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FFP ASSESSMENT REPORT
32” NATURAL GAS PIPELINE
PENÁPOLIS – SÃO CARLOS

TBG

1-5500-12584-FFP-32PENSAO Rev 0

Inspection Direction: PENÁPOLIS to SÃO CARLOS

empowered by technology

0	11/07/2018	96	Draft for Review	A.J. Blenkinsop A. Blenkinsop	A. Wynne	B. Kerrigan
Rev.	**Date**	**Pages**	**Description**	**Prepared by**	**Reviewed by**	**Approved by**

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EXECUTIVE SUMMARY

Transportadora Brasileira Gasoducto Bolívia-Brasil (TBG) owns the 32 inch, 244.45 km onshore gas pipeline from Penápolis to São Carlos, known as the 32PENSAO pipeline. The pipeline was designed according to ASME B31.8.

The GASBOL system was constructed and commissioned in 1999 from submerged arc welded (SAW) pipe conforming to API 5L Grade X70. The nominal wall thicknesses (wt.) of the pipeline are 11.46 mm, 13.74 mm, 16.51 mm.

ROSEN completed an internal inspection of 32PENSAO between November 2017 and January 2018 using the ROSEN MFL-C and the RoCD EMAT-C inspection tools. The data was combined with previous geometry and mapping tools which were run in 2014. The pipeline was also previously inspected by BAKER HUGHES in June 2017 using their CORRSIGHT™ HR+DEF combo inspection service.

Summary of ROSEN 2018 and 2014 Inspection Findings

2018 ROSEN EMAT-C & 2017 ROSEN MFL-C Inspections		
Feature	**Number Reported**	**Deepest Feature**
Crack-Like Anomaly	0[1]	n/a
Linear Anomaly in Longitudinal Weld Area	Nil	-
Internal Corrosion	Nil	-
External Corrosion	25	68% wt.
Corrosion (surface Location: N/A)	4	49% wt.
Pipe Mill Anomaly	10	16% wt.
Girth Weld Anomaly	42	26% wt.
Other Anomaly	31	-
Repaired Anomaly	7	-
2014 ROSEN Geometric Inspection		
Dent	34	2.66% Max. ID Reduction
Wrinkle	385	2 – 6 mm
Bending Strain Areas	27	0.49% Max. Strain
Strain - Construction Irregularities	17	0.41% Max. Strain
Total	**582**	**-**

This report provides TBG with a Fitness for Purpose (FFP) assessment of the 32PENSAO based upon the findings of the 2018 and 2014 ROSEN inspections.

[1] 6 crack-like anomalies reported in the preliminary report but none reported at the final reporting stage following in-field verification findings.

Key Findings

The primary findings of the study for the GASBOL pipeline (32PENSAO) are listed below. Detailed conclusions are provided in Section 16 of this report.

1. Four crack-like features were listed in the 2018 ROSEN EMAT-C final inspection report. However, all features have since been subject to investigation and remediated as such they are no longer considered to be an integrity threat to the 32PENSAO pipeline.

2. For illustrative purposes, a remnant life assessment was completed for a theoretical pipe body SCC crack located within the thinnest wall thickness (11.46 mm) with a depth of 2 mm, the detection threshold of the 2018 EMAT tool. Conservatively, a crack length of 100 mm and growth rate of 0.3 mm per year was assumed. The assessment predicted that a 2 mm deep, 100 mm long theoretical SCC crack would have a remnant life of 9.5 years from the 2018 EMAT-C inspection (i.e. June 2027).

3. Based on the pressure cycling data provided, the fatigue life of any long seam planar feature (with dimensions equal to the detection threshold at 90% confidence) is predicted have a fatigue life in excess of 100 years assuming the feature is not SCC (see point 2).

4. The 2017 EMAT inspection classified the levels of coating disbondment found on each pipe joint throughout the length of the pipeline into 5 categories. All of the pipe joints (100%) were identified to be in ‘excellent’ or ‘good’ coating condition. No joints were reported as ‘poor’ or ‘very poor’.

5. A total of 25 external corrosion features were reported by the ROSEN 2017 MFL-C inspection, the deepest of which was reported to have a depth of 68% wt at log distance 37220.495 m. This feature was verified in May 2018 to be 61% wt deep.

6. The 2017 ROSEN MFL-C inspection reported 4 corrosion features with the location classification “N/A”, the maximum depth being 49% wt associated with a feature at log distance 36520.597 m. For the purpose of the assessments these features have been treated as external corrosion features.

7. The significance of the reported corrosion features has been assessed in terms of their axial, circumferential and depth dimensions, according to the Modified B31.G, Detailed RSTRENG and Kastner assessment methods. 27 of the 29 corrosion features were found to be acceptable for operation, in terms of their respective axial, circumferential and depth dimensions, details of the two corrosion features requiring immediate repair are provided below. It should be noted that the feature located at log distance 37220.495 m was remediated in May 2018.

Log Distance (m)	Joint Number	Event	Location	Orientation (hh:mm)	Depth (%wt)	Length (mm)	Width (mm)
36520.597	30250	Cluster	N/A	03:45	49	303	45
37220.495	30880	Corrosion	External	08:34	68	90	24

8. Whilst a formal assessment of the features reported by the 2017 Baker Hughes MFL has not been completed as part of this contract, a screening assessment was completed and based on reported dimensions, none of the ‘unrepaired’ metal loss features (not reported by ROSEN) were predicted to have a burst pressure less than 1.39 x MAOP.

9. A future integrity assessment was completed for the reported ROSEN corrosion anomalies assuming a conservative external corrosion growth rate of 0.4 mm/year. Four (4) additional corrosion features were predicted to require repair within 5 years of the ROSEN 2017 MFL-C ILI, details of the 4 corrosion features are provided below:

Log Distance (m)	U/S Joint Number	Distance Feature Start to Close GW (m)	Orientation (hh:mm)	Depth (% wt)	Length (mm)	Repair Date (mmm-yy)
232148.600	191960	4.28	00:02	11	224	Jul-20
130164.983	107620	-0.01	08:19	54	52	Nov-20
130407.536	107810	2.73	05:55	17	121	Jul-22
130076.183	107540	2.90	05:58	11	148	Aug-22

10. A total of 10 pipe mill related anomalies were reported by the 2017 ROSEN ILI, the deepest reported anomalies had depths of 16% wt located at log distances 183444.130 m & 208398.637 m.

11. The significance of the reported pipe mill anomalies has been assessed in terms of their axial, circumferential and depth dimensions, according to the Shannon and Kastner assessment methods. All metal loss features were found to be acceptable for operation at both pressure scenarios, in terms of their length, width and depth dimensions at the time of the 2017 ROSEN MFL-C inspection.

12. The 2014 ROSEN geometry inspection reported 34 dents. The maximum ID reduction for a dent was 2.66% (0.7% dent part) located at log distance 105092.041 m. The maximum reported dent part ID reduction was 1.6%, associated with a dent reported at log distance 141500.954 m (Max. ID reduction 2.1%).

13. No dents were reported to be associated with metal loss or found to be interacting with a girth weld. No dents were found to exceed the OD upper limit for a dent within the pipe body (i.e. 7% OD reduction) or on a weld (2% OD reduction). The 34 dents reported were found to be located in the bottom of line (BOL). No immediate further action is recommended for the reported dents.

14. The fatigue life of the 34 dents have been determined using the approach developed by EPRG. The fatigue assessment has determined that all dents are predicted to have fatigue lives in excess of 100 years.

15. The 2014 ROSEN geometric inspection reported 385 wrinkles. The significance of the wrinkles was assessed at the MAOP. All wrinkles are considered to be acceptable in terms of their impact on the immediate integrity.

16. 4 locations of bending strain were coincident with 4 features reported within 32PENSAO. The 4 geometric anomalies listed in the table above are considered to be acceptable for operation based on their static assessment results and their associated bending strain areas being acceptable for operation.

17. The results of the bending strain assessment are shown in the table below:

	Compressive: Zero Pressure		Compressive: Operational Pressure		Tensile	
	PASS	FAIL	PASS	FAIL	PASS	FAIL
Number	38	6	44	0	44	0

The magnitude of strain at 38 of the 44 bending strain areas were found to be acceptable in terms of the critical compressive limits defined by CSA Z662 at zero internal pressure.

When considering the operational pressure of the pipeline (98 bar), The magnitude of strain at all 44 bending strain areas were found to be acceptable in terms of the critical compressive limits defined by CSA Z662.

18. All 6 sites that failed the compressive assessment at zero pressure were subject to detailed analysis. All sites were verified to be stable and should be monitored during the next inspection.

Recommendations

Item	Action Required
Immediate and Future Integrity Digs (All Features)	1. TBG should refer to the supplied EXCEL listing (1-5500-12584-FFP-32PENSAO-0.xlsx) which identifies any features recommended for investigation within the next 10 years. This is applicable to all features reported by ROSEN EMAT, MFL and Geometric inspections.
Stress Corrosion Cracking (SCC)	2. Please refer to the GASBOL SCC Management plan (1-5500-12584-SCCMP-32PENSAO-0) for detailed guidance to fully evaluate the threat of SCC along 32PENSAO. 3. To date, no SCC has been verified along the 32PENSAO pipeline. Should SCC be found during future investigations, the SCC growth rate applied (0.3 mm /year) and remnant life assessment should be reviewed. 4. The EMAT tool is not designed to accurately detect and size circumferentially orientated crack-like features Should TBG find circumferential SCC in-field, it is recommended that they refer to the GASBOL Critical Defect Manual for guidance on acceptable crack sizes, pressure reduction and repairs.
Internal Corrosion	5. In order to ensure there is no increase in the risk from internal corrosion growth the following actions are recommended: - The occurrence of upset conditions should be avoided / minimised; and - Effective dew point control should be monitored / maintained.
External Corrosion	6. The CP reading suggest that at the time of measurement, the majority of the pipeline was not adequately protected, i.e. between -850 mV and 1200 mV for the entire length. The 2017 survey reported over protection within the pipe section between ~135 km to the end of the pipeline. It is recommended that a detailed study is carried out to review the entire CP system. TBG should also consider completing a CIPS survey along 32PENSAO. The CP system should be operated in line with the guidance provided by international practices, such as ISO 15589:2015 or NACE SP0169-2013. 7. The assessment of the 2017 baker Hughes MFL-A data has not been completed under this current scope of work. As expected, an increased number of metal features were reported when compared to the ROSEN MFL-C inspection due to the differences in flux orientation. It is recommended that TBG ensure that these additional features are subject to a corrosion assessment to determine the current integrity status and define an appropriate MFL-C re-inspection interval.
Geometric Features	8. Following the next inspection, the dent fatigue assessment should be updated to calculate the remaining fatigue life of any new dents.
In-field Verification	9. Please refer to the GASBOL critical defect manual (1-5500-12584-CDM-32PENSAO Rev 0) for further guidance on acceptable feature sizes, pressure reduction and repairs 10. If during any in-field investigations, TBG find evidence that the corrosion growth rates used in this study are not conservative, then the

	investigation / repair schedule should be updated and consideration should be given to reducing the re-inspection interval.
Re-Inspection Interval	11. It is recommended that the GASBOL pipeline is inspected with a crack detection tool within 9.5 years of the previous inspection, i.e. June 2027. 12. It is recommended that the GASBOL pipeline is inspected with a geometry tool within 5 years of the previous inspection, i.e. January 2023. 13. From the perspective of the reported corrosion features, based upon the findings of this study it is recommended that 32PENSAO is subject to an internal MFL inspection within 5 years of the 2017 inspection i.e. before January 2023. It is also recommended that TBG consider running an independent MFL-A tool to fully investigate the threat of circumferential corrosion along the pipeline. This would allow for a detailed corrosion growth comparison between inspection datasets.
Bending Strain Areas	14. TBG should monitor all reported areas of bending strain within future ILI to identify any increase the reported maximum strain.

1 INTRODUCTION

Transportadora Brasileira Gasoducto Bolívia-Brasil (TBG) owns the 32 inch, 244.45 km onshore gas pipeline from Penápolis to São Carlos, known as the 32PENSAO pipeline. The pipeline was designed according to ASME B31.8 (ref. [1]).

The GASBOL system was constructed and commissioned in 1999 from submerged arc welded (SAW) pipe conforming to API 5L Grade X70. The nominal wall thicknesses (wt.) of the pipeline are 11.46 mm, 13.74 mm, 16.51 mm (ref. [1]).

ROSEN completed an internal inspection of 32PENSAO between November 2017 and January 2018 using the ROSEN MFL-C and the RoCD EMAT-C inspection tools. In addition, a RoGeo XT inspection tool was used to inspect the pipeline for geometric features between October 2013 and February 2014 (refs. [2,3]). The pipeline was previously inspected by BAKER HUGHES in June 2017 using their CORRSIGHT™ HR+DEF combo inspection service (refs. [4,5]).

This report provides TBG with a Fitness for Purpose (FFP) assessment of 32PENSAO based upon the findings of the recent inspections.

1.1 Scope of Work

The scope of work of the project is as follows:

1. Review the pipeline design, failure history, in-field activities and operational history.
2. Review the findings of the 2018 to 2014 ROSEN intelligent pig inspections.
3. Summarise the distribution and dimensions of any reported planar defects, e.g. crack-like anomalies, laminations.
4. Assess the significance of planar defects in relation to the agreed assessment pressures (i.e. MAOP).
5. Summarise the distribution of any reported metal loss features and identify concentrations of corrosion or 'hot-spots' along the pipeline.
6. Characterise and diagnose the likely nature and characteristics of the reported corrosion, by considering the shape, location within the pipeline and other data supplied in relation to the pipeline route and terrain.
7. Identify the potential causes of corrosion that are a threat to the integrity of the pipeline.
8. Assess the significance of the corrosion features reported in relation to the agreed assessment pressures (i.e. MAOP).
9. Assess the significance of any other reported anomalies, e.g. dents, milling features, etc.
10. Assess the areas of reported bending strain and any features within these areas.
11. Provide a statement on the current condition of the pipeline and identify and prioritise those features which require immediate repair / remedial action to ensure continued integrity.
12. Based on available pipeline data conduct a screening fatigue assessment to determine the remaining life of all (currently) sub-critical, sized planar defects.
13. Consider the threat of SCC and the potential growth rates associated with SCC.
14. Complete a corrosion growth assessment based upon the results of the previous and most recent inspections.
15. Based on available data, determine the future repair and rehabilitation needs of the pipeline to ensure the future integrity of the pipeline.
16. Identify an appropriate re-inspection interval.

2 PIPELINE DESIGN AND CONSTRUCTION

2.1 Pipeline Design

The pipeline details for 32PENSAO are listed below in Table 1.

Parameter	Description	Reference
Design Code	ASME B31.8	1,2,3
Diameter	32 inch	
Grade	API 5L X70	
Wall Thickness	11.46 mm, 13.74 mm, 16.51 mm	
Current MAOP	98 bar	
Pipe Type	Submerged Arc Welded (SAW)	
Product	Natural Gas	
Typical Operating Temperature	27°C	1,6
Coating Type	Coal Tar (Field Joints: Heat Shrink Sleeve)[2]	1
Construction Date	1999	
Manufacturer	CONFAB[3] and EBSE	7, 8
CP System	Impressed Current	1

Table 1 Pipeline Design Details

2 FBE and Liquid epoxy sections also visible in EMAT data
3 Some Sections have been installed using ESBE manufactured pipe joints.

2.2 Pipeline Construction

The 32PENSAO pipeline was constructed and commissioned in 1998/1999 using API 5L X70 32 inch line pipe. The 32PENSAO pipeline section represents approximately 7% of the entire 32" GASBOL system which is 3,150 km long and transports gas from Santa Cruz de la Sierra in Bolivia to Campinas in Brazil, see Figure 1.

Figure 1: GASBOL Pipeline System (32PENSAO Section highlighted)

The 32PENSAO pipeline is located between Penápolis and São Carlos. The gas receives compression at Penápolis (0 km), Iacanga (121 km) and Sao Carlos (244 km). The location of the 32PENSAO pipeline is shown in Figure 2.

Figure 2: Google Earth Image of 32PENSAO pipeline

The predominant nominal wall thickness along 32PENSAO (GASBOL) is reported to be 11.46 mm. The wall thickness variation along the entire section is summarized below.

- 11.46 mm (89%)
- 13.74 mm (9%)
- 16.51 mm (2%)

The variation in joint length is illustrated in Figure 3:

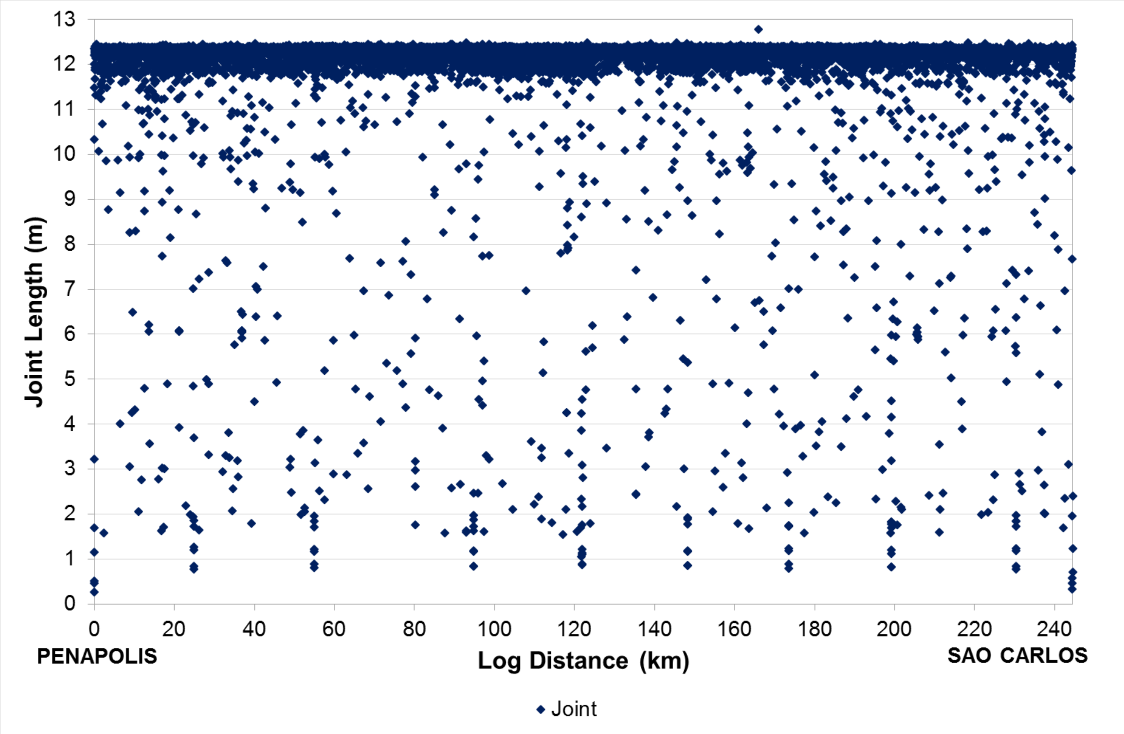


Figure 3: Joint Length along 32PENSAO

The pipeline is reported to be 244.45 km long. The terrain is mountainous and there are significant elevation changes along the route, particularly towards Sao Carlos see Figure 4.

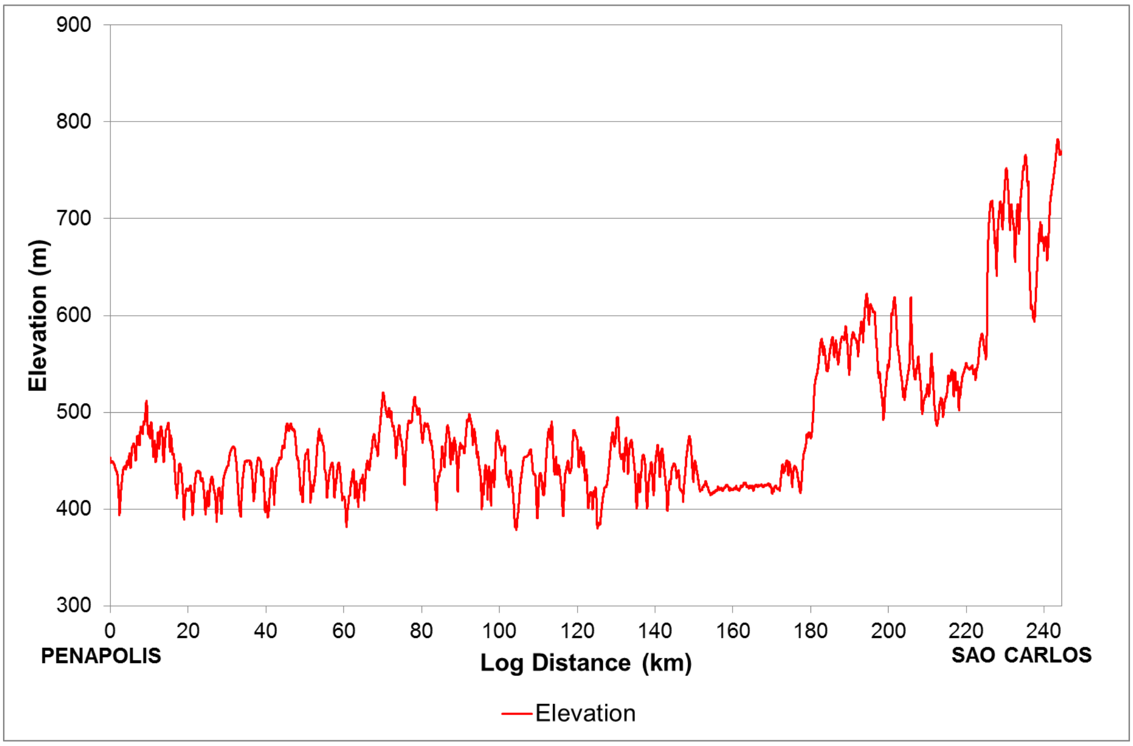


Figure 4: Elevation Profile along 32PENSAO

Figure 5 shows that the majority of field bends were constructed from pipe material of 11.45 mm wall thickness with a bend radius greater than 130D. One field bend was reported with no radius, at log distance 99230.115 m. This bend was not included in Figure 5.

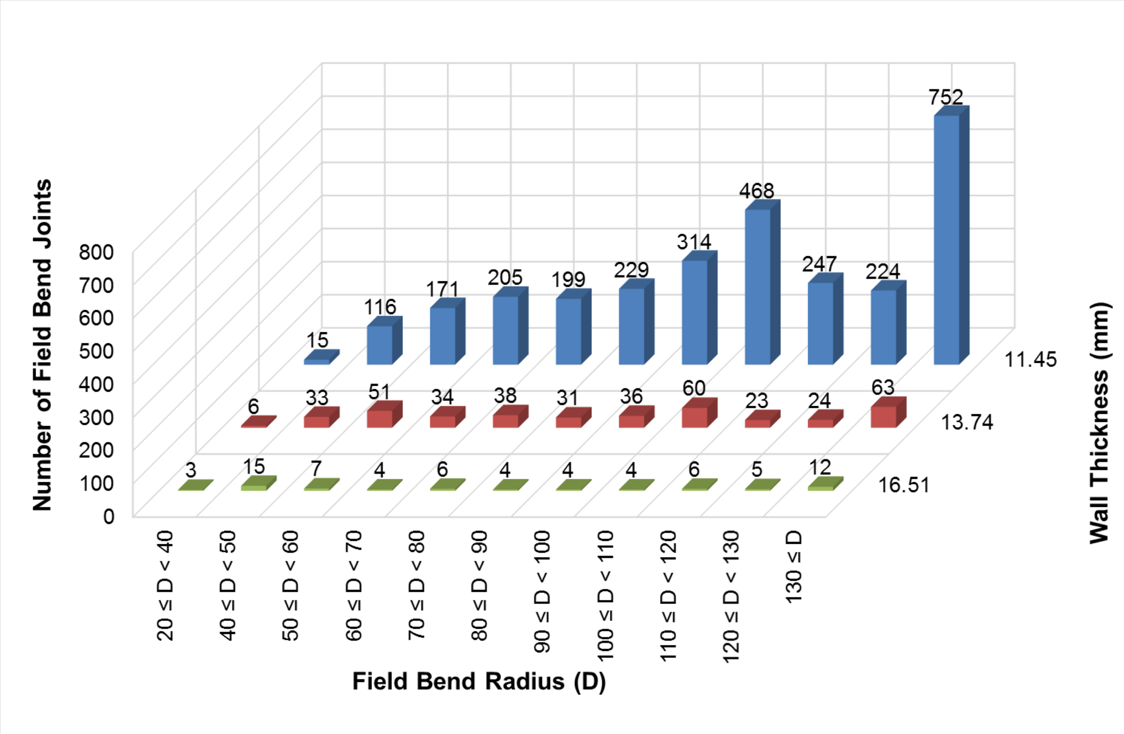


Figure 5: Number of Field Bends vs. Wall Thickness and Bend Radius.

17% of the length of the 32PENSAO pipeline is reported to have been subject to field bending.

3 PIPELINE FAILURE HISTORY

The 32PENSAO pipeline had one leak occur in December 2013, the leak was found to be associated with a drain plug, the leak was subsequently repaired during the infield investigation. The pipeline has experienced no ruptures during its service. No SCC failures have been recorded during the pipelines history (refs. [1,9]).

4 INSPECTION, DIRECT ASSESSMENT AND REPAIR HISTORY

4.1 ILI

The pipeline was inspected via ILI by ROSEN in 2017/2018, 2012 to 2014 & 2006. The pipeline was previously inspected by BAKER HUGHES in 2017 (refs. [2,3,4]). A summary of the recent inspection history since 2007 for 32PENSAO as provided by TBG (ref. [1]) is shown in Table 2.

Tool	ROSEN 2018/2017	BAKER HUGHES June 2017	ROSEN 2012 to 2014	ROSEN 2006
MFL	✓	✓	✓	✓
EMAT	✓	-	-	-
GEOMETRY	-	✓	✓	✓
Direction Inspection	PEN → SAO	PEN → SAO	PEN → SAO	PEN → SAO

Table 2: Inspection History for 32PENSAO

4.2 Repair History

TBG have investigated a number of anomalies between 2008-2015 following the 2006 & 2012 ILIs in addition to the DNV SCC Study, these investigations include the use of 7 type B sleeves (ref. [10]). The 2017 ILI data reports the following:

- Number of sleeves installed along the pipeline: 7 (reported at 18.2 km, 33.8 km, 40.0 km, 52.9 km & 75.8 km from Penapolis).
- Local Coating Repairs: 341 joints.

4.3 Direct Assessment – SCC Specific

The 32PENSAO pipeline was inspected using ROSENS Electromagnetic Acoustic Transducer (EMAT) technology in January 2018 (ref.[11]). Six crack-like indications were reported at the preliminary reporting stage along the 244 km pipeline (ref.[12]). These 6 features were deemed most representative of similar groups of less severe features present in the pipeline. Verification was recommended so the findings could be incorporated into the final reporting.

Log Distance (m)	Feature ID	Comment	Depth (%WT)	Length (mm)	Orientation (hh:mm)
32819.159	27170E0001	with metal loss	43	254	05:30
37220.517	30880E0001	weld area; with metal loss	42	74	08:46
38389.770	31840E0001		49	219	02:34
51184.344	42360E0001		33	164	03:03
162505.460	134250E0001	poss. manufacturing anomaly	33	90	09:16
231799.454	191670E0001		40	93	05:37

Table 3: EMAT Preliminary Results

4.3.1 Verification Results

Following the issue of the preliminary EMAT results (ref.[12]), TBG completed the verification of 4 crack-like indications. The sites selected for verification are listed below in Table 4. These features were selected following a review which considered SCC credibility, risk and accessibility.

Log Distance (m)	Feature ID	Comment	Depth (%WT)	Length (mm)	Orientation (hh:mm)
32819.159	27170E0001	with metal loss	43	254	05:30
37220.517	30880E0001	weld area; with metal loss	42	74	08:46
38389.770	31840E0001		49	219	02:34
51184.344	42360E0001		33	164	03:03

Table 4: EMAT features Selected for Verification

ROSEN were present for the verification of all 4 features to ensure the quick transfer of information to the EMAT evaluation team. The work was completed between April and May 2018 and ROSEN issued a summary report for all sites in June 2018 (ref.[13]). Whilst planar features were found at the reported crack-like location, no SCC was observed. A summary of the findings is shown in Table 5. At site 37220.517 m, deep axial corrosion was verified (7 mm deep) which was not reported by any previous MFL inspection.

Log Distance (m)	Feature ID	Comment	In-field Findings
32819.159	27170E0001	with metal loss	External Corrosion
37220.517	30880E0001	weld area; with metal loss	External Corrosion
38389.770	31840E0001		Mid wall planar features (mill related)
51184.344	42360E0001		Mid wall planar features (mill related)

Table 5: In-field Verification Summary

5 OPERATIONAL OVERVIEW

5.1 Temperature History

TBG have provided hourly temperature readings between 1st August 2012 and 2nd August 2017 (ref. [6]). The temperature readings recorded over the 5 year interval are shown in Figure 6 at the Penápolis compressor station.

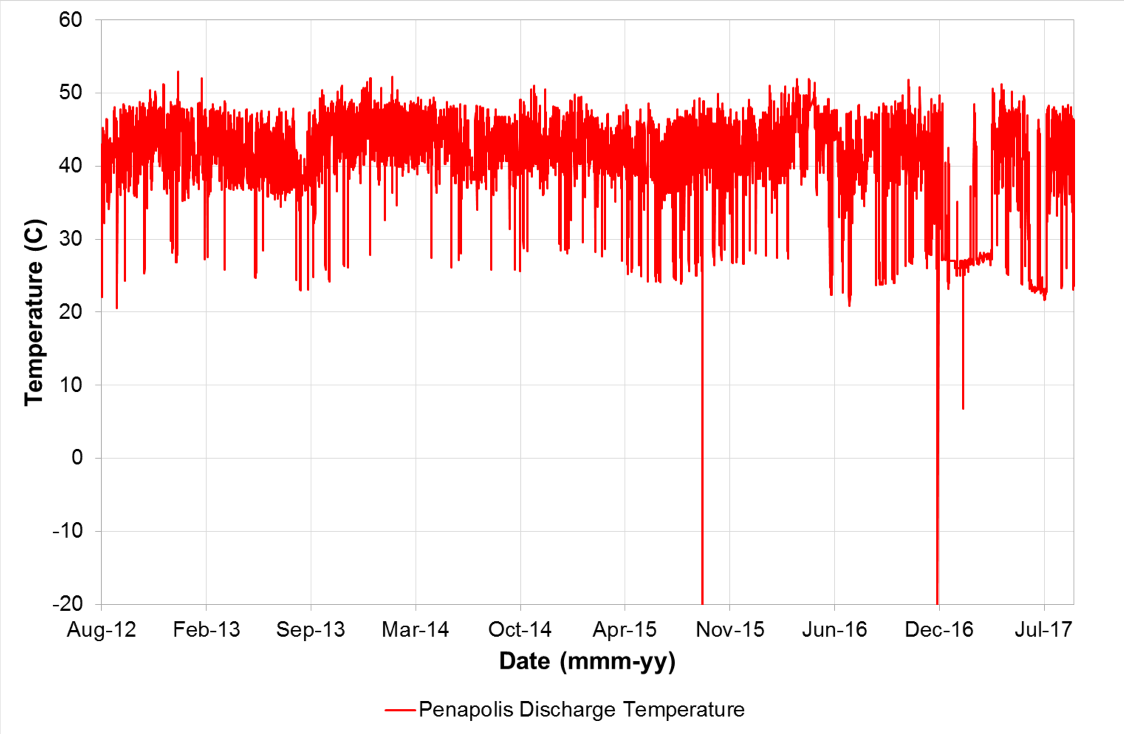


Figure 6: Temperature Readings – Penapolis Compression Station

The temperature readings have further been analysed and the results for 32PENSAO are shown in Table 6.

	Temperature Reading (°C) At Penápolis Compressor Station
Maximum	52.93
Average	41.37
Median	42.62

Table 6: Temperature Readings Analysis

5.2 Pressure History

TBG have provided hourly pressure readings between 1st August 2012 and 2nd August 2017 at the Penápolis compressor station (ref. [6]).The pressure readings are shown in Figure 7.

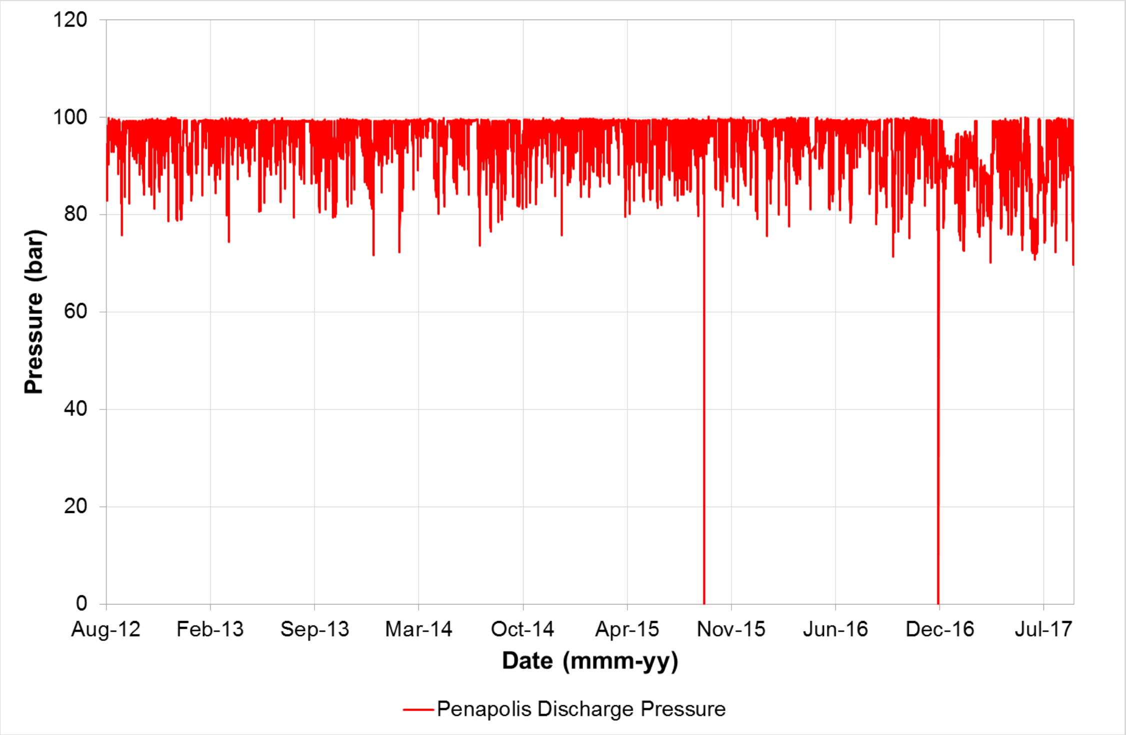


Figure 7: Pressure Readings Recorded at the Penápolis Compression Station

5.3 CP History

It is understood that the performance of the installed ICCP system is assessed through the recording of CP 'ON' and 'OFF' potentials, whilst a protection criterion of -850 mV is adopted by TBG (ref. [1]).

TBG have provided ROSEN with CP "OFF" potential readings, recorded by the 2017, 2016, 2015 & 2014 surveys (refs. [14,15,16,17]), see Figure 8. These reading suggest that at the time of measurement, the majority of the pipeline was not adequately protected, i.e. between -850 mV and 1200 mV for the entire length. The 2017 survey reported over protection within the pipe section between ~135 km to the end of the pipeline.

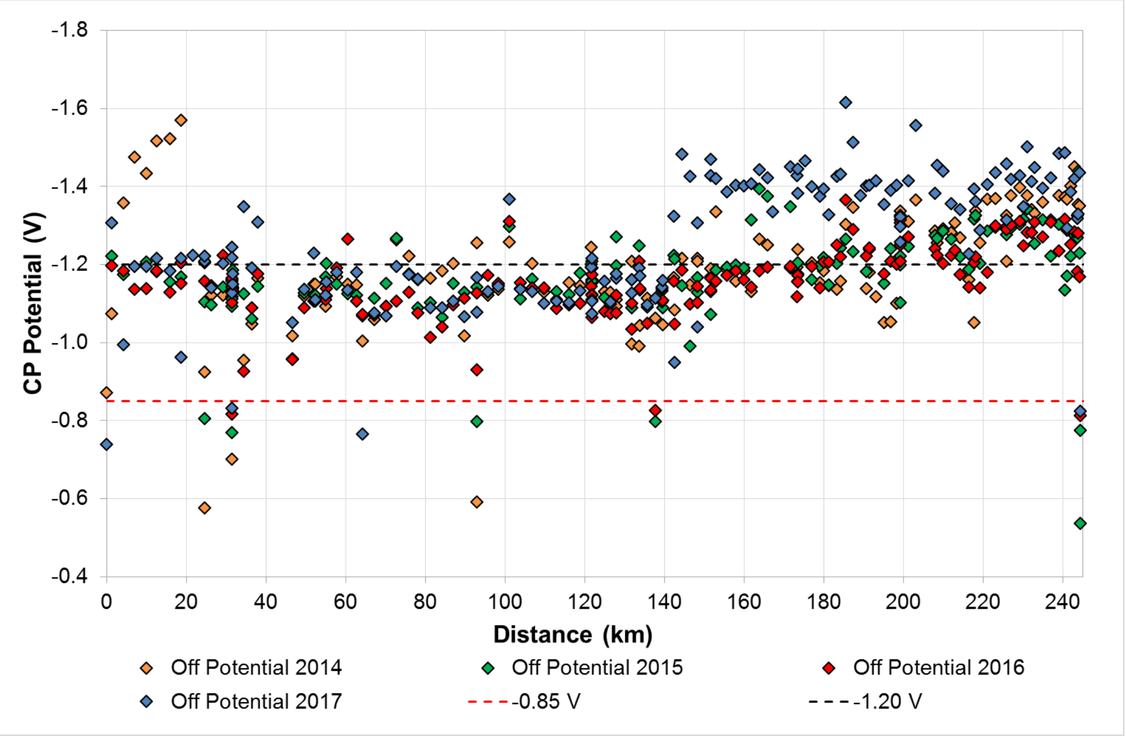


Figure 8: CP 'OFF' Potentials Recorded in 2014, 2015, 2016 & 2017

It is recommended that a full evaluation of the CP system performance is completed. This should include a close interval pipeline survey (CIPS) along the entire pipeline.

6 ILI OVERVIEW

6.1 Summary of Inspection Findings

The 32 inch, 244.45 km pipeline which transports natural gas from Penápolis to São Carlos (32PENSAO) was inspected for crack-like features, metal loss and geometry by ROSEN between 2018 and 2014 (refs. [2,3]). A summary of the inspection findings is shown in Table 7.

Feature	Number Reported	Deepest Feature
Crack-Like Anomaly	4[4]	N/A
Linear Anomaly in Longitudinal Weld Area	Nil	-
Internal Corrosion	Nil	-
External Corrosion	25	68% wt.
Corrosion (surface Location: N/A)	4	49% wt.
Pipe Mill Anomaly	10	16% wt.
Girth Weld Anomaly	42	26% wt.
Other Anomaly	31	-
Repaired Anomaly	7	-
Dent	34	2.66% Max. ID Reduction
Wrinkle[5]	385	2 - 6mm
Bending Strain Areas	27	0.49% Max. strain
Strain – Construction Irregularity	17	0.41% Max. strain
Total	**582**	**-**

Table 7:Summary of the 2018 to 2014 ROSEN Inspection Findings

The 2017 metal loss inspection was completed using an MFL-C tool which has circumferentially orientated magnetic flux and is particularly sensitive to detecting and reporting axially orientated features.

Previously the pipeline was inspected for metal loss and geometry by BAKER HUGHES in 2017 (ref. [4]). A summary of the inspection findings is shown in Table 8. The run used an MFL-A tool which has an axially orientated magnetic flux and is particularly sensitive to detecting and reporting circumferentially orientated features, for example external corrosion at field joints.

Feature	Number Reported	Deepest Feature
Internal Metal Loss	839	28.5% wt.
External Metal Loss	1229	61.5% wt.
Metal Loss Under Shell	8	85% wt.
Dent	19	Max. OD Reduction: 1.7%
Girth Weld Anomaly	1097	-
Girth Weld Anomaly (flat type discontinuity)	7	43.8% wt.
Possible Girth Weld Anomaly	50	-
Ripple	1	Max. OD Reduction: 0.7%
Total	**3250**	

Table 8: Summary of 2017 BAKER HUGHES Inspection Findings

[4] Six crack-like anomalies reported in the preliminary report. This reduced to 4 at the final reporting stage following a review of in-field verification findings. At the time of writing this report, all 4 reported crack-like indications have been remediated.
5: Reported as Ripple/Wrinkle by 2014 ROSEN inspection, considered as wrinkles for the purpose of this assessment.

For all features in both inspection the Pipeline Operators Forum (POF) feature interaction criteria have been applied (ref. [18]). The numbers above contain clustered features and single features that are not part of clusters because they are not interacting.

The difference in the number of metal loss features reported between inspections is discussed in Section 13.1.

6.1.1 Detection and Sizing Capabilities

The sizing capabilities of the ROSEN 2017 and BAKER HUGHES 2017 MFL inspection tools are shown in Table 9 (refs. [3,19]). This comparison is incorporated into the corrosion growth assessment.

POF Corrosion Classification	Sizing Accuracy at 80% Confidence (%wt)	
	2017 ROSEN MFL-C	2017 BAKER HUGHES MFL
General	15	10
Pitting	19	10
Axial Grooving	15	15
Circumferential Grooving	Not specified	10
Pin Hole	Not specified	18
Axial Slotting	15	18
Circumferential Slotting	Not specified	15

Table 9: Sizing Accuracy, ROSEN 2017 and BAKER HUGHES 2017 Inspection Tools

As stated above, it has been confirmed that the BAKER HUGHES MFL tool is an MFL-A tool, i.e. axially orientated flux.

6.2 2018 EMAT Inspection

6.2.1 Feature Detection

The crack detection and sizing capabilities for the EMAT inspection are applicable for the following crack types in longitudinally welded pipe types (ref. [2]):

- Isolated cracks
- Crack colonies
- Longitudinal fatigue cracks
- Toe cracks
- Hook cracks
- Fatigue cracks
- Lack of fusion cracks or other crack-like weld defects
- Surface breaking lamination

It is reported that the pipe type of 32PENSAO is longitudinal Submerged Arc Welded (SAW) (ref. [1]).[6]

6.2.2 Inspection Summary

Four crack-like features were listed in the 2018 ROSEN EMAT-C final inspection report (ref. [2]). However, all features have since been subject to investigation and remediated. Whilst none of the features were confirmed to be cracking, mill related planar features or sharp edges corrosion was observed. Please refer to Section 4.3 regarding the preliminary reporting and in-field findings.

[6] Material information was supplied for the CONFAB pipe. However, no data was supplied for ESBE pipe which is believed to also be present along the 32PENSAO pipeline.

6.2.3 Coating Disbondment

The pipeline is reported to be predominantly coated using coal tar enamel. The field joints are reported to be protected with heat shrink sleeves. The 2018 EMAT inspection (ref. [2]) has identified multiple coating types along the 32PENSAO pipeline, see Figure 9.

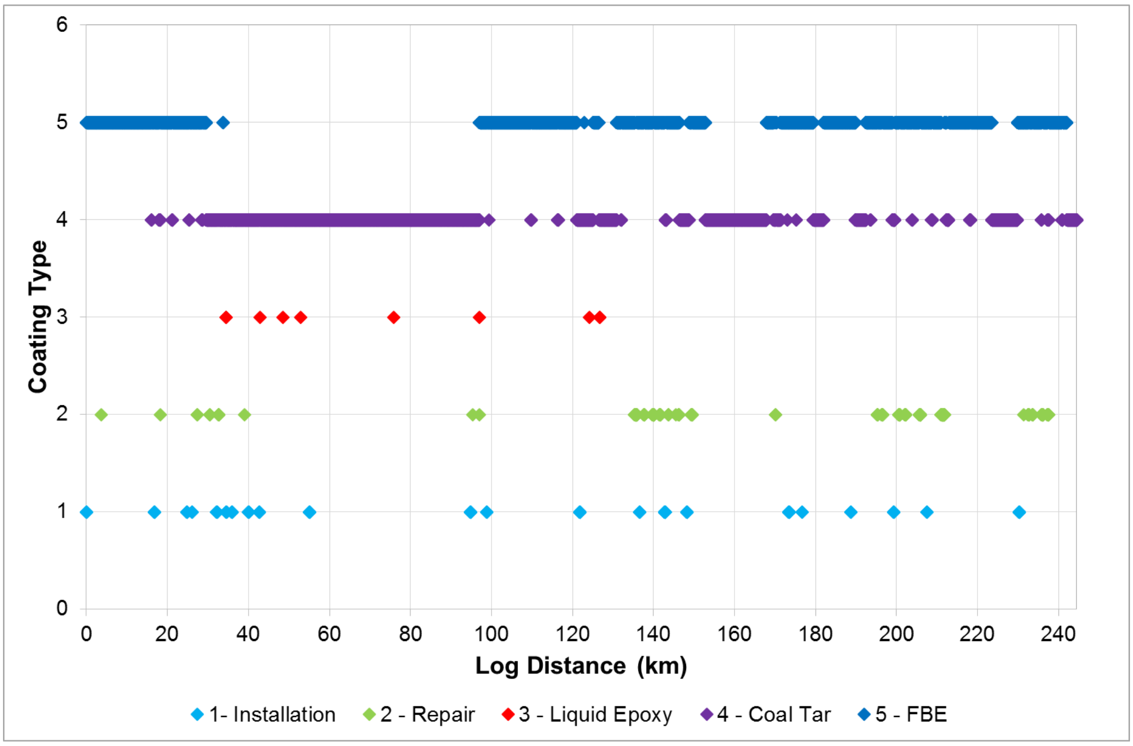


Figure 9: Coating Transitions along 32PENSAO (2018 EMAT)

The 2018 ROSEN EMAT-C inspection has classified the level of coating disbondment found on each pipe joint into 5 categories (based on total surface area disbanded). A summary of the results is provided in Table 10.

Classification (Surface area affected by coating disbondment)	Number of Affected Pipe Joints
Very Poor (≥ 80%)	0
Poor (≥ 50% and < 80%)	0
Fair (≥ 10% and < 50%)	0
Good (≥ 1% and < 10%)	74
Excellent (≥ 0% and < 1%)	20147
Total	**20221**

Table 10: Coating Disbondment Classification Categories

All pipe joints were identified to be in ‘excellent’ or ‘good’ coating condition, i.e <10% coating disbondment.

It should be noted that a number of local coating repairs are visible in the ILI data. Please refer to section 4.2 for further information.

6.3 2017 MFL-C Inspection

6.3.1 Internal Corrosion

The 32PENSAO pipeline transports natural gas and is typically operated between 35°C and 45°C, see Section 5.

The ROSEN 2017 MFL-C inspection reported no internal corrosion features.

See section 13.1 for a comparison of the 2017 ROSEN and 2017 BAKER HUGHES metal loss features.

6.3.2 External Corrosion

The 2017 ROSEN MFL-C inspection reported 25 external corrosion features, the maximum depth being 68% wt associated with a feature at log distance 37220.495 m.

The distribution of external corrosion features reported by the 2017 ROSEN MFL inspection is shown in Figure 10.

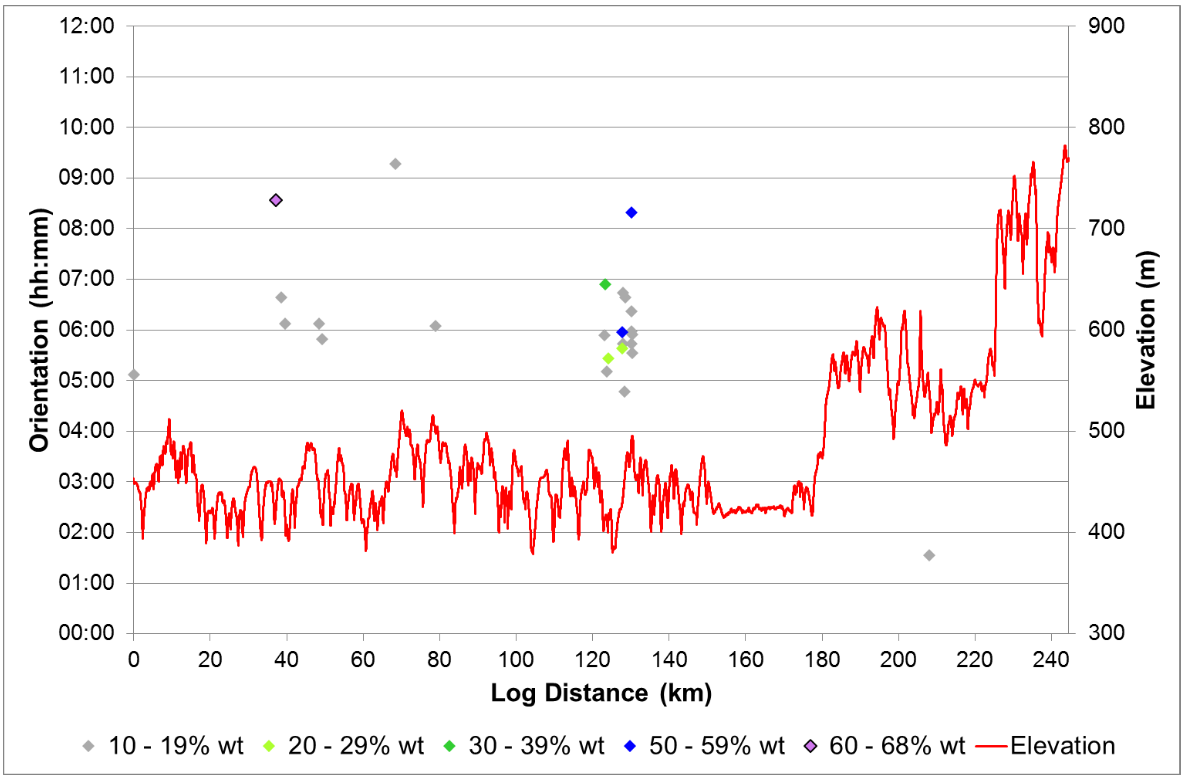


Figure 10: External Corrosion Features; Orientation and Elevation vs. Log Distance

The distribution of the external corrosion features with respect to their depth and relative distance to their closest girth weld is shown below in Figure 11.

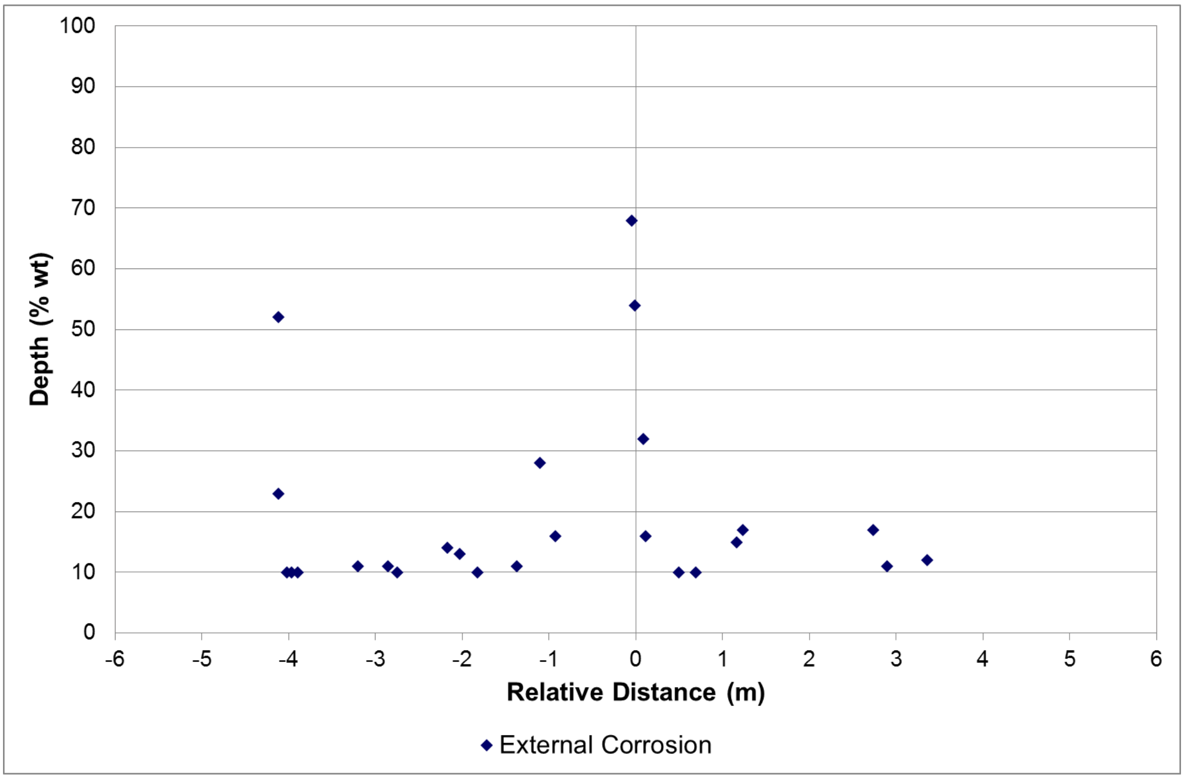


Figure 11: External Corrosion Features; Depth vs. Relative Distance to Girth Welds

Figure 11 shows that the deepest corrosion features are reported to be associated with a girth weld. Although the corrosion distribution does not suggest a concentration of external corrosion at girth welds, it should be noted that the inspection was completed using an MFL-C tool which is not as sensitive to detecting circumferentially orientated corrosion when compared to an MFL-A tool.

See section 13.1 for a comparison of the 2017 ROSEN and 2017 BAKER HUGHES metal loss features.

6.3.3 Corrosion: N/A Surface Location

The 2017 ROSEN MFL-C inspection reported 4 corrosion features with the location classification “N/A”, the maximum depth being 49% wt associated with a feature at log distance 36520.597 m.

The distribution of the “N/A” corrosion features reported by the 2017 ROSEN inspection is shown in Figure 12. Note, 3 or 4 features are reported at 232 km.

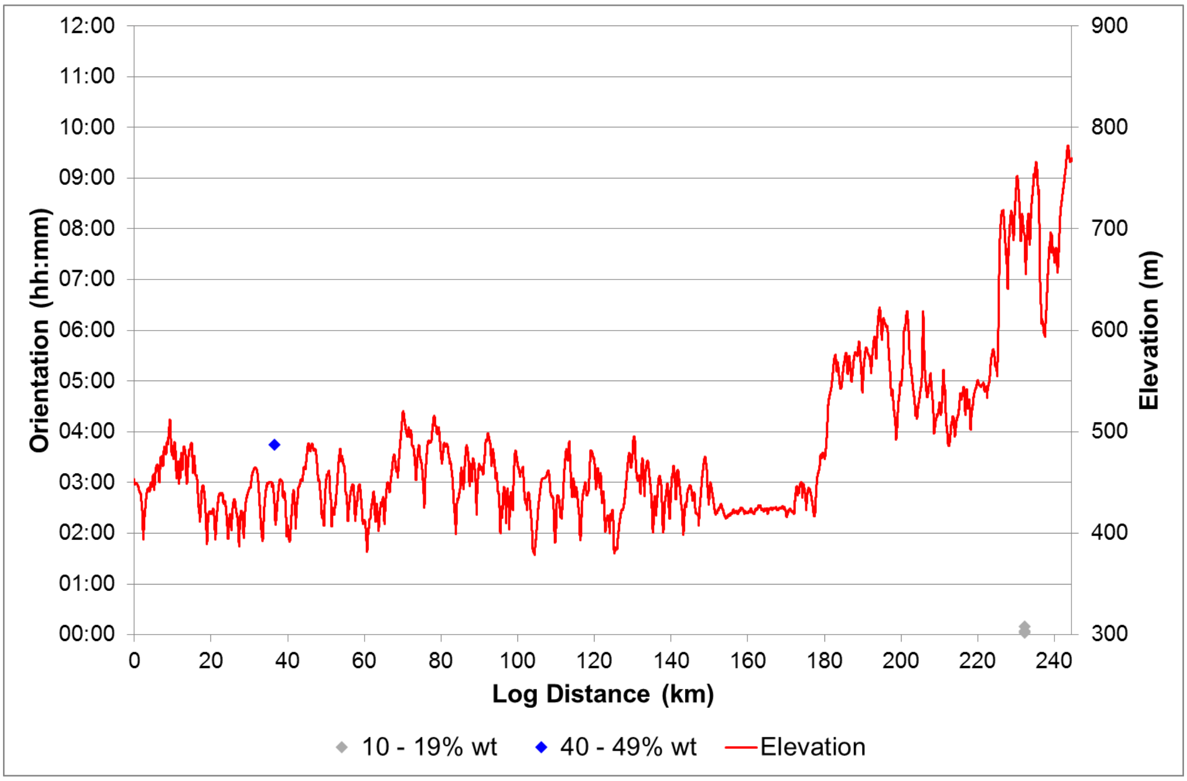


Figure 12: N/A Surface Location Corrosion Features; Orientation and Elevation vs. Log Distance

See section 13.1 for a comparison of the 2017 ROSEN and 2017 BAKER HUGHES metal loss features.

6.3.4 Milling Anomalies

The 2017 ROSEN MFL-C inspection reported 10 pipe mill related anomalies, the deepest reported anomalies have a depth of 16% wt, located at log distances 183444.130 m & 208398.637 m.

The distribution of milling anomalies reported by the 2017 ROSEN inspection are shown in Figure 13.

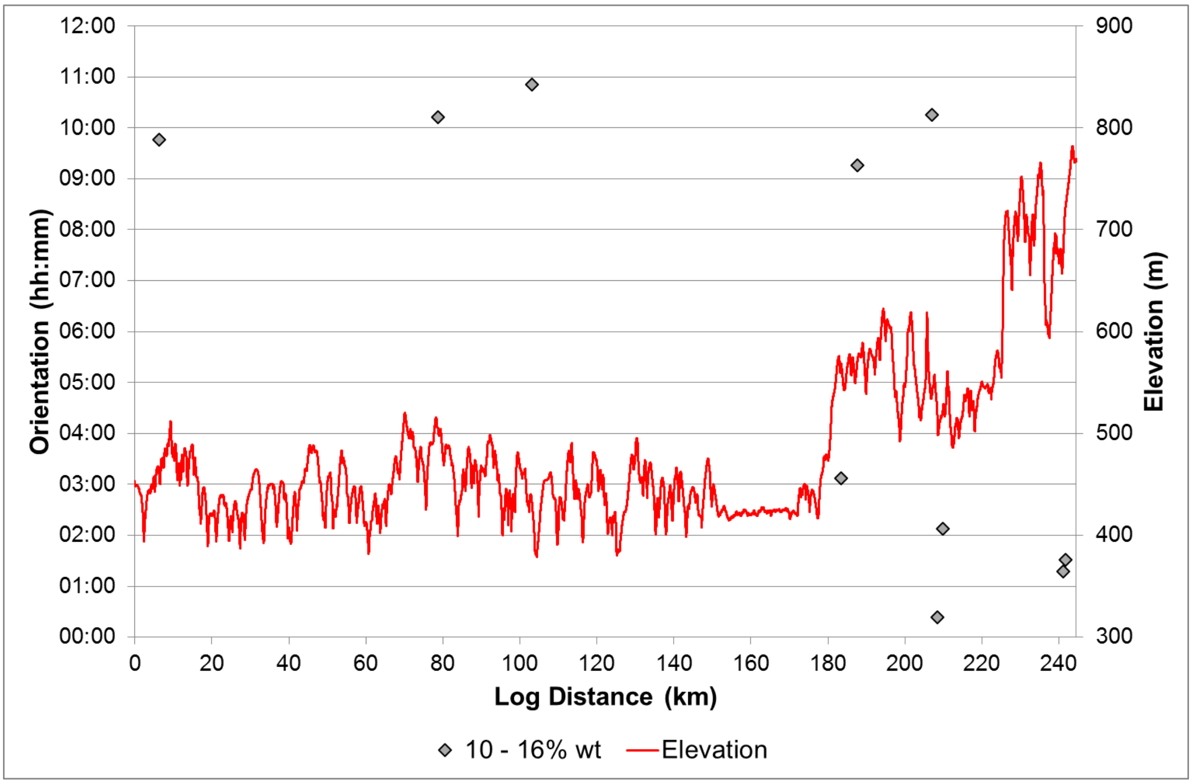


Figure 13: Milling anomalies; Orientation and Elevation vs. Log Distance

See section 13.1 for a comparison of the 2017 ROSEN and 2017 BAKER HUGHES metal loss features.

6.4 2017 Geometric Inspection

6.4.1 Dents

The 2014 ROSEN geometry inspection reported 34 dents. The maximum ID reduction for a dent was 2.66% (0.7% dent part) located at log distance 105092.041 m.

The maximum reported dent part ID reduction was 1.6%, associated with a dent reported at log distance 141500.954 m (Max. ID reduction 2.1%).

The distribution of the dents reported by the 2014 ROSEN inspection are shown in Figure 14.

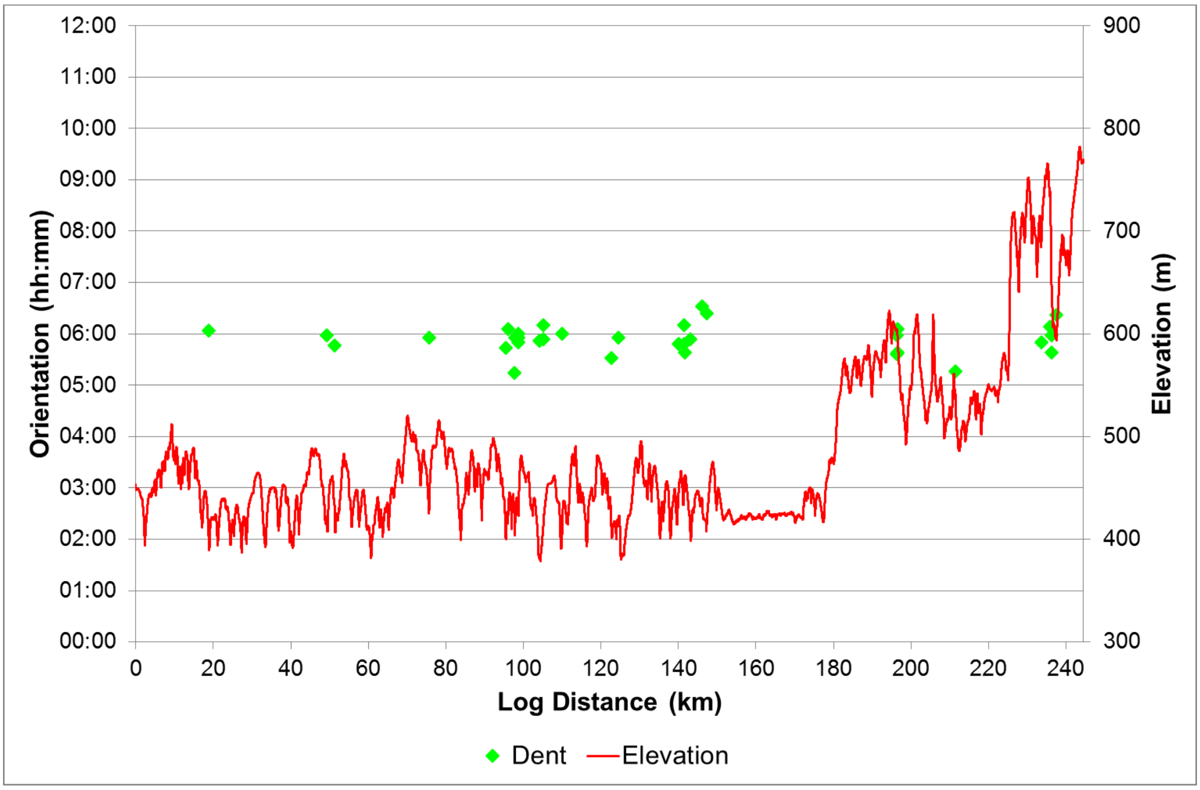


Figure 14: Dents; Centre Orientation and Elevation vs. Log Distance

The significance of the reported dents has been considered in Section 10.

6.4.2 Wrinkles

The 2014 ROSEN geometry inspection reported 385 ripple/wrinkles[7] along the pipeline. The peak-to-trough height has split into the following three categories:

- >6 mm;
- ≤6 mm and >2 mm;
- ≤2 mm.

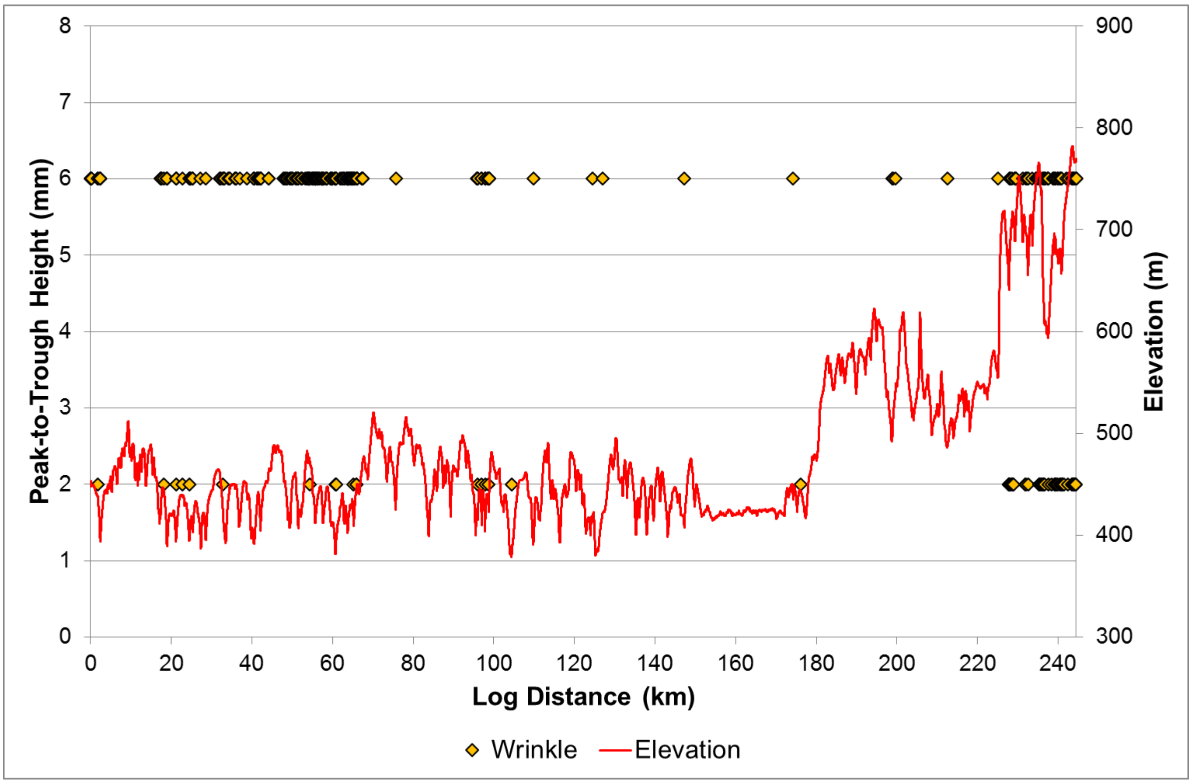


Figure 15: Wrinkles; Peak-to-Trough Maximum Possible Height and Elevation vs. Log Distance

Figure 16 shows the distribution of wrinkled joints throughout the length of the pipeline. The wrinkled joints have been split into 5 km intervals.

7: Reported as Ripple/Wrinkle by 2018 to 2013 ROSEN inspection, considered as wrinkles for the purpose of this assessment.

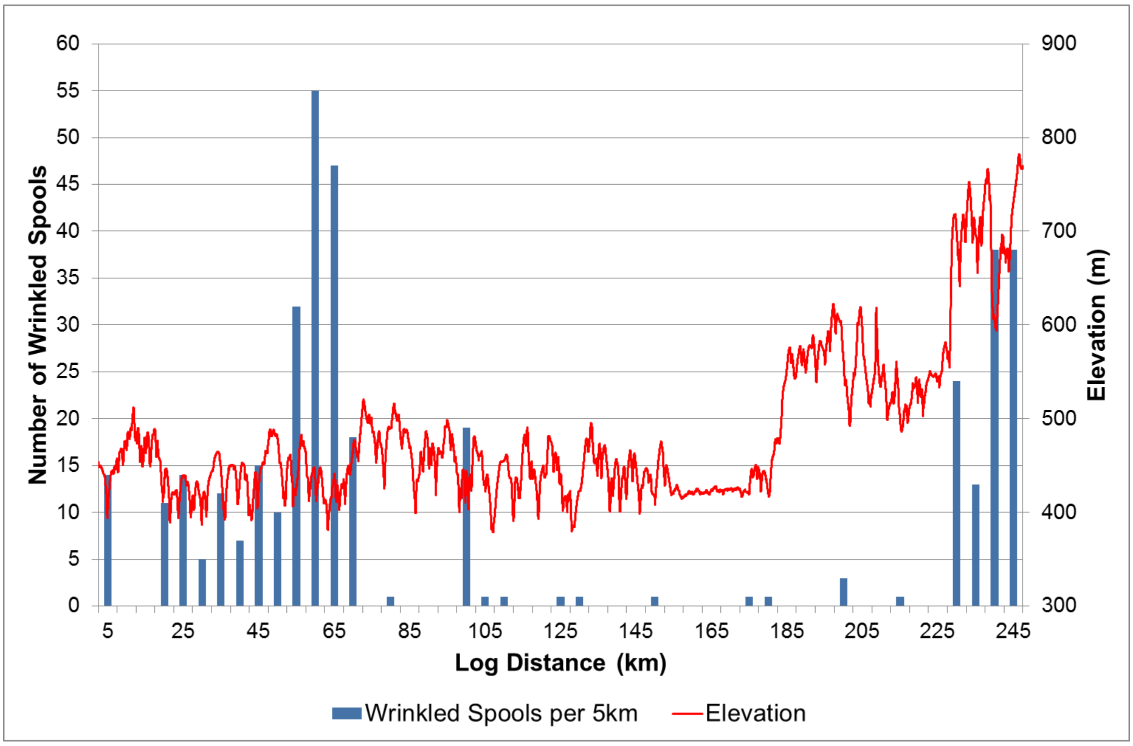


Figure 16: Wrinkled Joints per 5 km: Elevation vs. Log Distance

Figure 16 shows that there are several concentrations of wrinkled joints along the length of the pipeline, the most significant of which can be seen between 55 - 65 km & between 240 - 244 km.

The significance of the reported wrinkles has been considered in Section 10.2.

7 BENDING STRAIN AREAS

7.1 Inspection Summary

The 2014 ROSEN inspection reported 27 bending strain areas and 17 construction irregularities. For the purpose of this assessment the construction irregularities have been treated as areas of bending strain. The reporting threshold for a bending strain area was 0.18% (ref. [20]). The maximum bending strain reported was 0.49% associated with BSTR #034 located between log distances 205708.00 m & 205722.50 m.

A summary of the bending strain areas & construction irregularities along 32PENSAO is shown in Table 11.

Bending Strain Area Comment	Number	Max Strain
Vertical	25	0.49
Horizontal	1	0.35
None	18	0.41
Total	44	

Table 11: Breakdown of Types of Bending Strain Areas

The majority of the bending strain areas were reported as vertical (57%). A review of field bends identified that 28 were found in bending strain areas up to a maximum strain of 0.49%.

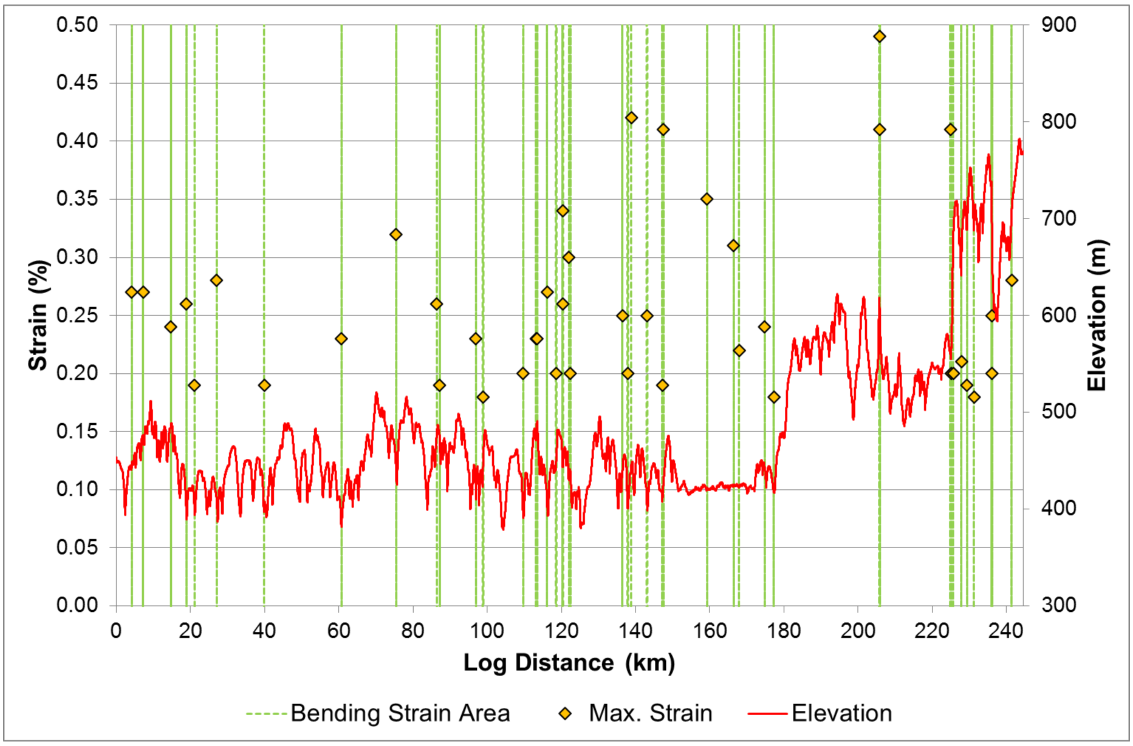


Figure 17: Bending Strain Areas; Stain & Elevation vs. Log Distance

No metal loss features reported by the recent ROSEN EMAT or MFL inspections were found to be within areas of bending strain or areas of construction irregularity. 2 wrinkles and 2 dents reported by the ROSEN 2014 inspection were found to be areas of bending strain & areas of construction irregularity.

7.2 Level 2 Assessment Methodology

Assessment of the acceptability of the reported bending strains to Level 2 involves 2 steps :

- The magnitude of tensile and compressive strain is assessed against the performance limits set out in Canadian Standard Z662 (ref [21]).
- The influence of any metal loss features within the area of bending strain is taken into account in the evaluation of strain acceptability.

Any areas of bending strain and / or metal loss features that are considered unacceptable in accordance with the above assessments have been reviewed further and prioritised, so that appropriate recommendations can be made. The assessment and prioritisation methodologies for the reported areas of bending strain magnitude and the metal loss features reported within the bending strain areas are presented in Sections 7.2.1 & 7.2.2 respectively.

7.2.1 Assessments Methodology

For displacement controlled loads such as ground movement, the acceptability of bending strains can be determined using the critical compressive strain and tensile strain limits set out in the Canadian standard Z662.

The assessment includes the following assumptions:

- The minimum wall thickness within the area of bending strain is used in the calculations.
- A crack tip opening displacement (CTOD) value of 0.127 mm has been assumed.

A description of the assessment method is provided in Appendix D.

7.2.2 Prioritisation of Unacceptable Areas of Bending Strain and Ground Movement

Locations of reported bending strain that exceed the allowable strain limits or are geometric features (buckles, wrinkles) that could have an external loading origin are reviewed to determine whether the source of the strain is likely to be associated with ground movement or external loads.

This assessment is based on:

- The vertical and horizontal bending strain profiles
- The vertical and horizontal pipeline profiles
- The ground topography
- The ground surface features
- Available soils information

The locations of unacceptable bending strain are categorised based on the level of reported strain, the indicated presence of ground movement or external loading and the presence of movement related geometric anomalies (e.g. buckles/wrinkles/ovalities etc.). Three categories are defined as:

- Priority 1 – Represents a significant threat to the pipeline, immediate actions required.
- Priority 2 – Represents a potential / credible threat to the pipeline, actions should be scheduled.
- Priority 3 – Stable areas of bending strain, to be monitored during next inspection.

Details of the prioritisation process and associated recommendations are provided in Appendix E.

7.3 Level 2 – Assessment of Bending Strain Magnitude

The results of the assessment of the bending strain areas is shown in Table 12.

	Compressive: Zero Pressure		Compressive: Operational Pressure		Tensile	
	PASS	FAIL	PASS	FAIL	PASS	FAIL
Number	38	6	44	0	44	0

Table 12: Summary of Bending Strain Assessment Results

The magnitude of strain at 38 of the 44 bending strain areas were found to be acceptable in terms of the critical compressive limits defined by CSA Z662 at zero internal pressure.

When considering the operational pressure of the pipeline (98 bar), The magnitude of strain at all 44 bending strain areas were found to be acceptable in terms of the critical compressive limits defined by CSA Z662.

The associated Excel listing (1-5500-12584-FFP-32PENSAO.xlsx) will provide details of the 6 bending strain and construction irregularities which fail the compressive assessment. These have been evaluated in detail below in Section 7.4.

7.4 Level 2 – Identification of Bending Strain Source

The six areas which failed the compressive at zero pressure were subject to a detailed review to identify the source of strain This included a detailed review of aerial imagery for each bending strain area. This assessment is based on the following:

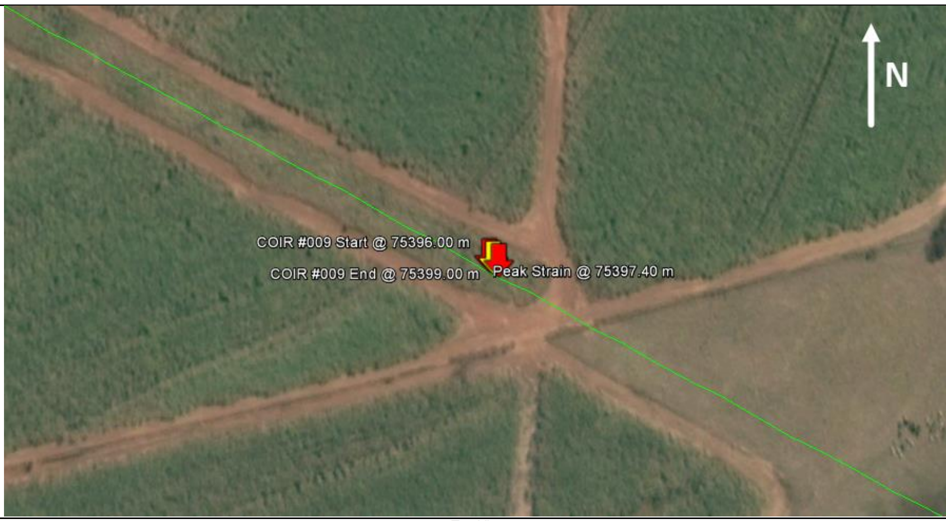
- The vertical and horizontal bending strain profiles
- The vertical and horizontal pipeline profiles
- The ground topography
- The ground surface features
- Available historical review of aerial imagery
- Coincident metal loss and geometric features

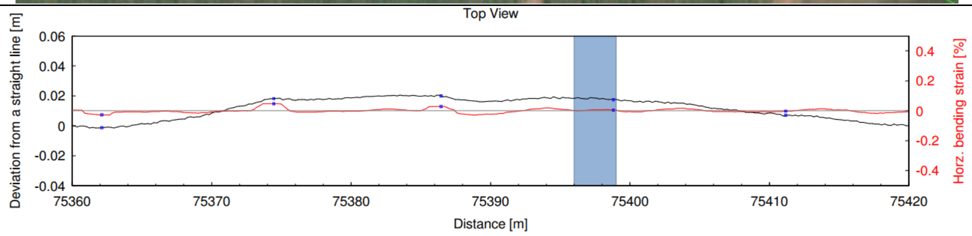
The following areas listed in Table 13 were included in the review:

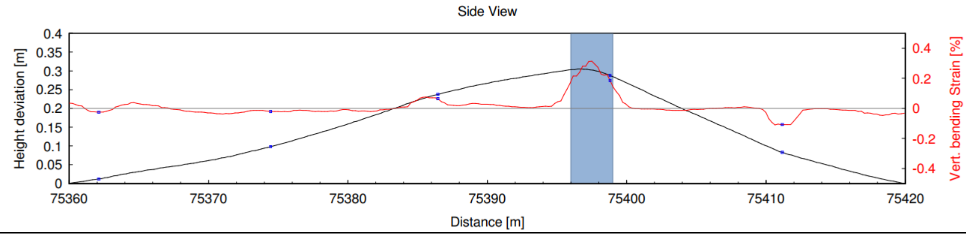
Bending Strain Area	Length (m)	Maximum Strain (%)	Start (m)
COIR #009	3.0	0.32	75396.0
COIR #020	7.5	0.34	120374.0
BSTR #025	12.0	0.42	138842.5
BSTR #029	18.0	0.35	159272.0
BSTR #034	14.5	0.49	205708.0
COIR #035	5.5	0.41	205836.0

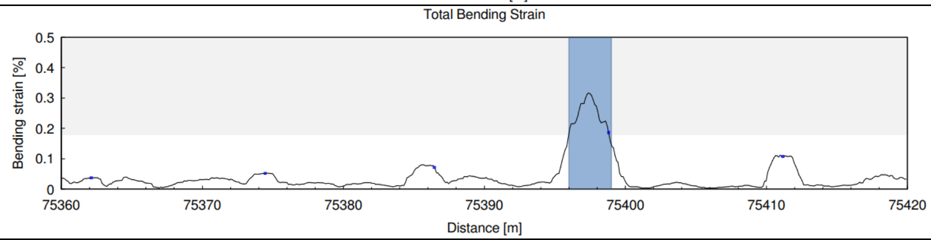
Table 13 Areas of Strain Subject to Detailed Review.

Construction Irregularity #009



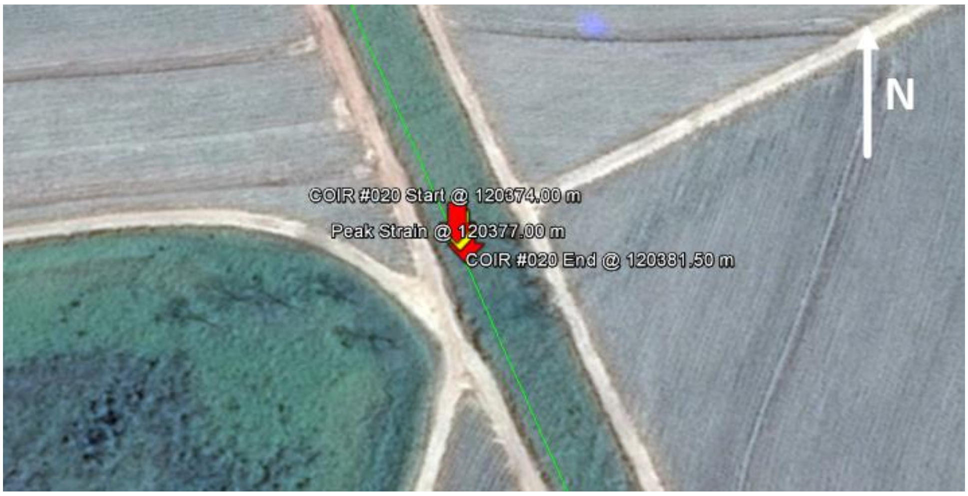


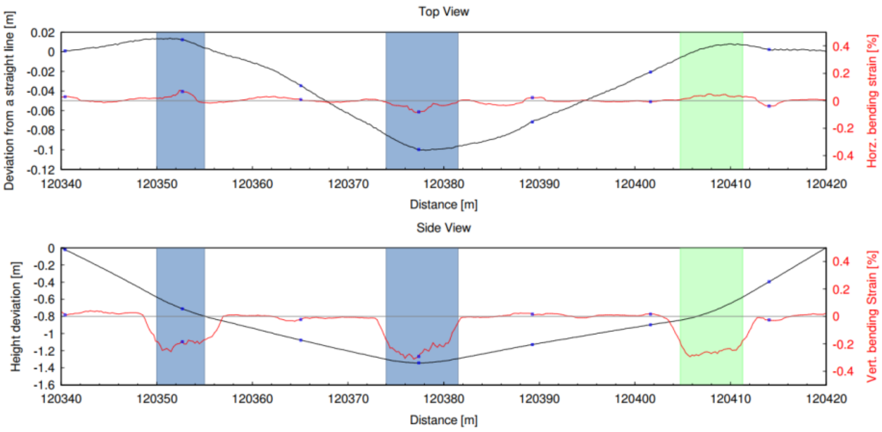


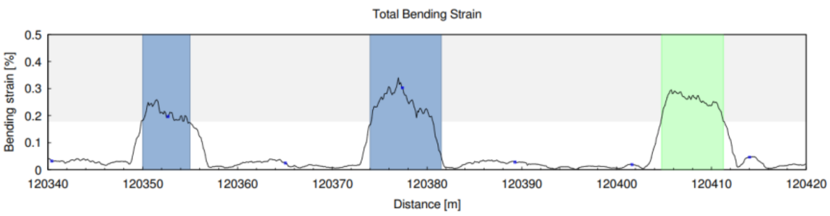


Orientation	Vertical	**Maximum Strain**	0.32%
Topography and Bending Strain Description	The pipeline is routed through flat agricultural land adjacent to multiple fields. The maximum point of strain is located at log distance 75397.4 m and is attributable to a vertical over bend adjacent to a girth weld located approximately 1.5 m downstream (log distance 75398.812 m). The bending strain appears to be related to a fabricated over bend at the location of the weld, on this basis the area is considered to be a construction irregularity. There is no evidence of external loading at this location and it is considered the vertical bending strain is derived from the pipeline construction.		
Conclusions	The bending strain appears to be related to a fabricated over bend at the location of a weld (construction irregularity). There is no evidence of external loading at this location and it is considered the bending strain is derived from the pipeline construction. Area to be reviewed following next inspection.		

Construction Irregularity #020





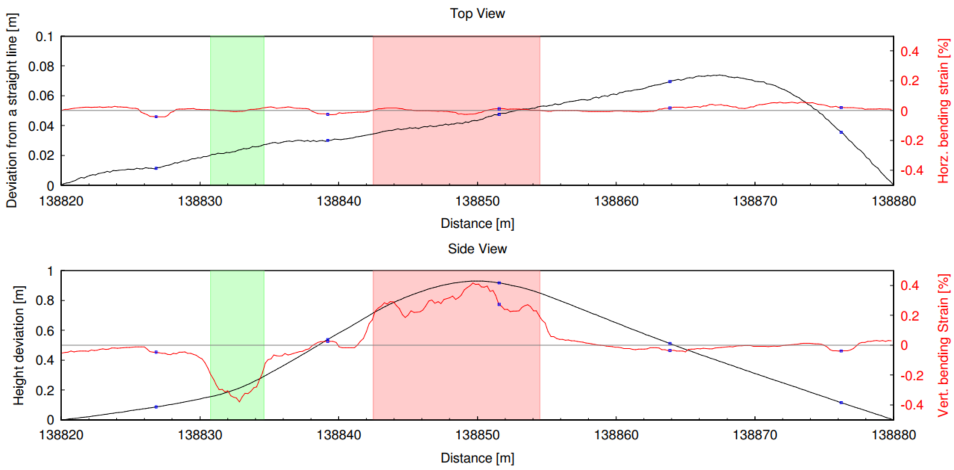


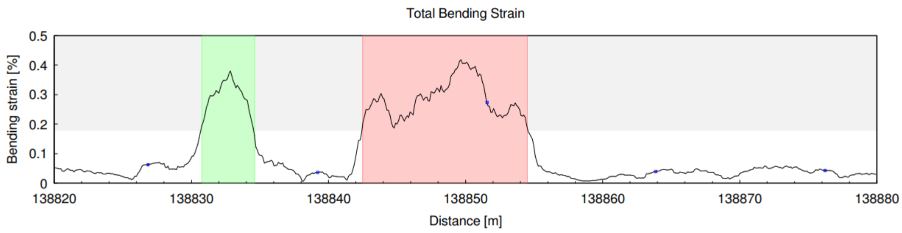
<table>
<tr><td>Orientation</td><td>Vertical</td><td>Maximum Strain</td><td>0.34%</td></tr>
<tr><td>Topography and Bending Strain Description</td><td colspan="3">The pipeline is routed through agricultural land adjacent to multiple fields. The pipeline is located in gently undulating land at the base of a minor elevation change with gradient of 5% and a transverse gradient of 5%. Based on a review of the aerial imagery a water course feature is located adjacent to the pipeline right of way.

The maximum point of strain is located at log distance 120377.0 m and appears to be attributable to a sag bend adjacent to a weld at log distance 120377.394 m. The bending strain appears to be related to a fabricated sag bend at the location of the weld, on this basis the area is considered to be a construction irregularity.

There is no evidence of external loading at this location and it is considered the vertical bending strain is derived from the pipeline construction.</td></tr>
<tr><td>Conclusions</td><td colspan="3">The bending strain appears to be related to a fabricated sag bend at the location of a weld (construction irregularity). There is no evidence of external loading at this location and it is considered the bending strain is derived from the pipeline construction. Area to be reviewed following next inspection.</td></tr>
</table>

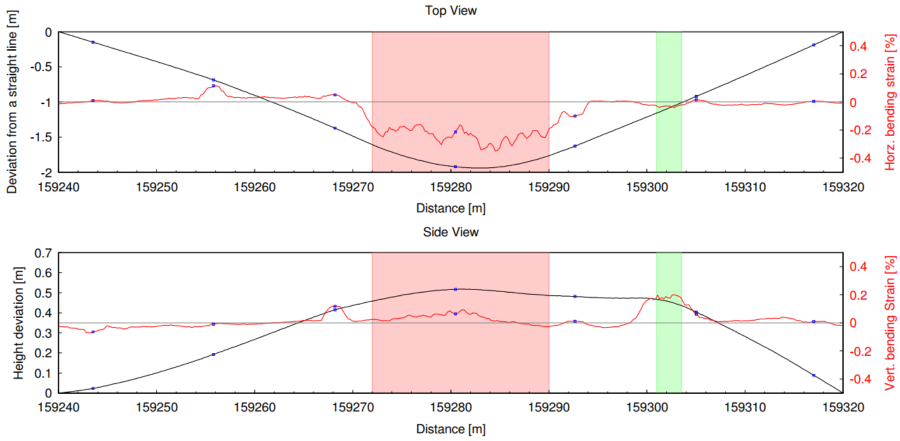
Bending Strain Area #025

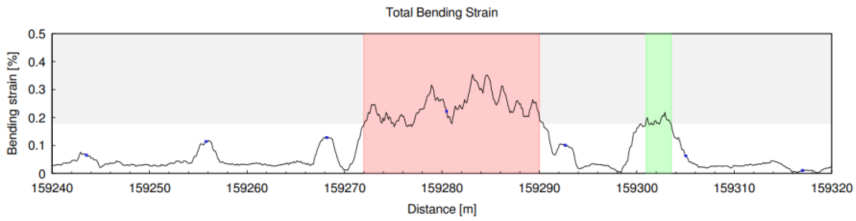




Orientation	Vertical	**Maximum Strain**	0.42%
Topography and Bending Strain Description	The pipeline is routed through flat agricultural land adjacent to multiple fields. The maximum point of strain is located at log distance 138849.7 m and is attributable to vertical over bending adjacent to a girth weld located approximately 1.5 m downstream (log distance 138851.560 m). The bending strain appears to be related to a fabricated over bend at the location of the weld, on this basis the area is considered to be a construction irregularity. There is no evidence of external loading at this location and it is considered the vertical bending strain is derived from the pipeline construction.		
Conclusions	The bending strain appears to be related to a fabricated over bend at the location of a weld (construction irregularity). There is no evidence of external loading at this location and it is considered the bending strain is derived from the pipeline construction. Area to be reviewed following next inspection.		

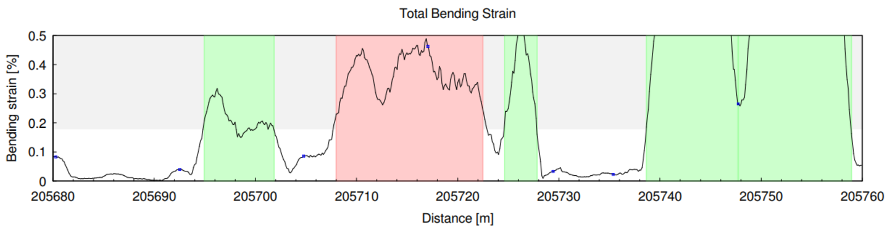
Bending Strain Area #029





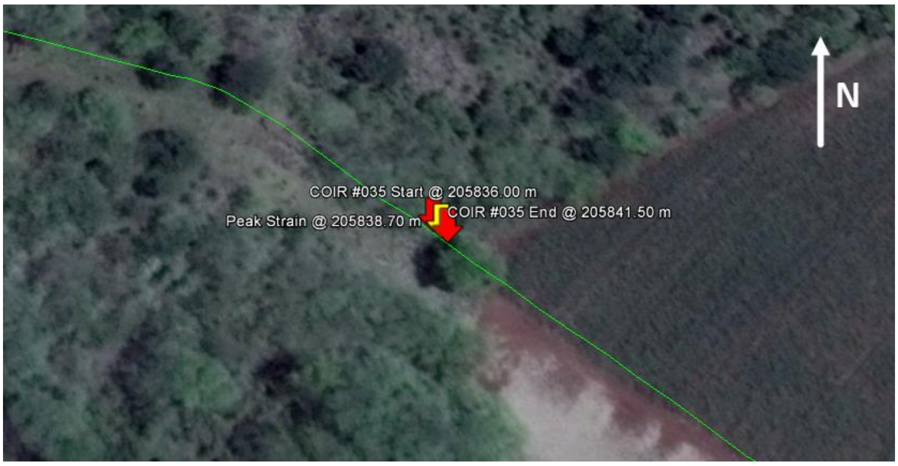
Orientation	Horizontal	**Maximum Strain**	0.35%
Topography and Bending Strain Description	The pipeline is routed across flat scrub terrain adjacent to a plantation. The maximum point of strain is located at log distance 159283.2 m and appears to be associated with a left side field bend. The bending strain appears to be related to a fabricated left horizontal bend at the location of the weld, on this basis the area is considered to be a construction irregularity. There is no evidence of external loading at this location and it is considered the horizontal bending strain is derived from the pipeline construction.		
Conclusions	The bending strain appears to be related to a fabricated left horizontal bend at the location of a weld (construction irregularity). There is no evidence of external loading at this location and it is considered the bending strain is derived from the pipeline construction. Area to be reviewed following next inspection.		

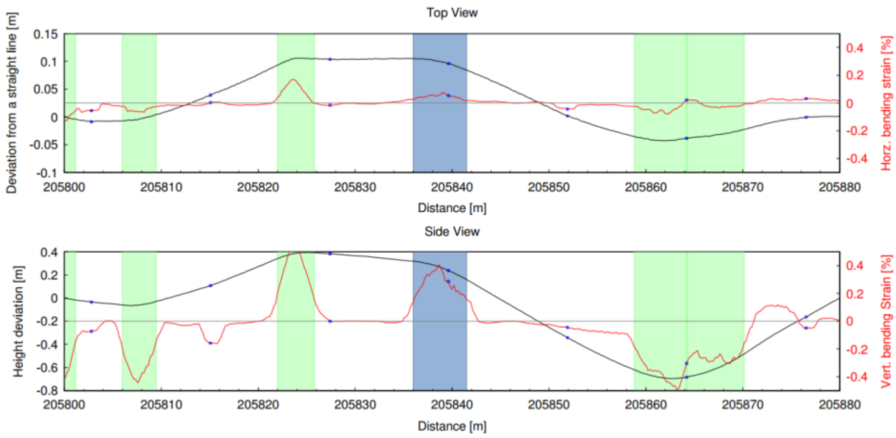
Bending Strain Area #034

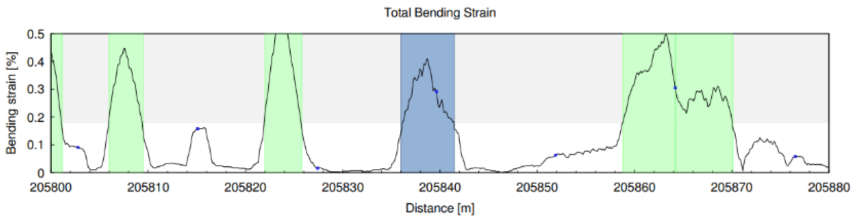


Orientation	Vertical	**Maximum Strain**	0.49%
Topography and Bending Strain Description	The pipeline crosses a shallow ridge between agricultural fields. The maximum point of strain is located at log distance 205716.9 m and is attributable to an over bend adjacent to a weld at log distance 205717.047 m. The bending strain appears to be related to a fabricated over bend at the location of the weld, on this basis the area is considered to be a construction irregularity. There is no evidence of external loading at this location and it is considered the vertical bending strain is derived from the pipeline construction.		
Conclusions	The bending strain appears to be related to a fabricated over bend at the location of a weld (construction irregularity). There is no evidence of external loading at this location and it is considered the bending strain is derived from the pipeline construction. Area to be reviewed following next inspection.		

Construction Irregularity #035







Orientation	Vertical	Maximum Strain	0.41%

Topography and Bending Strain Description	The pipeline is routed in through a shallow ridge adjacent to an agricultural field. The reported construction irregularity is located approximately 114 m downstream of bending strain area #034. The maximum point of strain is located at log distance 205838.7 m and appears to be attributable to a small over bend adjacent to a weld at log distance 205839.649 m. The bending strain appears to be related to a fabricated over bend at the location of the weld, on this basis the area is considered to be a construction irregularity. There is no evidence of external loading at this location and it is considered the vertical bending strain is derived from the pipeline construction.
Conclusions	The bending strain appears to be related to a fabricated over bend at the location of a weld (construction irregularity). There is no evidence of external loading at this location and it is considered the bending strain is derived from the pipeline construction. Area to be reviewed following next inspection.

The results of the assessment are presented below in .

- Priority 1 – Represents a significant threat to the pipeline, immediate actions required.
- Priority 2 – Represents a potential / credible threat to the pipeline, actions should be scheduled.
- Priority 3 – Stable areas of bending strain, to be monitored during next inspection.

Whilst all areas of strain appear to be stable, two of the six sites appear to be of significant interest where bending appears to continue across a girth weld (BSTR#29 and BSTR#34). These areas have been identified as good candidates to fully evaluate the threat of circumferential SCC, particularly BSTR#29 given its proximity to the Iacanga compressor station. The 2018 EMAT inspection has identified that BSTR#34 is possibly under an extensive coating repair. It is recommended that TBG review their records to confirm if this is the case.

Bending Strain Area	Length (m)	Maximum Strain (%)	Start (m)	Priority
COIR #009	3.0	0.32	75396.0	P3
COIR #020	7.5	0.34	120374.0	P3
BSTR #025	12.0	0.42	138842.5	P3
BSTR #029	18.0	0.35	159272.0	P3 – Consider SCC-DA
BSTR #034	14.5	0.49	205708.0	P3 – Consider SCC-DA
COIR #035	5.5	0.41	205836.0	P3

Table 14: Interpreted source of Bending Strain for 32PENSAO

7.5 Level 2 – Reported Features Combined with Bending Strain

7.5.1 Reported Features in Bending Strain Locations

4 location of bending strain were coincident with 4 features reported within 32PENSAO. The feature details are listed in .

Log Distance (m)	Event	Depth	Length (mm)	Width (mm)	Length of Bending Strain Area (m)	Associated Max. Strain (%)
18887.212	Ripple/Wrinkle	2-6 mm	7414	-	46.5	0.26
143074.340	Dent Plain	1.35% ID	440	86	40.0	0.25
229399.823	Ripple/Wrinkle	2-6 mm	8385	-	41.5	0.19
236146.847	Dent Plain	1.77% ID	897	194	3.5	0.25

Table 15: Summary of Features within Bending Strain Areas (32PENSAO)

7.5.2 Assessment Results

The 4 geometric anomalies listed in are considered to be acceptable for operation based on their static assessment results and their associated bending strain areas being acceptable for operation.

8 IMMEDIATE INTEGRITY ASSESSMENT; PLANAR FEATURES

This section of the report assesses the significance of any laminations and planar features (e.g. crack-like features and linear anomalies) upon the immediate integrity of the pipeline, i.e. at the time of the ROSEN 2018 EMAT-C inspection. Any features requiring investigation / repair are identified.

8.1 Crack-Like Features

Four crack-like features were listed in the 2018 ROSEN EMAT-C final inspection report (ref. [2]). However, all features have since been subject to investigation and remediated. Please refer to Section 4.3 regarding the preliminary reporting and in-field findings.

8.1.1 Acceptable Defect Sizes

In anticipation of verifying cracking in-field, ROSEN provided TBG with guidance on acceptable defect sizes along the 32PENSAO pipeline (ref. [23]). Acceptable crack sizes have been identified for axial and circumferential cracking within both the parent material, long seam and girth weld areas when subject to internal pressure only.

An example of an acceptable defect chart is shown below. This chart shows an axial crack located in the pipe body. The guidance note also provides acceptable crack sizes for other scenarios.

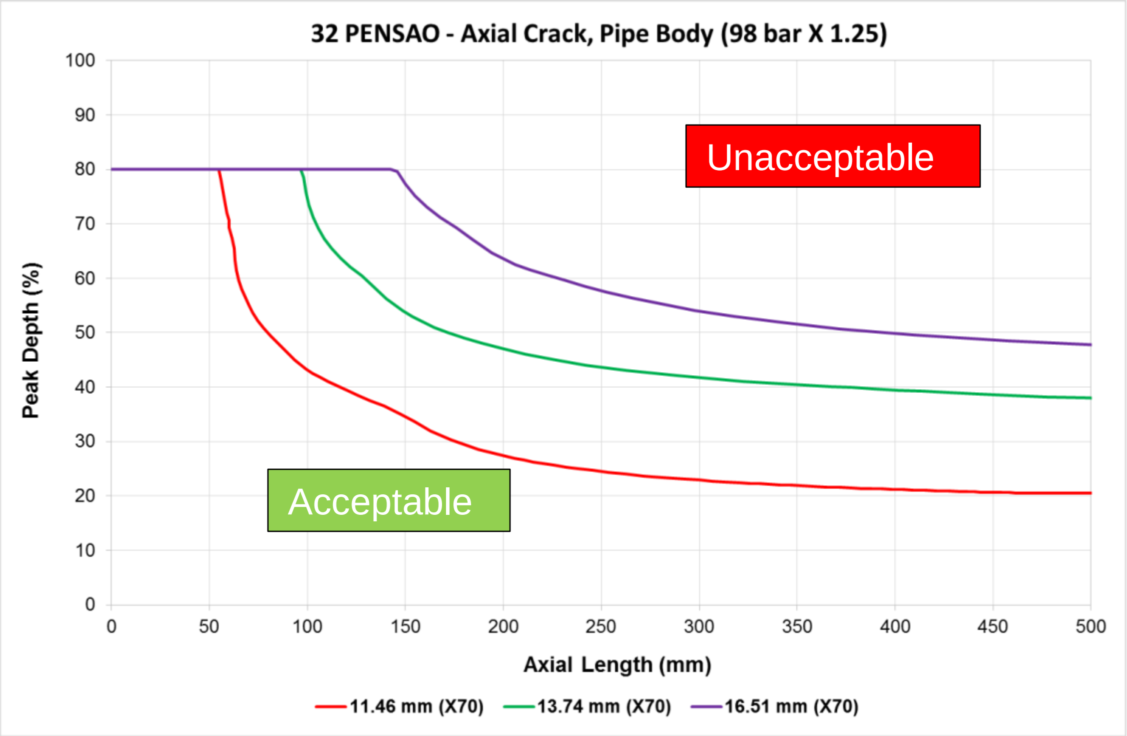


Figure 18: Acceptable Defect Size Chart – Axial Crack located on the Pipe Body

9 IMMEDIATE INTEGRITY ASSESSMENT; METAL LOSS FEATURES

This section of the report assesses the significance of the reported metal loss features upon the immediate integrity of the pipeline, i.e. at the time of the 2017 MFL-C inspection. Any features requiring immediate investigation / repair are identified.

9.1 Pipeline Parameters used in the Feature Assessment

The following pipeline data has been used for conducting the feature assessment (ref. [1]).

Parameter	Value
Nominal Diameter	32 inch (812.8 mm)
Type of Pipe	Longitudinal Weld (SAW)
Assessment Pressure	MAOP 98 bar
Wall Thickness (nominal)	11.46 mm / 13.74 mm / 16.51 mm
Pipe Grade	API 5L X70
SMYS	482 MPa
SUTS	565 MPa.
Length	244.45 km
Construction Date	1999
Pipeline Product	Natural Gas

Table 16: Feature Assessment Parameters

9.2 Safety Factors

The repair criteria which has been accepted world-wide and codified within ANSI/ASME B31.G, PRCI Report RSTRENG Defect assessment, etc, is that a defect is considered acceptable providing it would survive a hydrotest to 100% of SMYS (ref. [24]). This hydrotest criterion defines a minimum safety factor for pipelines operating at 72% of SMYS:

Consequently, a safety factor of 1.39 (100/72) has been used throughout this assessment. In addition any corrosion exceeding 80% of wall thickness is not acceptable due to the risk of leakage.

In summary, features require repair if the following criteria is met:

- Effective or reported dimensions exceed the size tolerable at the assessment pressure x safety factor; or
- Maximum reported depth exceeds 80% wt.

9.2.1 Inspection Tool Tolerances

The assessment described within this report contain an inherent conservatism i.e. it has been based on specified minimum tensile properties. Given that a safety of 1.39 has been applied, the assessment is considered to contain sufficient conservatism to take account of a 10% wt variation in depth sizing. Consequently, only a proportion of the depth sizing tolerance in excess of 10% wt has been applied. For example, for a feature with an associated tolerance of ±15% wt, 5% wt has been added to the reported feature depth. Some areas of increased tool velocity / magnetization were identified, features located in such areas have retained a conservative approach as discussed above and have not had a reduced 10% wt tolerance in the assessments below.

Features have been classified in accordance with the POF specification based upon their aspect ratio (width x length) prior to applying the appropriate tolerance (ref. [18]).

A summary of the additional depth sizing applied in the assessment is shown in Table 17 (ref. [3]).

POF Classification	Feature Location	
	Pipe Body and Near or On Seam Weld (% wt)	Girth Weld or HAZ (% wt)
General	5	15
Pitting	9	15
Axial Grooving	5	15
Axial Slotting	5	15
Circumferential Grooving	Not specified	Not specified
Circumferential Slotting	Not specified	Not specified
Pinhole	Not specified	Not specified

Table 17: Additional Feature Depth Sizing Used in the Assessment

9.3 Assessment Methods

In this FFP assessment, the corrosion features have been assessed against the Modified B31.G criterion in terms of their axial and depth dimensions (ref. [24]). This can be a conservative assessment method and has been used as an initial 'screening' assessment.

Following this initial assessment, any corrosion feature found to exceed tolerable dimensions has been assessed according to the Detailed RSTRENG assessment method (ref. [24]). This assessment method considers the profile of a corrosion feature and in some cases, particularly for 'long' irregular features under the pressure based portion of the assessment curve, extends the repair date. Both Modified B31.G and Detailed RSTRENG are appropriate assessment methods for this pipeline and are widely accepted throughout the industry.

The significance of the milling features reported with associated metal loss in terms of their axial length and depth dimensions has been assessed using the Shannon assessment method (ref. [25]). The assessment method proposed by Shannon is based on the original NG-18 equations developed by Battelle but uses a modified term for the material flow stress (ref. [26]). This provides a more accurate estimation of the failure stress of metal loss defects in ductile line pipe material.

In addition, the significance of all metal loss features in terms of their circumferential length and depth dimensions has been assessed using the Kastner method (ref. [27]). The maximum axial stress due to pressure used in this assessment has been taken as 0.5 x hoop stress, i.e. it is based on the conservative assumption that the pipeline is unrestrained.

Further details of the assessment methods are provided in Appendix A.

9.4 Assessment Results; Corrosion Features

Figure 19 shows the significance of the reported corrosion features in terms of their reported log distance and their calculated safe working pressure.

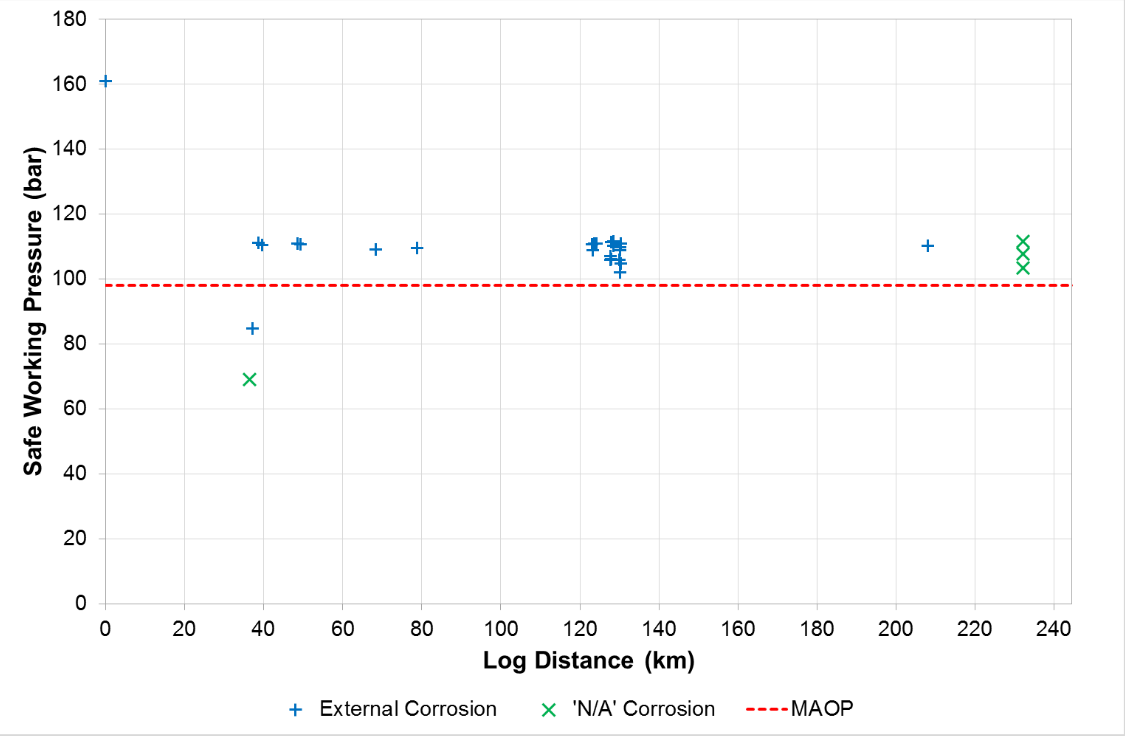


Figure 19: Corrosion Features; Safe Working Pressure According to Modified B31.G

27 of the 29 corrosion features were found to be acceptable for operation, in terms of their respective axial, circumferential and depth dimensions, at the time of the 2017 MFL-C ROSEN inspection. Details of the two features found to be unacceptable are provided below in Table 18. Both features are in close proximity to a girth weld.

It should be noted that the feature located at log distance 37220.495 m was investigated in May 2018 (reported as possible crack-like feature in the EMAT preliminary report). The feature was confirmed to be deep axial corrosion with a depth of 7 mm, see Section 4.3.

Log Distance (m)	Joint Number	Joint Length (m)	Event	Location	Orientation (hh:mm)	Depth (%wt)	Length (mm)	Width (mm)
36520.597	30250	12.31	Cluster	N/A	03:45	49	303	45
37220.495	30880	12.38	Corrosion	External	08:34	68	90	24

Table 18: Immediate Repairs: Corrosion Feature Details

Whilst a formal assessment of the features reported by the 2017 Baker Hughes MFL-A has not been completed as part of this contract, a screening assessment was completed and based on reported dimensions, none of the 'unrepaired' metal loss features (not reported by ROSEN) were predicted to have a burst pressure less than 1.39 x MAOP.

9.5 Assessment Results; Non-Corrosion Metal Loss

Figure 20 shows the significance of all pipe mill anomalies in terms of their reported log distance and their calculated safe working pressure.

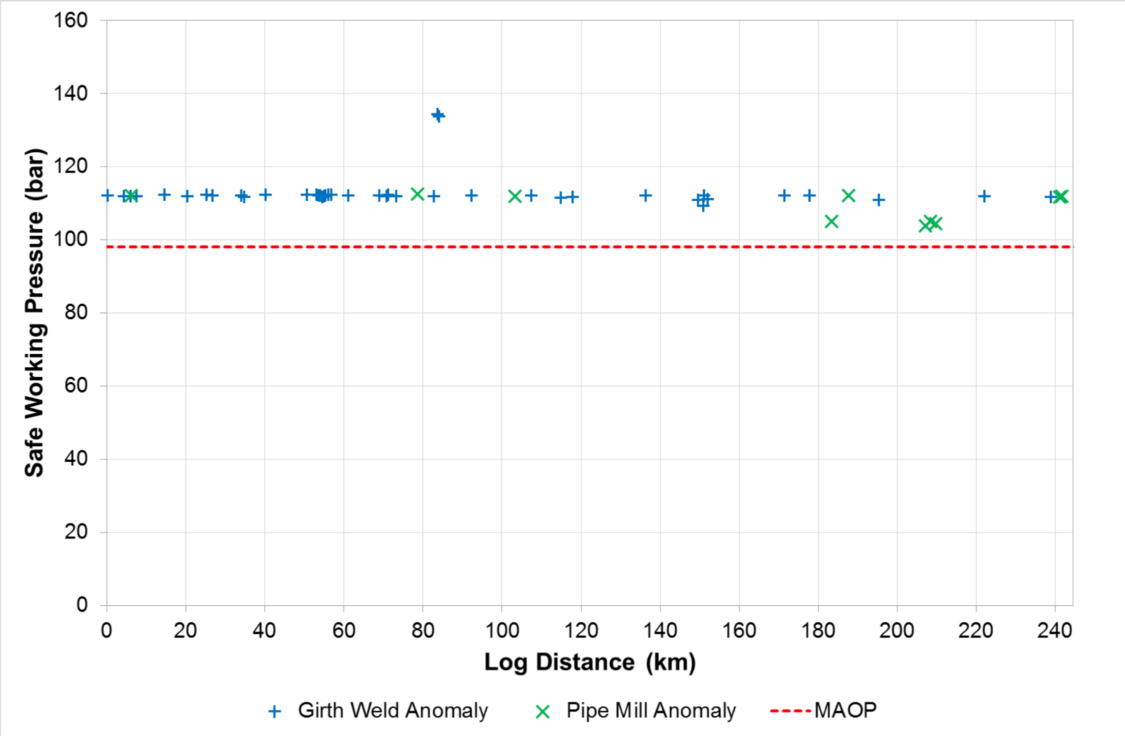


Figure 20: Milling Features; Safe Working Pressure According to Shannon

All non-corrosion metal loss features were found to be acceptable for operation, in terms of their respective axial, circumferential and depth dimensions, at the time of the 2017 ROSEN MFL-C inspection.

10 IMMEDIATE INTEGRITY ASSESSMENT; GEOMETRIC ANOMALIES

This section of the report assesses the significance of geometric anomalies upon the immediate integrity of the pipeline, i.e. at the time of the 2014 ROSEN geometric inspection. Any features requiring investigation / repair are identified.

10.1 Dents

The maximum ID reduction comprises the sum of an ovality part, attributable to general ovalisation of the pipe, and a dent part. Previous experience has found there to be a greater correlation between in-field measurements of ID reduction with the reported dent component (%). Consequently for the purposes of this assessment the part of the ID reduction considered to be purely attributed to the ovalisation of the pipe, i.e. the ovality part, has been excluded from the assessment, see Figure 21.

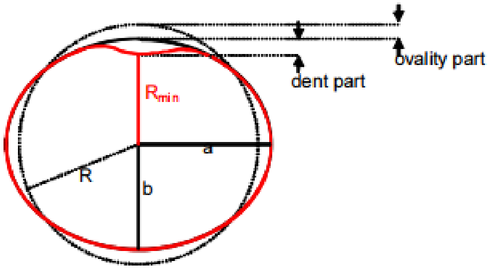


Figure 21: Schematic of Deformation Reporting

10.1.1 Assessment Methodology – Static Assessment

The dent acceptance criteria for static loading which have been used for this assessment are shown in Table 19 below. These are based on a review of current code guidance and recent research work.

A summary of the relevant assessment criteria and background information for each of the main dent types is provided in Appendix B.

Dent Type	Assessment Criteria
Plain Dent[1]	Up to 7% OD or 6% strain[4]
Associated with Ductile Weld[2]	Up to 2% OD or 4% strain on ductile[3] weld
Associated with Brittle Weld	Not allowed
Associated Corrosion	Assess dent and metal loss[5] separately. Corrosion must be ≤ 40% wt in depth and acceptable to an appropriate corrosion assessment method e.g. ASME B31.G. If Mechanical Damage likely, investigate as below.
Associated Mechanical Damage (cracks, gouges, scrapes, etc.)	Investigate In-field / Repair

Table 19: Summary of Static Dent Acceptance Criteria

(1) A dent which is not associated with other features detected by ILI, i.e. welds, corrosion, gouges, etc., may not be a plain dent i.e. features may be present which are outside the ILI detection capability.

(2) It is assumed that the weld meets typical construction specifications, e.g. API 1104 (ref. [28]).

(3) Full size weld Charpy energy greater than a minimum of 27 J and an average of 40 J (from 3 specimens) (ref. [29,30]), at the minimum design temperature.

(4) Inspection with a high resolution geometry pig is required to determine strain levels. Sufficient sensor channels in both the axial and circumferential direction are required in order to determine representative strain levels.

(5) Further investigation may be required to support ILI classification of metal loss as corrosion.

10.1.2 Assessment Results

Each of the reported dents has been categorised against the dent assessment criteria summarised in Table 19, to determine their significance in relation to the immediate integrity of the pipeline. A process flow diagram is provided in Appendix B.

All 34 dents reported were found to be located in the bottom of line (BOL). Therefore no immediate further action is recommended for the reported dents.

Dent Type Reported by ILI	Assessment Criteria	No. of Dents	Immediate Action / Comment	Recommendation
Any Dent	Top of line (TOL) (between 8 & 4 o'clock)	0	Determine risk of 3rd party damage	**Monitor if –** • Low risk of 3rd party damage **Investigate in-field if–** • High risk of 3rd party damage **Repair if –** • In-field investigation confirms associated Mechanical Damage (MD)
Dent on Weld	≤ 2% OD	0	Monitor	**Repair if –** • Weld is brittle **Monitor if –** • Weld is ductile
Dent on Weld	> 2% OD	0	In-field investigation or complete strain based assessment	**Repair if -** • (Strain > 4% **OR** unknown) **AND** (Depth confirmed > 2% OD) **OR** • Associated with MD **OR** • Weld is brittle

Table 20: Summary of Actions Required, Under Static Conditions, in Relation to the Immediate Integrity of the Dents

See section 12.1 and 12.2 for the fatigue assessment of the dents.

10.2 Wrinkles

10.2.1 Assessment Methodology – Static Assessment

In accordance with ASME B31.8 (ref. [31]), field bend areas should be free from buckling, cracks or other evidence of mechanical damage, with ripples or wrinkling reported in these areas meeting a set requirement. For small ripples or wrinkles which exhibit no cracks, no repair is required if the peak-to-trough height (h) as a percentage of the outer diameter does not exceed a calculated value (dependent on the maximum stress at the MAOP of the pipeline at the local wall thickness).

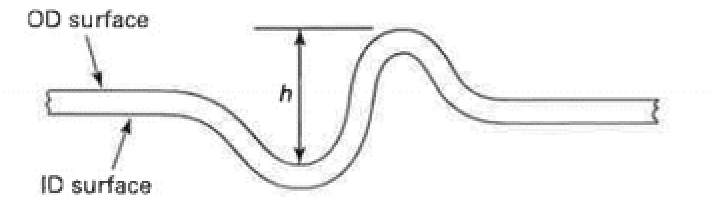


Figure 22: Peak-to-Trough Height Measurement of Wrinkles

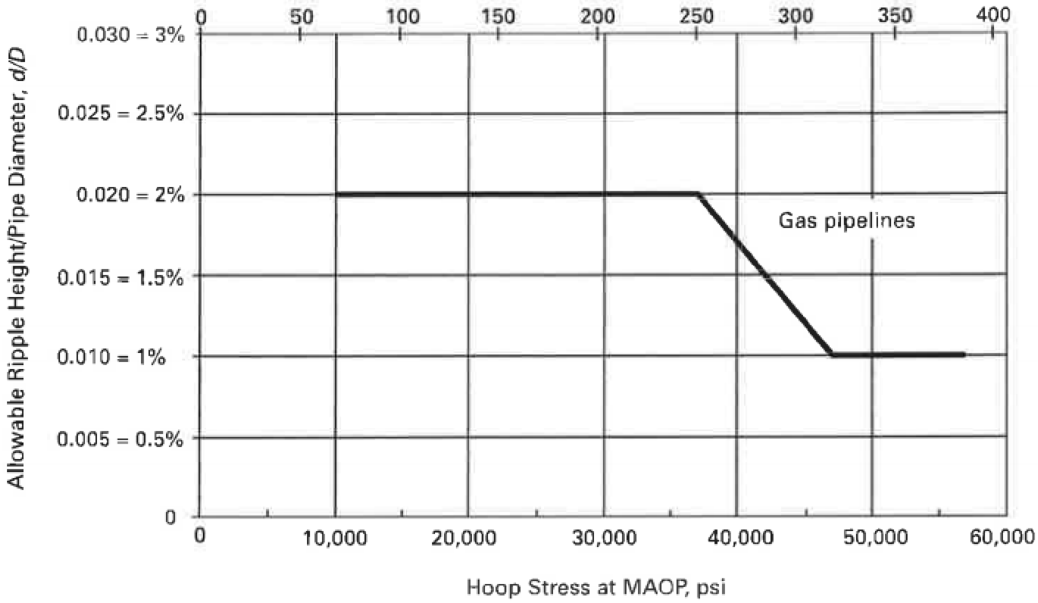


Figure 23: ASME B31.8 Acceptance Criteria for Ripples (ref. [31])

10.2.2 Assessment Results

The results of the assessment based on the MAOP (98 bar) is shown in Figure 24.

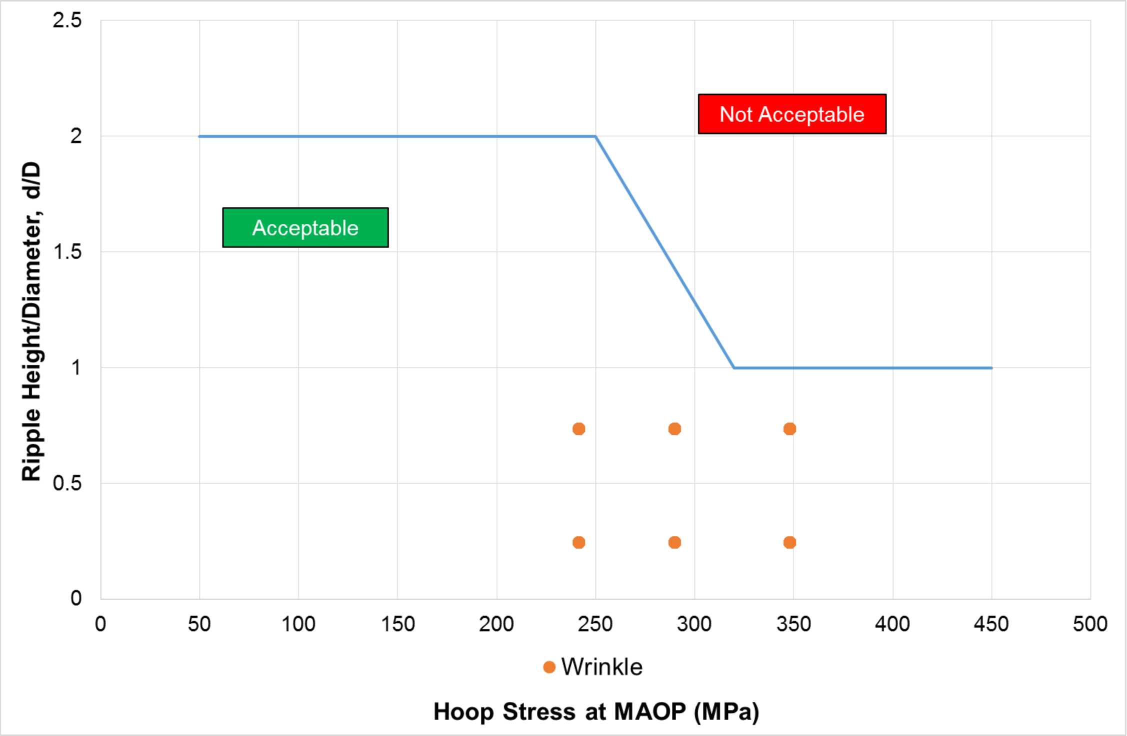


Figure 24: Assessment Results of Reported Winkles in Accordance with ASME B31.8.

With reference to the acceptance criteria noted above, all 385 wrinkles are considered to be acceptable in terms of their impact on the immediate integrity of the pipeline at the MAOP of 98 bar. Note, all 385 wrinkles are presented as 6 groups (orange dots, grouped by hoop stress) in the chart above.

11 IMMEDIATE ASSESSMENT SUMMARY

A summary of the immediate assessment results for each feature type is listed below in Table 21.

Feature Type	Number Reported	Immediate Assessment Fail - Further Action Required	Assessment Methodology
Crack-like	4	0	See Section 8
Metal Loss (Corrosion)	29	2	See Section 9
Milling	52	0	See Section 9
Dent	34	0	See Section 10
Wrinkle/ripple	385	0	See Section 10
Bending Strain Areas	44	0[8]	See Section 11

Table 21 Immediate Integrity Assessment Summary

[8] 6 areas fail the compressive assessment at zero pressure. However these areas are acceptable at typical operating pressure. Each site has since been subject to a detailed review and are all considered to be acceptable.

12 FUTURE INTEGRITY ASSESSMENT; PLANAR FEATURES

In this section, the growth of (currently) sub-critical planar features, i.e. linear anomalies and crack-like anomalies, due to the effects of pressure cycling is considered. Furthermore, the future significance of these features due to continued growth due to Stress Corrosion Cracking (SCC) is also considered.

Four crack-like features were listed in the 2018 ROSEN EMAT-C final inspection report (ref. [2]). However, all features have since been subject to investigation and remediated. Please refer to Section 4.3 regarding the preliminary reporting and in-field findings.

Given that low level cracking is considered credible, For the purpose of determining future integrity, a theoretical crack has been assumed with dimensions below the reporting specification of the tool, i.e. 40 mm long x 3 mm deep.

12.1 Fatigue Assessment

Fatigue Assessment Methodology

Where the reported crack-like feature is not likely to be SCC, a fatigue assessment is relevant to determine future integrity.

The fatigue assessment has been conducted in accordance with Section 9.5 API 579 (ref. [32]). For the purpose of this assessment the simplified Paris-Erdogan crack growth model has been used (ref. [33]). Crack growth equations and material constants have been taken from Annex F API 579 (ref. [32]).

Further details are provided in Appendix C.

Both the length and depth dimensions were grown incrementally. After each increment the current flaw size (i.e. the previous flaw size plus the increment of crack growth) was assessed for its acceptability within the FAD. This process continues until the flaw reaches an unacceptable size i.e. is just outside the FAD. The fatigue life is defined as the time required to grow the anomaly to a critical size at the MAOP (98 bar).

As with the immediate crack assessment, a safety factor of 1.25 was applied to the primary stress during the fatigue assessment of crack like anomalies.

12.1.1 Input Data

TBG have provided hourly pressure readings between 1st August 2012 and 2nd August 2017 at the Penápolis compressor station (ref. [6]).The pressure readings are shown in Figure 7.This operational data was used for the crack fatigue assessment.

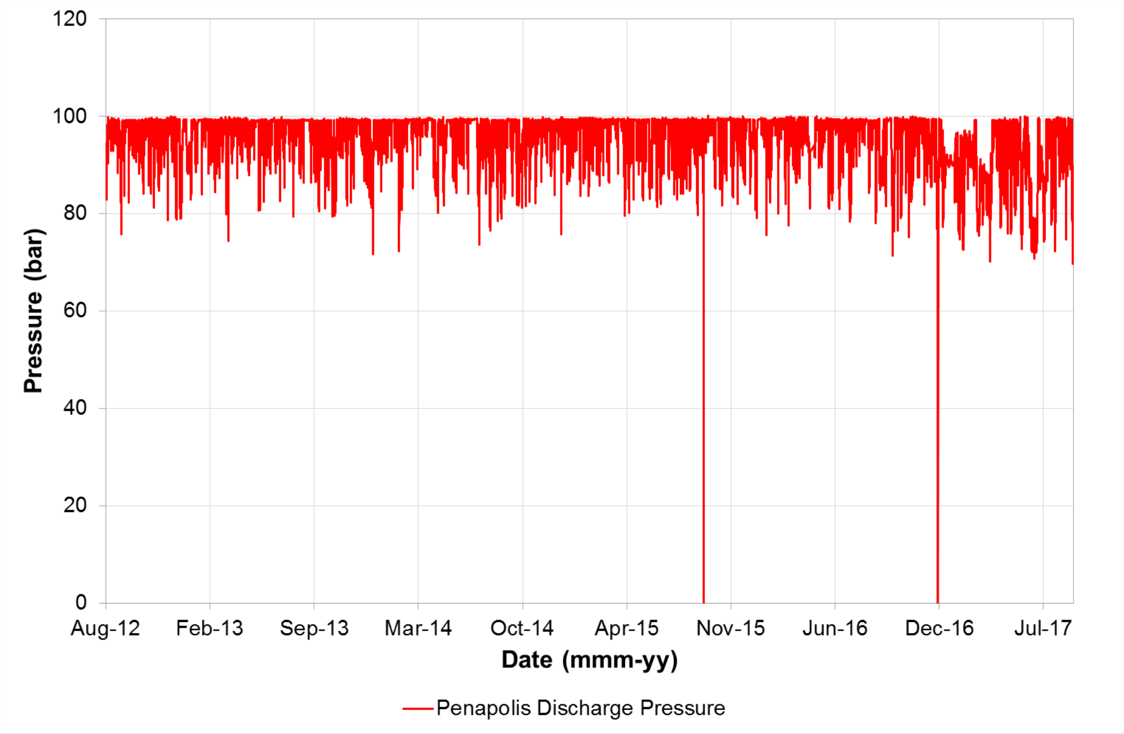


Figure 25: Pressure Readings Recorded at the Penápolis Compression Station

The pressure data was simplified using the Rainflow cycle counting method (ref. [34]). The Rainflow method breaks down the time series data into a series of half cycles of various amplitudes (independent of frequency), by matching pressure pairs of similar magnitude but opposite sense. This information was then converted into an equivalent number of cycles at the maximum stress range identified using the Miner's rule (ref. [35]).

The result of this analysis for crack-like features is shown in Table 22.

Section	Cyclic Pressure (bar)	Number of Equivalent Cycles per Year (at 98 bar)
32PENSAO	98	0.69

Table 22: Rainflow and Miner's Rule Analysis Results (Crack-Like Features)

12.1.2 Fatigue Assessment Results

When assessed for growth due to fatigue, the assessment has determined that the theoretical feature has an estimated fatigue life in excess of 100 years (inclusive of the 1.25 safety factor).

Following the next inspection, the fatigue assessment should be updated for any planar features reported in order to confirm their remaining fatigue life.

12.2 Remnant Life – Stress Corrosion Cracking

Growth rates for stress corrosion cracks typically vary considerably over time, and as the pipeline ages the crack growth velocity is likely to increase due to growth and coalescence. Industry recommendations cover a wide range of credible rates and selecting the most appropriate rate is difficult given that the recommended rates can vary considerably, see Table 23.

Literature	Method of Determining SCC Growth Rate	Maximum SCC Growth Rate (Depth) (mm/year)
ASME STP-PT-011 (2008)	Metallographic examinations of cracks which had survived an earlier hydrostatic test	0.76
CEPA RP (2007)	Laboratory testing which simulates field conditions	0.89
	"Beach Mark" observations	No Available Data
	Repeat ILI	No Available Data
	SCC size distributions generated from field inspection data	0.03
	Growth rates derived from failures	0.63 (NPS 36)
IPC 10180 (2006)	Repeat ILI	0.25
IPC 31140 (2010)	Repeat ILI / SCC size distributions generated from ILI	0.30
IPC 33059 (2014)	Probabilistic Crack Growth Modelling	0.30
PPIM 2012, Evaluation of EMAT Tool Performance by Monitoring Industry Experience	Probabilistic Crack Growth Modelling	0.25
PPIM 2011, A Review of Crack Detection ILI Case Studies	Probabilistic Crack Growth Modelling	0.30
RIO 2013	Industry Review	0.76

Table 23 Comparison of Typical SCC Growth Rates

For the purposes of determining the remnant life of an theoretical crack, a rate of 0.3 mm per year has been selected. This rate is deemed fair when considering the spread of possible rates above and is also similar to the environmental rates observed by ROSEN elsewhere in South America.

For illustrative purposes, a remnant life assessment was completed for a theoretical pipe body SCC crack located within the thinnest wall thickness (11.46 mm) with a depth of 2 mm, the detection threshold of the 2018 EMAT tool. Conservatively, a crack length of 100 mm and growth rate of 0.3 mm per year was assumed. The assessment predicted that a 2 mm deep, 100 mm long theoretical SCC crack would have a remnant life of 9.5 years from the 2018 EMAT-C inspection (i.e. June 2027).

Furthermore, a sensitivity analysis has been completed to considering possible remnant life scenarios (3, 5, 7 & 10 years) to calculate the required crack growth rate, please refer to Table 24.

Assumed Feature Length (mm)	Assumed Feature Depth (mm)	Predicted SCC Growth Rate Vs Remnant Life (mm/year)			
		3 Years	5 Years	7 Years	10 Years
40	2.00	2.39	1.43	1.02	0.72
100	2.00	0.96	0.58	0.41	0.29

Table 24: SCC Growth Rate Sensitivity Analysis

As per the SCC credibility technical note (ref. [37]), SCC is still considered a threat along 32PENSAO, particularly as the pipeline ages beyond 20 years. Considering this and the analysis above, it is recommended that the 32PENSAO pipeline is re-inspected with a crack detection tool within 9.5 years of the recent ILI, i.e. before June 2027.

This is discussed further in the SCC management Plan (1-5500-12584-SCCMP-32PENSAO-0).

13 FUTURE INTEGRITY ASSESSMENT; CORROSION FEATURES

This section presents the results of the comparison between the 2017 ROSEN MFL-C and 2017 BAKER HUGHES MFL-A inspection. It should be noted that due to the absence of the previous BAKER HUGHES MFL-A inspection signal data it has not been possible to perform a signal comparison of the inspection data.

This section of the report considers the future significance of (currently) sub-critical corrosion features in order to develop a schedule of future investigations / repairs.

13.1 Corrosion Growth Assessment

13.1.1 Methodology

The corrosion growth study has been initially conducted by comparing the lists of features reported by the 2017 ROSEN and BAKER HUGHES inspections. The depths of features reported in both inspections are compared and the apparent growth rates are calculated.

Inconsistences in the number of features / depths reported is attributed to differences in inspection technology (ROSEN MFL-C compared to BAKER HUGHES MFL-A), detection / reporting thresholds and/or by corrosion growth. Features reported in 2017 that could not be matched to any of the features reported previously are classified as ‘unmatched’ and a growth rate is calculated on the basis that the feature has grown to its current depth since the date of the previous inspection.

The feature matching process is conducted on all ‘individual’ features reported by the 2017 inspections. This includes each single feature that forms part of a cluster.

Where significant unmatched rates are apparent or there are a significant number of unmatched features, standard industry rates will be considered.

13.1.2 Comparison of Previous Inspection Results

The 2017 ROSEN MFL-C inspection reported a total of 86 individual metal loss features compared with 2086 reported by the 2017 BAKER HUGHES MFL-A inspection. A simple depth comparison of all metal loss features reported by the 2017 inspections is shown in Figure 26.

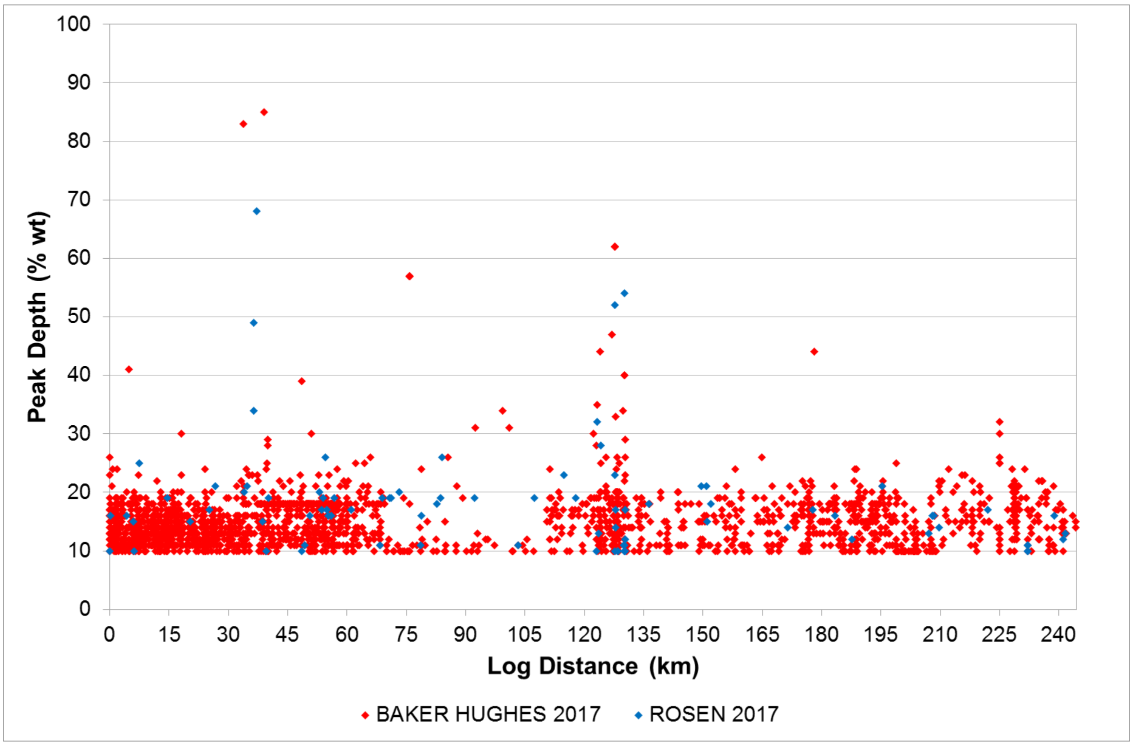


Figure 26: Comparison of Depths Reported by the ROSEN and BAKER HUGHES MFL Inspections

13.2 Corrosion Growth Assessment Results

External & "N/A" Corrosion Growth

The ROSEN 2017 MFL-C inspection reported a total of 28 individual external corrosion features. The maximum depth was reported to be 68% wt associated with a feature at log distance 37220.496 m. This feature was confirmed to be 7 mm deep in-field (61% wt), see section 4.3.

In addition to the external corrosion features, the ROSEN 2017 MFL-C inspection reported 6 corrosion features with the location classification "N/A". the maximum depth was reported to be 49% wt associated with a feature at log distance 36520.688 m. For the purpose of the future assessment of these features they have been considered to have the "external" location classification. The feature reported with a depth of 49% wt was located in close proximity to a girth weld which suggests external corrosion is most credible.

As discussed in Section 13.1, the difference in the number of reported external metal loss features between the ROSEN December 2017 and BAKER HUGHES June 2017 inspections is likely to be dominated by the difference between the magnetic flux orientation and their respective sensitivity to a specific feature type. The 2017 ROSEN MFL-C tool is more sensitive to axial features, which complements the analysis of the EMAT data. However the BAKER HUGHES inspection tool (MFL-A) is more sensitive to circumferential corrosion which is typical at girth welds.

Rather than complete a box matching exercise and grow features by unrepresentative 'unmatched' rates (likely to be in excess of 1.00 mm/year), all external corrosion features reported byu the ROSEN MFL-C tool were conservatively grown by 0.40 mm/year, the recommended NACE rate for unprotected steel in soil (ref.[40]).

Three (3) external corrosion features & one (1) unclassified corrosion feature are predicted to require investigation / repair within 5 years of the ROSEN 2017 ILI, details of which are provided in Table 25.

Log Distance (m)	U/S Joint Number	Distance Feature Start to Close GW (m)	Orientation (hh:mm)	Wall Thickness (mm)	Depth (% wt)	Length (mm)	Repair Date (mmm-yy)
232148.600	191960	4.28	00:02	11.45	11	224	Jun-20
130164.983	107620	-0.01	08:19	11.45	54	52	Nov-20
130407.536	107810	2.73	05:55	11.45	17	121	Jul-22
130076.183	107540	2.90	05:58	11.45	11	148	Aug-22

Table 25: External & "N/A" Corrosion Features Found to Require Repair Within 5 Years of the ROSEN 2017 ILI

13.3 Schedule of Future Repairs

Please refer to the prioritisation listing '1-5500-12584-FFP-32PENSAO-0.xlsx' which identifies any corrosion feature recommended for investigation within the next 10 years, i.e. the feature has reached critical dimensions within 10 years when grown at the corrosion growth rates stated above..

Note, TBG should consider the threat of circumferentially orientated corrosion when determining any future MFL re-inspection interval.

14 FUTURE INTEGRITY ASSESSMENT; DENTS

This section of the report considers the remaining life of the 34 dents reported by the ROSEN 2017 inspection due to internal pressure cycling, i.e. fatigue.

14.1 Assessment Methodology

The fatigue life of the reported dents has been determined using the approach developed by EPRG (ref. [38]). The approach itself is an empirical method for predicting the fatigue life of an unconstrained dent due to variations in internal pressure. As all dents are BOL, this method is conservative as most dents will likely be constrained.

In order to account for the large scatter in the published test data a safety factor of 6.42 is applied to the calculated fatigue life to ensure a 95% confidence level for predicting a conservative result. For dents associated with welds an additional safety factor of 10 is recommended (i.e. 10 x 6.42 = 64.2).

Details of the EPRG fatigue assessment methodology are provided in Appendix C.

14.2 Input Data

The same pressure data as outlined and described in Section 5.2 has been used to calculate the remaining fatigue life of the reported dents. The exponent used to calculate the number of equivalent cycles per year (Table 26) was calculated using an exponent of 4.292. This is recommended for the EPRG dent assessment.

The results of the Rainflow and Miner's analysis for dents is shown in Table 26.

Section	Cyclic Pressure (bar)	Number of Equivalent Cycles per Year
32PENSAO	98	0.44

Table 26: Rainflow and Miner's Rule Analysis Results (Dents)

14.3 Fatigue Assessment Results

The fatigue assessment has determined that all dents are predicted to have fatigue lives in excess of 100 years. Consequently, based on the available data, the operational pressure cycling of the pipeline is not considered to pose a significant risk to the future integrity of the pipeline.

Following the next inspection, the fatigue assessment should be updated for all geometric features in order to determine their remaining fatigue life.

15 INTEGRITY MANAGEMENT PLAN

15.1 Stress Corrosion Cracking Management

Please refer to the GASBOL SCC management plan (1-5500-12584-SCCMP-32PENSAO Rev 0) which includes specific guidance associated with the 32PENSAO pipeline.

15.2 General Integrity Management

Please refer to the prioritisation listing '1-5500-12584-FFP-32PENSAO-0.xlsx' which identifies any features recommended for investigation within the next 10 years.

The immediate integrity summary is outlined below (at 98 kgf/cm^2):

- 2 metal loss features require immediate investigation (1 remediated in May 2018).
- No other features reported by the recent inspections require immediate investigation.

15.3 Internal Corrosion Mitigation

No internal corrosion was reported by the 2017 ROSEN MFL-C inspection which used a circumferentially orientated MFL tool, on this basis and under current operational conditions the risk from internal corrosion is considered to be low. However, it is noted that the 2017 BAKER HUGHES MFL-A inspection reported 840 individual internal metal loss features.

Therefore, in order to ensure that the risk from internal corrosion is controlled the following actions are recommended:

- The occurrence of upset conditions should be avoided / minimised;
- Effective dew point control should be monitored / maintained; and
- Monitoring during future inspections.

15.4 External Corrosion Mitigation

The 2017 ROSEN MFL-C inspection reported external corrosion with a maximum depth of 68% wt (confirmed to be 61% WT deep infield in May 2018). However, without a comparison of like-for-like signal data, it is not possible to fully discount the possibility of active external corrosion growth upon the pipeline, particularly associated with circumferentially orientated corrosion at the girth welds. Therefore, to manage the threat of external corrosion, it is recommended that TBG:

- Ensure that the polarisation levels are achieved along the pipeline; and
- Ensure that the CP system is operated in line with the guidance provided by international practices, such as ISO-15589:2015 (ref. [39]) or NACE SP0169-2013 (ref. [40]).
- Inspect the pipeline with both MFL-A and MFL-C technology given that the feature verified to be 61% wt deep (reported by the ROSEN 2017 MFL-A tool) was not reported by the BAKER Hughes 2017 MFL-C inspection.
- The assessment of the 2017 baker Hughes MFL-A data has not been completed under this current scope of work. As expected, an increased number of metal features were reported when compared to the ROSEN MFL-C inspection due to the differences in flux orientation. It is recommended that TBG ensure that these additional features are subject to a corrosion assessment to determine the current integrity status and define an appropriate MFL-C re-inspection interval.

15.5 Suitable Repair Methods

A summary of typical structural repairs for each reported anomaly type, based upon current industry guidance is shown in Table 27 (ref. [29]). As the pipeline has a number of known physical features such as field bends, wrinkles and ovality, the general guidance from Table 27 may not be suitable for all scenarios.

A risk assessment should initially be performed on each repair system and its application to a pipeline and its specific operating parameters and location. Furthermore, removal of a section of pipe and replacing it with new pipe of equal or greater design pressure is another acceptable repair method which is applicable to all anomaly types.

Defect Type	Repair Method							
	Grinding	Type A Sleeve	Compression Sleeve	Type B Sleeve	Composite Sleeve	Weld Deposition	Bolt on Clamp with Seals	Hot Tapping
Leak or Defect >80% wt	NO	NO	NO	YES	NO[9]	NO	YES	YES
External Corrosion <80%wt	NO	YES	YES	YES	YES	YES[10]	YES	YES
Internal Corrosion <80%wt	NO	YES[11]	YES[11]	YES	YES[11]	NO	YES[11]	NO
Plain Dent	NO	YES[12]	YES[12]	YES	YES[13]	NO	YES	NO
Dent with stress concentrator on seam/ spiral weld or pipe body	YES[14]	YES[12,13,15]	YES[12,13,15]	YES	YES[12,13,15]	NO	YES	YES
Dent with Stress Concentrator on Girth Weld	YES[14]	NO	YES[12,13,15]	YES	NO	NO	YES[16]	NO
Shallow Crack <40% wt	YES[17]	YES[15]	YES[18]	YES[19]	YES[15]	YES[10, 19]	YES[19]	YES
Deep Crack >40% wt & <80% wt	NO	NO	YES[18]	YES[19]	NO	NO	YES	YES
Gouge or Other Metal Loss on Pipe Body	YES[17]	YES[15]	YES [15]	YES[20]	YES[15]	YES[10,15]	YES[20]	YES
Arc Burn, Inclusion or Lamination	YES[17]	YES	YES	YES	YES[15]	YES[10,15]	YES	YES
Hard Spot	NO	YES	YES	YES	NO	NO	YES	YES
Blisters, HIC	NO	YES	YES	YES	NO	NO	YES	NO

Table 27: Summary of Acceptable Structural Repair Options

Please refer to the GASBOL critical defect manual (1-5500-12584-CDM-32PENSAO-0) for further guidance on acceptable feature sizes, pressure reduction and repairs.

9 Some composite repair providers indicate that their repairs are suitable for leaking defects
10 Confirm remaining wall thickness is in excess of minimum wall thickness for in service welding
11 Ensure that the threat of internal corrosion has been controlled and the feature does not continue to grow beyond acceptable limits
12 Use of a filler material in the dent and an engineering assessment of fatigue are recommended
13 Code and regulatory restrictions on maximum dent size should be followed
14 Code and regulatory limits on amount of permitted grinding should be satisfied
15 Repair may be used for defects less than 0.8t deep, provided that damaged material has been removed by grinding and removal has been verified by inspection and the absence of any associated cracking has been confirmed
16 The split-sleeve clamp should be the type that transfers axial loads and provides full structural integrity
17 Provided defect and defective material are removed and local wall thickness is acceptable, grinding alone up to 40% wt may be used
18 Not suitable for circumferential crack
19 Make sure defect length is sub-critical or pressurise sleeve
20 It is recommended that the damaged material be removed with removal verified by inspection or that carrier pipe be tapped for this repair.

15.6 Re-inspection Interval

15.6.1 Crack-Like Features and Coating Condition

As per the SCC credibility technical note (1-5500-12584-SCCTN-32PENSAO-0), SCC is still considered a threat along 32PENSAO, particularly as the pipeline age extends beyond 20 years. Considering this and the analysis in Section 12.2, it is recommended that the 32PENSAO pipeline is re-inspected with a crack detection tool within 9.5 years of the recent ILI, i.e. before June 2027.

Please refer to the GASBOL SCC management plan (1-5500-12584-SCCMP-32PENSAO Rev 0) which includes specific guidance associated with the 32PENSAO pipeline.

15.6.2 Corrosion, Dents and Other Associated Features

Based upon the findings of this study it would be recommended that 32PENSAO be subject to an internal MFL (MFL-C) and Geometric inspection within 5 years of the previous inspection i.e. Before January 2023.

Assuming that any EMAT run will be combined with an MFL-C (Axial flaw detection) inspection, it is recommended that TBG consider running an independent MFL-A tool to fully evaluate the threat of circumferentially orientated corrosion along the length of the pipeline[21]. This would allow for a detailed corrosion growth comparison between inspection datasets.

If for any reason (e.g. during any in-field investigations) TBG find evidence that the internal / external corrosion growth rates used in this study are not conservative, then the investigation / repair schedule should be updated and consideration should be given to reducing the re-inspection interval.

[21] This FFP assessment only considers the metal loss features reported in the ROSEN inspections as per the scope of work. The burst pressure and future integrity of any anomalies reported only by the 2017 BAKER HUGHES inspection has not been considered.

16 CONCLUSIONS

The main conclusions of the study are:

1. Four crack-like features were listed in the 2018 ROSEN EMAT-C final inspection report. However, all features have since been subject to investigation and remediated as such they are no longer considered to be an integrity threat to the 32PENSAO pipeline.

2. For illustrative purposes, a remnant life assessment was completed for a theoretical pipe body SCC crack located within the thinnest wall thickness (11.46 mm) with a depth of 2 mm, the detection threshold of the 2018 EMAT tool. Conservatively, a crack length of 100 mm and growth rate of 0.3 mm per year was assumed. The assessment predicted that a 2 mm deep, 100 mm long theoretical SCC crack would have a remnant life of 9.5 years from the 2018 EMAT-C inspection (ih.e. June 2027).

3. Based on the pressure cycling data provided, the fatigue life of any long seam planar feature (with dimensions equal to the detection threshold at 90% confidence) is predicted have a fatigue life in excess of 100 years assuming the feature is not SCC (see point 2).

4. The 2017 EMAT inspection classified the levels of coating disbondment found on each pipe joint throughout the length of the pipeline into 5 categories. All of the pipe joints (100%) were identified to be in ‘excellent’ or ‘good’ coating condition. No joints were reported as ‘poor’ or ‘very poor’.

5. A total of 25 external corrosion features were reported by the ROSEN 2017 MFL-C inspection, the deepest of which was reported to have a depth of 68% wt at log distance 37220.495 m. This feature was verified in May 2018 to be 61% wt deep.

6. The 2017 ROSEN MFL-C inspection reported 4 corrosion features with the location classification “N/A”, the maximum depth being 49% wt associated with a feature at log distance 36520.597 m. For the purpose of the assessments these features have been treated as external corrosion features.

7. The significance of the reported corrosion features has been assessed in terms of their axial, circumferential and depth dimensions, according to the Modified B31.G, Detailed RSTRENG and Kastner assessment methods. 27 of the 29 corrosion features were found to be acceptable for operation, in terms of their respective axial, circumferential and depth dimensions, details of the two corrosion features requiring immediate repair are provided below. It should be noted that the feature located at log distance 37220.495 m was remediated in May 2018.

Log Distance (m)	Joint Number	Event	Location	Orientation (hh:mm)	Depth (%wt)	Length (mm)	Width (mm)
36520.597	30250	Cluster	N/A	03:45	49	303	45
37220.495	30880	Corrosion	External	08:34	68	90	24

8. Whilst a formal assessment of the features reported by the 2017 Baker Hughes MFL has not been completed as part of this contract, a screening assessment was completed and based on reported dimensions, none of the ‘unrepaired’ metal loss features (not reported by ROSEN) were predicted to have a burst pressure less than 1.39 x MAOP.

9. A future integrity assessment was completed for the reported ROSEN corrosion anomalies assuming a conservative external corrosion growth rate of 0.4 mm/year. Four (4) additional corrosion features were predicted to require repair within 5 years of the ROSEN 2017 MFL-C ILI, details of the 4 corrosion features are provided below:

Log Distance (m)	U/S Joint Number	Distance Feature Start to Close GW (m)	Orientation (hh:mm)	Depth (% wt)	Length (mm)	Repair Date (mmm-yy)
232148.600	191960	4.28	00:02	11	224	Jul-20
130164.983	107620	-0.01	08:19	54	52	Nov-20
130407.536	107810	2.73	05:55	17	121	Jul-22
130076.183	107540	2.90	05:58	11	148	Aug-22

10. A total of 10 pipe mill related anomalies were reported by the 2017 ROSEN ILI, the deepest reported anomalies had depths of 16% wt located at log distances 183444.130 m & 208398.637 m.

11. The significance of the reported pipe mill anomalies has been assessed in terms of their axial, circumferential and depth dimensions, according to the Shannon and Kastner assessment methods. All metal loss features were found to be acceptable for operation at both pressure scenarios, in terms of their length, width and depth dimensions at the time of the 2017 ROSEN MFL-C inspection.

12. The 2014 ROSEN geometry inspection reported 34 dents. The maximum ID reduction for a dent was 2.66% (0.7% dent part) located at log distance 105092.041 m. The maximum reported dent part ID reduction was 1.6%, associated with a dent reported at log distance 141500.954 m (Max. ID reduction 2.1%).

13. No dents were reported to be associated with metal loss or found to be interacting with a girth weld. No dents were found to exceed the OD upper limit for a dent within the pipe body (i.e. 7% OD reduction) or on a weld (2% OD reduction). The 34 dents reported were found to be located in the bottom of line (BOL). No immediate further action is recommended for the reported dents.

14. The fatigue life of the 34 dents have been determined using the approach developed by EPRG. The fatigue assessment has determined that all dents are predicted to have fatigue lives in excess of 100 years.

15. The 2014 ROSEN geometric inspection reported 385 wrinkles. The significance of the wrinkles was assessed at the MAOP. All wrinkles are considered to be acceptable in terms of their impact on the immediate integrity.

16. 4 locations of bending strain were coincident with 4 features reported within 32PENSAO. The 4 geometric anomalies listed in the table above are considered to be acceptable for operation based on their static assessment results and their associated bending strain areas being acceptable for operation.

17. The results of the bending strain assessment are shown in the table below:

	Compressive: Zero Pressure		Compressive: Operational Pressure		Tensile	
	PASS	FAIL	PASS	FAIL	PASS	FAIL
Number	38	6	44	0	44	0

The magnitude of strain at 38 of the 44 bending strain areas were found to be acceptable in terms of the critical compressive limits defined by CSA Z662 at zero internal pressure.

When considering the operational pressure of the pipeline (98 bar), The magnitude of strain at all 44 bending strain areas were found to be acceptable in terms of the critical compressive limits defined by CSA Z662.

18. All 6 sites that failed the compressive assessment at zero pressure were subject to detailed analysis. All sites were verified to be stable and should be monitored during the next inspection.

17 RECOMMENDATIONS

The recommendations of this study are:

1. TBG should refer to the supplied EXCEL listing (1-5500-12584-FFP-32PENSAO-0.xlsx) which identifies any features recommended for investigation within the next 10 years. This is applicable to all features reported by EMAT, MFL and Geometric ILI tools.
2. To date, no SCC has been verified along the 32PENSAO pipeline. Should SCC be found during future investigations, the SCC growth rate applied (0.3 mm /year) and remnant life assessment should be reviewed.
3. The EMAT tool is not designed to accurately detect and size circumferentially orientated crack-like features Should TBG find circumferential SCC in-field, it is recommended that they refer to the GASBOL Critical Defect Manual for guidance on acceptable crack sizes, pressure reduction and repairs.
4. In order to ensure there is no increase in the risk from internal corrosion growth the following actions are recommended:
   - The occurrence of upset conditions should be avoided / minimised; and
   - Effective dew point control should be monitored / maintained; and
   - Monitoring during future inspections.
5. The CP reading suggest that at the time of measurement, the majority of the pipeline was not adequately protected, i.e. between -850 mV and 1200 mV for the entire length. The 2017 survey reported over protection within the pipe section between ~135 km to the end of the pipeline. It is recommended that a detailed study is carried out to review the entire CP system. TBG should also consider completing a CIPS survey along 32PENSAO. The CP system should be operated in line with the guidance provided by international practices, such as ISO-15589:2015 or NACE SP0169-2013.
6. Following the next inspection, the dent fatigue assessment should be updated to calculate the remaining fatigue life of any new dents.
7. It is recommended that the GASBOL pipeline is inspected with a crack detection tool within 9.5 years of the previous inspection, i.e. June 2027.
8. From the perspective of the reported corrosion features, based upon the findings of this study it is recommended that 32PENSAO is subject to an internal MFL inspection within 5 years of the 2017 inspection i.e. before January 2023. It is also recommended that TBG consider running an independent MFL-A tool to fully investigate the threat of circumferential corrosion along the pipeline. This would allow for a detailed corrosion growth comparison between inspection datasets.
9. The assessment of the 2017 baker Hughes MFL-A data has not been completed under this current scope of work. As expected, an increased number of metal features were reported when compared to the ROSEN MFL-C inspection due to the differences in flux orientation. It is recommended that TBG ensure that these additional features are subject to a corrosion assessment to determine the current integrity status and define an appropriate MFL-C re-inspection interval.
10. If during any in-field investigations, TBG find evidence that the corrosion growth rates used in this study are not conservative, then the investigation / repair schedule should be updated and consideration should be given to reducing the re-inspection interval.
11. It is recommended that TBG inspect the pipeline regularly using IMU technology to identify any areas of increasing strain between subsequent inspections.

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Appendix A Metal Loss Assessment Method Summary

A 1. ASME B31G (2012)

The first version of ASME B31G “Manual for Determining the Remaining Strength of Corroded Pipelines” was issued in 1984. Further revisions were issued in 1991 and 2009; the most recent version was issued in 2012. The 2012 version incorporates the Modified B31G and effective area (also known as Detailed RStreng) assessment methods, which were originally developed at Battelle as part of a study sponsored by the American Gas Association (AGA).

Analysis Levels

The ASME B31G manual describes four different analysis levels (Level 1 has three options), as summarised below:-

- Level 0: Original B31G (Allowable Length and Depth Lookup Tables)
- Level 1:
  - Level 1a: Original B31G
  - Level 1b: Modified B31G (or 0.85dL)
  - Level 1c: API 579 (Part 5, Level 1)
- Level 2: Effective Area (or Detailed RStreng)22
- Level 3: Detailed Analysis e.g. FEA

Level 0 is based on tables of allowable defect length and depth (as provided in Section 3 of the manual). The tables are carried over without change from earlier editions of ASME B31G. It is intended that a Level 0 evaluation can be conducted in the field without the need for performing detailed calculations.

With each increasing analysis level the degree of conservatism reduces, but more detailed and accurate input data and processing capabilities are required.

Analysis levels 1a, 1b and 2 are described below.

Exclusions

The ASME B31G manual is not applicable to the following applications:-

- Crack like defects or mechanical surface damage
- Metal loss in indentations or buckles resulting in radial distortion of the pipe wall larger than 6% of the pipe outside diameter
- Grooving corrosion, selective corrosion, or preferential corrosion affecting pipe seams or girth welds

[22] The method given in API 579 (Part 5, Level 2), when reduced to its simplest form, is equivalent to an Effective Area method and is also referenced in the ASME B31G manual as a Level 2 assessment method.

- o Metal loss in fittings other than bends or elbows
- o Metal loss having brittle fracture initiation characteristics23
- o Pipe operating at temperatures outside the range of operating temperature recognised by the governing standard or operating at temperatures in the creep range

Nomenclature

M	=	bulging stress magnification factor (or folias factor), as defined below
L	=	Axial Length (mm)
D	=	Outside Diameter (mm)
T	=	Pipe wall thickness
D	=	depth of the metal loss (mm)
SF	=	Estimated failure stress level (MPa)
PF	=	Estimated failure pressure (bar) = 20tSF / D
SF	=	Safety factor
P_{Safe}	=	PF / SF
S_{Flow}	=	Flow stress (MPa), as defined below
SMYS	=	Specified Minimum Yield Strength
A	=	local area of metal loss in the longitudinal plane
Ao	=	local original metal area = Lt

Original B31G - Level 1a

The bulging stress magnification factor (M) is given by the following equation:-

$$M = (1 + 0.8z)^{0.5}$$

Where

$$z = \frac{L^2}{Dt}$$

[23] Pipe body material may be considered to have adequate ductile fracture initiation properties for purposes of the ASME B31G standard if the material operates at a temperature no colder than 100°F (55°C) below the temperature at which 85% shear appearance is observed in a Charpy V-notched impact test.

For z ≤ 20

$$S_F = S_{Flow}\left[\frac{1-\frac{2}{3}\left(\frac{d}{t}\right)}{1-\frac{2}{3}\left(\frac{d}{t}\right)\left(\frac{1}{M}\right)}\right]$$

For z > 20

$$S_F = S_{Flow}\left[1-\left(\frac{d}{t}\right)\right]$$

ASME B31G (2012) allows different definitions of the flow stress (SFlow) to be used, however for the purposes of the Level 1a assessment, a flow stress equal to 1.1 x SMYS has been selected (for grades ≤ X70). This is recommended in ASME B31G (2012) and is also consistent with the definition as defined in previous versions of ASME B31G.

Modified B31G - Level 1b

For z ≤ 50

$$M = (1+0.6275z-0.003375z^2)^{0.5}$$

For z > 50

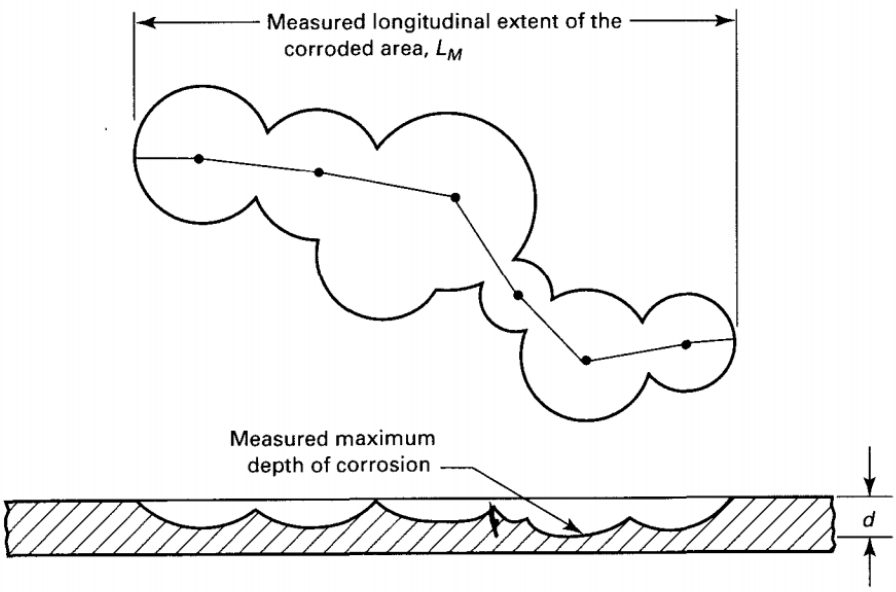
$$M = 0.032z+3.3$$

$$S_F = S_{Flow}\left[\frac{1-0.85\left(\frac{d}{t}\right)}{1-0.85\left(\frac{d}{t}\right)\left(\frac{1}{M}\right)}\right]$$

ASME B31G (2012) allows different definitions of the flow stress (SFlow) to be used, however for the purposes of the Level 1b assessment, a flow stress equal to SMYS + 69 MPa has been selected (for grades ≤ X70). This is consistent with the definition as defined in the original 1989 AGA report.

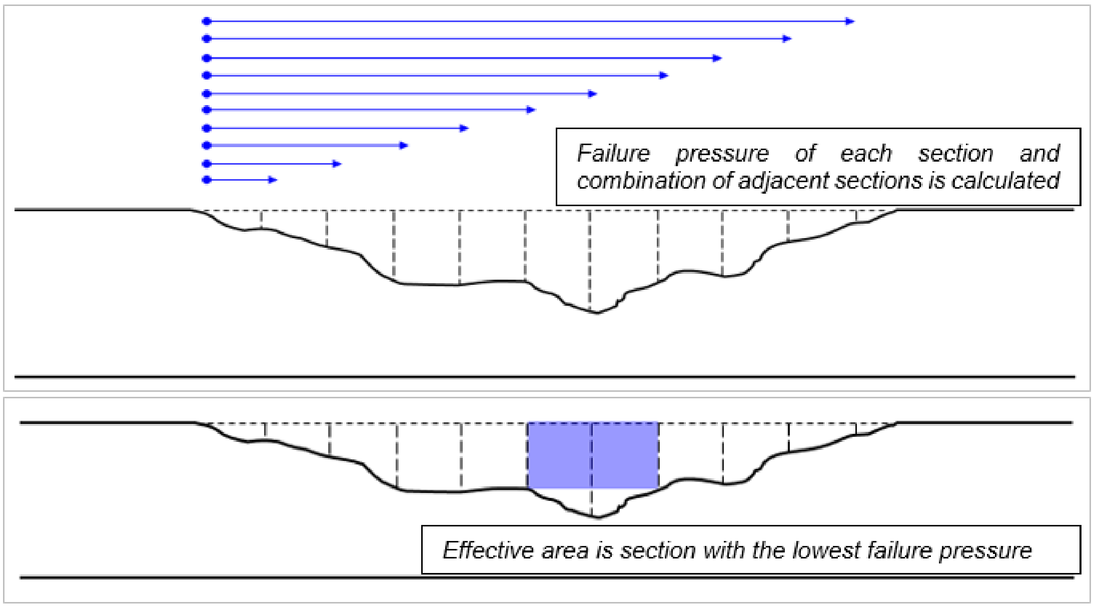
Effective Area (Detailed RStreng) - Level 2

In order to carry out an effective area assessment, a detailed profile of the metal loss is required. This profile is established by obtaining depth or remaining wall thickness measurements throughout the metal loss feature. These measurements are used to determine the river bottom profile (RBP or 'deepest path') through the metal loss area (see Appendix Figure A-1). The assessment can be carried out using the corrosion box data that make up corrosion clusters (from MFL or UT ILI listings), or using detailed profile data (e.g. RBPs from ultrasonic or laser scan data).



Appendix Figure A-1: Illustration of River Bottom Profile (ASME B31G, Figure 2.1-1)

The iterative calculation procedure uses the corresponding lengths and corrosion pit depths to calculate an effective area of missing metal and an effective length. Each combination of local metal loss with a corresponding effective length and effective area is assessed, to determine the predicted failure stress. The predicted failure stress according to the effective area method, is defined as the effective area of metal loss and corresponding effective length which results in the lowest failure stress (see illustration below). The total effective area is used in the assessment, unlike the Level 1b assessment which uses 85% of the metal loss area based on depth and length.



Appendix Figure A-2: Illustration of Detailed RStreng (Effective Area) Method

The effective area assessment method uses the same definitions of M as defined above for Modified B31G (level 1b), except that z is based on an effective length (Le). The failure stress is given by the following equation:-

$$S_F = S_{Flow}\left[\frac{1-\frac{A}{Ao}}{1-\left(\frac{A}{Ao}\right)\left(\frac{1}{M}\right)}\right]$$

ASME B31G (2012) allows different definitions of the flow stress (SFlow) to be used, however for the purposes of this assessment a flow stress equal to SMYS + 69 MPa has been selected (for grades ≤ X70). This is consistent with the definition as defined in the original 1989 AGA report.

A 2. Shannon

The assessment method proposed by Shannon is based on the original NG-18 equations developed by Battelle but uses a modified term for the material flow stress. This provides a more accurate estimation of the failure stress of metal loss defects in ductile linepipe material.

The details of the method are provided below:

$$P_f = \bar{\sigma}\frac{2t}{D}\frac{\left(1-\frac{d}{t}\right)}{\left(1-\frac{d}{t}\frac{1}{M}\right)}$$

Where

P_f is the estimated failure pressure

$\bar{\sigma}$ is the material flow stress

t is the wall thickness

d is the defect depth

D is the pipeline outer diameter

M is the 'Folias' factor and is given by the following equation:

$$M = \sqrt{1+0.6275\left(\frac{2c}{\sqrt{Dt}}\right)^2 - 0.003375\left(\frac{2c}{\sqrt{Dt}}\right)^4}$$

Where

$2c$ is the defect length

A 3. Kastner

The details of the Kastner assessment method are provided below:

$$\rho = \frac{\eta[\pi - \beta(1-\eta)]}{\eta\pi + 2(1-\eta)\sin\beta}$$

where:

ρ	=	axial failure stress / flow stress
η	=	1-d/t
d	=	defect depth
t	=	wall thickness
β	=	c/R
c	=	half defect (circumferential) length
R	=	pipe radius

The flow stress is taken to be 1.15 x SMYS.

The axial stress due to pressure loading is conservatively assumed to be half of the hoop stress, which implies that the pipeline is free to expand axially.

A 4. DNV RP-F101

Assessment Method

Section 7 of DNV RP-F101 “Assessment of a Single Defect (Part B)” uses an Allowable Stress Design (ASD) format. Using the basic procedure detailed in Section 7, the failure pressure for a single defect subject to internal pressure is given by:

$$P_f = UTS\frac{2t}{(D-t)}\left[\frac{1-\frac{d}{t}}{1-\frac{d}{t}\left(\frac{1}{Q}\right)}\right]$$

where

$$Q = \sqrt{1+0.31\left(\frac{l}{\sqrt{Dt}}\right)^2}$$

This formula can be simplified to obtain a very conservative estimate of failure pressure for an axial corrosion defect of infinite length at the 6 o’clock position, a characteristic which would for example, be consistent with the experience of damage in water injection pipelines:

$$P_f = UTS\frac{2t}{(D-t)}\left[1-\frac{d}{t}\right]$$

Where:

UTS is the material ultimate tensile strength

D is the outside pipeline diameter

t is the nominal wall thickness

d is the depth of metal loss or corrosion

The Total Usage Factor (or Safety Factor) to be applied in determining safe working pressure has 2 components:

F1 = 0.9 (Modelling Factor)

F2 = Operational Usage Factor

which is introduced to ensure a safe margin between the maximum allowable operating pressure (MAOP) and the failure pressure of the defect (normally taken as equal to the design factor).

The Total Usage Factor (F) to be applied to determine the safe working pressure is calculated from

F = F1 x F2

Appendix B Dent Assessment Methodology

Dents reported by in-line inspection tools are initially categorised as follows according to their association (or otherwise) with other pipeline features to determine their significance i.e.:-

- plain smooth dents
- dents on girth or seam welds
- dents with associated corrosion
- dents with associated mechanical damage* (MD), etc.

Further categorisation can be carried out according to location around the pipe circumference:-

- Dents located at the bottom of the line (between 4 & 8 o'clock) are more likely to be rock dents that were introduced during construction. In this case they will therefore have survived the pre-service hydrotest and be restrained from flexing under cyclic pressure.
- Dents located at the top of the line (between 8 & 4 o'clock) could have been caused in service (i.e. by excavator teeth, agricultural activity, etc.) and are more likely therefore to contain other features such as gouges and/or cracks (outside the detection capability of the ILI).

The centre of the dent circumferentially± has been used to determine the location of the dent (top or bottom of line) for the purpose of this assessment, as this is likely to be where the indenter acted on the pipeline. In cases where dent width was not reported the orientation categorisation is based on reported orientation.

It is highlighted that there are differences in the dent acceptance criteria provided in liquid and gas codes, for example in ASME B31.4 and B31.8. In addition, the risk from pressure cycle dent fatigue may be more significant for a liquid line, compared with a gas line, since liquid lines are typically more heavily pressure cycled. However, under static loading it is considered that a dent would behave in the same way regardless of the pipeline product. Consequently the dent acceptance criteria are based on guidance in both liquid and gas codes. This is consistent with the approach suggested by a recent review conducted for the US Department of Transportation (ref. [41]).

A summary of relevant acceptance criteria (under static conditions) for each of the main dent types is provided below.

Plain Dents

Most pipeline codes allow plain dents up to 6% of the pipe outer diameter (OD). However current guidance in API 579 (2007) (ref. [42]) allows plain dents up to 7% OD. This limit is based on testing carried out by the European Pipeline Research Group (EPRG) (ref. [43]).

Dents that exceed the depth based limit may be acceptable if a strain based assessment shows them to have a maximum strain of ≤ 6% (as defined in ASME B31.8 (ref. [31]).

*Including but not limited to cracking, gouging, scrapes, smeared metal, indications of cold work.
± Since ROSEN report dent orientation at the start of the dented area, the orientation at the centre has been estimated by taking the reported orientation and adding half the reported dent width.

Dents on Welds

Dents that affect the pipe curvature at a weld are susceptible to cracks at the internal weld toe during denting, particularly in low toughness material. ASME B31.4 (ref. [44]) does not allow dents on welds regardless of depth, however both ASME B31.8 and DOT Part 192 (ref. [45]) state that dents located on a ductile weld which are ≤ 2% OD are acceptable. It is assumed that the weld meets typical construction specifications for example API 1104 (ref. [46]). There is no safe dent depth limit for non ductile welds such as acetylene welds or welds that are prone to brittle fracture, such as pre 1970’s ERW pipe.

Dents greater than 2% OD in depth on ductile welds may be acceptable according to ASME B31.8, if a strain based assessment shows them to have a maximum strain of ≤ 4% and they are shown to have acceptable fatigue lives.

Industry guidance recommends a full size weld Charpy energy greater than a minimum of 27 J and an average of 40 J (from 3 specimens), at the minimum design temperature (ref. [47, 48]).

Dents Associated with Corrosion

A number of different acceptance criteria are provided in pipeline codes for the assessment of dent / corrosion combinations.

ASME B31.4 allows dents associated with corrosion, providing 87.5% of the nominal wall thickness remains.

ASME B31.8 allows dents associated with corrosion, provided the corrosion is acceptable according to an appropriate corrosion assessment method e.g. ASME B31.G (ref. [49]).

The Canadian Standards Association (CSA) Z662-07 (applicable to oil and gas pipelines) (ref. [50]) provides similar acceptance criteria as ASME B31.8, but they are limited to corrosion features with a depth of ≤ 40% wt, which are acceptable to ASME B31.G.

It is noted that as an in-line metal loss inspection tool passes over the dent, the dent can cause sensor lift off. Depending on the geometry of the dent, this can limit the ability of the ILI tool to detect and size accurately metal loss or gouging associated with the dent. This is a recognised limitation of current ILI technology.

Due to the potential ILI metal loss sizing limitations, the corrosion depth limit of 40% wt (as adopted in CSA Z662-07), is considered the most appropriate for the assessment of corrosion associated with dents reported by ILI tools.

Due consideration should also be given to the possibility that the dent has associated mechanical damage which has been misclassified as metal loss corrosion. Further investigation is required to support the ILI classification of metal loss as corrosion, particularly for top of line dents where there is an increased risk that the metal loss could be due to mechanical damage. Excavation may be negated if a low risk of 3rd party damage can be demonstrated or corrosion is confirmed as likely to be internal, considering the potentially reduced capability of the ILI tool to classify and size associated corrosion.

For a fully constrained dent (e.g. a bottom of line rock dent), it would be expected that the rock would act to prevent the pipe containing the corrosion from bulging outwards. However to confirm the absence of corrosion growth due to either coating damage or possible CP shielding caused by the rock, the dent should continue to be monitored during future in-line inspections.

Dents Associated with Mechanical Damage

A dent with mechanical damage is potentially a serious defect as the process results in embrittlement of the pipeline surface and often leads to cracking. Such dents can record very low burst pressures and low fatigue lives (refs. [51] & [52]).

Dents with cracking or gouges are not allowed according to most pipeline codes, including ASME B31.8 and B31.4.

Dent Fatigue

The above assessment criteria consider dents under static conditions, however if the pipeline is subject to significant internal pressure cycling, a fatigue assessment should be considered.

Dents located on welds or dents containing stress raisers can exhibit significantly lower fatigue lives than plain dents of the same magnitude. Plain, unconstrained dents > 2% OD which are free to flex in response to pressure cycling, are also considered to be at risk from fatigue (refs. [53] & [54]). Unconstrained dents are more likely to be located at the top of the pipeline.

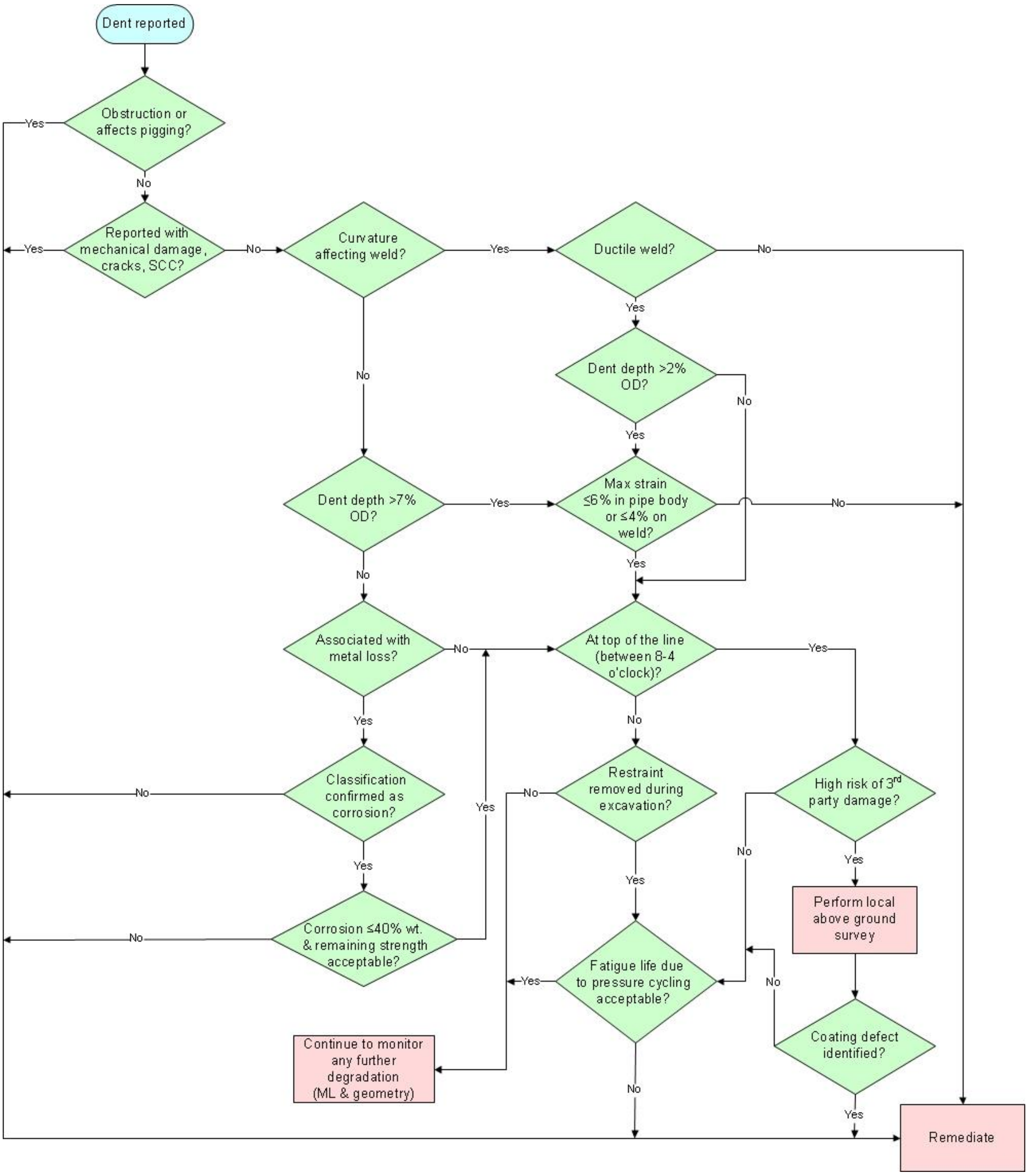
The fatigue life for fully constrained dents will be in the order of magnitude longer than unconstrained dents (refs. [53], [54], [55] & [56]). These are dents typically located at the bottom of the pipeline (e.g. rock dents). The exception to this is in the case where two constrained dents are closely spaced. In this scenario the gap between the dents is free to flex in response to pressure cycling and could result in fatigue failure (ref. [51]) within the useful life of a pipeline. This failure mode is of most concern for liquid lines which are typically more heavily pressure cycled than gas lines. Double dents can be defined as having a spacing of < 1 pipe diameter (1D) between the dent centres (ref. [55]).

A fatigue assessment should be considered for dents located in areas of significant pressure cycling. The following priority is suggested for dents located in areas of significant pressure cycling:

- TOL dents associated with welds or stress raisers
- TOL dents > 2% OD
- BOL double dents
- TOL dents < 2% OD
- BOL dents

Dent Assessment Process

A summary of the dent assessment process is provided in Appendix Figure B-1.



Appendix Figure B-1: Dent Assessment Process

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Appendix C Fatigue Assessment Methodology

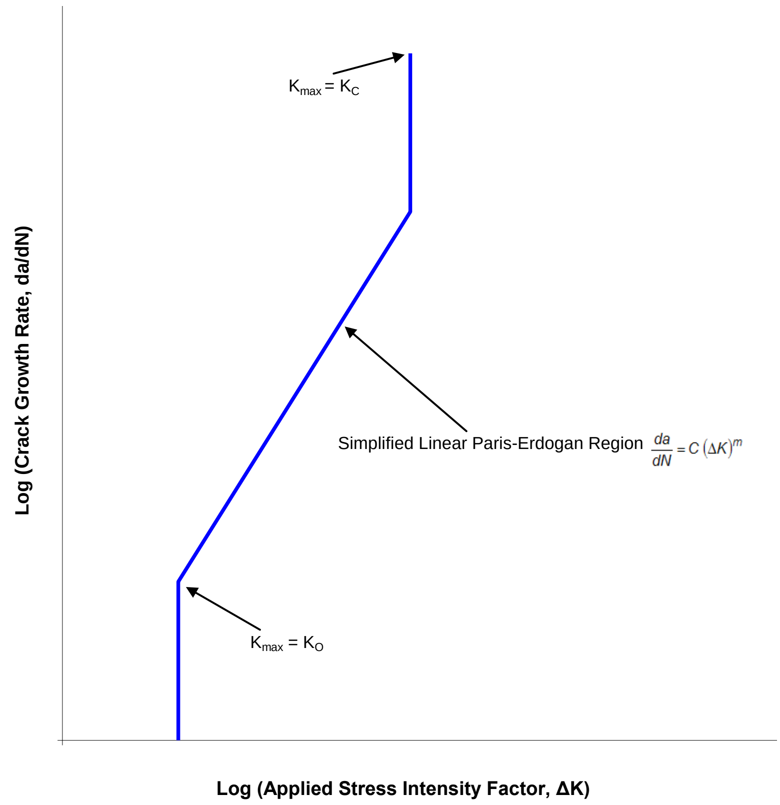
The fatigue assessment has been conducted in accordance with API 579 (API 579, Section 9.5).

Fatigue Crack Growth Rate

The relationship between crack growth rate (da/dN) and the applied stress intensity factor (ΔK) is normally described by a sigmoid or "S" shaped curve showing log (da/dN) versus log (ΔK). The applied stress intensity factor is a function of structural geometry, stress range (determined from the supplied pressure cycling information) and instantaneous crack size. Since ΔK is proportional to cyclic stress, variations in hoop stress (or pressure) will cause ΔK to vary and hence result in crack growth.

A schematic showing the relationship between da/dN and ΔK is shown in Appendix Figure C-1. The central portion of the graph can be described by a number of different equations. However for the purpose of this assessment the simplified Paris-Erdogan crack growth model has been used which assumes a linear relationship for the entire central portion of the graph.

At low values of ΔK the crack growth rate reduces and below a threshold stress intensity factor, ΔK0, the crack growth rate becomes insignificant. At high values of ΔK the crack growth rate accelerates as ΔK approaches the critical stress intensity factor, KC, for failure under static loading conditions.



Appendix Figure C-1: Simplified Paris-Erdogan Crack Growth Relationship

The Paris-Erdogan crack growth relationship is shown below:

$$\frac{da}{dN} = C\left(\Delta K\right)^{m}$$

for

$\Delta K < \Delta K_0$, $\frac{da}{dN}$ is assumed to be insignificant

Where,

$\frac{da}{dN} =$ Crack growth rate (mm/cycle)

$\Delta K =$ Stress intensity factor (MPa√m)

$\Delta K_0 =$ Threshold stress intensity factor ($63\ Nmm^{\frac{3}{2}}$ as per Annex F API 579)

C = Constant depending on material and applied conditions.

m = Constant depending on material and applied conditions.

Note: for the purpose of this assessment it has been assumed that the pipeline is operating in air or other non-aggressive service environment at temperatures of up to 100°C. Consequently constants C and m have been selected in accordance with Annex F API 579, i.e. $5.22x10^{-13}$ and 3 respectively.

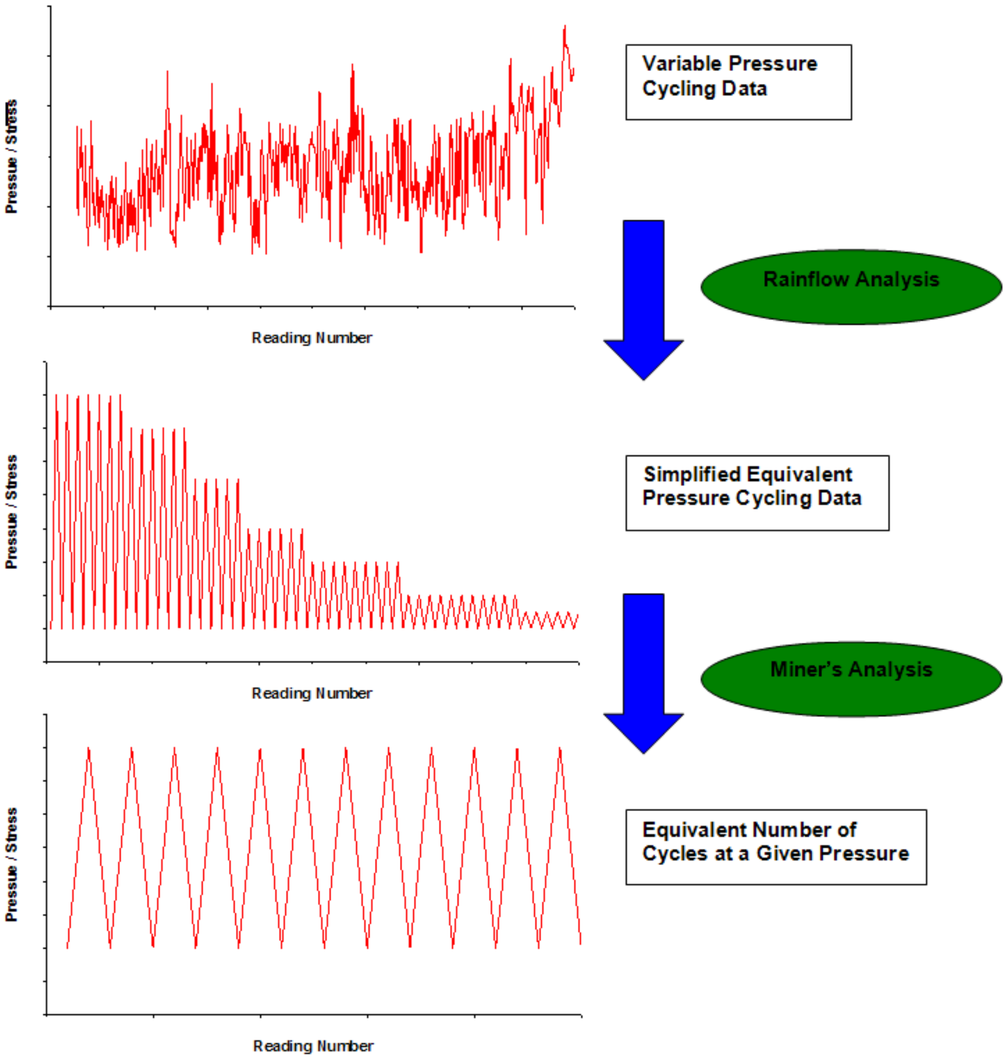
The increment of crack growth is established based on the applied stress intensity associated with the anomaly and the Paris-Erdogan crack growth relationship.

Both the length and depth dimensions are grown incrementally, after each increment the current flaw size (i.e. the previous flaw size plus the increment of crack growth) is assessed for its acceptability within the FAD. This process continues until the flaw reaches an unacceptable size i.e. is just outside the FAD. The fatigue life is defined as the number of cycles required to grow the anomaly to an unacceptable size at the MOP.

Rainflow and Miner's Analysis

The pressure cycling data supplied by TBG was simplified using the Rainflow cycle counting method. The Rainflow method breaks the complex time series data down into a series of half cycles of various amplitude (binned ranges independent of frequency). Half-cycles of similar magnitude but opposite sense are matched to give whole cycles. The results of this analysis can then be converted into an equivalent number of stress cycles at a single pressure using Miner's rule.

A schematic of the Rainflow and Miner's process is shown in Appendix Figure C-2.



Appendix Figure C-2: Simplification of the Pressure Cycling Data using Rainflow Analysis and Miner's Rule

Dent Fatigue Assessment

The EPRG offers an approach for a method to determine the fatigue life of an unconstrained dent based on S-N fatigue curves taken from DIN 2413 for longitudinal submerged arc welded pipe, which are modified for the stress concentration induced by the dent.

EPRG Dent Fatigue Methodology

The fatigue strength of an unconstrained plain dent is given by the following equation:

$$N = 1000\left[\frac{(\sigma_u - 50)}{2\sigma_A k_s}\right]^{4.292}$$

Where,

N = Predicted number of cycles to failure,

σ_u = Ultimate tensile strength (MPa),

Ks = Stress concentration factor,

$2\sigma_A$ = Cyclic stress range at R =0.

and,

$$K_s = 2.871\sqrt{K_d}$$

$$2\sigma_A = \sigma_u\left[B\,(4 + B^2)^{0.5} - B^2\right]$$

$$B = \frac{\frac{\sigma_a}{\sigma_u}}{\left[1 - \left(\frac{\sigma_{max} - \sigma_a}{\sigma_u}\right)\right]^{0.5}} = \frac{\frac{\sigma_a}{\sigma_u}}{\left[1 - \frac{\sigma_a}{\sigma_u}\left(\frac{1+R}{1-R}\right)\right]^{0.5}}$$

$$R = \frac{\sigma_{min}}{\sigma_{max}}$$

$$K_d = H_o\,\frac{t}{D}$$

$$H_o = 1.43\,H_r$$

where,

σ_{max} = Maximum stress in cycle (MPa)

σ_{min} = Minimum stress in cycle (MPa)

t = Pipe wall thickness (mm)

D = Outer diameter (mm)

Ho = Dent depth at zero pressure (mm)

Hr = Dent depth measured at pressure (mm)

It is highlighted that the above method is based on tests in which the dent was introduced at zero pressure. Dents in pipelines are generally measured at pressure therefore a correction factor is required to estimate the dent depth at zero pressure. EPRG recommend an empirical rerounding correction factor of 1.43 (equation B7) to estimate the dent depth at zero pressure.

Recommended Safety Factors

In order to account for the large scatter in the published test data a safety factor of 13.3 is applied to the calculated fatigue life to ensure a 95% confidence level for predicting a conservative result. For dents associated with welds an additional safety factor of 10 is recommended (i.e. 10 x 13.3 =133).

Pressure Cycling

The pressure cycling data supplied by TBG were simplified using the Rainflow cycle counting method; this is described in Appendix Figure E-2 above.

Appendix D Bending Strain Assessment Method Summary

ASSESSMENT METHOD

The bending strain areas have been assessed against the allowable compressive and tensile strain limits for the pipeline. The compressive and tensile limits have been determined using the calculations in the Canadian Standard Z662. Allowable compressive and tensile strain levels incorporate resistance factors of 0.8 and 0.7 respectively, as defined by Z662.

COMPRESSIVE STRAIN ASSESSMENT

The compressive strain assessment can be used both as a local or global buckling check. The assessment uses the equations from section C.6.3.3.3 of Z662 which defines an allowable strain level based on the pipeline parameters. This value is directly compared with the bending strain determined by the inspection tool to determine the acceptability of the bending strain area in relation to local buckling. The compressive strain calculations are mainly dependent upon the operating stress of the pipeline, the wall thickness to pipe diameter ratio and the pipeline steel grade.

The effect of thermal loading has been considered based on the assumption of a tie in temperature and the maximum operating temperature for each section. This produces an additional compressive strain. A pipeline under compressive bending will be most at risk from local buckling during a shutdown case where internal pressure is low. Therefore the calculations for compressive strain are based on this situation.

The details of the method are provided below:

$$\varepsilon_c^{\;crit} = 0.5\frac{t}{D} - 0.0025 + 3000\left(\frac{(p_i - p_e)D}{2tE_s}\right)^2 \; for \; \frac{(p_i - p_e)D}{2tF_y} < 0.4$$

$$\varepsilon_c^{\;crit} = 0.5\frac{t}{D} - 0.0025 + 3000\left(\frac{0.4F_y}{E_s}\right)^2 \; for \; \frac{(p_i - p_e)D}{2tF_y} \geq 0.4$$

Where

ε_c^{crit}	ultimate compressive strain capacity of the pipe wall
t	pipe wall thickness, mm
D	pipe outer diameter, mm
p_i	maximum internal design pressure, MPa
p_e	minimum external pressure, MPa
E_s	Youngs Modulus of Steel 207,000 MPa
F_y	effective specified minimum yield strength, MPa

TENSILE STRAIN ASSESSMENT

Tensile strain assessment has been adopted from the fracture mechanics based assessment described in section C.6.3.1.1 of Z662. These calculations require detailed information on defect size and material toughness (crack tip opening displacement (CTOD)). Equations are provided for both surface breaking and embedded defects. The tensile strain limit is defined as when the crack driving force exceeds the material toughness. The equations were developed and validated against wide-plate experimental test data which was predominately for surface breaking defects. The surface breaking defect equations have been adopted.

The results produced by this method in some cases may be overly conservative and for pipelines where the girth weld procedure and inspection has been tightly controlled the tensile strain limit could be increased.

Based on the results of the 2016 metal loss inspection, the reported bending strain areas have been correlated with the reported anomalies. These anomalies have been assessed using the reported flaw dimensions. In the areas of bending strain with no reported features it is assumed that any features within these areas were:

- Below the reporting threshold of 5% wt in the 2016 inspection
- Has a maximum defect circumferential length equal to 50 mm (allowable weld defect length in API 1104 has been assumed).

The allowable length of a girth weld defect has been adopted as the weld is the most likely location of a defect in a pipeline system following commissioning due to construction techniques and inspection process, particularly in the circumferential extent. It is noted that issues at girth welds are considered to be more likely than at other locations due to the combined influences of welding residual stresses, misalignment of the pipe wall and variations in material strength and toughness. In the event that detailed inspection data is available (either in-field NDT or ILI technology capable of detecting and sizing defects in the girth weld – e.g. axial MFL or ultrasonic wall measurement tools) or more stringent girth weld acceptance criteria have been applied during construction, it may be possible to reduce the assumed defect size.

In the absence of CTOD or other fracture toughness measurement data and assuming the welds are not brittle, a CTOD of 0.127 mm has been adopted based on the limit of Charpy value in Z662 (single specimen 30 J and average Charpy impact energy 45 J.

The details of the method are provided below:

$$\varepsilon_t^{crit} = \delta^{(2.36-1.58\lambda-0.101\xi\eta)}(1+16.1\lambda^{-4.45})(-0.157+0.239\xi^{-0.241}\eta^{-0.315})$$

Where

ε_t^{crit}	longitudinal tensile strain capacity (in %)
δ	apparent CTOD toughness, mm
λ	ratio of yield strength to tensile strength
η	ratio of defect depth to pipe wall thickness
ξ	ratio of defect length to pipe wall thickness

Appendix E Bending Strain Prioritisation

Background

Many operators perform regular inspections of its gas transmission pipelines using technologies capable of detecting metal loss and geometric anomalies. Most inspections also include an inertial measurement unit in order to map the pipeline and to allow any areas of bending strain or pipeline movement to be identified.

Where metal loss or geometric anomalies are coincident with areas of bending strain it is necessary to consider the significance of those anomalies under the combined loading due to internal pressure and bending strain. There are a limited number of defect assessment methodologies available that consider this scenario and what methods are available are typically conservative, often overly so. The methods are also based on the assumption that the bending strain has been caused by a load controlled mechanism (that are typically assessed using stress-based methods) as opposed to a displacement controlled mechanism (for which strain-based assessment is appropriate).

Based on recent fitness for purpose studies conducted, an increasing number of metal loss anomalies (many of which have reported depths <10% wt.) have failed the combined loading assessment and it would be impractical and unnecessary to repair all of them.

In order to address the above, this note describes a pragmatic, prioritization approach that will be used to assess anomalies subject to combined loading and to provide clear recommendations for addressing any unacceptable anomalies.

Prioritization Approach

In order for a failure to occur within a bending strain area, one of the following must occur:

- An increase in load (for example an increase in bending strain due to continued ground settlement / instability or an increase in internal pressure), or
- An anomaly within an area of bending strain grows, e.g. through continued corrosion activity or fatigue crack growth

Therefore, the prioritization approach described below aims to identify those anomalies that are associated with a significant threat of failure.

The prioritisation of metal loss features within areas of bending strain involves categorising an individual feature as ‘active’. For the purpose of this process, ‘active’ metal loss is defined as metal loss that is associated with an increase in depth between inspections that exceeds a statistically significant limit (at a 95% confidence level) and is therefore more likely to represent active corrosion. This ‘active’ classification can be validated through detailed signal comparison if more than one set of inspection signal data are available. For first time inspections, all metal loss features will conservatively be categorised as ‘active’.

Bending Strain Areas Combined with Metal Loss Anomalies

Priority Categories

<u>Priority 1</u>

Priority 1 cases represent a significant threat of pipeline failure and therefore require short term action to investigate and mitigate the affected areas. Priority 1 cases include:

1. Metal loss features that have all the following:
   - o have reported depths > 15% wt [24]
   - o have calculated growth rate > Statistically Significant Growth Rate (SSGR)
2. Metal loss features that:
   - o fail an assessment based on internal pressure loading only
3. Metal loss features that have all the following:
   - o have reported depths > 50% wt
   - o review of aerial imagery indicates potential external loading
4. Metal loss features that have all the following:
   - o have reported depths > 50% wt
   - o reported as active corrosion features or weld anomalies

<u>Priority 2</u>

Priority 2 cases represent a credible threat of pipeline failure and require action prior to the next in-line inspection to investigate and, where necessary, mitigate the affected areas. Priority 2 cases include:

1. Metal loss features that have all the following:
   - o have calculated growth rate > Statistically Significant Growth Rate (SSGR)
2. Metal loss features that have all the following:
   - o have depths exceeding 15% wt
   - o are predicted to require repair before the next ILI (internal pressure)
3. Metal loss features that have all the following:
   - o have depths exceeding 50% wt [25]
   - o confirmed though signal comparison to be static features
   - o review of aerial imagery indicates no external loading
4. Metal loss features that:
   - o are reported as weld anomalies with reported depths > 20% wt

It is not considered good practice to apply individual corrosion growth rates to individual features for the purposes of integrity management planning. This therefore criterion captures scenarios where higher growth rates than the individual calculated growth rate are applied to predict when a feature may exceed critical dimensions (i.e. individual feature may not be ‘active’ but active corrosion may be present nearby).

[24] This 15% wt. limit has been selected based on the failure depth of an infinitely long corrosion feature subject to a hoop stress of 100% SMYS in pipe grades up to API 5L Grade X70. Consideration should be given to tool sizing accuracy.
[25] An arbitrary upper depth limit of 50% wt. has been applied to capture any deep (>15% wt.) features that would otherwise be a Priority 3.

Priority 3

Priority 3 cases include areas of bending strain that contain metal loss features that fail the combined loading assessment are not considered as Priority 1 or Priority 2.

Typical Recommended Actions for Each Priority Level

Priority Level	Recommended Actions
Priority 1	1. For metal loss anomalies associated with areas of bending strain that exceed calculated tensile and/or compressive limits, ensure that the recommendations for those areas of bending strain are completed. 2. Metal loss anomalies that are unacceptable according to an internal pressure only assessment should be investigated and repaired as soon as practicable and should receive priority within the repair schedule due to the presence of combined loading. 3. Metal loss anomalies with depths > 15% wt. and are considered ‘active’ should be investigated and repaired as soon as practicable and should receive priority within the repair schedule due to the presence of combined loading. 4. During investigation / repair of corrosion features within the area of bending strain, an investigation should be performed for any evidence of ground instability. 5. Actions should be taken to prevent further corrosion activity. For external corrosion this would involve recoating affected areas and / or upgrading the CP system.
Priority 2	1. For metal loss anomalies associated with areas of bending strain that exceed calculated tensile and/or compressive limits, ensure that the recommendations for those areas of bending strain are completed. 2. Metal loss anomalies that are considered ‘active’ should be investigated and remediated as soon as practicable and should receive priority within the repair schedule due to the presence of combined loading. 3. Metal loss anomalies that are predicted to exceed the assessment criteria prior to the next ILI should be investigated and remediated within approximately 12 months or prior to their predicted repair date according to an internal pressure only assessment. 4. The remediation for priority 2 features may involve re-coating or repair depending on the results of in-field investigation. 5. During investigation / repair of corrosion features within the area of bending strain, an investigation should be performed for any evidence of ground instability. 6. Actions should be taken to prevent further corrosion activity. For external corrosion this would involve recoating affected areas and / or upgrading the CP system.
Priority 3	1. For metal loss anomalies associated with areas of bending strain that exceed calculated tensile and/or compressive limits, ensure that the recommendations for those areas of bending strain are completed. 2. Metal loss anomalies should be monitored during future in-line inspections to confirm the absence of growth.

Bending Strain Areas Only

Priority Categories

Priority 1

Priority 1 cases represent a significant threat of pipeline failure and therefore require short term action to investigate and mitigate the affected areas. Priority 1 cases include:

1. Bending strain areas with all of the following:
   - o Review of aerial imagery and bending strain review showed strong evidence of potential external loading
   - o High reported bending strains (>0.75%)

2. Bending strain areas associated with geometric anomalies reported as buckles or wrinkles
3. Bending strain areas associated with geometric anomalies that strongly indicate the onset of buckling / wrinkling, such as:
   - o Ovalities and unclassified ID anomalies
   - o Reported dents in axial and circumferential locations of high strain indicating potential pipeline movement

Priority 2

Priority 2 cases include:

1. Bending strain associated with other ID anomalies (ovalities / unclassified etc.)
2. Any areas of bending strain that exceed acceptable tensile and/or compressive strain limits and:
   - o have a maximum strain >0.5%
3. Areas of bending strain that exceed acceptable tensile and/or compressive strain limits and:
   - o have been identified as potential ground movement areas from a desktop review of aerial imagery and bending strain characteristics (e.g. direction, affected pipeline length, association with girth welds).

Priority 3

Priority 3 cases include:

1. Areas of bending strain that exceed acceptable compressive/tensile limits and:

   - o show no characteristics of ground movement
   - o No coincident features
2. Areas of bending strain associated with geometric anomalies (i.e. Wrinkles / Ovalities / Dents) and:

   - o where associated geometric anomalies have been subject to further assessment and are considered to be acceptable for continued operation.
   - o Review of aerial imagery and bending strain review showed no clear evidence of additional external loading.

Typical Recommended Actions for Each Priority Level

Priority Level	Recommended Actions
Priority 1	**For cases that involve confirmed pipeline movement, a study should be initiated to address the following:** 1. Source of the pipeline movement 2. Rate of pipeline movement 3. Estimated time for associated bending strain to exceed critical levels 4. Options for stabilizing the pipeline and relieving any accumulated bending strain **For other Priority 1 bending strain areas, the following actions should be taken:** 1. Review construction records to investigate potential cause of bending strain 2. Perform detailed desktop study using site-specific information (e.g. terrain data, soil information) to investigate potential cause of bending strain 3. A site survey should be performed to confirm the stability of the ground in the local area. 4. Based on the outcome of the above activities, the requirement to repair the pipeline / relieve the strain should be confirmed.
Priority 2	1. Review construction records to investigate potential cause of bending strain 2. Perform detailed desktop study using site-specific information (e.g. terrain data, soil information) to investigate potential cause of bending strain 3. If above actions confirm that there is a significant risk of the bending strain area not being stable, a site survey should be performed, otherwise the continued stability of bending strain areas should be monitored through repeat in-line inspections using IMU or alternative in-field methods (e.g. use of strain gauges) 4. Based on the outcome of the above activities, the requirement to repair the pipeline / relieve the strain should be confirmed.
Priority 3	1. The continued stability of bending strain areas should be monitored through repeat in-line inspections using IMU or alternative in-field methods (e.g. use of strain gauges)