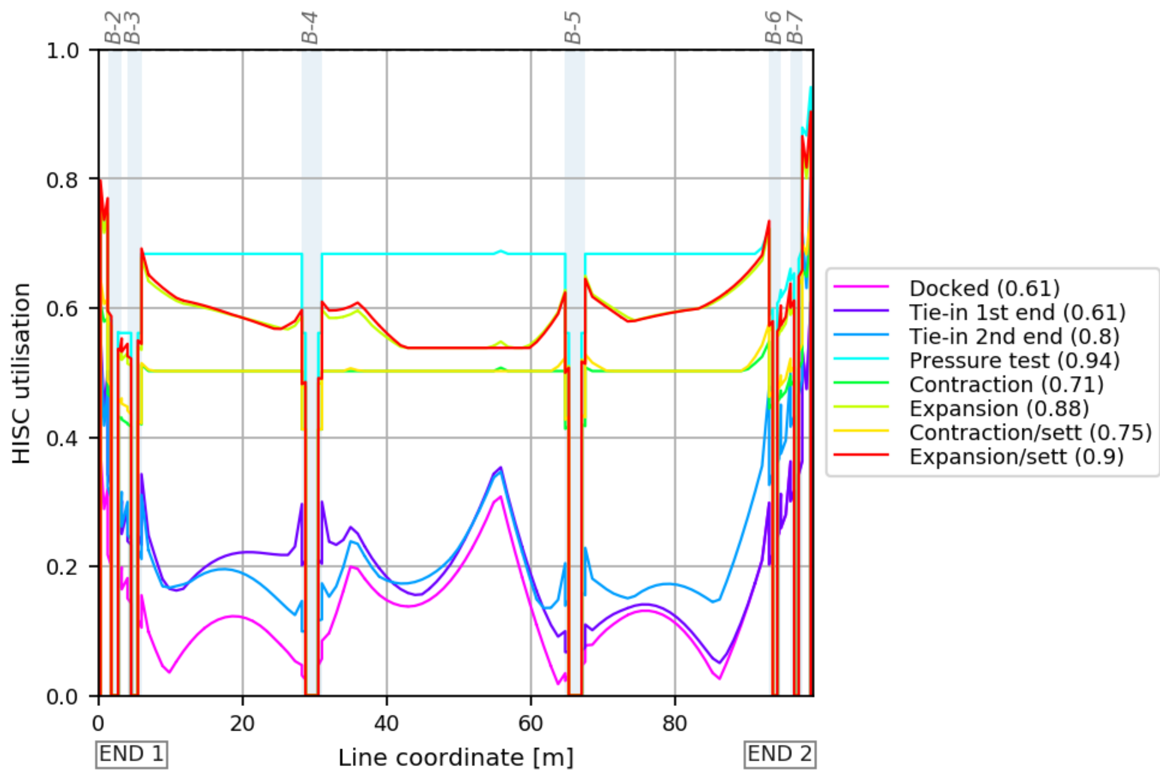
The maximum HISC utilisation along the spool, for each load case and load step, is shown in Figure 9.7.

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.

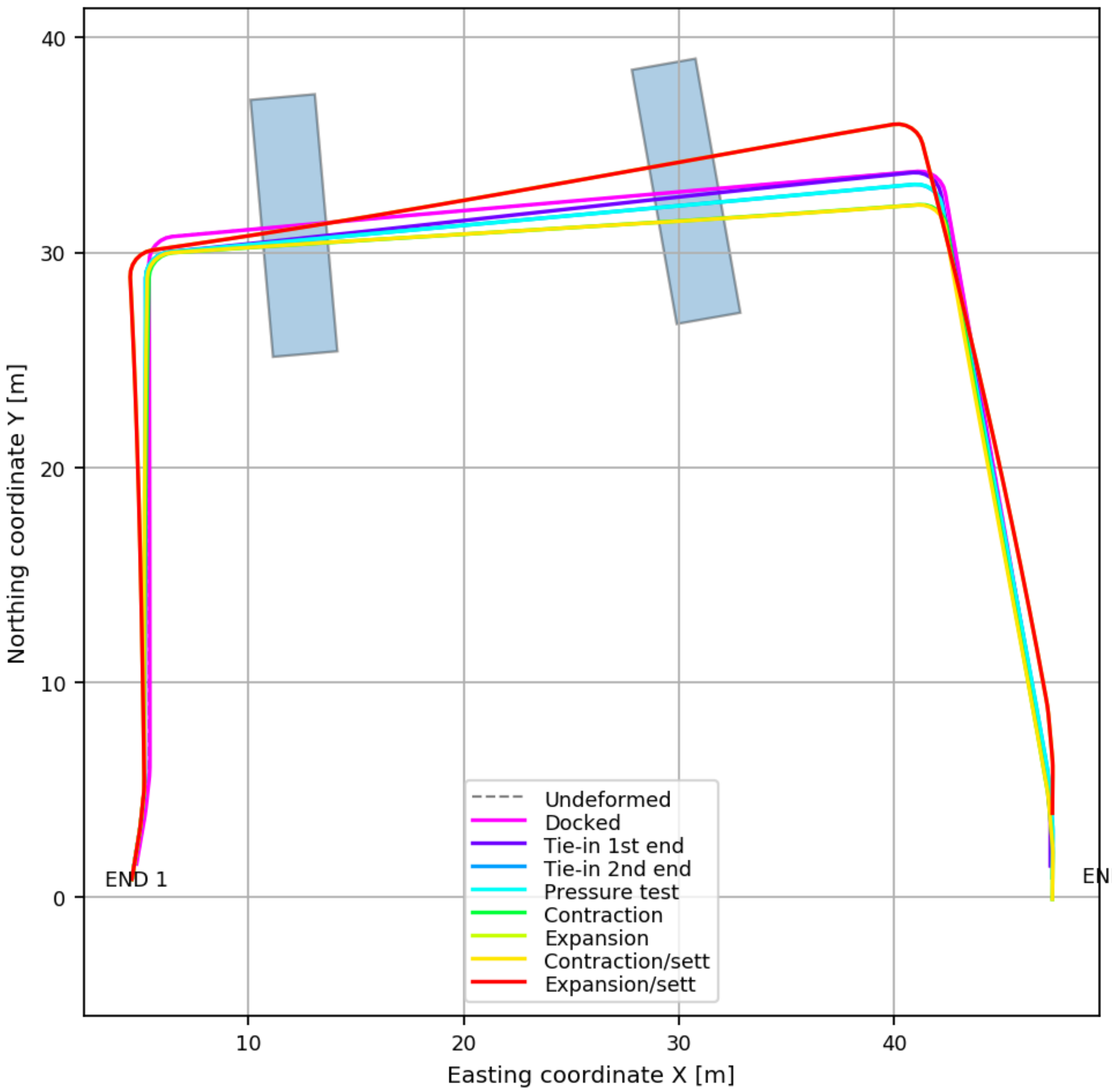
Longitudinal Stress Concentration Factors has been applied at each weld.

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 7

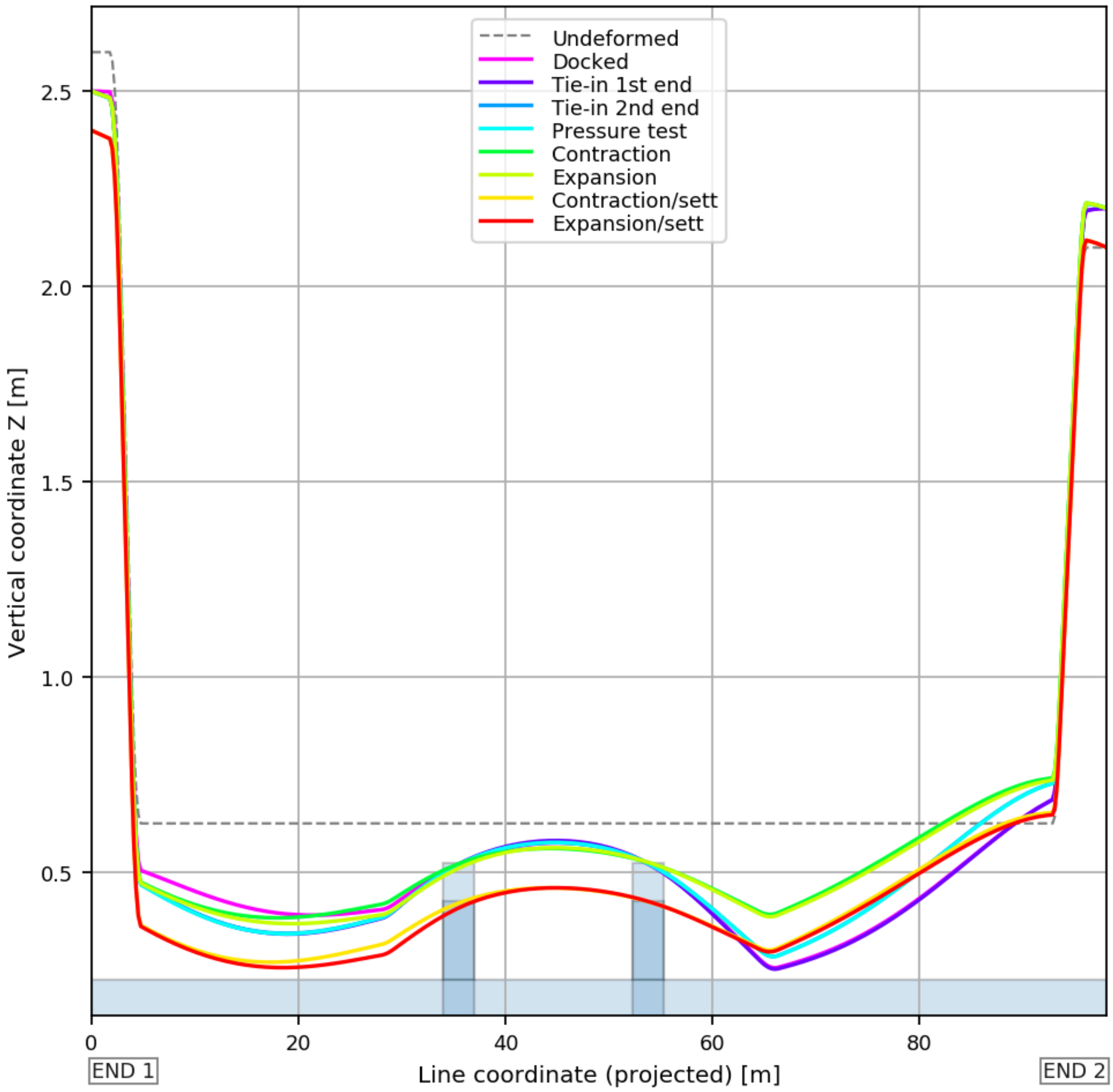
A top-view of the deformed shapes, for the most utilised load case (number 7), are shown for each load step in Figure 9.9.

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 7), 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.

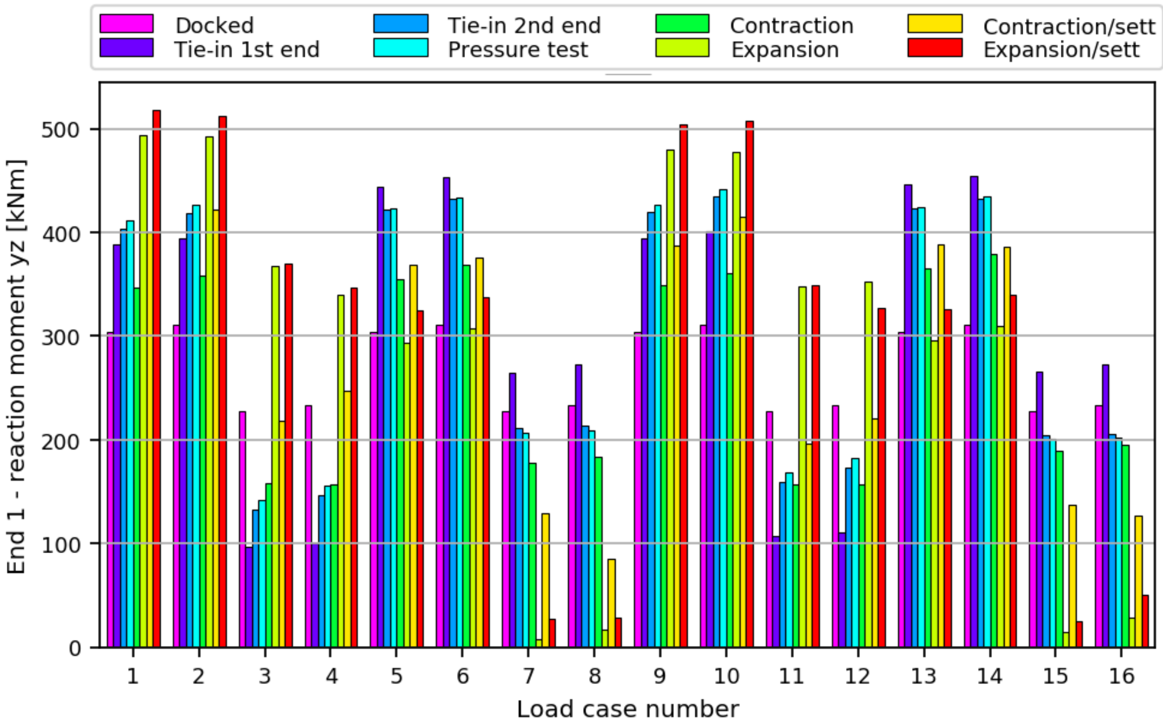
Table 9.4 – Maximum Magnitude Reaction Loads at End 1

Load Step	End Reaction Forces [kN]			End Reaction Moments [kNm]			
	RFx	RFy	RFz	RMx	RMy	RMz	RMb
Docked	8.4	1.5	83.2	-0.0	310.6	-18.2	311.1
Tie-in 1st end	30.7	-13.3	87.2	-0.0	394.4	260.5	454.8
Tie-in 2nd end	24.3	-7.5	87.3	14.2	409.0	195.7	434.4
Pressure test	19.9	-7.4	87.2	14.7	414.1	188.5	441.7
Contraction	4.2	10.5	70.5	48.0	330.4	208.7	379.2
Expansion	12.3	-9.1	71.0	37.8	323.9	-387.2	494.0
Contraction/sett	-6.6	13.7	71.6	57.4	366.8	-246.7	422.4
Expansion/sett	11.2	-10.5	72.1	37.6	354.8	-393.3	518.6
Max	30.7	13.7	87.3	57.4	414.1	-393.3	518.6

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

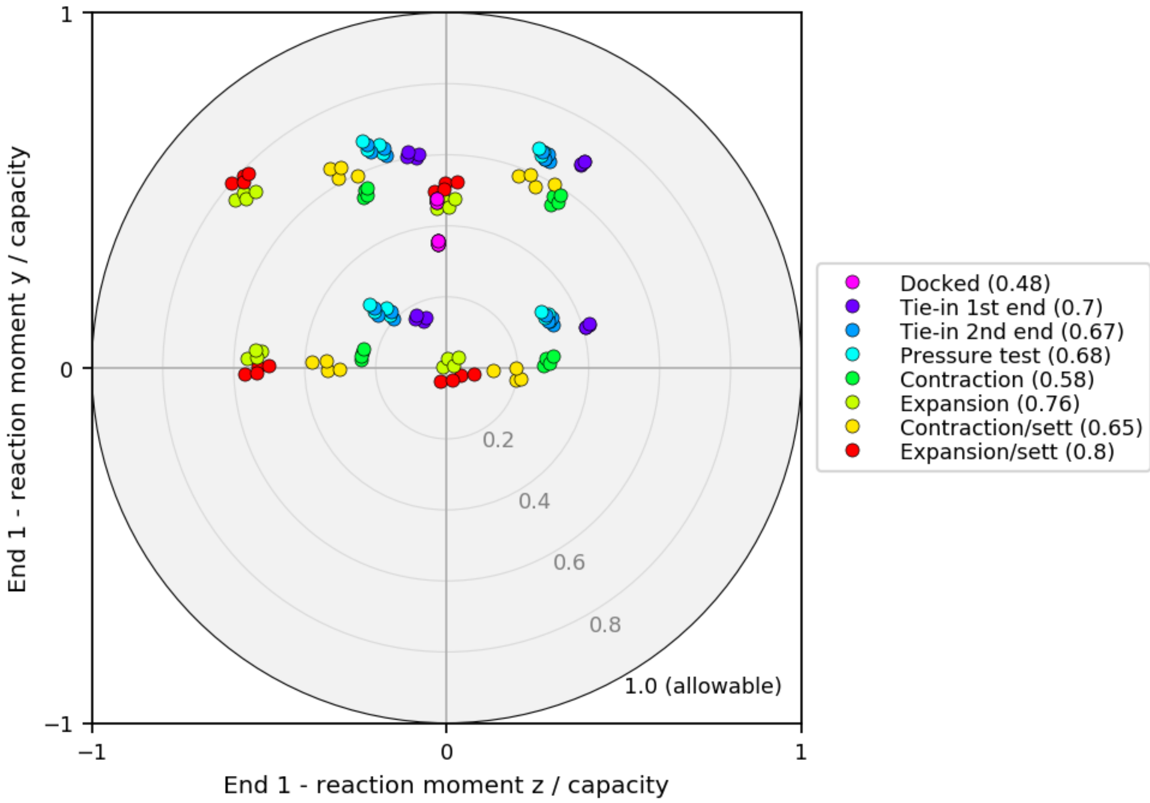
The maximum magnitude reaction bending moment at End 1, for each load case and load step, is shown in Figure 9.11.

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.

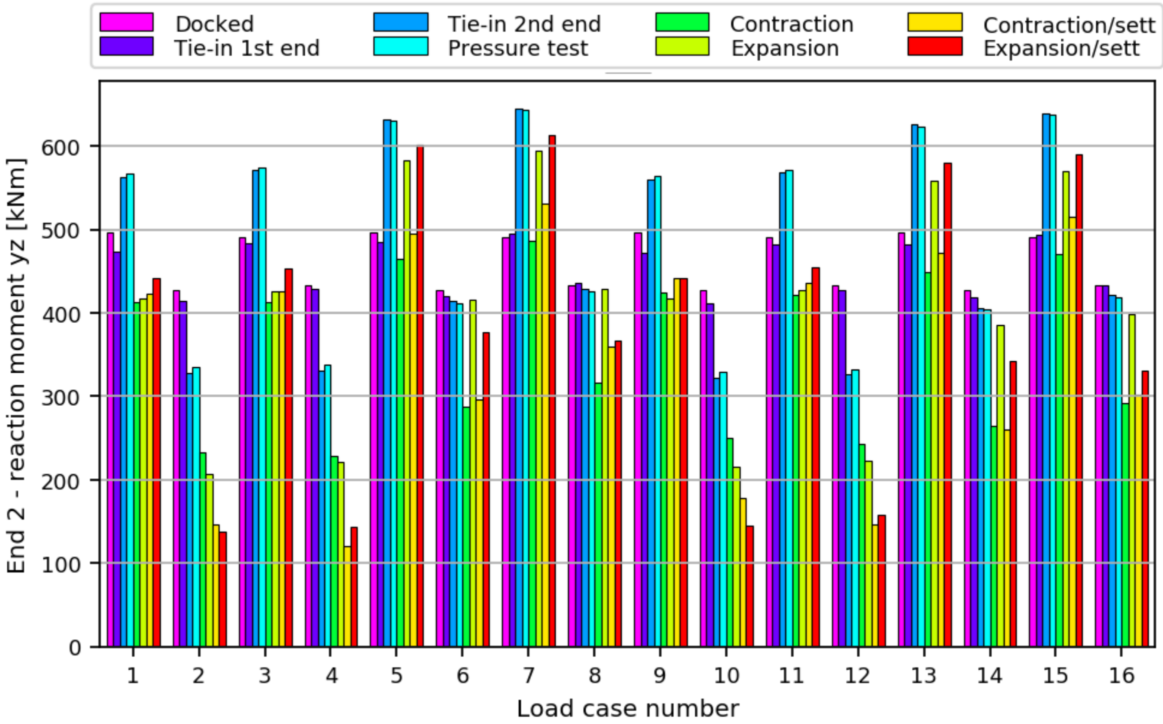
Table 9.5 – Maximum Magnitude Reaction Loads at End 2

Load Step	End Reaction Forces [kN]			End Reaction Moments [kNm]			
	RFx	RFy	RFz	RMx	RMy	RMz	RMb
Docked	6.7	1.3	90.9	-0.0	496.5	-7.9	496.5
Tie-in 1st end	13.8	1.4	91.3	-0.0	493.3	-47.9	495.6
Tie-in 2nd end	20.3	17.9	94.6	-0.0	576.0	-291.8	645.6
Pressure test	16.1	16.7	94.6	-1.6	577.6	-283.6	643.4
Contraction	17.9	17.4	75.4	-11.0	414.7	-253.7	486.2
Expansion	-24.7	-16.8	74.7	-26.1	449.8	-388.6	594.4
Contraction/sett	17.2	22.9	76.3	-15.4	439.4	-339.2	530.5
Expansion/sett	-30.5	-17.9	75.7	-31.5	476.3	-387.2	613.8
Max	-30.5	22.9	94.6	-31.5	577.6	-388.6	645.6

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

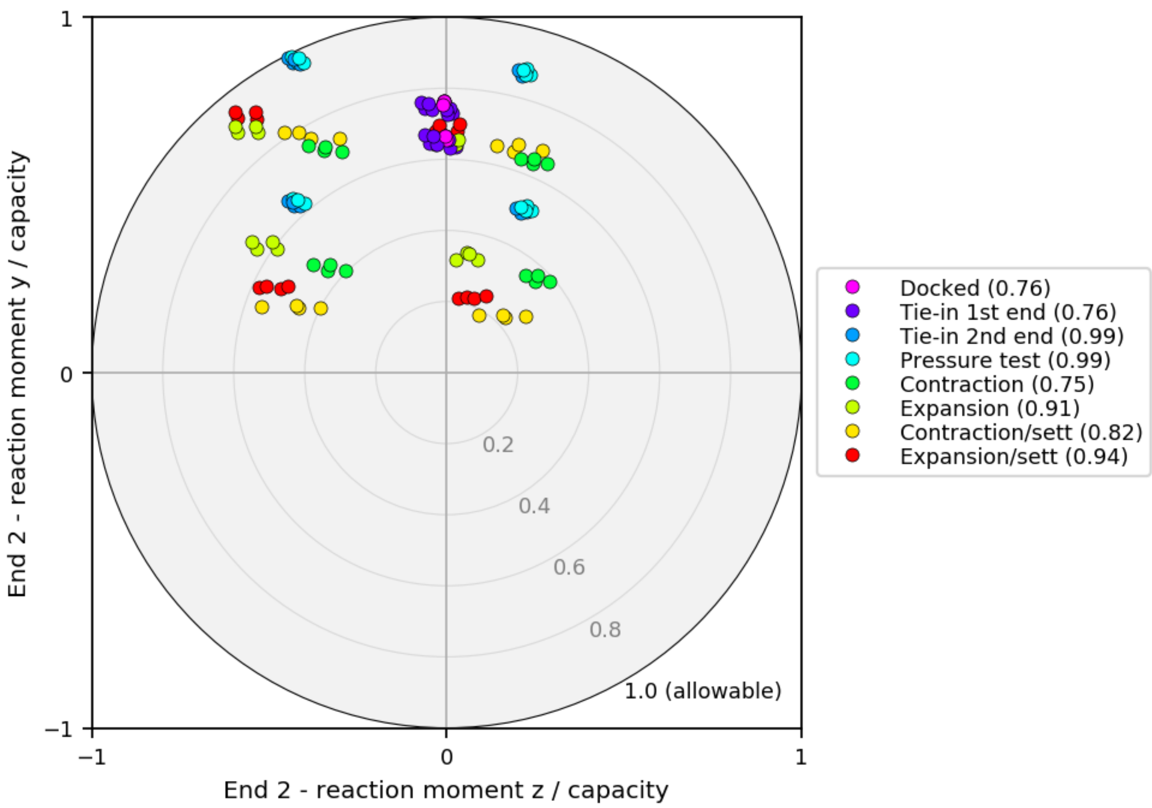
The maximum magnitude reaction bending moment at End 2, for each load case and load step, is shown in Figure 9.13.

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

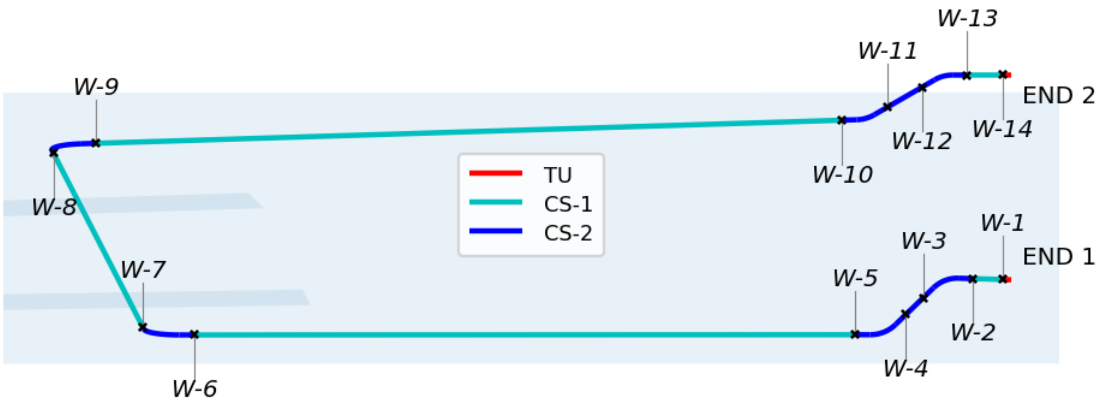


The shaded circular area indicates the allowable. The maximum utilisation is presented for each load step within parenthesis in the figure legend.

9.9 FATIGUE DAMAGE DUE TO VIV

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

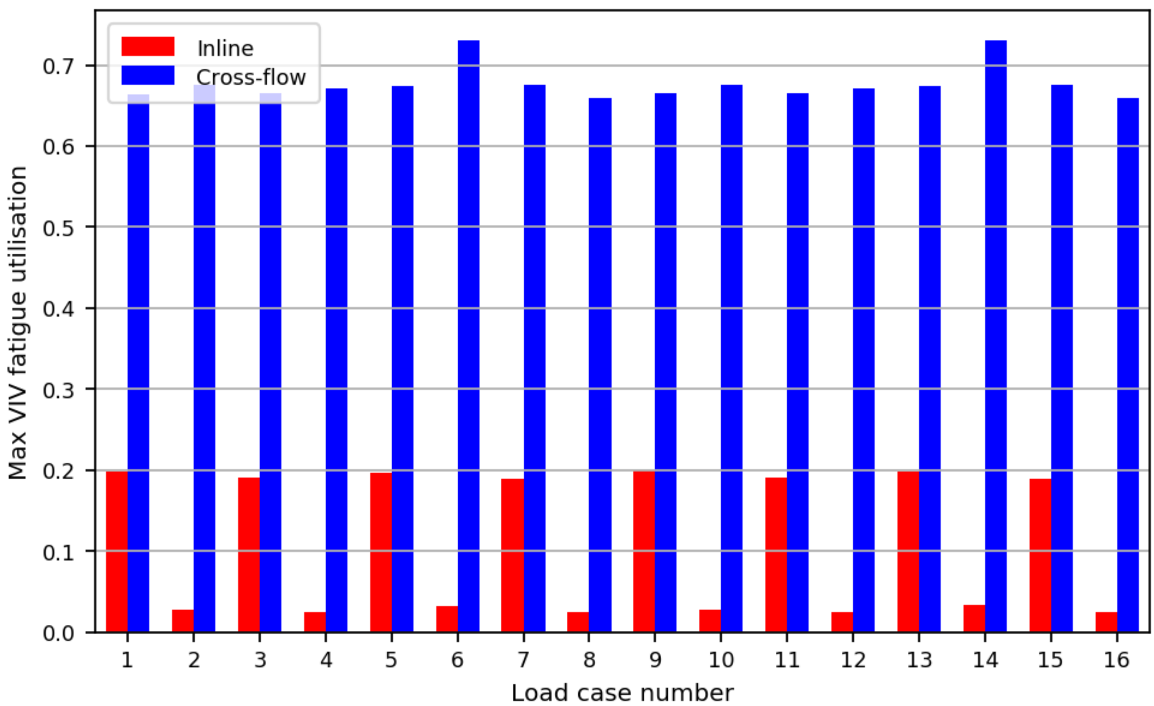
Figure 9.15 – Assessed Welds



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

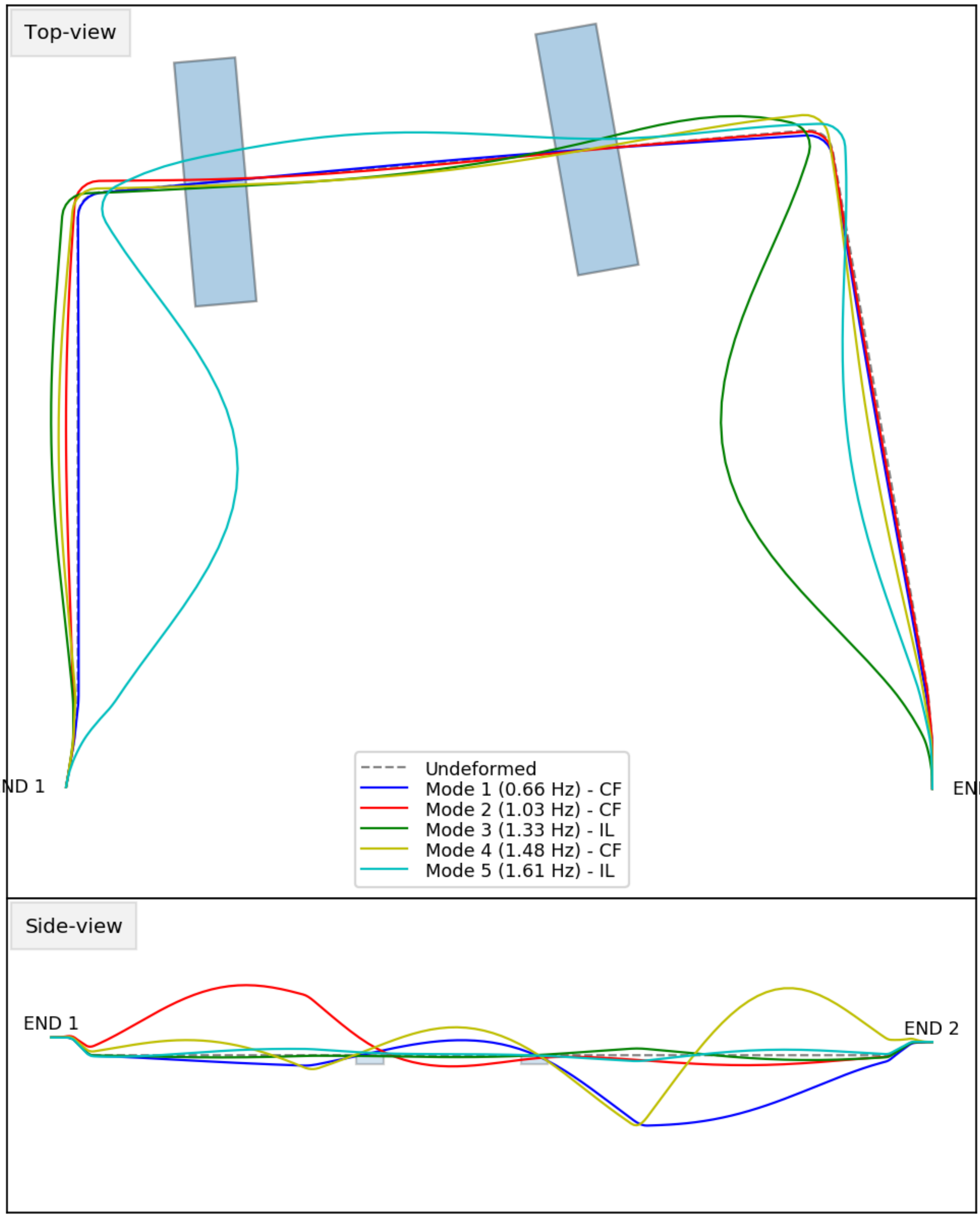


Inline and Cross-Flow utilisations are presented separately, and indicated that the damage has been accumulate at a specific location around the circumference.

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 6 (most critical in terms of fatigue damage) are shown in Figure 9.17.

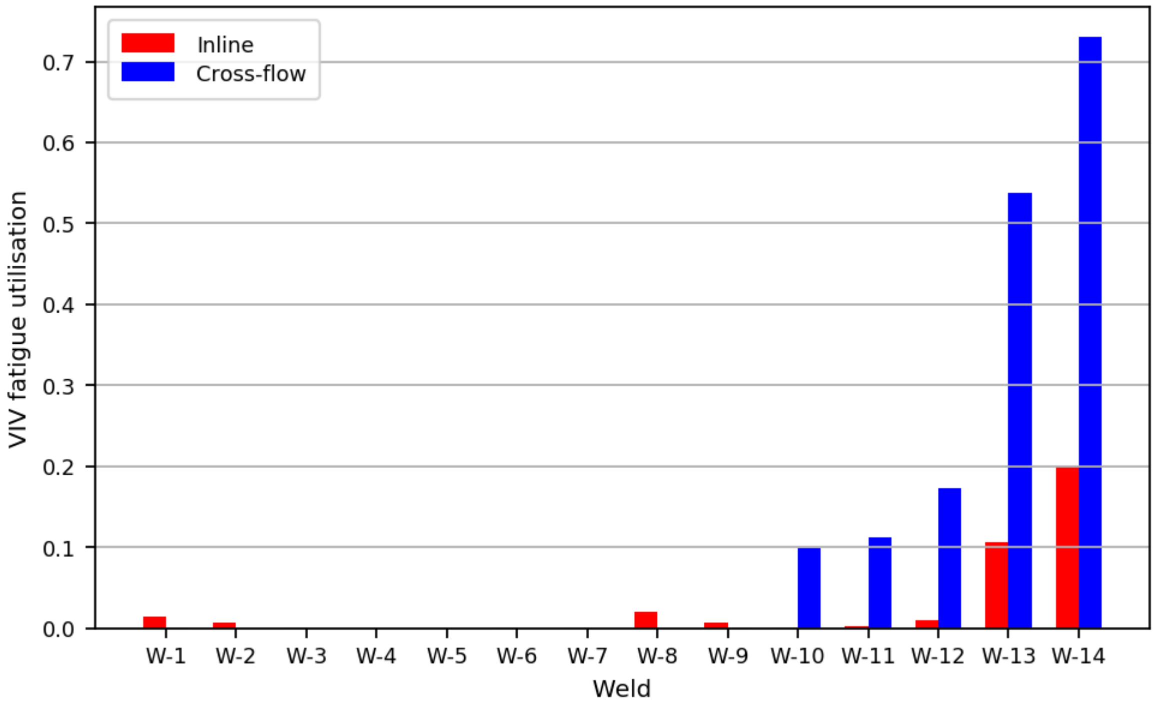
Figure 9.17 – Eigen-Modes of Most Utilised Load Case



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-4	Support-5
Docked	4.1	53.5	71.0
Tie-in 1st end	2.4	59.5	70.5
Tie-in 2nd end	10.1	61.7	68.4
Pressure test	10.2	61.8	68.3
Contraction	0.0	43.3	47.4
Expansion	0.0	46.5	47.5
Contraction/sett	10.6	45.3	40.4
Expansion/sett	12.3	51.7	39.6
Max	12.3	61.8	71.0

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

10 CONFIGURATION MAX_L3

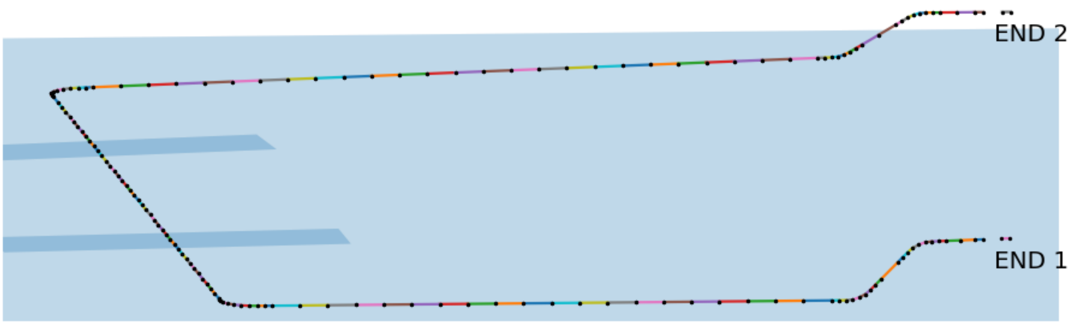
This section presents the following detailed results for configuration "max_L3".

- 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

10.1 FE-Model

The FE-model consists of the spool and two connecting structures at each end. The mesh density used is shown in Figure 10.1.

Figure 10.1 – 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.

10.2 Spool Geometry

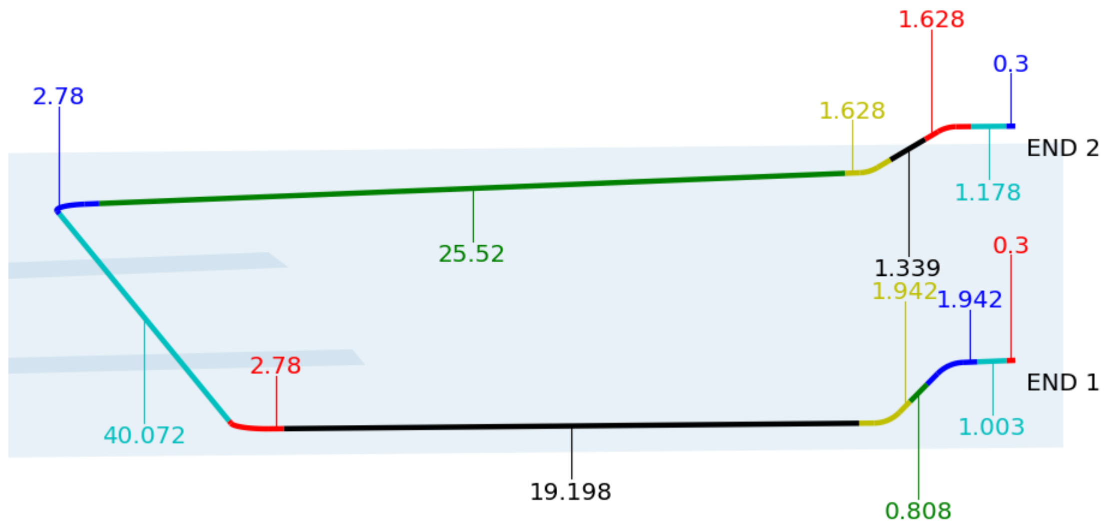
The coordinates at the spool ends and at the intersection points between the extended straight lines / sections, are presented in Table 10.1.

Table 10.1 – 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	42.181	33.878	0.626
IP-6	47.033	6.362	0.626
IP-7	47.259	3.779	2.1
IP-8	47.259	1.779	2.1
End 2	47.259	1.479	2.1

An isometric view of the spool showing each section length (units in meter) is shown in Figure 10.2.

Figure 10.2 – Isometric View with Section Lengths



10.3 Load Cases

A set of 16 load case combinations has been analysed, as presented in Table 10.2. The prescribed end displacement / rotation values refer to uncertainties regarding make-up tolerances at each spool end.

Table 10.2 – 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.

10.4 LOAD STEPS

The spool have been analysed for the subsequent load steps presented in Table 10.3.

Table 10.3 – Subsequent Load Steps

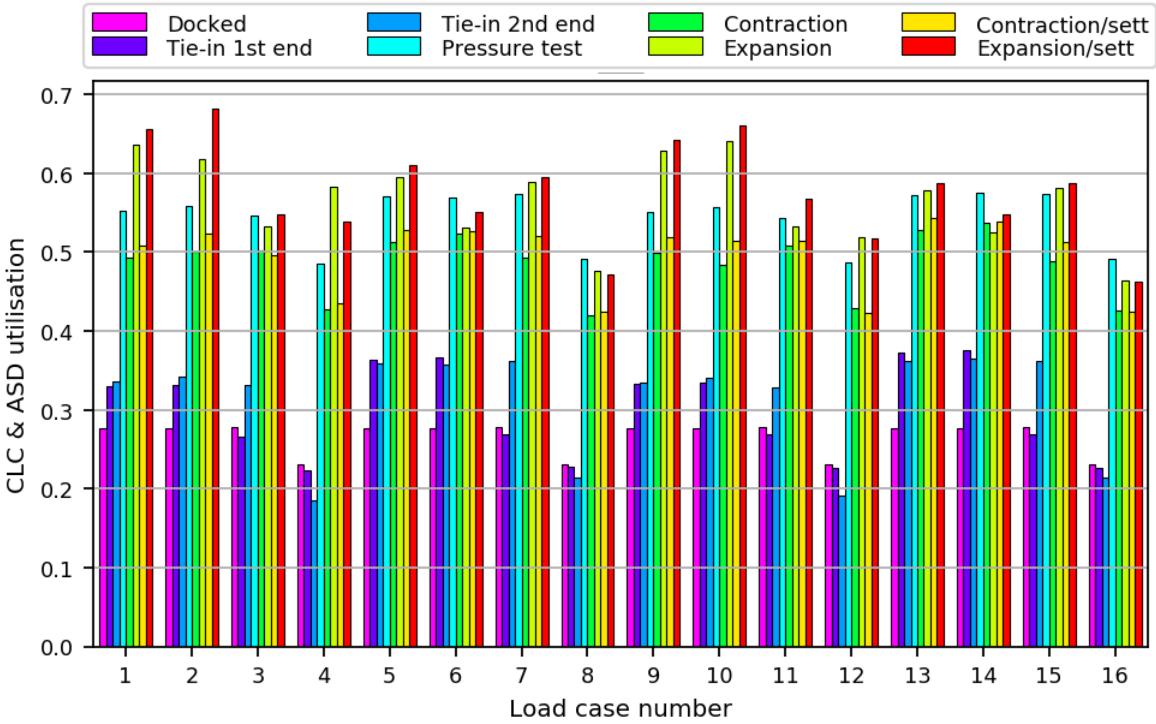
Load Step	Internal Pressure [bara]	Temperature [°C]	Content Density [kg/m3]	Axial Expansion - End 2 [m]
Docked	20	10	1150	0
Tie-in 1st end	20	10	1150	0
Tie-in 2nd end	20	10	1150	0
Pressure test	400	10	1150	0
Contraction	300	-20	250	-1.0
Expansion	300	100	250	3.0
Contraction/sett	300	-20	250	-1.0
Expansion/sett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

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

10.5 SPOOL CLC / ASD UTILISATION

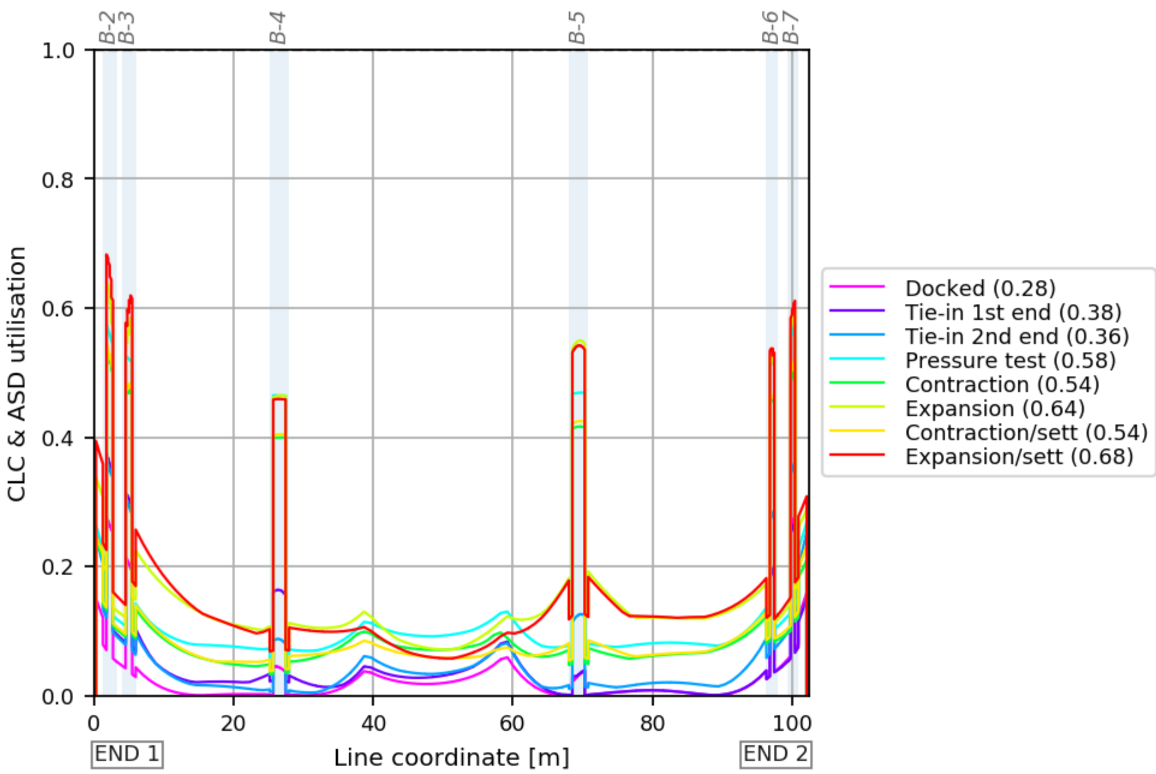
The maximum CLC / ASD utilisation along the spool, for each load case and load step, is shown in Figure 10.3.

Figure 10.3 – 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 10.4.

Figure 10.4 – Spool CLC / ASD Utilisation

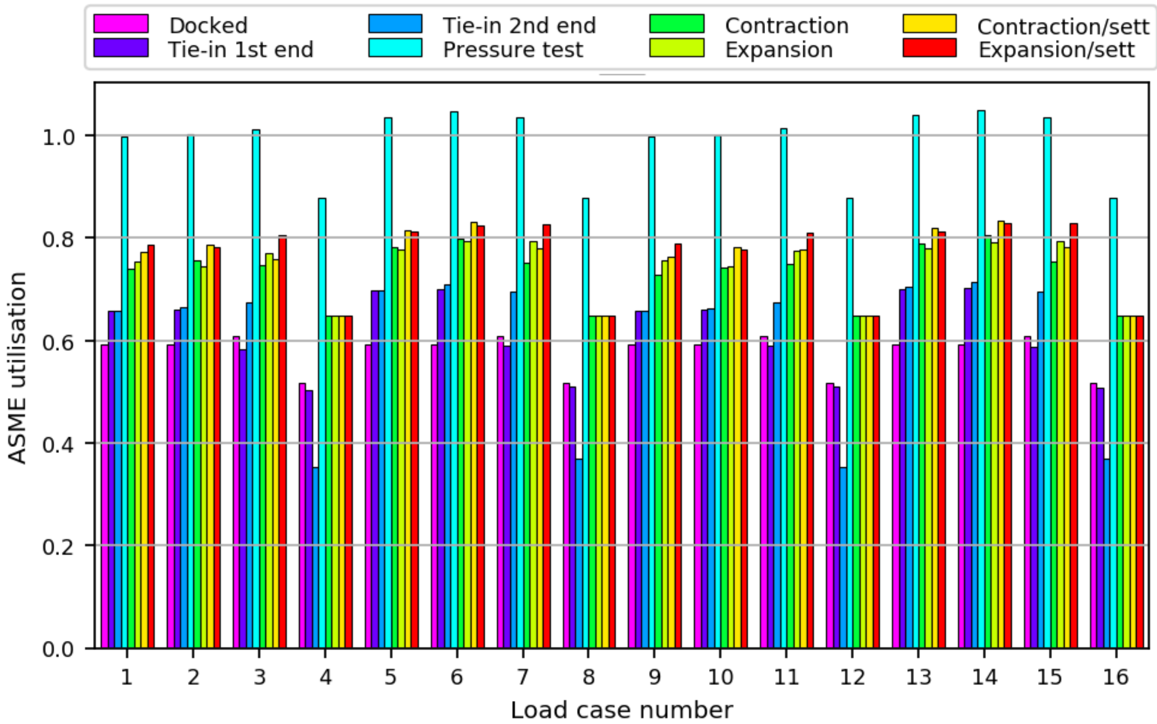


The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

10.6 Spool ASME Utilisation

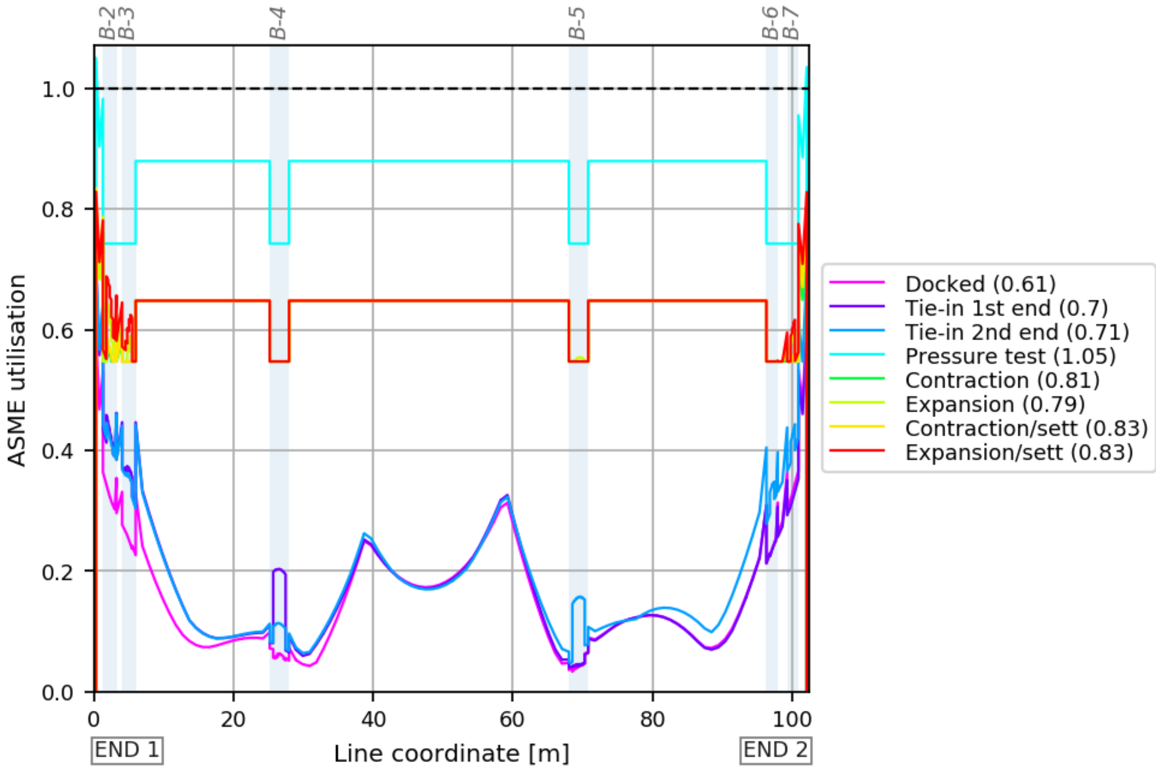
The maximum ASME utilisation along the spool, for each load case and load step, is shown in Figure 10.5.

Figure 10.5 – 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 10.6.

Figure 10.6 – Spool ASME Utilisation



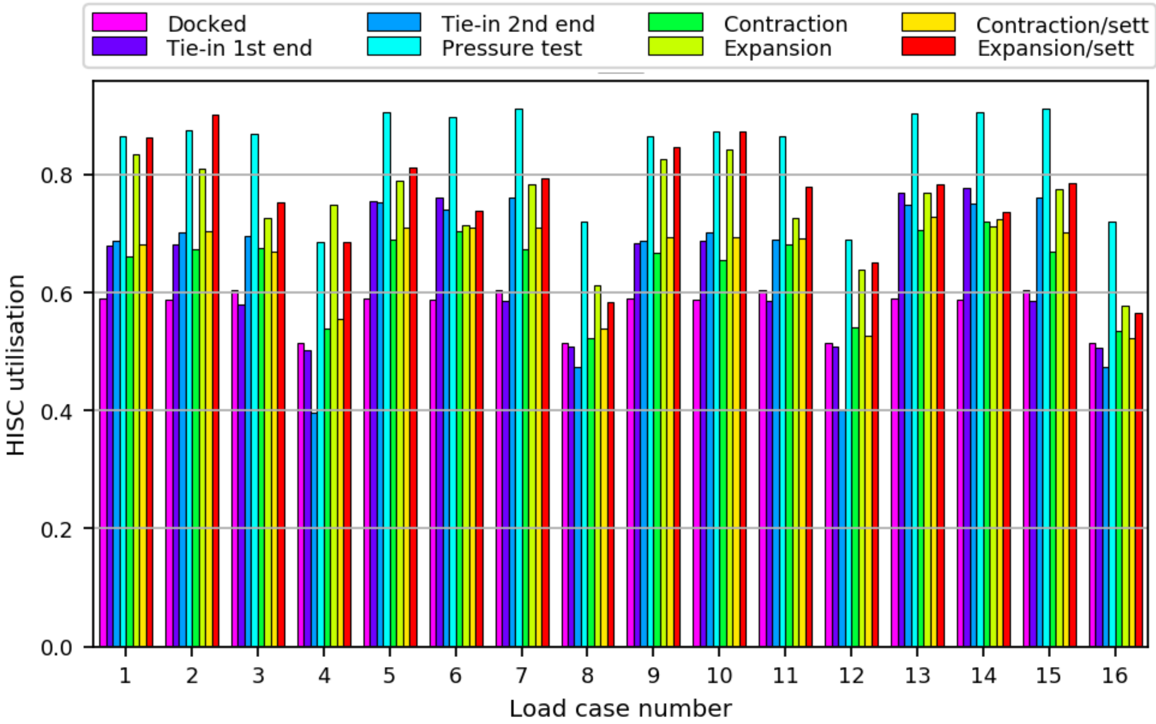
The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

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

10.7 Spool HISC Utilisation

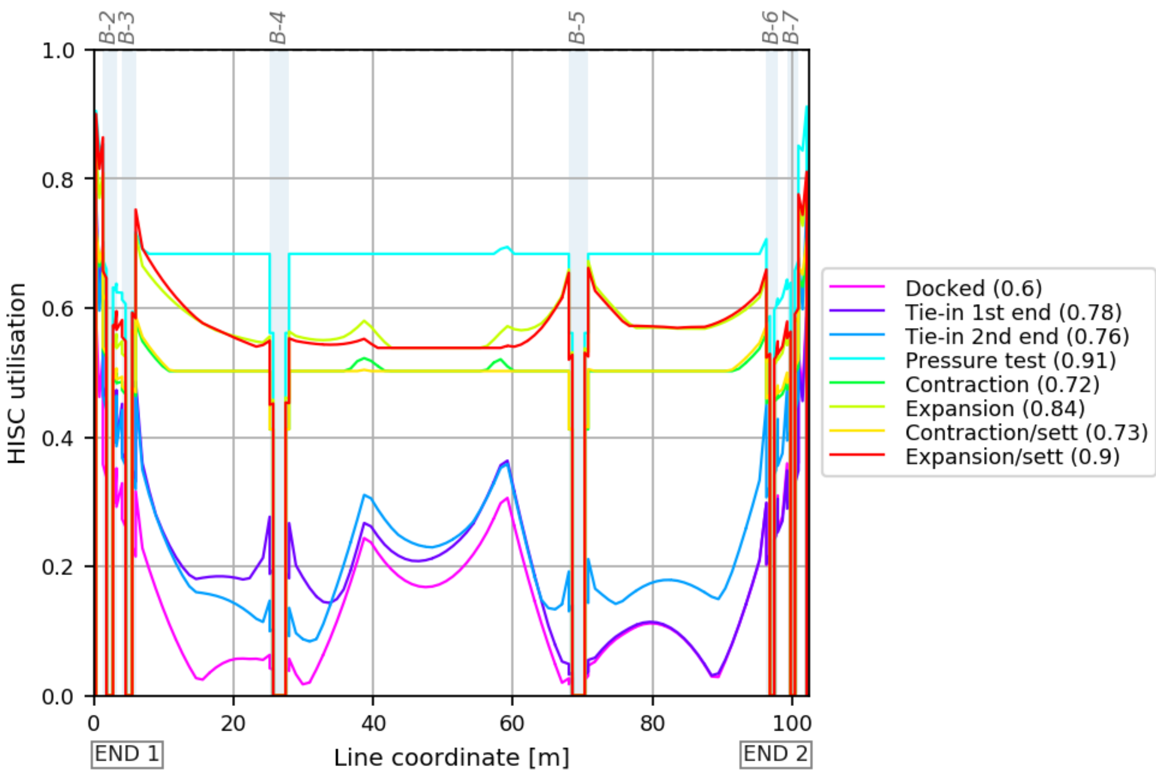
The maximum HISC utilisation along the spool, for each load case and load step, is shown in Figure 10.7.

Figure 10.7 – 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 10.8.

Figure 10.8 – 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.

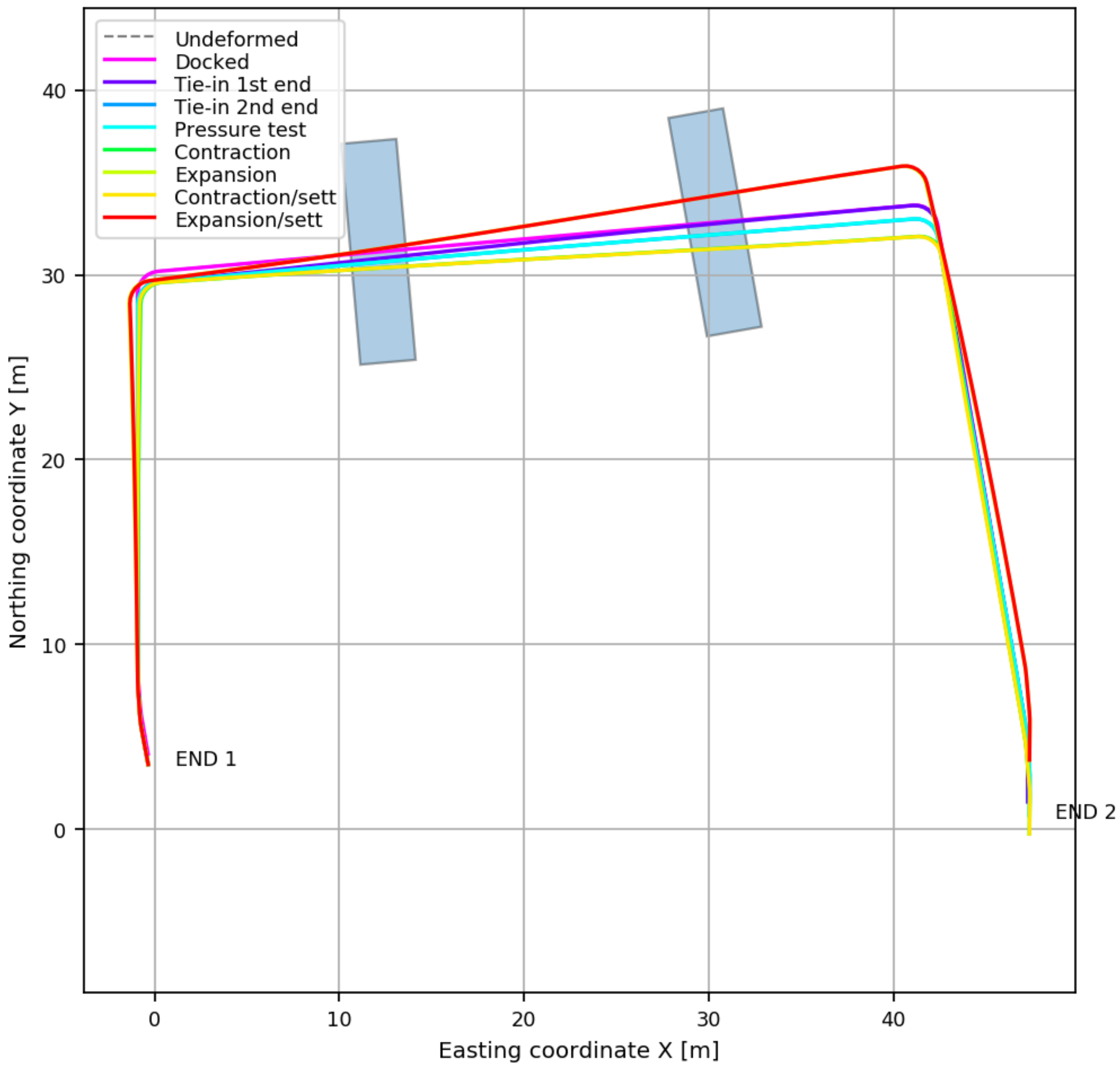
Longitudinal Stress Concentration Factors has been applied at each weld.

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.

10.7.1 Most Utilised Load Case - Number 15

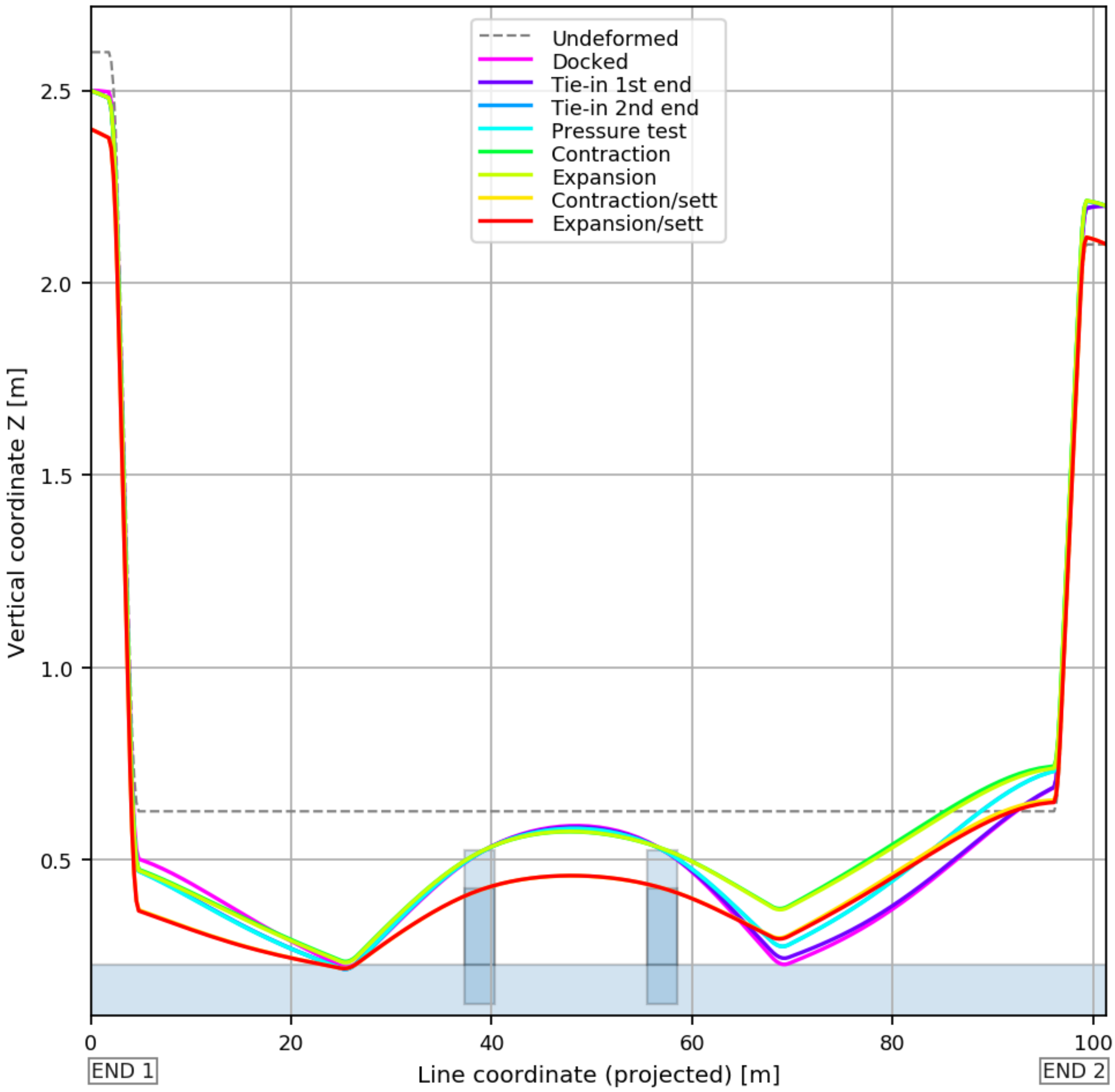
A top-view of the deformed shapes, for the most utilised load case (number 15), are shown for each load step in Figure 10.9.

Figure 10.9 – Top-View of Deformed Shapes of Critical Load Case



A profile view of the deformed shapes, for the most utilised load case (number 15), are shown for each load step in Figure 10.10.

Figure 10.10 – Profile View Deformed Shape of Critical Load Case



10.8 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.

10.8.1 End 1

The maximum magnitude reaction loads at End 1 of the spool, from any of the analysed load cases, are presented in Table 10.4 for each subsequent load step.

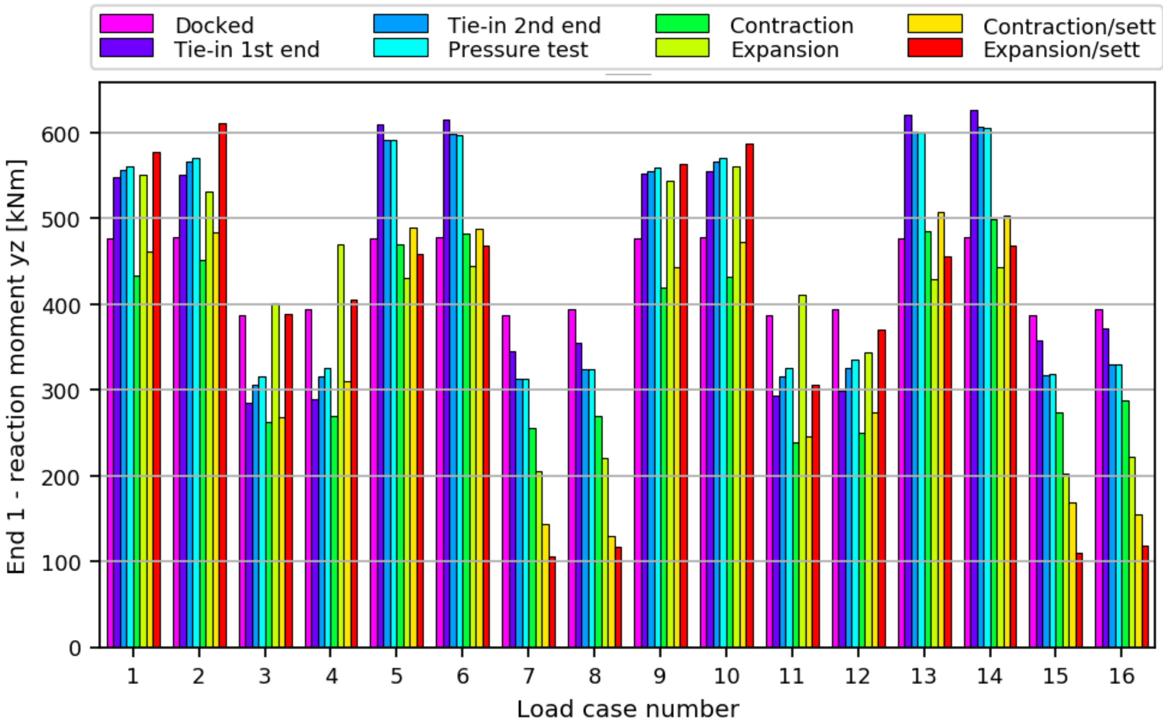
Table 10.4 – Maximum Magnitude Reaction Loads at End 1

Load Step	End Reaction Forces [kN]			End Reaction Moments [kNm]			
	RFx	RFy	RFz	RMx	RMy	RMz	RMb
Docked	2.9	-0.9	88.3	0.0	477.7	-9.8	477.7
Tie-in 1st end	24.5	-23.1	93.2	-0.0	567.1	268.1	627.3
Tie-in 2nd end	23.2	-14.9	93.2	17.7	574.4	-210.6	607.2
Pressure test	18.6	-13.4	93.1	19.9	575.8	-219.7	605.7
Contraction	7.2	11.6	75.5	40.6	450.1	216.3	499.4
Expansion	9.5	-14.2	75.7	41.3	439.6	-435.2	560.7
Contraction/sett	5.8	16.2	76.5	53.4	471.0	-294.4	507.8
Expansion/sett	6.9	-11.4	76.7	51.1	466.4	-434.6	611.1
Max	24.5	-23.1	93.2	53.4	575.8	-435.2	627.3

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

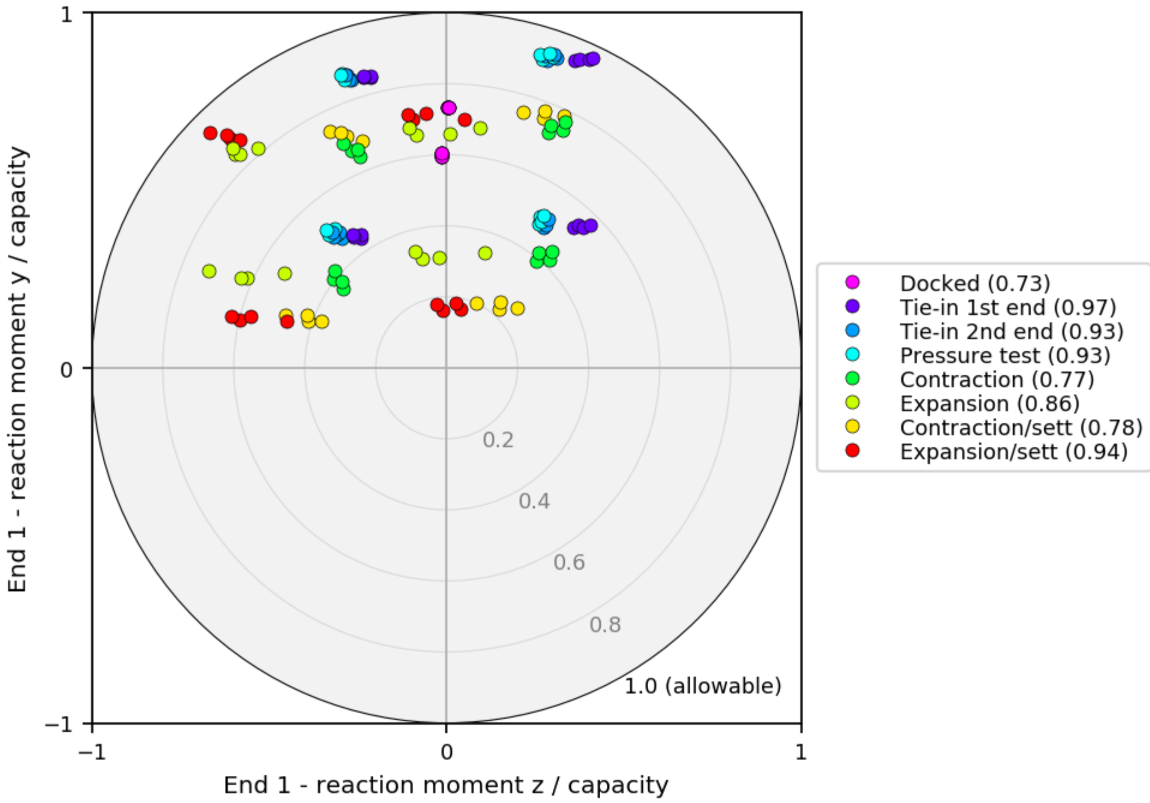
The maximum magnitude reaction bending moment at End 1, for each load case and load step, is shown in Figure 10.11.

Figure 10.11 – 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 10.12.

Figure 10.12 – 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.

10.8.2 End 2

The maximum magnitude reaction loads at End 2 of the spool, from any of the analysed load cases, are presented in Table 10.5 for each subsequent load step.

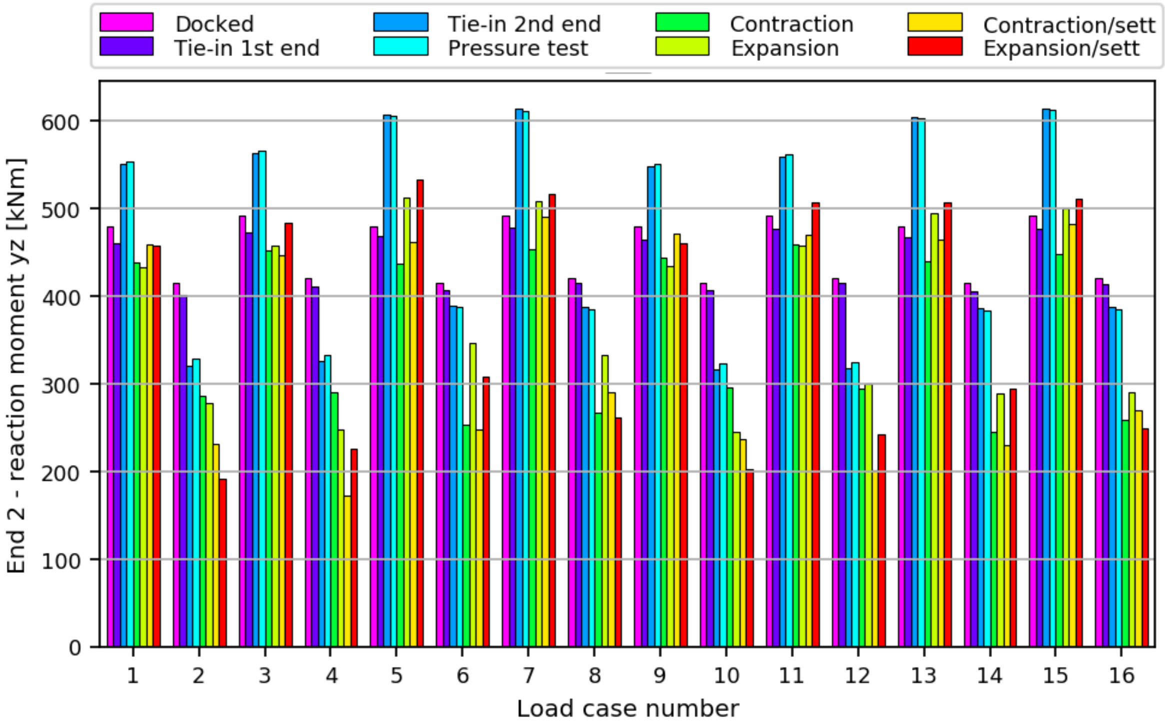
Table 10.5 – Maximum Magnitude Reaction Loads at End 2

Load Step	End Reaction Forces [kN]			End Reaction Moments [kNm]			
	RFx	RFy	RFz	RMx	RMy	RMz	RMb
Docked	5.1	1.1	90.2	-0.0	491.7	-5.0	491.7
Tie-in 1st end	18.1	4.1	90.3	-0.0	477.0	-27.7	477.5
Tie-in 2nd end	23.3	17.0	93.3	-0.0	561.9	-255.5	614.5
Pressure test	18.8	15.6	93.3	-1.6	563.6	-247.7	612.7
Contraction	17.0	14.9	74.2	-15.2	410.3	233.2	459.0
Expansion	-24.7	-22.7	73.7	-35.2	442.5	-279.7	512.5
Contraction/sett	16.7	18.5	75.3	-20.2	431.2	-264.3	489.9
Expansion/sett	-28.4	-22.9	74.7	-47.5	468.1	-277.3	532.6
Max	-28.4	-22.9	93.3	-47.5	563.6	-279.7	614.5

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

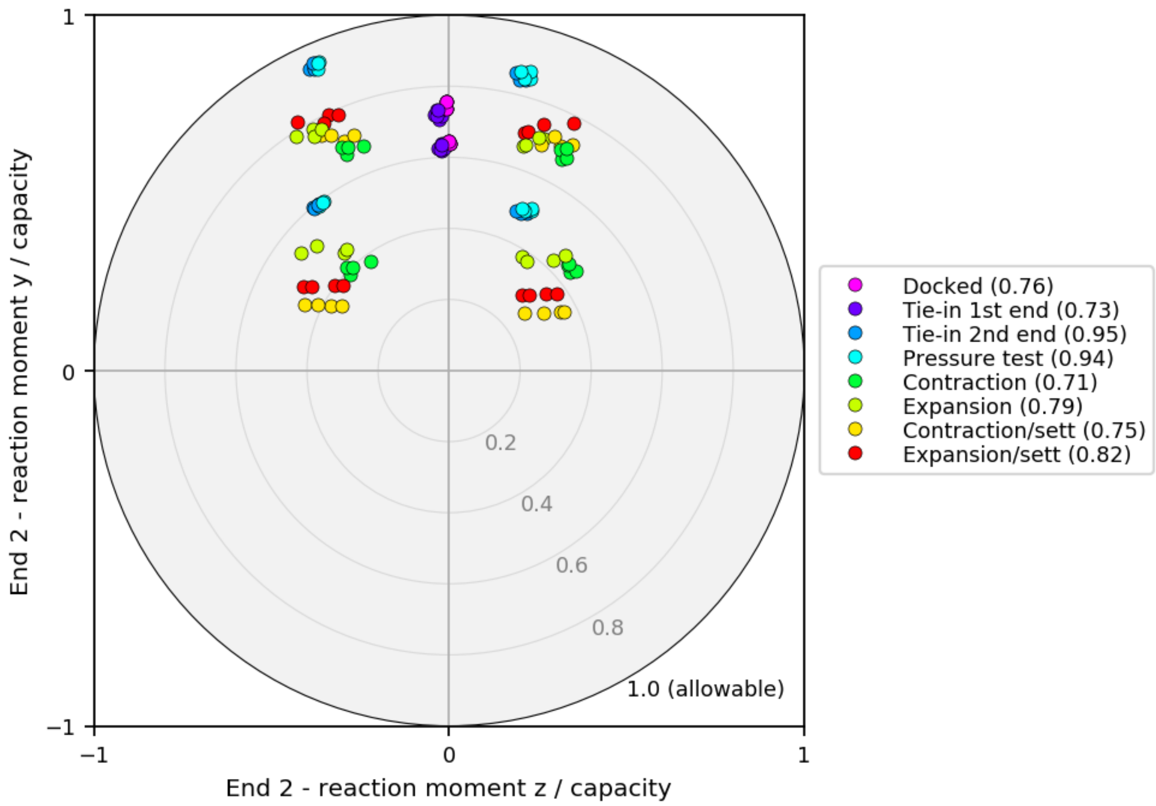
The maximum magnitude reaction bending moment at End 2, for each load case and load step, is shown in Figure 10.13.

Figure 10.13 – 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 10.14.

Figure 10.14 – Reaction Bending Moment Components at End 2

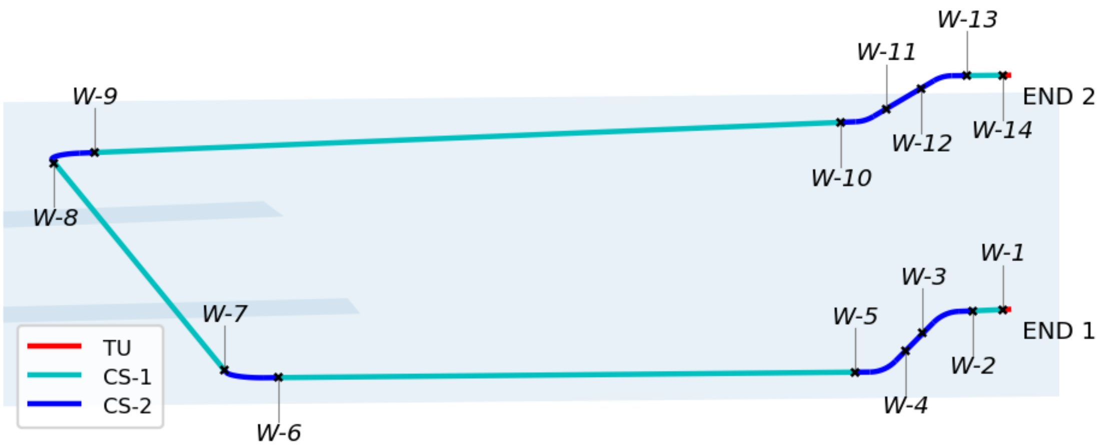


The shaded circular area indicates the allowable. The maximum utilisation is presented for each load step within parenthesis in the figure legend.

10.9 Fatigue Damage due to VIV

The welds assessed for fatigue damage due to VIV are shown in Figure 10.15.

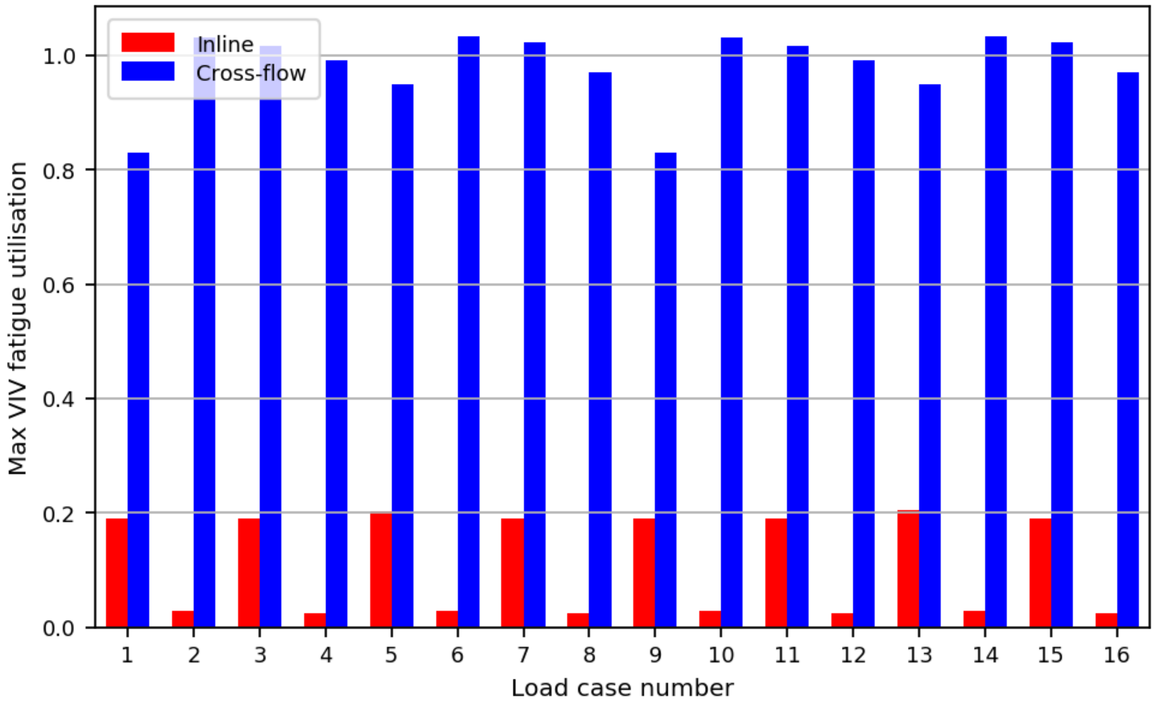
Figure 10.15 – Assessed Welds



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 10.16.

Figure 10.16 – Maximum VIV Fatigue Utilisation for Each Load Case

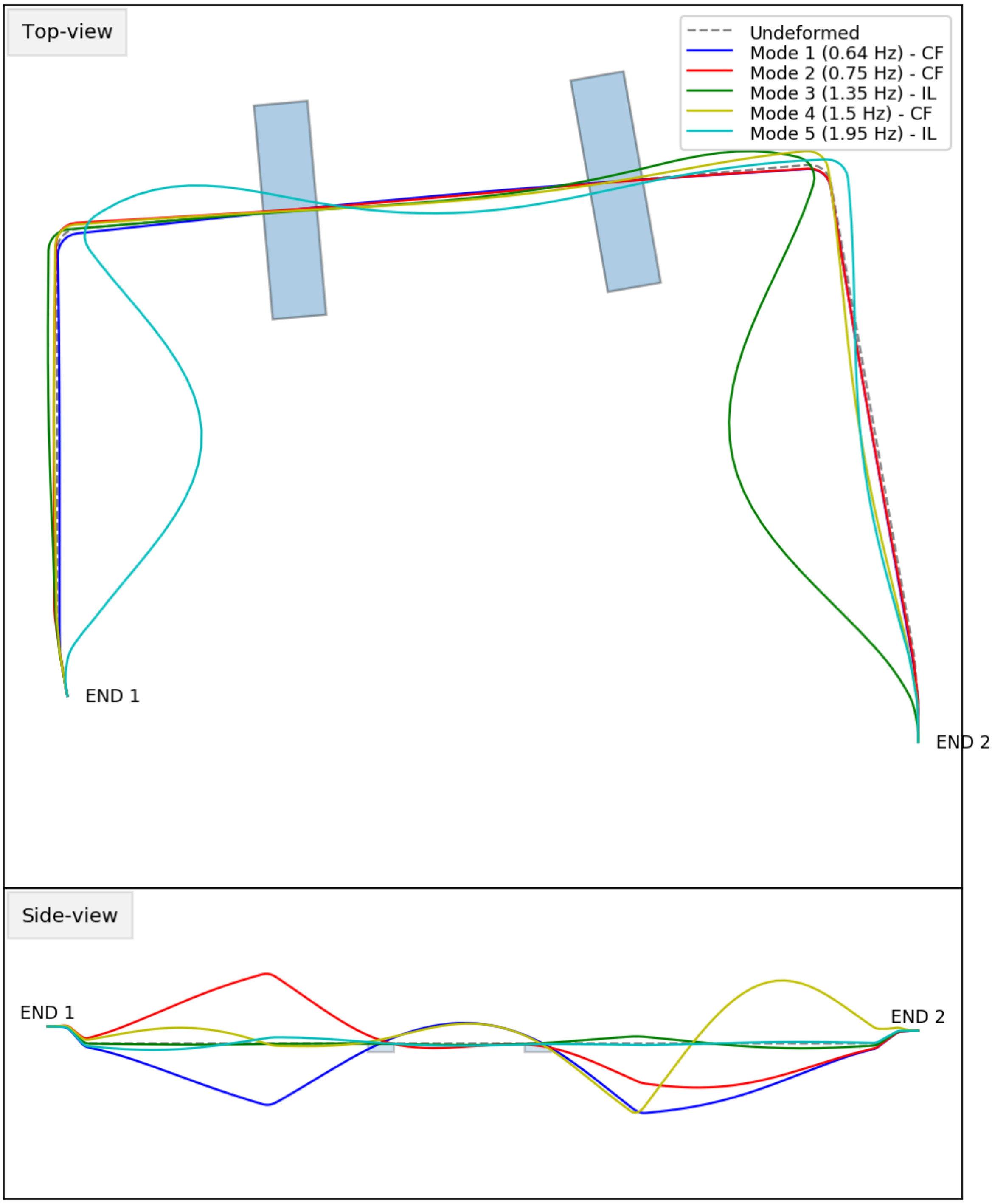


Inline and Cross-Flow utilisations are presented separately, and indicated that the damage has been accumulate at a specific location around the circumference.

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 10.17.

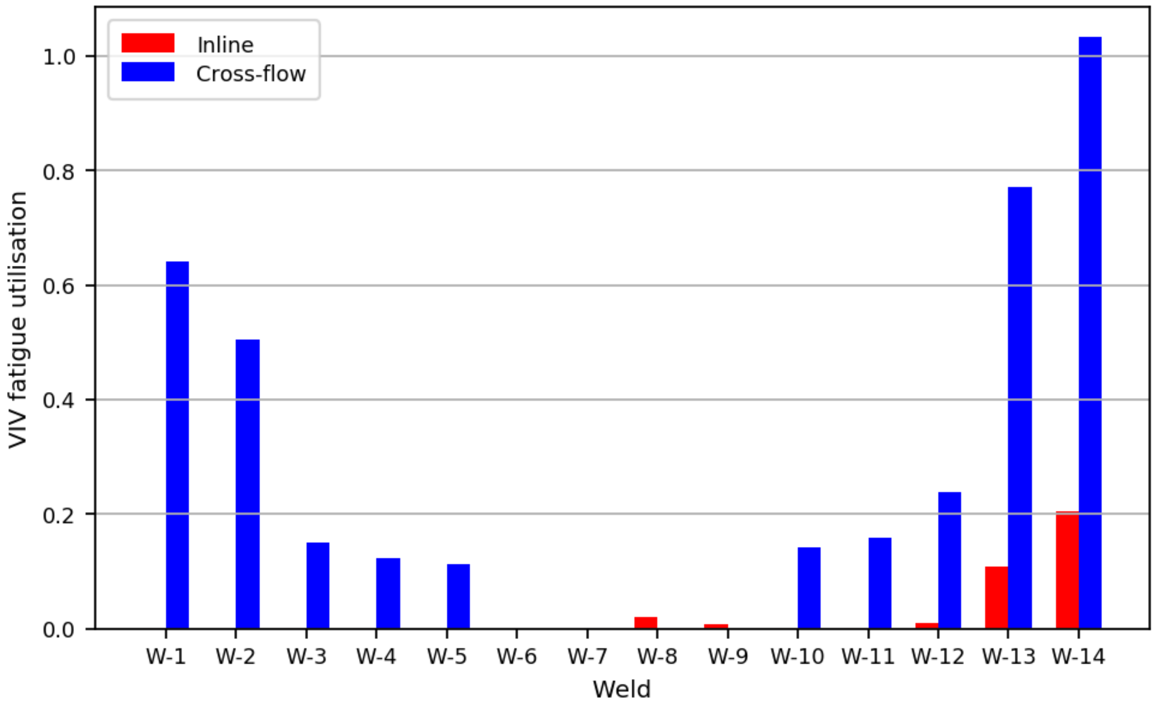
Figure 10.17 – Eigen-Modes of Most Utilised Load Case



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 10.18.

Figure 10.18 – Maximum VIV Fatigue Utilisation at Each Weld



10.10 Support Loads

The maximum vertical support forces, from any of the analysed load cases, are presented in Table 10.6, for each subsequent load step.

Table 10.6 – Maximum Vertical Forces Acting on Supports and Seabed

Load Step	Vertical Force [kN]		
	SEABED	Support-4	Support-5
Docked	5.7	53.7	68.0
Tie-in 1st end	13.9	53.0	72.2
Tie-in 2nd end	21.3	56.3	70.4
Pressure test	21.6	56.3	70.3
Contraction	0.0	42.7	57.1
Expansion	0.0	43.6	51.7
Contraction/sett	21.4	35.9	44.6
Expansion/sett	23.0	35.6	46.4
Max	23.0	56.3	72.2

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

11 CONFIGURATION MAX_L4

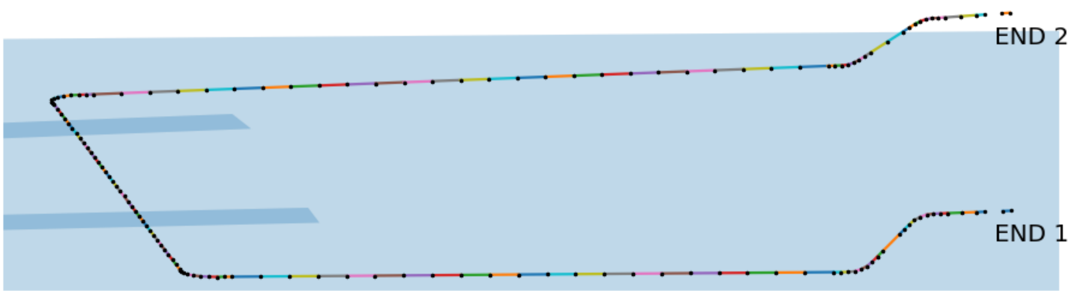
This section presents the following detailed results for configuration "max_L4".

- 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

11.1 FE-MODEL

The FE-model consists of the spool and two connecting structures at each end. The mesh density used is shown in Figure 11.1.

Figure 11.1 – 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.

11.2 SPOOL GEOMETRY

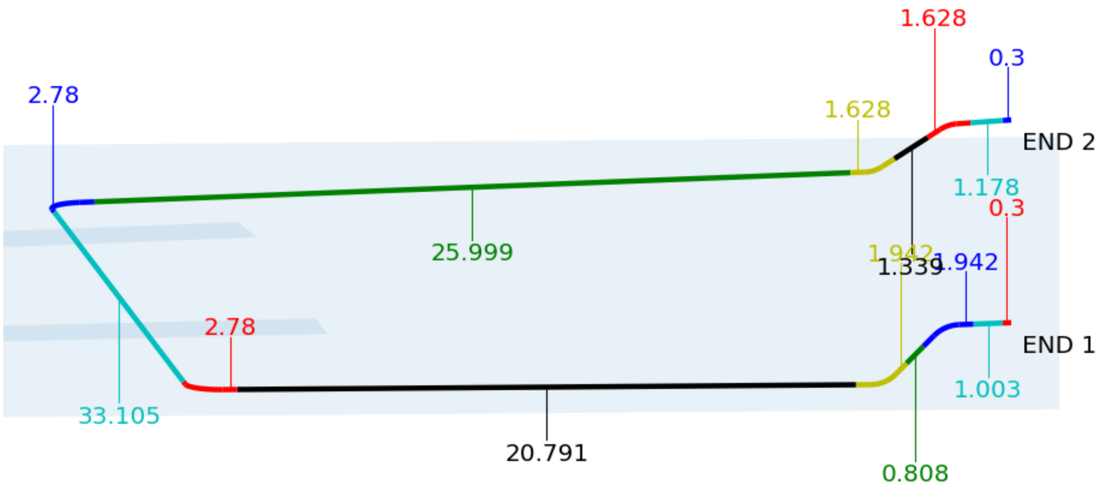
The coordinates at the spool ends and at the intersection points between the extended straight lines / sections, are presented in Table 11.1.

Table 11.1 – 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	36.704	33.399	0.626
IP-6	41.639	5.411	0.626
IP-7	42.31	2.906	2.1
IP-8	42.994	1.027	2.1
End 2	43.097	0.745	2.1

An isometric view of the spool showing each section length (units in meter) is shown in Figure 11.2.

Figure 11.2 – Isometric View with Section Lengths



11.3 Load Cases

A set of 16 load case combinations has been analysed, as presented in Table 11.2. The prescribed end displacement / rotation values refer to uncertainties regarding make-up tolerances at each spool end.

Table 11.2 – 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.

11.4 Load Steps

The spool have been analysed for the subsequent load steps presented in Table 11.3.

Table 11.3 – Subsequent Load Steps

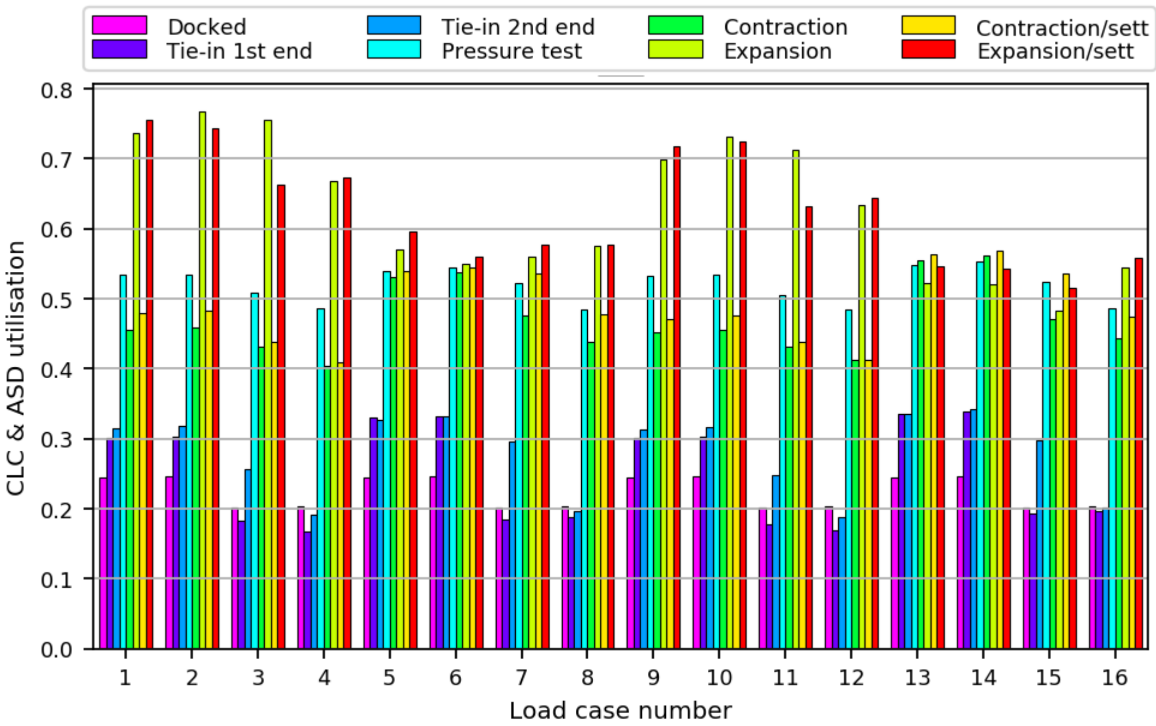
Load Step	Internal Pressure [bara]	Temperature [°C]	Content Density [kg/m3]	Axial Expansion - End 2 [m]
Docked	20	10	1150	0
Tie-in 1st end	20	10	1150	0
Tie-in 2nd end	20	10	1150	0
Pressure test	400	10	1150	0
Contraction	300	-20	250	-1.0
Expansion	300	100	250	3.0
Contraction/sett	300	-20	250	-1.0
Expansion/sett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

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

11.5 Spool CLC / ASD Utilisation

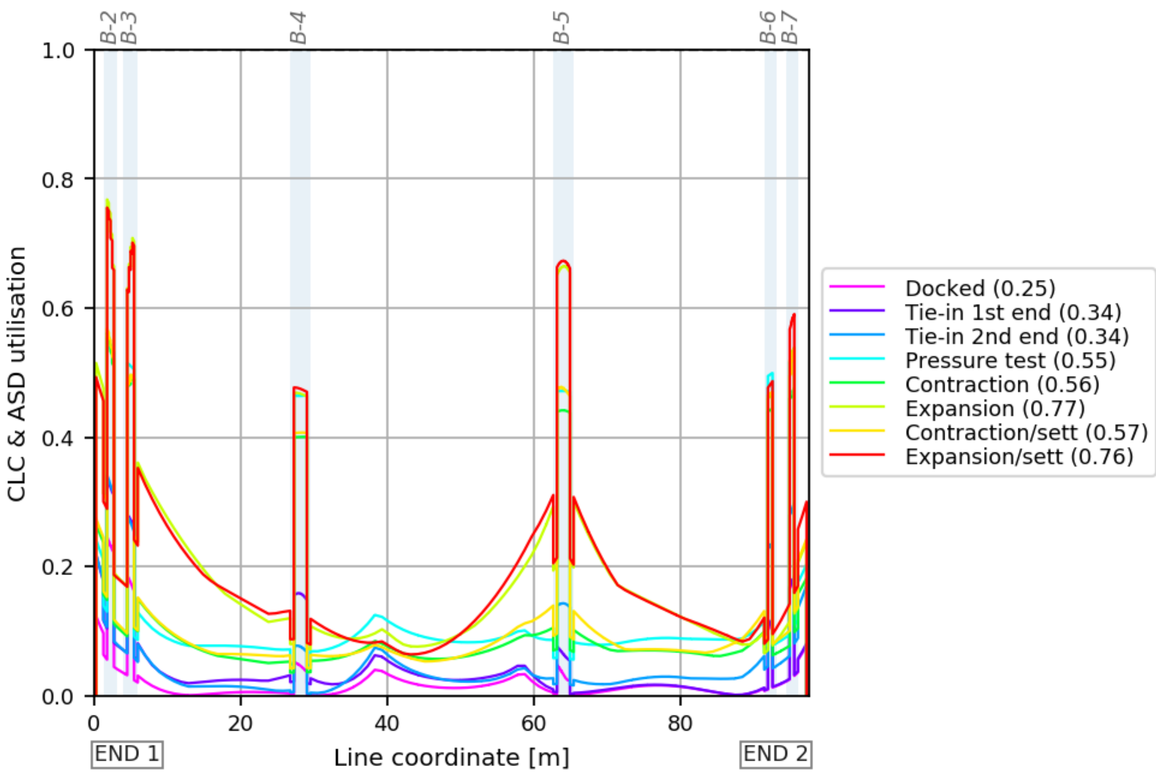
The maximum CLC / ASD utilisation along the spool, for each load case and load step, is shown in Figure 11.3.

Figure 11.3 – 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 11.4.

Figure 11.4 – Spool CLC / ASD Utilisation

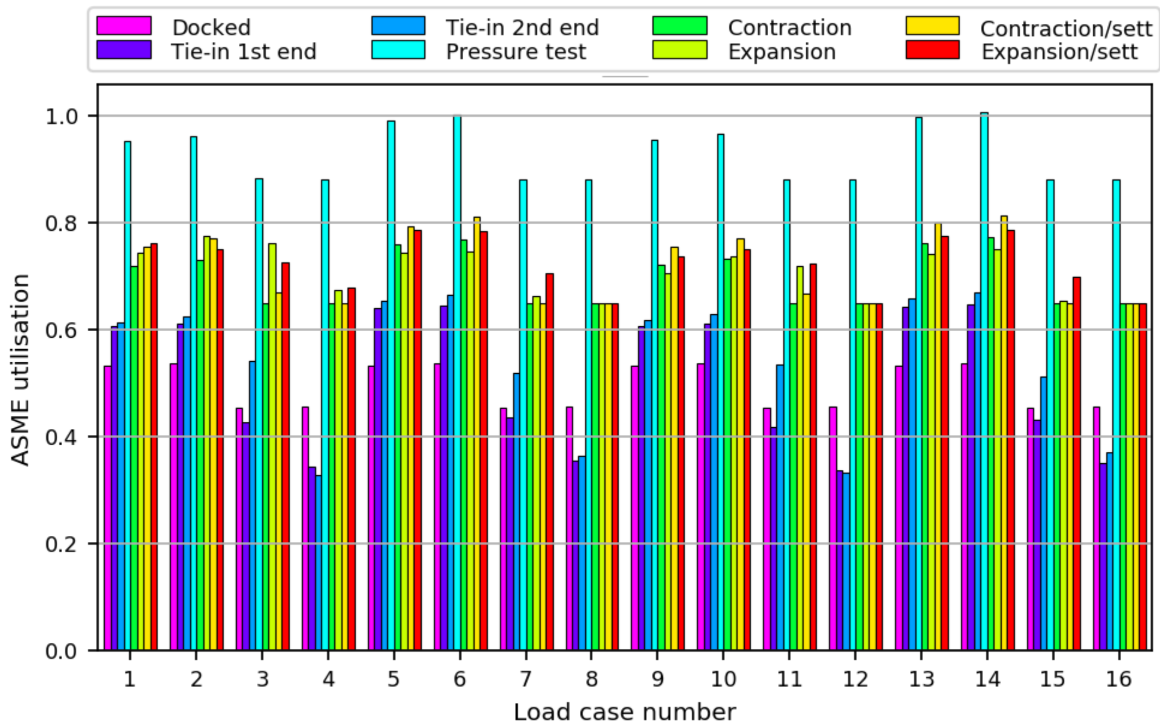


The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

11.6 Spool ASME Utilisation

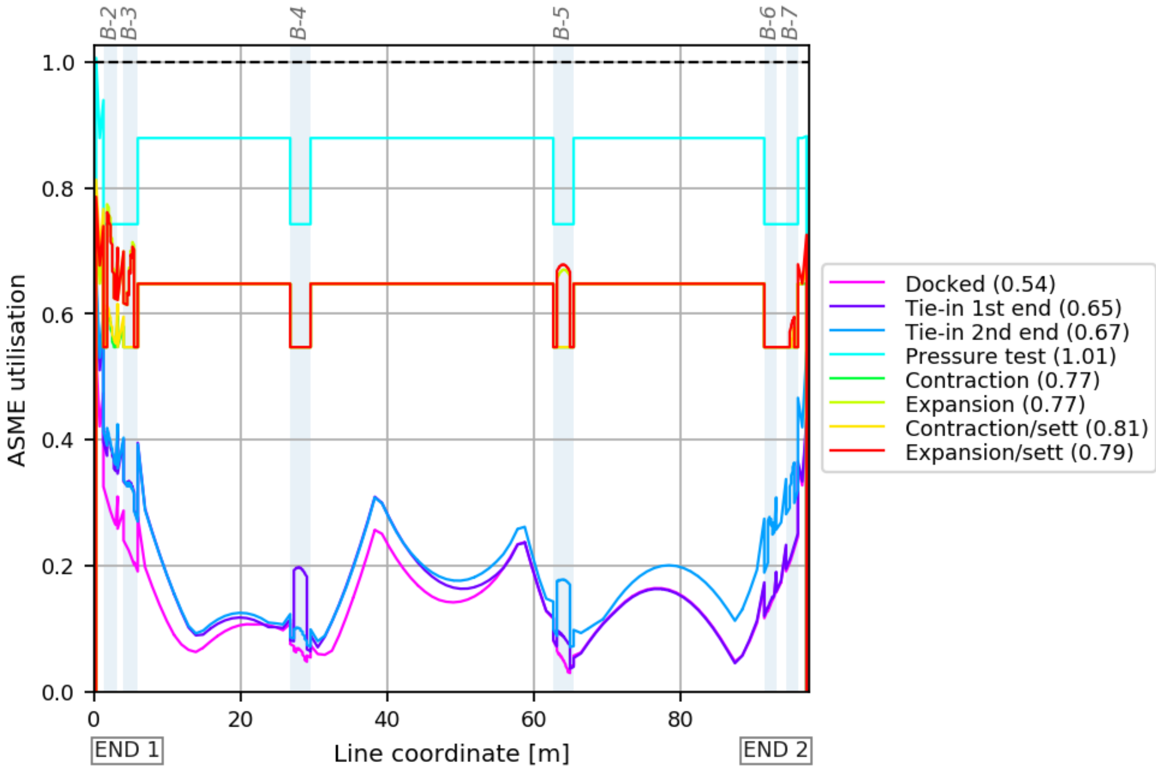
The maximum ASME utilisation along the spool, for each load case and load step, is shown in Figure 11.5.

Figure 11.5 – 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 11.6.

Figure 11.6 – Spool ASME Utilisation



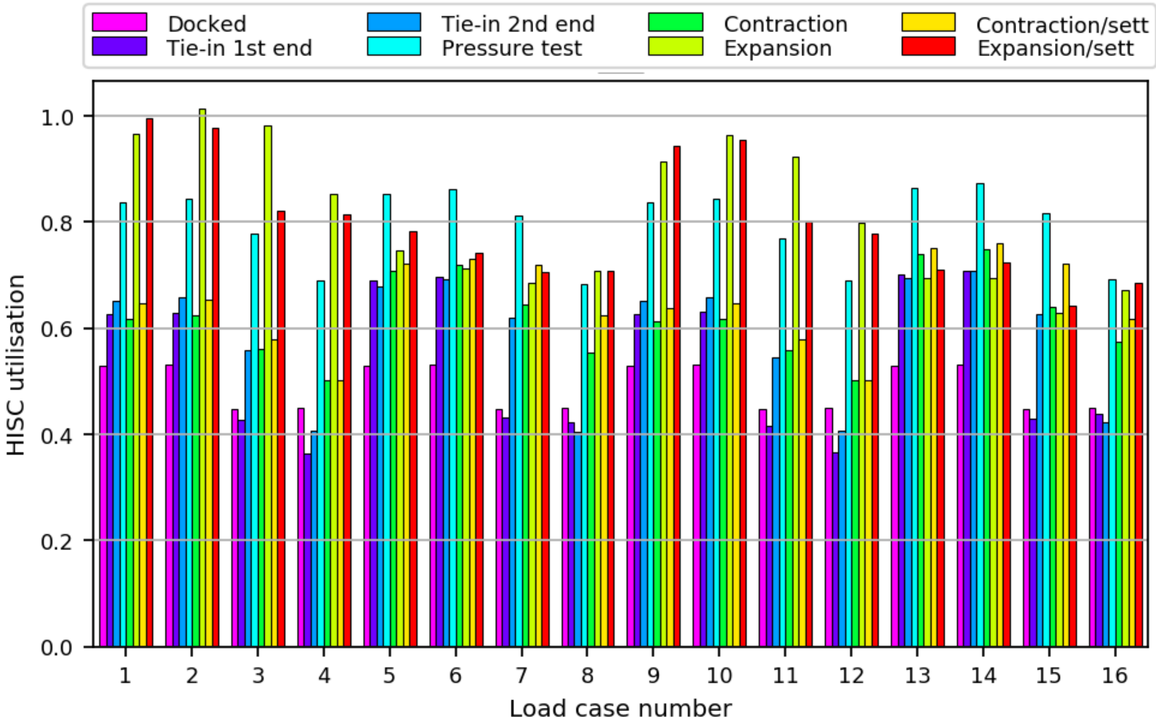
The line coordinate on the horizontal axis starts at End 1 of the spool and finish at End 2. The shaded area in the figure indicates spool bends including tangents. Bend labels are shown above the shaded areas. The maximum utilisation for each load step is presented within parenthesis in the figure legend.

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

11.7 Spool HISC Utilisation

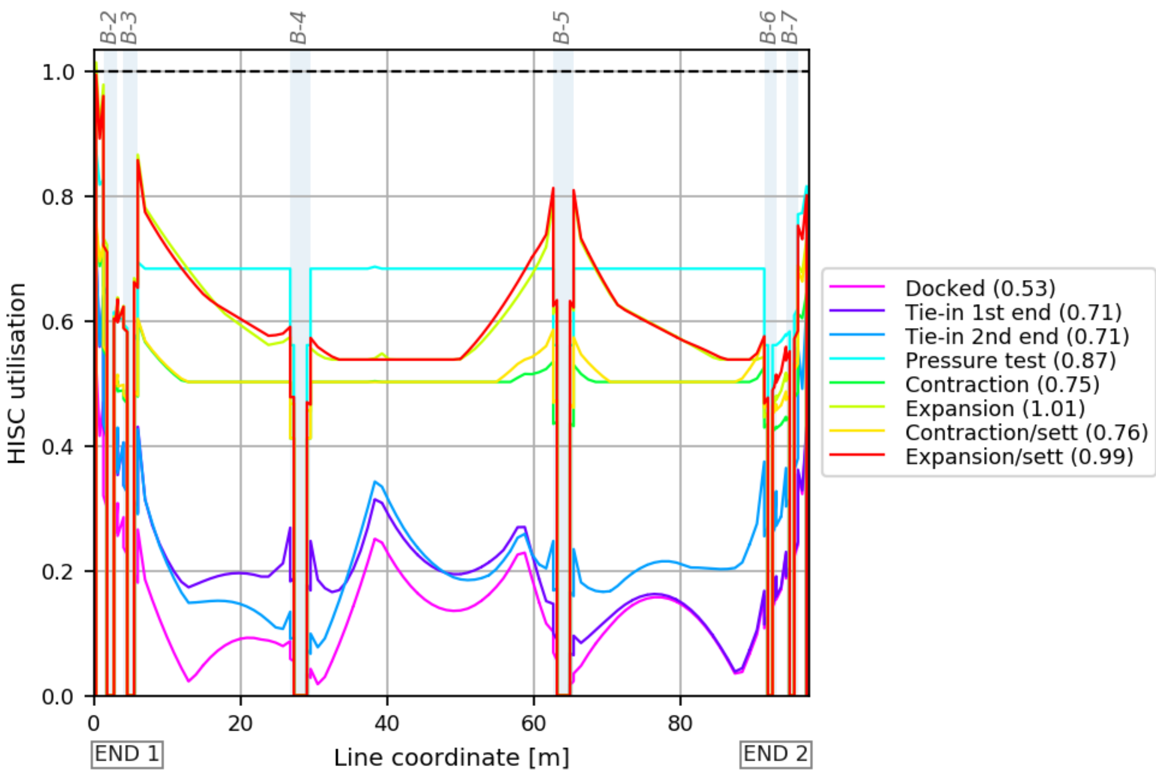
The maximum HISC utilisation along the spool, for each load case and load step, is shown in Figure 11.7.

Figure 11.7 – 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 11.8.

Figure 11.8 – 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.

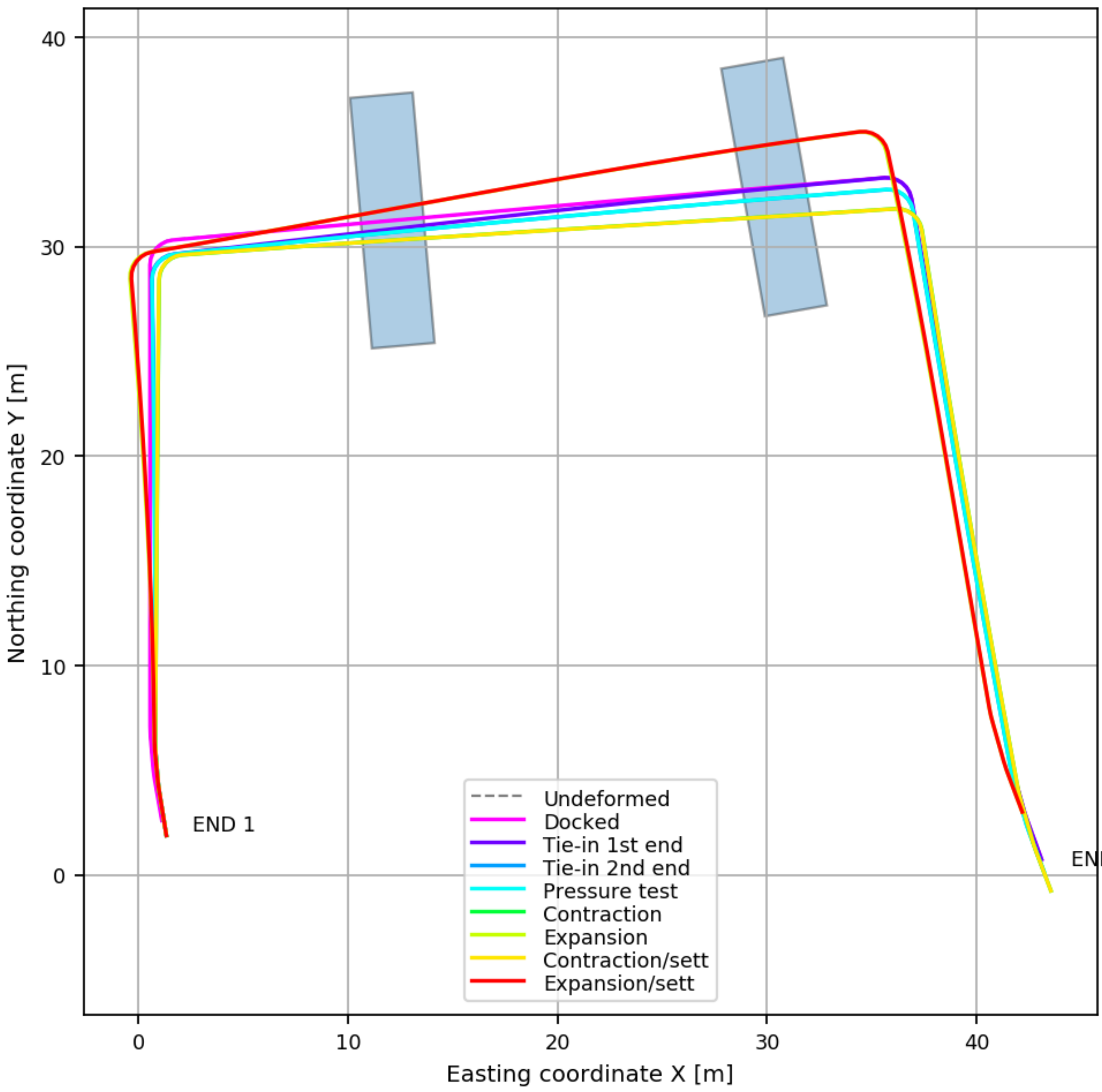
Longitudinal Stress Concentration Factors has been applied at each weld.

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.

11.7.1 Most Utilised Load Case - Number 2

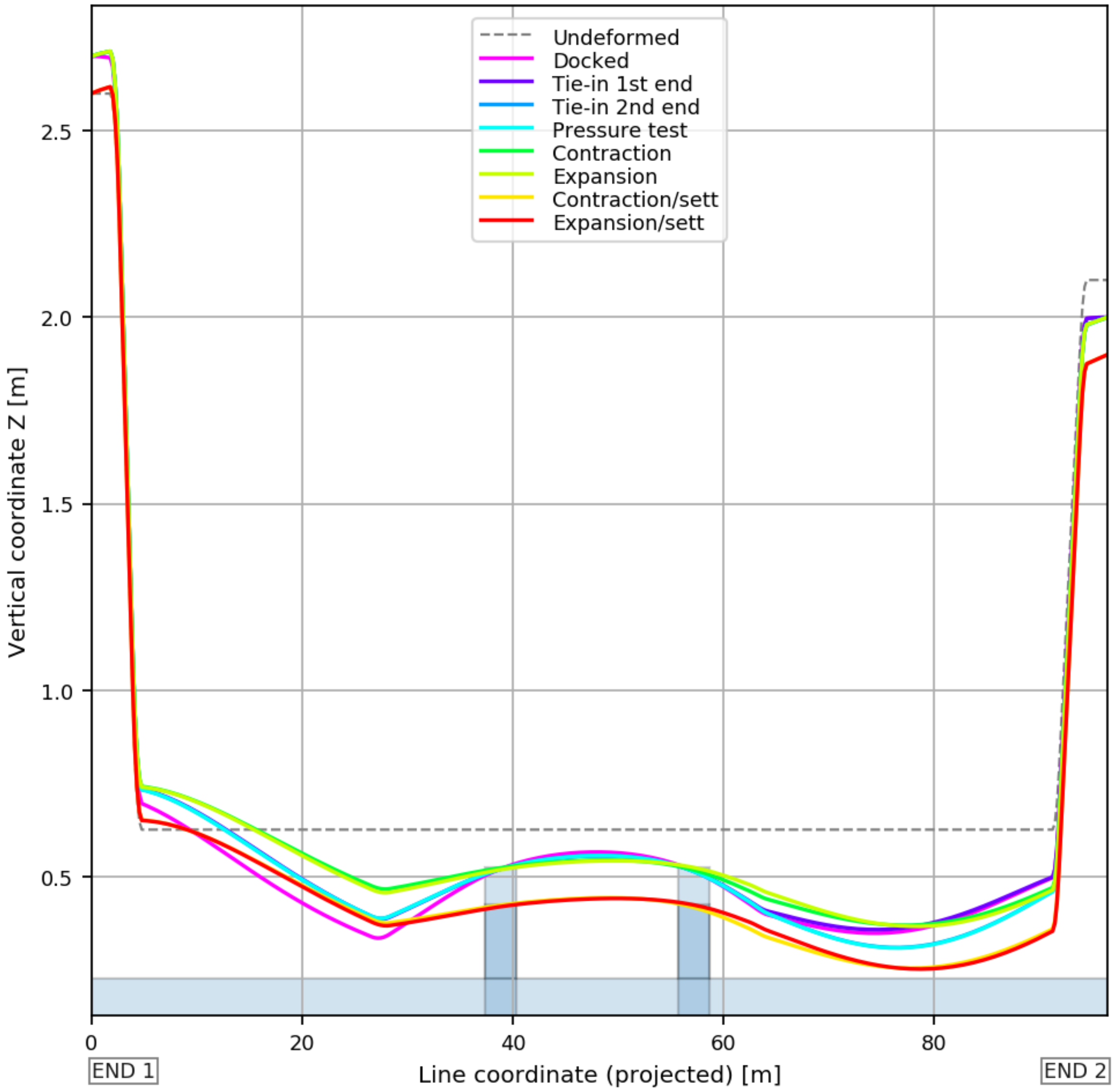
A top-view of the deformed shapes, for the most utilised load case (number 2), are shown for each load step in Figure 11.9.

Figure 11.9 – 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 11.10.

Figure 11.10 – Profile View Deformed Shape of Critical Load Case



11.8 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.

11.8.1 End 1

The maximum magnitude reaction loads at End 1 of the spool, from any of the analysed load cases, are presented in Table 11.4 for each subsequent load step.

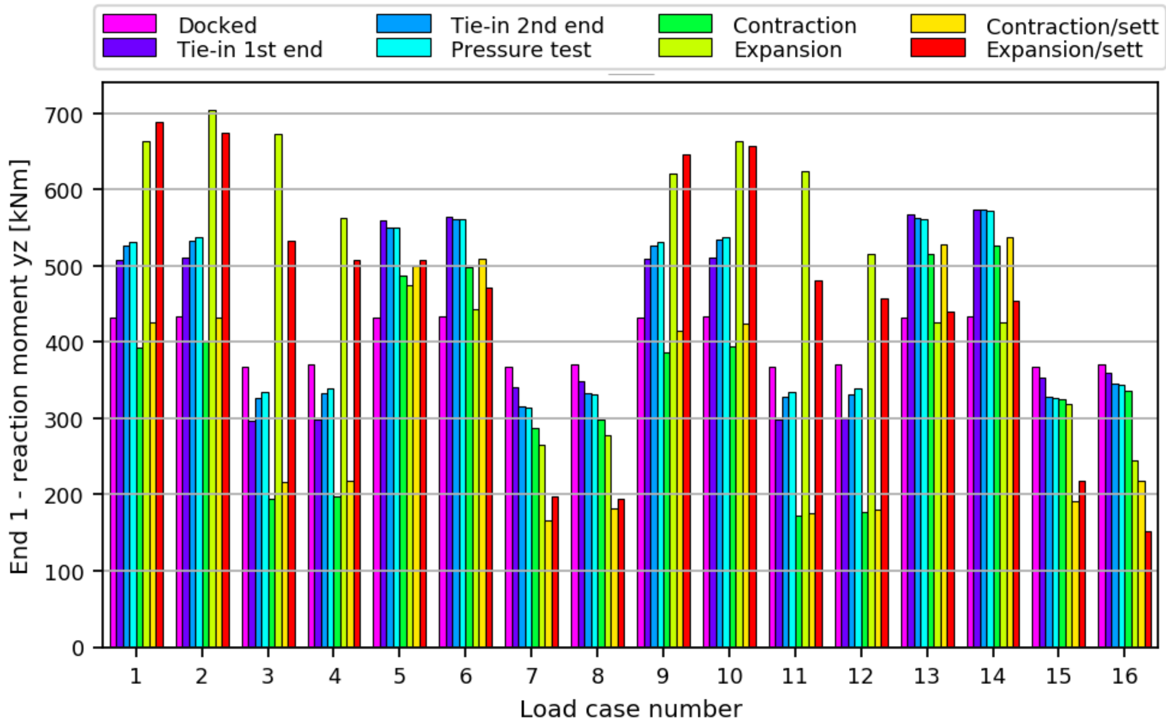
Table 11.4 – Maximum Magnitude Reaction Loads at End 1

Load Step	End Reaction Forces [kN]			End Reaction Moments [kNm]			
	RFx	RFy	RFz	RMx	RMy	RMz	RMb
Docked	3.0	-1.5	87.8	-0.0	433.8	9.1	433.9
Tie-in 1st end	22.1	-19.0	92.4	-0.0	522.3	235.9	573.1
Tie-in 2nd end	17.1	-11.1	92.6	17.2	540.0	-197.5	573.1
Pressure test	15.5	-10.1	92.6	18.8	541.9	-206.0	572.0
Contraction	-5.1	-8.8	74.9	29.2	424.7	311.6	526.8
Expansion	18.1	16.9	75.7	46.0	404.6	-656.7	704.9
Contraction/sett	-7.8	13.2	76.0	45.9	456.7	282.3	536.9
Expansion/sett	17.2	11.3	76.9	46.7	433.5	-565.1	688.4
Max	22.1	-19.0	92.6	46.7	541.9	-656.7	704.9

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

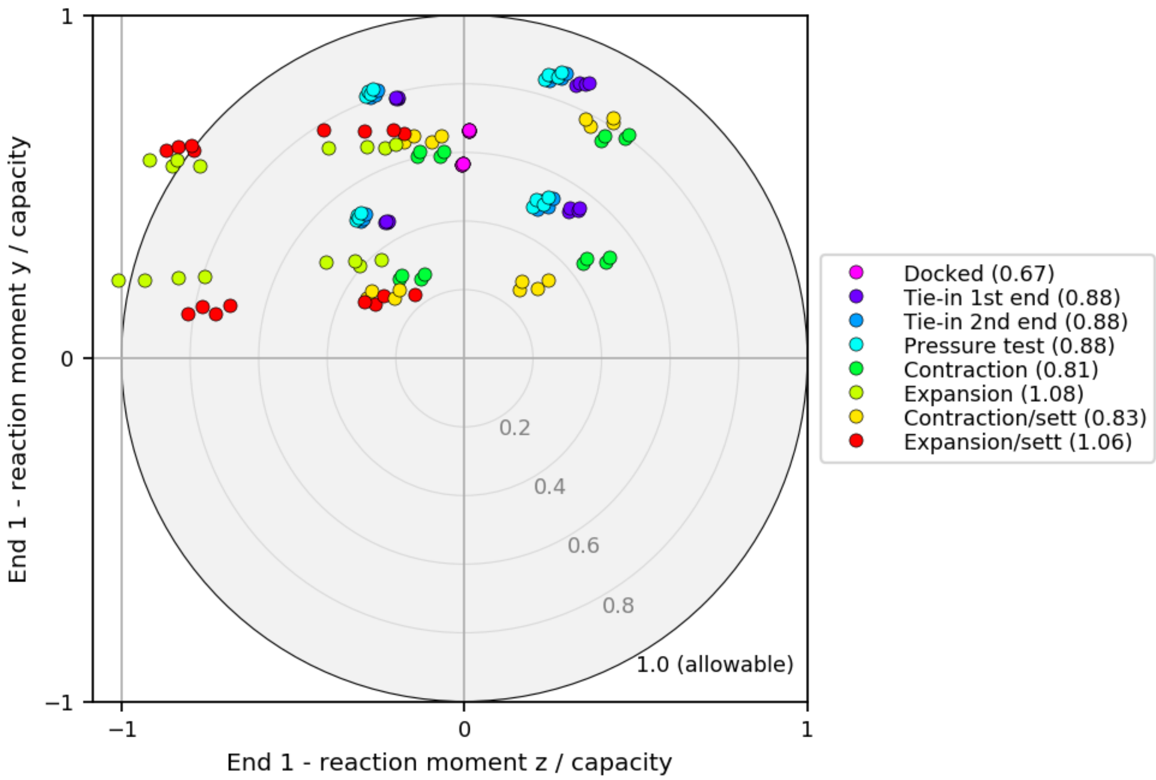
The maximum magnitude reaction bending moment at End 1, for each load case and load step, is shown in Figure 11.11.

Figure 11.11 – 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 11.12.

Figure 11.12 – 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.

11.8.2 End 2

The maximum magnitude reaction loads at End 2 of the spool, from any of the analysed load cases, are presented in Table 11.5 for each subsequent load step.

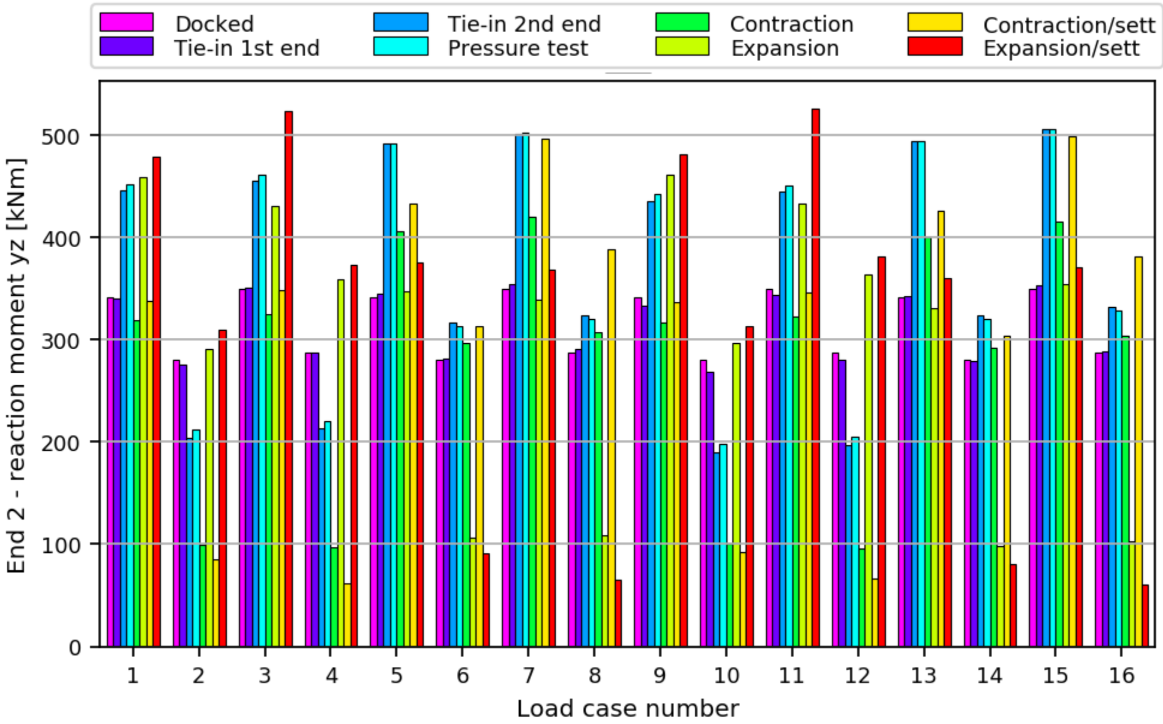
Table 11.5 – Maximum Magnitude Reaction Loads at End 2

Load Step	End Reaction Forces [kN]			End Reaction Moments [kNm]			
	RFx	RFy	RFz	RMx	RMy	RMz	RMb
Docked	8.9	-1.2	85.9	0.0	349.0	10.0	349.1
Tie-in 1st end	19.5	-5.5	86.2	-0.0	354.5	48.2	354.7
Tie-in 2nd end	28.9	10.7	89.3	-0.0	439.2	-291.3	505.7
Pressure test	24.3	10.7	89.2	-0.2	443.6	-284.6	505.7
Contraction	25.7	14.2	71.2	-21.1	313.4	-305.1	419.9
Expansion	-41.1	-20.9	70.2	-58.2	350.1	347.8	461.2
Contraction/sett	29.5	18.3	72.2	-24.1	342.8	-388.3	499.0
Expansion/sett	-37.4	-22.6	71.2	-66.0	386.0	373.2	526.5
Max	-41.1	-22.6	89.3	-66.0	443.6	-388.3	526.5

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

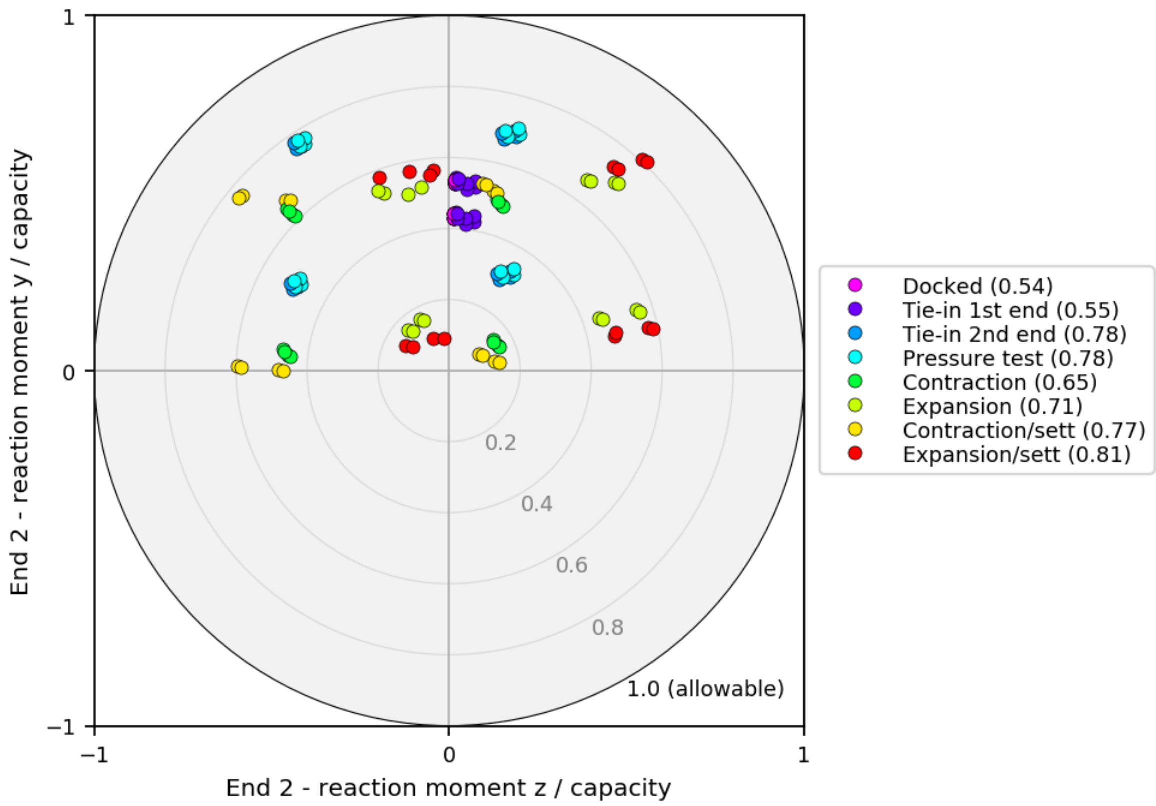
The maximum magnitude reaction bending moment at End 2, for each load case and load step, is shown in Figure 11.13.

Figure 11.13 – 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 11.14.

Figure 11.14 – Reaction Bending Moment Components at End 2

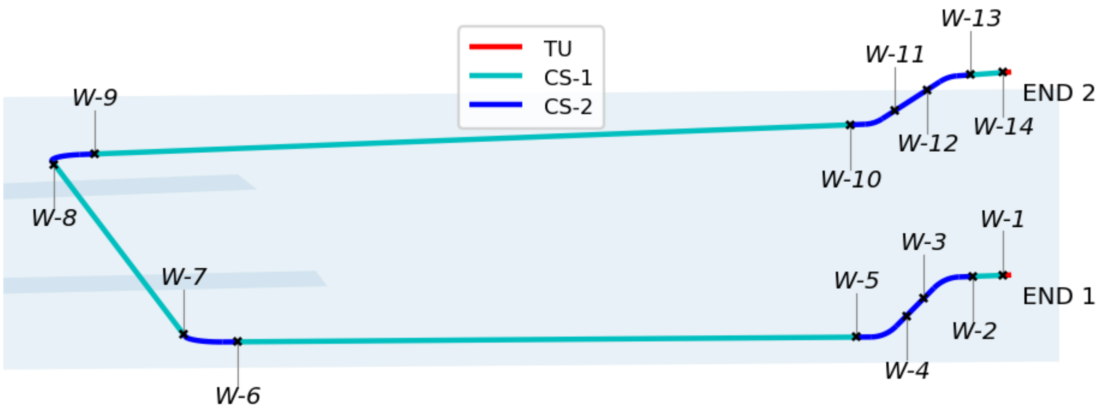


The shaded circular area indicates the allowable. The maximum utilisation is presented for each load step within parenthesis in the figure legend.

11.9 Fatigue Damage due to VIV

The welds assessed for fatigue damage due to VIV are shown in Figure 11.15.

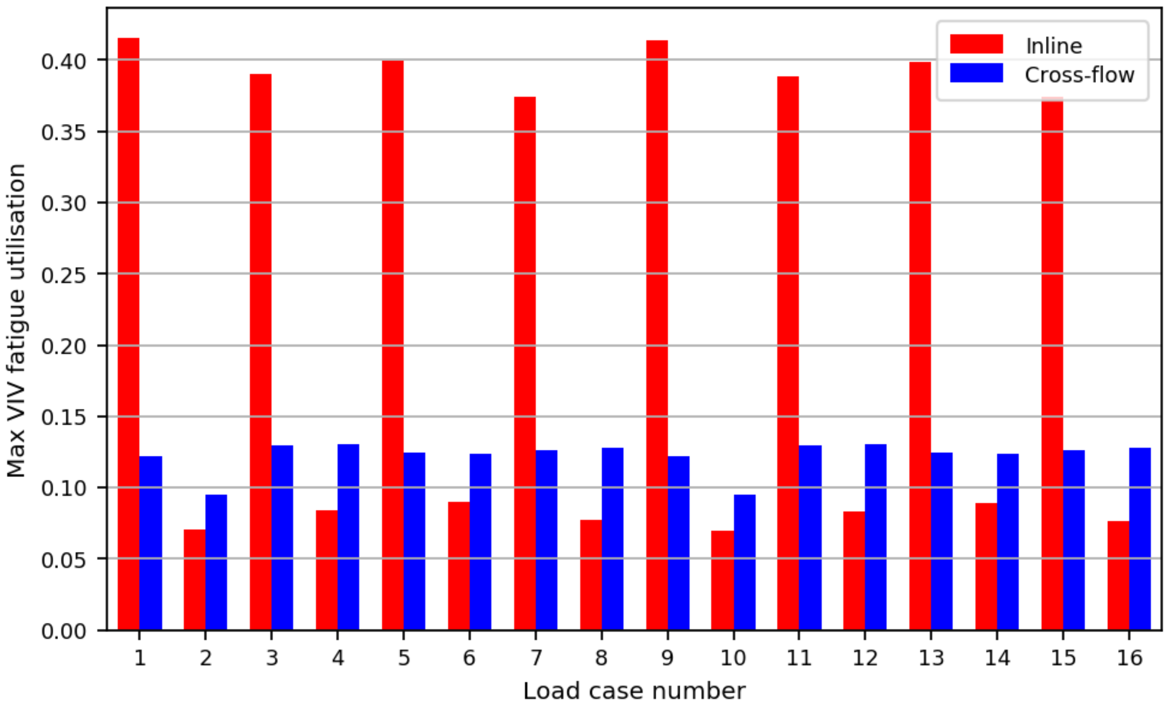
Figure 11.15 – Assessed Welds



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 11.16.

Figure 11.16 – Maximum VIV Fatigue Utilisation for Each Load Case

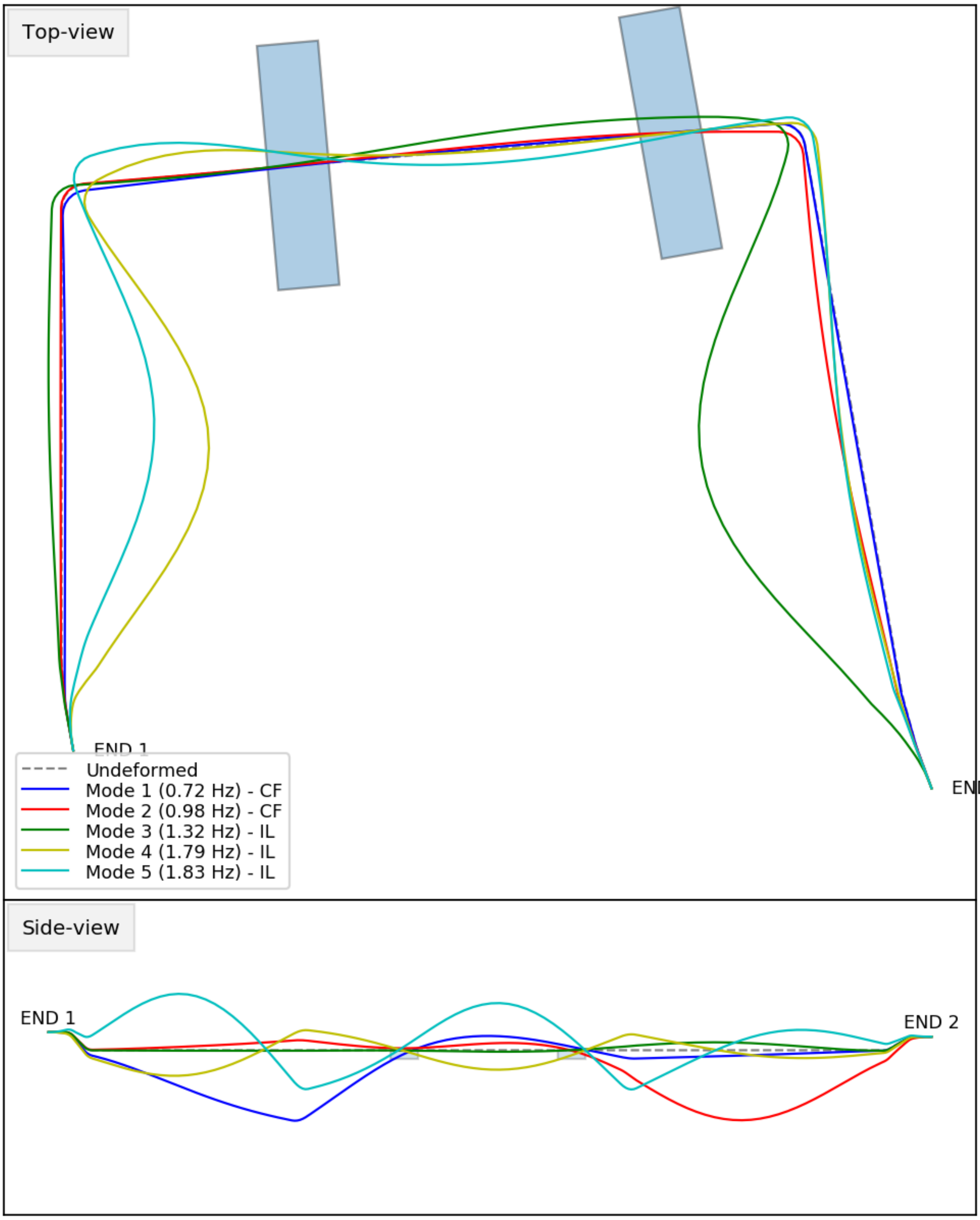


Inline and Cross-Flow utilisations are presented separately, and indicated that the damage has been accumulate at a specific location around the circumference.

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 11.17.

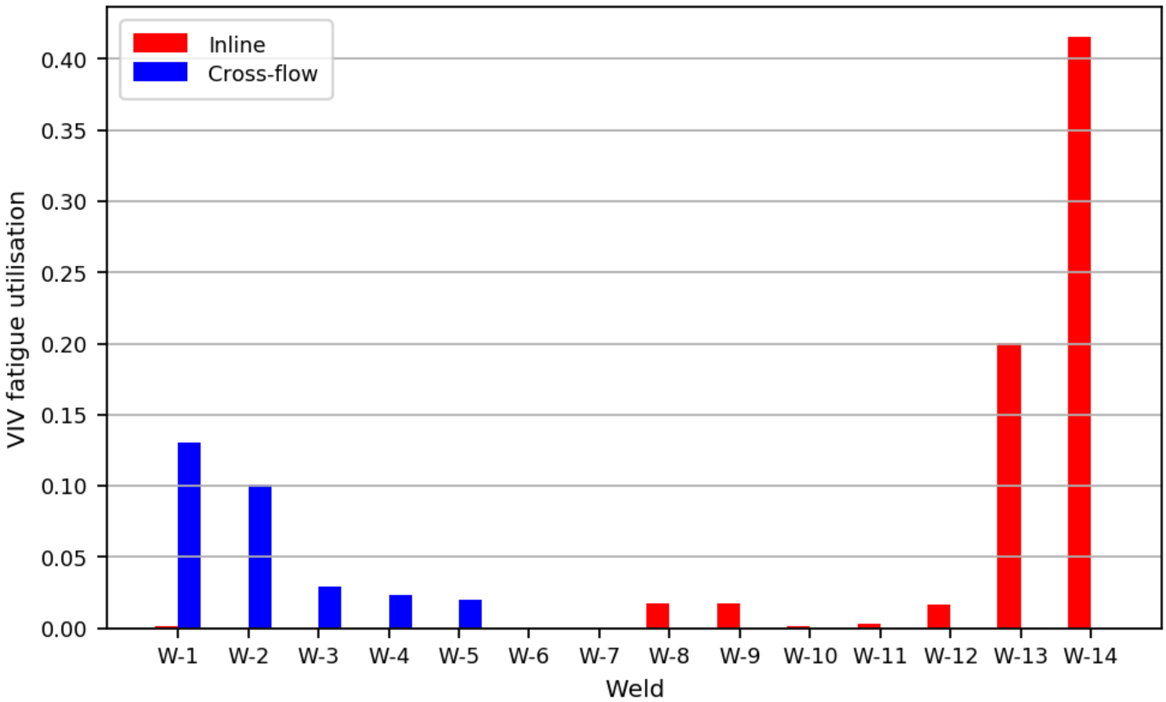
Figure 11.17 – Eigen-Modes of Most Utilised Load Case



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 11.18.

Figure 11.18 – Maximum VIV Fatigue Utilisation at Each Weld



11.10 Support Loads

The maximum vertical support forces, from any of the analysed load cases, are presented in Table 11.6, for each subsequent load step.

Table 11.6 – Maximum Vertical Forces Acting on Supports and Seabed

Load Step	Vertical Force [kN]		
	SEABED	Support-4	Support-5
Docked	0.0	60.3	62.3
Tie-in 1st end	1.1	65.5	64.4
Tie-in 2nd end	2.1	66.4	68.7
Pressure test	2.2	66.5	68.8
Contraction	0.0	41.6	46.7
Expansion	0.0	42.7	45.3
Contraction/sett	6.7	39.5	48.4
Expansion/sett	10.2	36.3	47.1
Max	10.2	66.5	68.8

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