ULVERSTON CANAL STRAIN GAUGES

# Strain Gauge Measurement Summary Q1 2022

Cadent Gas Limited

**Report No.:** 10325560/01, Rev. 0
**Document No.:** 1592293
**Date:** 2022-08-18

| | | |
|---|---|---|
| Project name: | Ulverston Canal Strain Gauges | DNV |
| Report title: | Strain Gauge Measurement Summary Q1 2022 | Energy Systems |
| Customer: | Cadent Gas Limited, | Safety and Integrity |
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| Project No.: | 10325560 | |
| Organisation unit: | O&G UK GLIS - Asset Health | |
| Report No.: | 10325560/01, Rev. 0 | |
| Document No.: | 1592293 | |

Applicable contract(s) governing the provision of this Report:
TCS Framework Purchase Order 3200897249

Objective:

Undertake strain measurements for Ulverston to Barrow pipeline and estimate the stresses in the pipeline at chainage 170 m and 570 m. Provide recommendations to Cadent for managing the short term risks to pipeline's integrity.

| Prepared by: | Verified by: | Approved by: |
|---|---|---|
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Keywords:
Ulverston, Ulverston Canal, Embankment, Settlement, Strain Gauges

| Rev. No. | Date | Reason for Issue | Prepared by | Verified by | Approved by |
|---|---|---|---|---|---|
| A | 2022-06-28 | Draft issue for client comment | A Farrance | P Ng | A Connell |
| 0 | 2022-08-18 | First issue | A Farrance | P Ng | A Connell |

# Table of contents

# 1 INTRODUCTION

Cadent Gas Limited (Cadent) own and operate the 300 mm diameter Barrow to Whasset High Pressure (HP) Gas Pipeline which is located within the northern shoulder of the Ulverston Canal embankment / towpath in Cumbria. The embankment's crest is bituminous-surfaced and carries a single carriageway road used by private users and pedestrians. The embankment has a long history of settlement and a series of investigations, monitoring regimes and remedial works have been carried out by the canal owner in the past to retain the integrity of the canal structure. The pipeline also has a history of leakages linked to Stress Corrosion Cracking (SCC) and therefore any effects of future settlement pose a threat to the pipeline's integrity.

As part of a developed management and protection strategy, Cadent (formerly National Grid Gas Distribution) commissioned Residual Stress Measurements (RSM) at two locations on the pipeline in February 2008 [/1/] to determine the actual stresses within the pipeline. Vibrating wire strain gauges were subsequently installed at two of the RSM locations to monitor any stress changes in the pipeline. Installation of the strain gauges allowed for measurements to be undertaken until 2011, when DNV (formerly Advantica) recommended that the pipeline be diverted [/2/]. At the request of Cadent, monitoring of the strain gauges by DNV continued with the last set of readings undertaken in 2021 [/3/].

As Cadent have planned to divert the pipeline in the long term, they require evidence to determine whether the integrity of the pipeline may be compromised before any diversionary works are complete. Cadent have therefore requested that DNV, using reasonable skill and care, to obtain and analyse a new set of strain gauge measurements in order to provide short term recommendations to help manage any perceived risk to the pipeline integrity until the diversion can be undertaken.

## 1.1 Scope and Objectives

The scope of the project is to measure the current strain gauge values and to assess the stress levels within the pipeline, in order for Cadent to manage any risk to the pipeline integrity. To achieve the scope, the following objectives were identified:

1. Undertake 1 no. site visits by DNV to read current strain gauge measurements at the two locations – chainage 170 m and 570 m. The site visit included a walkover of the site along the length of the pipeline, to identify, if any, visual signs of ongoing ground movement.

2. Undertake an assessment of the longitudinal stresses in the pipeline, compare with historical data and acceptable limits to provide an overview of the current pipeline stress condition.

3. Summarise the stress results and observations from the site visit within a technical report and provide conclusions and recommendations.

# 2 SITE DATA

## 2.1 Site Location and Description

Ulverston Canal in Ulverston, Cumbria runs in an easterly direction from the A590 Canal Street to Morecombe Bay. The canal has been dammed at its entrance to Morecombe Bay and is now classed as a raised reservoir.

The 300 mm diameter Ulverston to Barrow High Pressure Steel Gas Pipeline runs underneath the northern slope of the canal embankment / towpath. The pipeline runs along the canal embankment from an AGI near the western end at approximate Ordinance Survey National Grid Coordinates 329651E, 478435N and travels for approximately 750 m east, before turning 90° south and crossing beneath the canal (330350E, 478116N). A site location plan is included in Appendix A and chainage along the section of interest including strain gauge locations can be seen within the drawing in Appendix B. The chainages along the embankment are measured from the railway bridge.

## 2.2 Pipeline Details

The following pipeline details have been taken from the IGEM TD/1 affirmation report [/4/] and are listed in Table 2-1.

**Table 2-1 Pipeline Details**

| Parameter | Ulverston to Barrow Pipeline |
|---|---|
| Pipeline PSR ID | 1091 |
| Commissioning Date | 1975 |
| Nominal Diameter | 300 mm (12”) |
| Nominal Wall Thickness | 9.52 mm |
| Material Grade | X46 steel |
| Specified Minimum Yield Strength (SMYS) | 317 N/mm$^2$ |
| Maximum Operating Pressure (MOP) | 17.2 bar |
| Hydro-test Pressure | 103.5 bar |
| GDN/PM/P/18 [/5/] applicable? | Yes |

# 3 SITE VISIT OBSERVATIONS

The site was visited on Thursday 17th February 2022 by Andrew Connell and Adam Farrance (both from DNV), and both were able to walk the length of the embankment that supports the pipeline.

Observations made during the site visit suggest that there were no new visible signs of ground movement or settlement of the embankment along the pipeline alignment.

As per previous observations, there are a number of locations where ground movement stabilisation should be made if the pipeline is to remain in situ. Examples include:

- Rutting from traffic (see Figure 3-1);
- Removal of trees (see Figure 3-2); and
- Repair/remediation of the canal wall.

In summary, there were no obvious signs of new modes of ground movement. It is expected that the invert level of the pipeline could continue to be subjected to minor ground movement as the ground moves through the seasons and traffic passes along the embankment.

**Figure 3-1 Examples of ongoing road rutting and damage from traffic**

*[Tree removal marked by yellow arrows]*

**Figure 3-2 Examples showing tree removal / heavy pruning**

# 4 BASIS OF STRAIN GAUGE MONITORING

Vibrating wire strain gauges were installed on the pipeline following girth weld repairs, which were required following a number of girth weld inspections [/1/]. The pipeline has a previous history of leakage, which was attributed to the presence of stress corrosion cracking (SCC). Issues with SCC are primarily driven by sustained loads that cause high longitudinal stresses (such as ground movement). As it is perceived that the hazard of ongoing settlement of the embankment cannot be discounted, there remains a risk of high longitudinal stresses developing in the future which could be detrimental to the integrity of the pipeline due to the presence of SCC.

The basis of this monitoring is to therefore measure the changes in strain within the pipeline, which can then be converted into an equivalent stress and compared against acceptable limits for longitudinal stress. Changes in the pipeline stress state could indicate that ground settlement or embankment movement has occurred, which cannot be wholly discounted due to the nature of the embankment structure as a water retaining structure.

## 4.1 Hazards Identified

The following hazards have been identified in relation to the Ulverston to Barrow pipeline in its current operating condition:

1. Circumferential bending of the pipeline due to surface loading from heavy vehicles tracking above the pipeline.
2. Longitudinal bending of the pipeline along the embankment due to surface loading from heavy vehicles tracking above the pipeline.
3. Longitudinal bending of the pipeline along the embankment due to ground settlement.
4. Pipelines with defective girth welds or welds of unknown quality (P/18).
5. Fatigue crack growth leading to rupture/leak due to cyclic stresses.
6. Unplanned excavations to install street furniture adjacent to the pipeline.

The risks associated with 1) and 2) cannot be determined without additional soil/pipeline interaction analysis, which is outside the scope of this report.

The risks associated with the remaining hazards are the premise of the strain gauge monitoring and cannot be eliminated in the pipeline's current position, due to the potential of ongoing settlement and the nature of the embankment structure.

Elimination of the risks from the associated hazards can be achieved through the proposed diversion.

# 5 MONITORING METHODOLOGY

Vibrating wire strain gauges (VWSG) were installed at two locations along the pipeline – chainage 170 m and chainage 570 m. Chainage is measured from the nearby railway overbridge, which is adjacent to the AGI. These positions were chosen due to their proximity to locations of high ground movement (based upon previous surveys) [/1/] and thus at locations of calculated high longitudinal stress.

At both of these locations, three VWSG were installed onto the pipeline. The VWSG used the weldable block type, such that the gauges are mounted directly to the outer face of the pipe wall; the gauges were then wrapped under the pipeline coating upon coating repair. The three gauges are positioned at 120° intervals around the pipe circumference: at the 240°, 0° (top dead centre) and 120° positions. The orientation of the gauge positions is taken through the pipeline section, looking in the direction of flow, as shown in Figure 5-1.

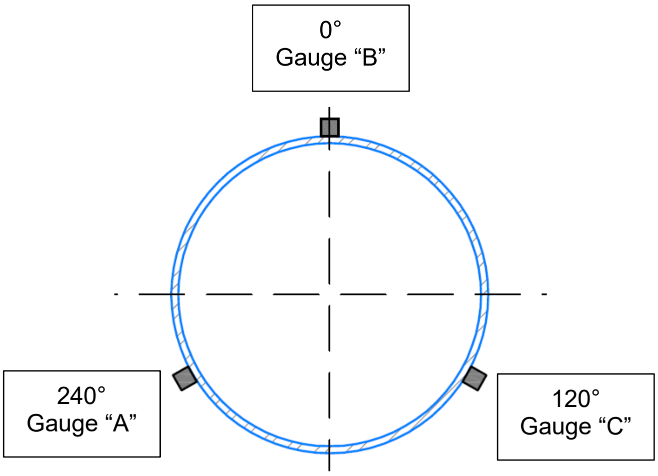



**Figure 5-1 Orientation of strain gauges around pipe circumference, assuming gas flow into page**

The cabling from the VWSG is run into the adjacent verge and a connection point installed into a repurposed concrete cathodic protection post. Readings are undertaken manually by connecting a VWSG compatible hand readout to the connection point in the CP post.

## 5.1 Performance Acceptance Criteria

The history of leakage in the pipeline has been primarily attributed to the stress corrosion cracking (SCC), which was found adjacent to a number of girth welds. The circumferential orientation of the cracks led to the primary limits being applied in the longitudinal direction of the pipeline. Applicable performance acceptance criteria for the Ulverston-Barrow pipeline were determined within the 2008 report [/1/], which outlined the following limits for the longitudinal tensile stresses:

1. Based on the maximum girth weld defect depth of 4.5 mm and circumferential defect length of 50 mm, the maximum longitudinal primary stress above which the defect will fail was estimated to be 50 N/mm$^2$.

2. A second failure limit of 100 N/mm$^2$ was also established that was based on defect depth of 3.4 mm which is the mean depth of all reported defect depths in the pipeline.

The longitudinal tensile stress limit of 50 N/mm$^2$ is considered reasonable when taking into account Poisson stress due to internal pressure, pipeline construction stresses and displacement stresses induced by ground movement; hence this limit has been adopted as the lower bound limit within the assessment.

The tensile stress limit of 100 N/mm$^2$ has been adopted as the upper bound limit.

# 6 MONITORING RESULTS

Manual readings were taken from each of the strain gauges at chainages 170 m and 570 m, during the site visit in February 2022. Measured strain values were then used to calculate any bending stress within the pipeline, in order to estimate the peak longitudinal stress around the pipe ring at that location (as the peak stress might not coincide with the position of a gauge).

Tables containing the calculated stresses are shown within Appendix C. Associated plots are included in Appendix D.

Although the excavations were undertaken and gauges installed in 2008, key observations have been compared with data commencing from July 2009, as consolidation of backfill could affect any trends between 2008 and 2009.

Chainage 170 m

For chainage 170 m, the results are within expected operational limits, suggesting there is no change in the overall pipeline stress state. The calculated maximum longitudinal tensile stress is 77.8 N/mm$^2$, which is within the upper bound limit, but above the lower bound limit; this has been apparent since the installation of the gauges and commencement of the monitoring. The calculated maximum tensile stress is similar to previous winter months, but below the maximum recorded in February 2011 (91.7 N/mm$^2$).

Chainage 570 m

For chainage 570 m, the results are within expected operational limits. The measured and calculated strain gauge values are within the historically recorded maxima. The calculated maximum longitudinal tensile stress is 120.1 N/mm$^2$, which is above the upper bound limit. However, this has been apparent since the installation of the gauges and as mentioned, is below the historical maxima.

However, the plots suggest that for the individual gauges the following observations can be made when comparing data since July 2009:

- Gauge A (240°) has seen a small increase in compressive stress (approx. 15 N/mm$^2$). Gauge A has been in compression since installation of the gauges.
- Gauge B (0°) has seen a small gradual increase in tensile stress since 2009 (approx. 10 N/mm$^2$), although the readings in February 2022 are similar to the previous January reading in 2018. There appears to be small fluctuations between readings in the Q1 period, but these are mostly similar; and
- Gauge C (120°) has seen a small gradual decrease in measured tensile stress (approx. 20 N/mm$^2$) since 2009. Gauge C presents the peak measured tensile stresses compared to gauges A and B.

The stress profile around the pipeline ring as shown by the gauges suggests that the pipeline is subjected to a combined lateral and hogging moment at this location, which has been apparent since installation of the gauges. However, the calculated bending stresses are currently remaining fairly consistent.

# 7 DISCUSSION

During the site visit in February 2022, it was noted that the vegetation along the canal embankment had been cut back; this made access to the connection posts easy. The concrete posts containing the strain gauge connections were noted to be in good condition. The connectors were also in good condition, providing a clean connection to the strain gauges. All strain gauges returned strong, clear signals demonstrating that their condition can be perceived to be good.

The strain readings taken suggest that the overall pipeline stress state is similar to previous readings undertaken in the winter months. It can be inferred that the pipeline is likely to be in a similar operating condition as the previous winter readings, last taken in 2017.

The maximum calculated longitudinal tensile stress at chainage 170 m is above the lower bound limit of 50 $N/mm^2$, but below the upper bound limit of 100 $N/mm^2$, with the current stresses similar to the previous winter readings in 2017. At chainage 570 m, the calculated longitudinal tensile stresses are above the upper bound limit of 100 $N/mm^2$, but they are still within previously recorded maxima.

Although chainage 570 m is above the upper bound limit of 100 $N/mm^2$, this has been apparent since installation of the gauges. Based upon the individual gauges at this location, the pipeline is subjected to a lateral and hogging moment, with the lateral bending directed north (away from the canal).

In order to strengthen any observations from the strain gauges, it is recommended that more frequent readings are undertaken to ensure that the stress peaks and troughs are captured. Monthly or bi-monthly readings would allow for more definitive stress profiles to be generated and conclusions to be more definitive. This would help to identify the cyclic behaviour, which could be linked to shrink/swell behaviour of the ground or related to operating temperature changes of the pipeline.

For both locations, any effects of SCC would have now become apparent, if any were present. This could suggest that the condition of the pipeline at this location can accommodate the current stress regime. However, should the stresses increase above those seen previously, the integrity of the pipeline could not be guaranteed in the long term.

Observations from site suggest that there were no new visible signs of ground movement or settlement of the embankment along the pipeline alignment. It was noted however, that in a few locations the canal side of the embankment had minor localised damage, possibly due to the varying water level weakening the canal face; rutting of the road was also still apparent. Although this has not resulted in any leakage or additional movement of the canal embankment, it does demonstrate that the embankment could be susceptible to ongoing maintenance issues in the future.

It should be noted that a number of girth weld repairs had been undertaken as part of the 2008 works. At the locations of the weld repairs, it can be assumed that the effects of SCC are contained and that the longitudinal stress limits outlined within Section 5.1 no longer apply.

# 8 CONCLUSIONS

Based upon the information provided within this report, the following conclusions can be made. The conclusions below are similar to those provided in the previous monitoring report [/3/]:

1. Observations from site suggest that there were no new visible signs of ground movement or settlement of the embankment along the pipeline alignment. However, localised damage to the canal wall and ongoing rutting of the road suggests that the embankment could be susceptible to ongoing maintenance issues in the future.

2. Stresses at chainage 170 m are similar to those previously measured in winter months and is within expected operating conditions. The maximum calculated longitudinal tensile stresses are above the lower bound limit of 50 $N/mm^2$ and within the upper bound limit of 100 $N/mm^2$, although this has been apparent since installation of the gauges.

3. Stresses at chainage 570 m are similar to those previously measured in winter months and is within expected operating conditions. The calculated maximum longitudinal tensile stress is 120.1 $N/mm^2$, which is above the upper bound limit. However, this has been apparent since the installation of the gauges and is within historical recorded maxima.

4. The pipeline stress regime continues to be above the recommended limits previously set out in the 2008 report [/1/]. However, any effects of SCC would have now become apparent, if any were present, which suggests that the condition of the pipeline can accommodate the current stress regime. However, should the stresses increase above those seen previously or the bending stress profiles change, then the integrity of the pipeline cannot be guaranteed in the long term.

# 9 RECOMMENDATIONS FOR RESIDUAL RISK CONTROL

Based upon the findings within this report, the following recommendations are provided in order to monitor the risks to the pipeline integrity until the diversion can be undertaken. The recommendations below are the same as those provided in the previous monitoring report:

1. It is recommended that more frequent readings are undertaken to ensure that the stress peaks and troughs are captured. Monthly or bi-monthly readings would allow for more representative stress profiles to be generated and conclusions to be more definitive.

2. Site visits should be undertaken on an annual basis by a geotechnical specialist in order to identify any potential visible signs of settlement.

3. Cadent should continue to obtain the canal survey reports from Glaxo Smith Kline and review for any anomalies or signs of movement.

# 10 REFERENCES


/1/ Report No. 8189, “Investigation of the settlement of Ulverston Canal embankment on the integrity of the 300mm Barrow to Whasset pipeline.” Advantica, 10th Nov 2008.

/2/ Technical Note No. 11507, “The 300mm Barrow to Whasset pipeline. Summary of analysis and results of Ulverston canal strain gauges.” GL Noble Denton, 18th July 2011.

/3/ Report No. 10300156/01, “Ulverston Canal Strain Gauges. Strain Gauge Measurement Summary 2021.” Rev 0., DNV, 28th September 2021.

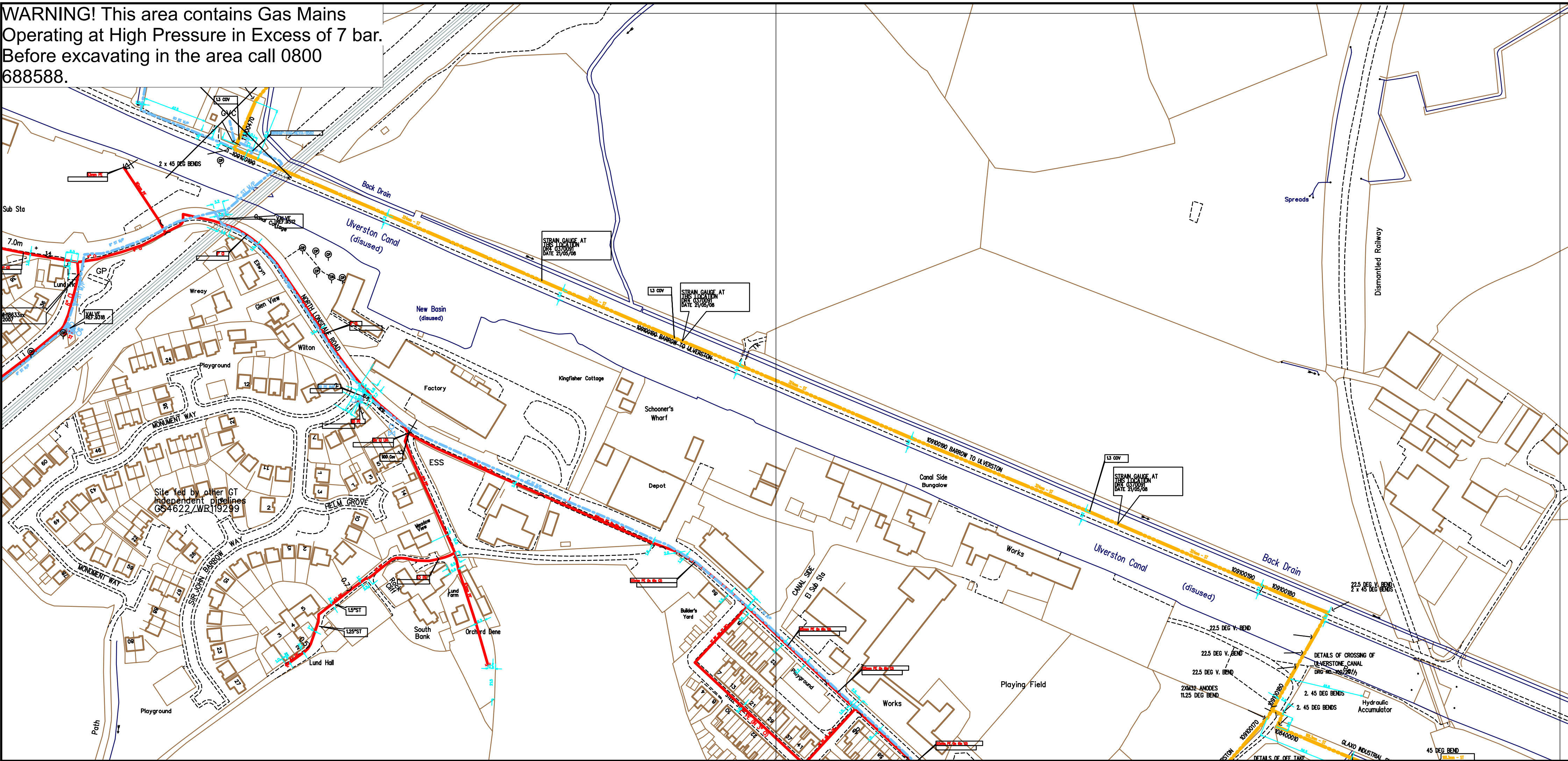
/4/ Report No. 16538, “IGE/TD/1 Report, Ulverston – Barrow Pipeline (1091) including: Glaxo Supply (1084)”. Rev 1., DNV GL, 31st December 2015.

/5/ GDN/PM/P/18, “Management procedure for working on pipelines containing defective girth welds or girth welds of unknown quality”, Cadent, Northern Gas Networks, SGN and Wales & West Utilities (GDNs), dated: August 2020.

## APPENDIX A
## Site Location


**Site Location**
**[Contains OS data © Crown copyright and database rights 2022]**

WARNING! This area contains Gas Mains Operating at High Pressure in Excess of 7 bar. Before excavating in the area call 0800 688588.




| | |
|---|---|
| SCALE: Not to scale | |
| USER ID: ADAFAR | |
| DATE: 05/11/2018 | |
| EXTRACT DATE: 13/06/2018 | |
| MAP REF: SD3078 | |
| CENTRE: 330006, 478265 | |

LP MAINS
MP MAINS
IP MAINS
LHP MAINS

Some examples of Plant Items:
Valve
Depth of Cover
Syphon
Diameter Change
Material Change
Out of Standard Service

This plan shows those pipes owned by Cadent Gas Ltd in their role as a Licensed Gas Transporter (GT). Gas pipes owned by other GTs, or otherwise privately owned, may be present in this area. Information with regard to such pipes should be obtained from the relevant owners. The information shown on this plan is given without warranty, the accuracy thereof cannot be guaranteed. Service pipes, valves, syphons, stub connections, etc. are not shown but their presence should be anticipated. No liability of any kind whatsoever is accepted by Cadent Gas Ltd or their agents, servants or contractors for any error or omission. Safe digging practices, in accordance with HS(G)47, must be used to verify and establish the actual position of mains, pipes, services and other apparatus on site before any mechanical plant is used. It is your responsibility to ensure that this information is provided to all persons (either direct labour or contractors) working for you on or near gas apparatus. The information included on this plan should not be referred to beyond a period of 28 days from the date of issue. Further information on all DR4s can be determined by calling the DR4 hotline on 01455 892426 (9am-5pm) A DR4 is where a potential error has been identified within the asset record and a process is currently underway to investigate and resolve the error as appropriate.

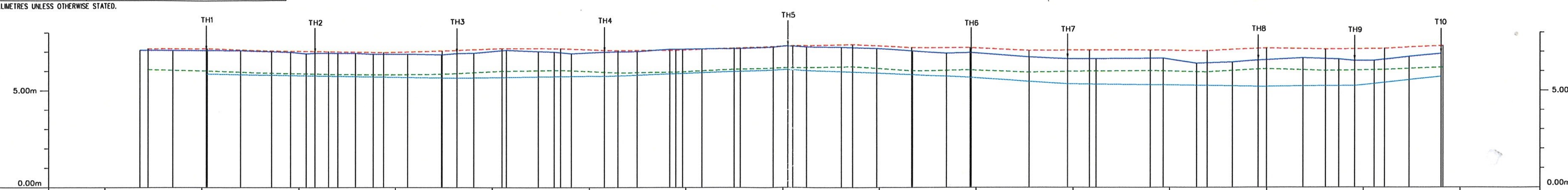
MAPS Viewer Version 5.8.0.1

Local Machine

# APPENDIX B
## Strain Gauge Locations

Drg No: | Site: | Title:

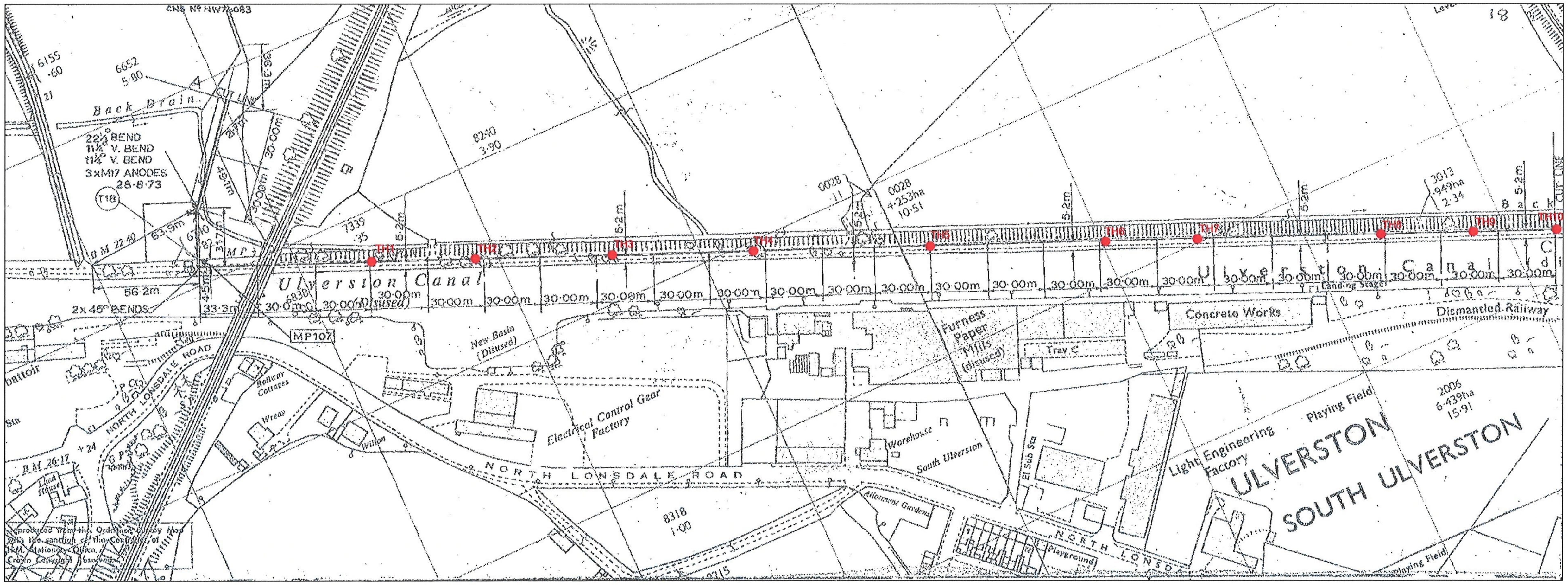
DO NOT SCALE. IF IN DOUBT ASK. ALL DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE STATED.




| | |
|---|---|
| CHAINAGE FROM BRIDGE (METRES) | 0, 50, 100, 150, 200, 250, 300, 350, 400, 450, 500, 550, 600, 650, 700 |
| GROUND LEVEL DIFFERENCE (METRES) | -0.11, -0.10, -0.17, -0.10, -0.01, -0.27, -0.46, -0.62, -0.62, -0.42 |
| PIPE LEVEL DIFFERENCE (METRES) | -0.16, -0.10, -0.24, -0.20, -0.10, -0.38, -0.65, -0.89, -0.80, -0.47 |
| ORIGINAL GROUND LEVEL (METRES A.O.D.) | 7.18, 7.20, 7.07, 7.02, 6.98, 7.06, 7.18, 7.17, 7.09, 7.10, 7.22, 7.34, 7.40, 7.24, 7.24, 7.11, 7.13, 7.12, 7.07, 7.22, 7.16, 7.20, 7.33 |
| ORIGINAL PIPE LEVEL (TOP) (METRES A.O.D) | 6.09, 6.03, 5.90, 5.83, 5.81, 5.84, 5.99, 6.03, 5.92, 5.96, 6.10, [illegible], 6.23, 6.02, 6.07, 5.97, 6.01, 6.03, 5.95, 6.13, 6.03, 6.08, 6.19 |
| CURRENT GROUND LEVEL (METRES A.O.D.) | 7.11, 7.09, 7.09, 7.08, 6.99, 6.90, 6.93, 6.93, 6.93, 6.88, 6.89, 6.85, 6.92, 6.94, 7.08, 7.01, 6.98, 6.90, 7.01, 7.02, 7.13, 7.14, 7.16, 7.19, 7.26, 7.32, 7.28, 7.25, 7.18, 7.06, 6.95, 6.97, 6.76, 6.66, 6.66, 6.68, 6.41, 6.46, 6.58, 6.69, 6.63, 6.56, 6.56, 6.75, 6.91 |
| CURRENT PIPE LEVEL (TOP) (METRES A.O.D.) | 5.87, 5.75, 5.63, 5.74, 6.09, 5.69, 5.35, 5.21, 5.25, 5.71 |

## LONGITUDINAL SECTION ALONG PIPELINE FROM BRIDGE TO TH 10

HORIZONTAL SCALE 1:1250, VERTICAL SCALE1:125




## EXTRACT FROM STRIP MAP NO 100/154

FOR INFORMATION ONLY

UNCONTROLLED WHEN PRINTED

NOTES:

1. ALL LEVELS RELATIVE TO OSBM (VALUE) 6.82M LOCATED APPROX. 40M WEST OF ULVERSTON AGI.

| Rev | Rev Ref | Date | Drn by | Chk by | Apr by | Description |
|---|---|---|---|---|---|---|
| | | | | | | |

nationalgrid

A1

NATIONAL GRID PLC
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| | | Date | Sheet |
|---|---|---|---|
| FILESPEC: | | | |
| Drawn By | J.R.H. | 14/1/08 | Scale (@ A1) 1:1250 |
| CAD Check by | | | |
| ENG Check By | | | |
| Approved By | | | |

Site: BARROW-WHASSET 12" HP GAS PIPELINE

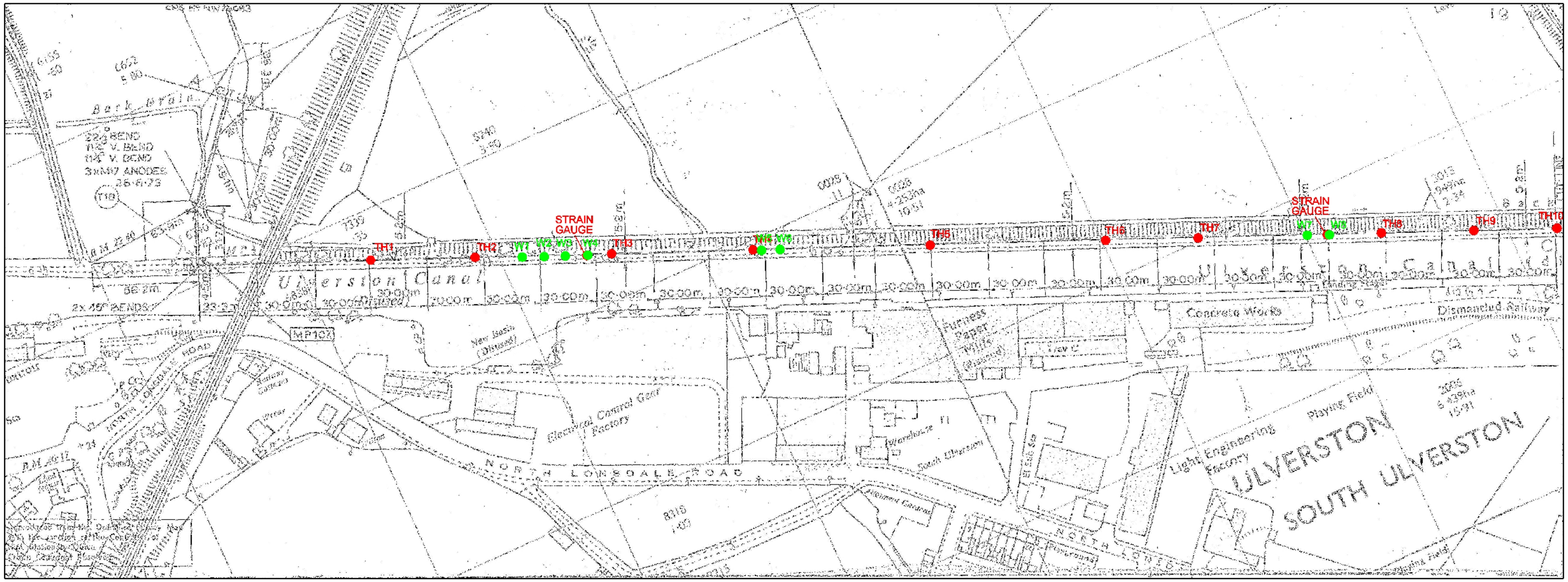
Title: LONGDITUDINAL SECTION ALONG PIPELINE ADJACENT TO ULVERSTON CANAL COMPARING EXISTING WITH ORIGINAL LEVELS

Drg No: 53074 | Revision

| Project | Ulverston, Canal Embankment Settlement | Site | Ulverston, Cumbria |
|---|---|---|---|

LONGITUDINAL SECTION ALONG PIPELINE FROM BRIDGE TO TH 10

HORIZONTAL SCALE 1:1250, VERTICAL SCALE 1:125




| | |
|---|---|
| ● | Girth Weld Inspection |
| ● | Trial Hole Location |
| STRAIN GAUGE | VWSG fitted and residual stress measurement carried out |

| Figure 1 | Location of girth weld inspections, strain gauge locations and trial hole excavations on the embankment section. | | | | | | |
|---|---|---|---|---|---|---|---|
| Report/File ref | | Drawn by | DF | Date | 17/04/09 | Revision | 0.0 |

# APPENDIX C
## Strain Gauge Results Tables

**Table C-1 Chainage 170 m calculated longitudinal stresses in N/mm$^2$.**

| Date | | Max. Total | Min. Total | Axial Component | Bending Component |
|---|---|---|---|---|---|
| Initial Reading | | | | | |
| | 09/05/2008 | 78.8 | -26.3 | 26.2 | 52.6 |
| 2008 | | | | | |
| | 05/06/2008 | 77.7 | -21.7 | 28.0 | 49.7 |
| | 17/06/2008 | 76.4 | -24.6 | 25.9 | 50.5 |
| | 22/07/2008 | 75.7 | -31.7 | 22.0 | 53.7 |
| 2009 | | | | | |
| | 11/03/2009 | 91.2 | -18.7 | 36.3 | 54.9 |
| | 01/05/2009 | 84.2 | -25.9 | 29.1 | 55.1 |
| | 27/07/2009 | 71.6 | -40.6 | 15.5 | 56.1 |
| | 08/12/2009 | 82.6 | -30.7 | 26.0 | 56.7 |
| 2010 | | | | | |
| | 07/04/2010 | 88.9 | -23.6 | 32.6 | 56.2 |
| 2011 | | | | | |
| | 22/02/2011 | 91.7 | -23.6 | 34.0 | 57.6 |
| | 18/07/2011 | 73.7 | -45.1 | 14.3 | 59.4 |
| 2016 | | | | | |
| | 13/07/2016 | 67.9 | -48.5 | 9.7 | 58.2 |
| 2017 | | | | | |
| | 26/01/2017 | 83.0 | -35.5 | 23.8 | 59.2 |
| | 05/04/2017 | 79.9 | -37.0 | 21.5 | 58.4 |
| 2018 | | | | | |
| | 20/04/2018 | 86.4 | -32.3 | 27.1 | 59.4 |
| 2021 | | | | | |
| | 22/06/2021 | 66.7 | -48.9 | 8.9 | 57.8 |
| 2022 | | | | | |
| | 17/02/2022 | 77.8 | -36.8 | 21.0 | 57.8 |

**Table C-2 Chainage 570 m calculated longitudinal stresses in N/mm².**

| Date | | Max. Total | Min. Total | Axial Component | Bending Component |
|---|---|---|---|---|---|
| Initial Reading | | | | | |
| | 09/05/2008 | 137.4 | -95.9 | 20.8 | 116.6 |
| 2008 | | | | | |
| | 05/06/2008 | 127.1 | -85.6 | 20.8 | 106.3 |
| | 17/06/2008 | 123.5 | -86.6 | 18.4 | 105.1 |
| | 22/07/2008 | 121.6 | -93.2 | 14.2 | 107.4 |
| 2009 | | | | | |
| | 11/03/2009 | 136.4 | -77.0 | 29.7 | 106.7 |
| | 01/05/2009 | 128.3 | -84.5 | 21.9 | 106.4 |
| | 27/07/2009 | 112.5 | -99.7 | 6.4 | 106.1 |
| | 08/12/2009 | 125.5 | -87.7 | 18.9 | 106.6 |
| 2010 | | | | | |
| | 07/04/2010 | 131.1 | -80.3 | 25.4 | 105.7 |
| 2011 | | | | | |
| | 22/02/2011 | 133.5 | -78.0 | 27.7 | 105.7 |
| | 18/07/2011 | 111.6 | -100.6 | 5.5 | 106.1 |
| 2016 | | | | | |
| | 13/07/2016 | 108.8 | -106.7 | 1.1 | 107.8 |
| 2017 | | | | | |
| | 26/01/2017 | 124.6 | -91.1 | 16.8 | 107.9 |
| | 05/04/2017 | 122.0 | -94.7 | 13.7 | 108.3 |
| 2018 | | | | | |
| | 20/04/2018 | 128.2 | -88.6 | 19.8 | 108.4 |
| 2021 | | | | | |
| | 22/06/2021 | 106.1 | -110.4 | -2.1 | 108.2 |
| 2022 | | | | | |
| | 17/02/2022 | 120.1 | -97.4 | 11.4 | 108.7 |

# APPENDIX D
## Strain Gauge and Stress Plots

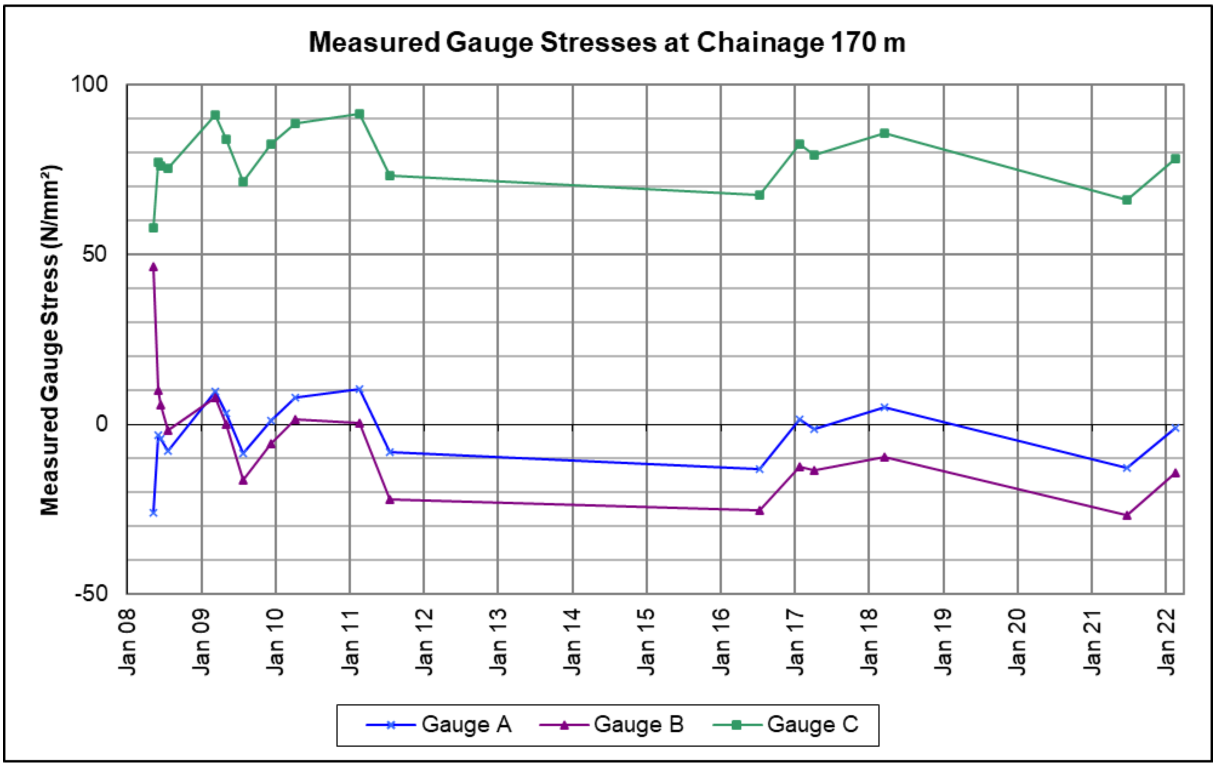



**Figure D-1  Chainage 170 m plot of measured strain gauge stress**

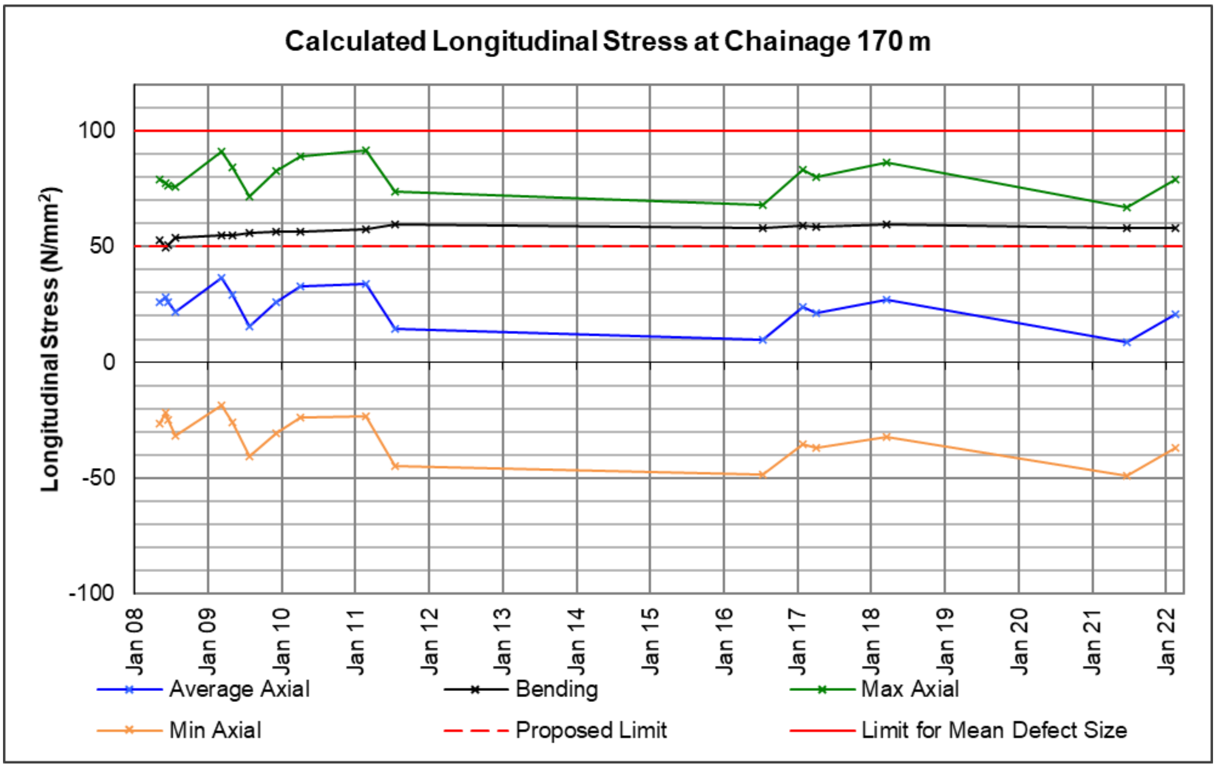



**Figure D-2  Chainage 170 m plot of calculated longitudinal stresses**

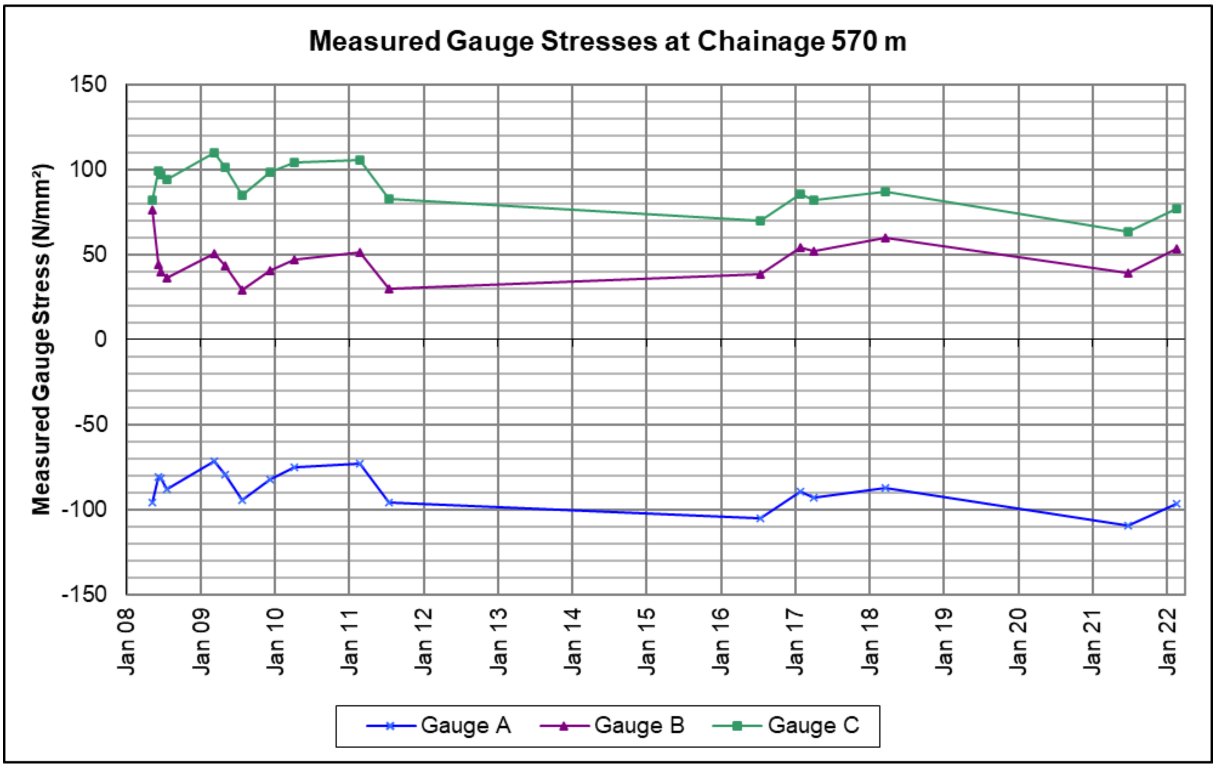



**Figure D-3 Chainage 570 m plot of measured strain gauge stress**

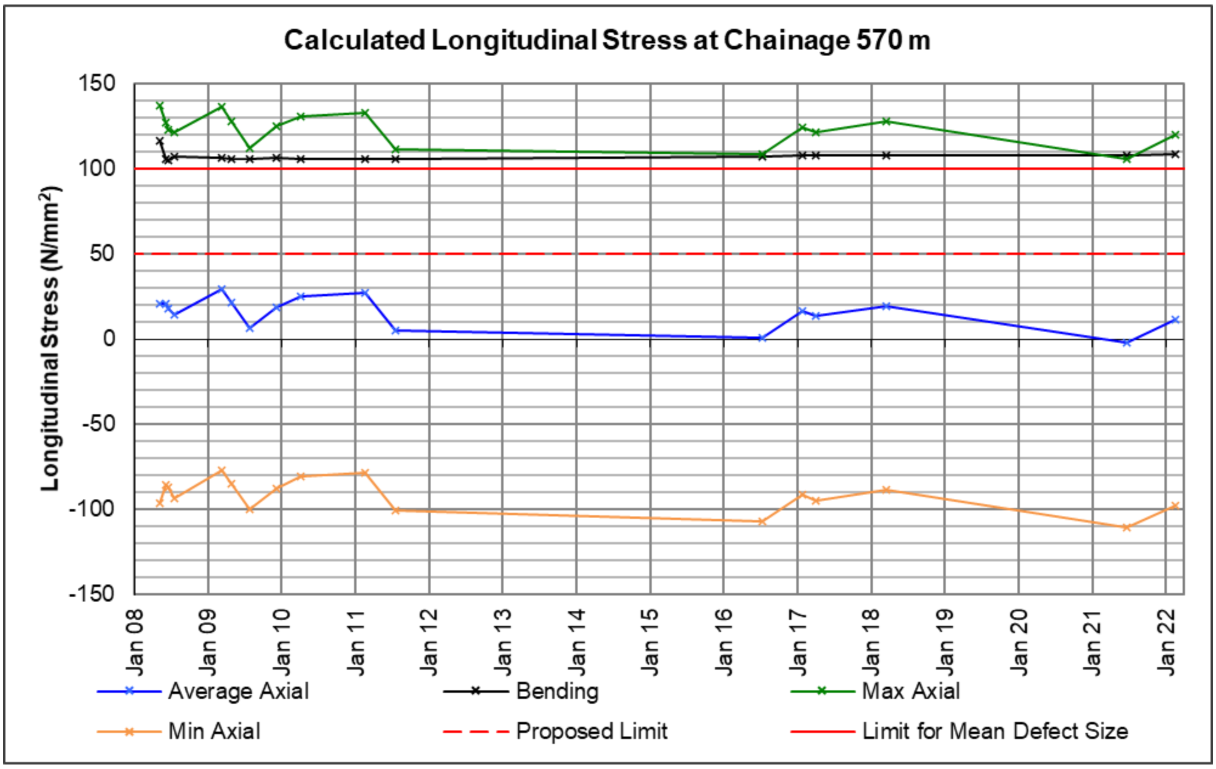



**Figure D-4 Chainage 570 m plot of calculated longitudinal stresses**

## About DNV

DNV is the independent expert in risk management and assurance, operating in more than 100 countries. Through its broad experience and deep expertise DNV advances safety and sustainable performance, sets industry benchmarks, and inspires and invents solutions.

Whether assessing a new ship design, optimizing the performance of a wind farm, analyzing sensor data from a gas pipeline or certifying a food company's supply chain, DNV enables its customers and their stakeholders to make critical decisions with confidence.

Driven by its purpose, to safeguard life, property, and the environment, DNV helps tackle the challenges and global transformations facing its customers and the world today and is a trusted voice for many of the world's most successful and forward-thinking companies.