ULVERSTON CANAL

Soil / Pipeline Interaction Analysis

Cadent Gas Limited

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Objective:

Based upon all available information, carry out necessary analysis (including soil / pipe interaction analysis) to establish the remaining life of the pipeline section.

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EXECUTIVE SUMMARY

Cadent Gas Limited own and operate the 300mm diameter Barrow to Whasset High Pressure (HP) Gas Pipeline located within the embankment / towpath of the Ulverston Canal in Cumbria. The gas pipeline has a history of leakage due to stress corrosion cracking (SCC) and the embankment / towpath also has a history of ground settlement and instability. Cadent Gas Limited plan to divert the pipeline but wish to assess the threat posed to the gas pipeline from this ground settlement in the interim.

The Soil / Pipeline Interaction Analysis (SPIA) report was prepared following the most recent ground movement / pipeline surveys and the findings from the Ground Investigation Report (GIR), undertaken as part of phased works to support the ongoing integrity of the pipeline.

As part of the SPIA assessment, the current condition of the pipeline was assessed using commercially available software Ple4Win. The stresses induced in the pipeline are estimated using an elastic stress analysis approach by modelling the gas pipeline as a circular ring cross-section, supported on an elastic foundation. The soil springs supporting the pipeline are inferred from the soil parameters outlined within the GIR and the geometry was based upon the original as-built information. There were some limitations on the data available for the section of pipeline that runs underneath the canal, so assumptions based upon engineering judgement of what was available were made.

Two settlement cases were considered. The first was based upon the ground level changes measured in 2007 / 2008 as part of a previous assessment. The second settlement profile was based upon the topographical survey and a Ground Penetrating Radar (GPR) survey (to determine the depth of cover to the pipe) undertaken as part of the current project. Due to the spacing between pipeline survey points, a curve smoothing exercise was undertaken to minimise any stress peaks within the SPIA.

The pipeline acceptance criteria were based upon the previous assessment in 2008, that considered revised limits to be used for the longitudinal tensile stresses which were based upon weld inspections and fracture mechanics assessments. There were estimated to be 50 N/mm^2 for a worse case defect and thus the lower bound, and a second failure limit of 100 N/mm^2 was established that was based on the mean depth of all reported defect depths in the pipeline.

The results of the analyses suggest that the pipeline continues to operate above the previously established axial stress limits; this can also be seen within the measured strain gauge results.

An estimation of the allowable settlement increase for the pipeline was assessed, to review what magnitude of settlement is required to exceed allowable limits, should future settlements occur. Additional ground movement profiles were assessed within Ple4Win to understand the pipeline behaviour and thus the stress response. For this assessment it was assumed that in the long term, the pipeline would be remediated such that normal T/SP/GM/1 limits could be applied. The assessment suggests that an overall increase in the magnitude of the current settlement profile of 175% would put the pipeline at the limit of the GM/1 criterion. Ongoing monitoring of the embankment would need to be undertaken to measure these values and to ensure that the assumptions are correct.

Considerations should be made to the stress condition of the bends where the pipeline runs underneath the canal. It is recommended that inspection and residual stress measurements are made on the linear section of pipe in this area to ensure that excessive bending stresses are not apparent. These investigations should be undertaken to inform any future asset management decisions regarding the method of remediation, including which diversion routes would be most viable.

1 INTRODUCTION

Cadent Gas Limited (Cadent) own and operate the 300mm diameter Ulverston to Barrow Gas Pipeline which is located within the embankment / towpath of the Ulverston Canal in Cumbria. The embankment carries a single carriage road used by private users and pedestrians. The embankment has a long history of settlement and a series of investigations, monitoring and remedial works have been carried out by the canal owner in the past to retain the integrity of the structure. The pipeline also has a history of leakages linked to stress corrosion cracking and therefore the effects of continuing settlement pose a threat to its integrity.

As part of a developed management and protection strategy, Cadent (then National Grid Gas Distribution) commissioned Residual Stress Measurements (RSM) at two locations on the pipeline in February 2008 to determine the actual stress in the pipeline. Vibrating wire strain gauges were subsequently installed to monitor the stress changes of the pipeline at the two locations. DNV GL (then Advantica and later GL Industrial Services) was tasked with providing continued assessment of the readings obtained from the strain gauges and produced a series of monitoring reports between 2008 and 2011 [/1//2//3//4/]. In 2014, it was recommended that the pipeline be diverted, and subsequent monitoring of the strain gauges was carried out by DNV GL in 2017 [/5/] and 2018 [/6/] at the request of Cadent.

Cadent plans to divert the pipeline in the long term and requires continuing support to determine whether the integrity of the pipeline may be compromised before the diversion is complete. Therefore in 2018, Cadent commissioned DNV GL to carry out a Soil / Pipeline Interaction Analysis (SPIA) to determine the stresses induced within pipeline from the settlement. As part of these assessments, Cadent require a remaining life assessment of the pipeline and viable interim measures that can be initiated while preparing for diversion.

This report considers the SPIA assessment and its findings.

1.1 Scope and Objectives

The scope of this element of the project is to advise on the remaining life of this section of pipeline and to provide recommendations relating to the ongoing integrity of the pipeline. The following objectives are therefore identified:

1. Reference the findings of the Ground Investigation Report (GIR) [/7/] and latest pipeline survey [/8/] undertaken as part of this project to predict the current stress profile of the pipeline utilising SPIA.
2. Compare previous fracture mechanics findings and current strain gauge data to the outputs of the SPIA to identify potential areas at risk.
3. Utilise the outputs and findings to advise on subsequent phases of the project relating to ongoing monitoring, potential diversion and / or remediation of the embankment to ensure gas supply is not compromised.

2 SITE DATA

2.1 Site Location

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 300mm diameter Ulverston to Barrow High Pressure 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 750m 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 can be seen within the drawing in Appendix B. The chainages along the embankment are measured from the railway bridge.

2.2 Pipeline Properties

The pipeline details have been taken from the associated IGE/TD/1 affirmation report [9] and are listed in Table 2-1.

Table 2-1 Properties for the Ulverston to Barrow pipeline

Parameters	Ulverston to Barrow Gas Pipeline
Pipeline PSR ID	1091
Commissioning Date	1975
Outside Diameter	323.9 mm
Nominal Wall Thickness	9.52 mm
Material Grade	X46
Specified Minimum Yield Strength (SMYS)	317 N/mm^2
Maximum Operating Pressure (MOP)	17.2 bar
Hydro-test Pressure	103.5 bar
T/PM/P/18 [10] applicable	Yes

2.3 Ground Conditions

The ground conditions for the embankment and thus the soil surrounding the pipeline were inferred from a desktop study and ground investigations undertaken on site. A summary of the study and investigations, as well as the interpretation of results can be found within DNV GL Report 119H8FGN-6 [7].

In summary, the embankment in which the pipeline was constructed consists of Made Ground, which contains both granular and cohesive strata. The stratum in which the pipeline is situated is cohesive, which consists of a low to medium strength silty Clay, which is likely to be locally won material during construction.

2.3.1 Geotechnical Parameters

Table 2-2 summarises the geotechnical parameters of the embankment fill adopted for the soil surrounding and supporting the pipeline.

Table 2-2 Soil Parameters for Embankment Fill

Properties	Unit	Low Strength Silty Clay
Soil Type		Cohesive Fill
Volume weight	kN/m^3	17
Angle of internal friction	°	30
Soil/Pipeline friction angle	°	17
Cohesion	kN/m^2	1
Stiffness	kN/m^2	3500
Shear Modulus	kN/m^2	1400

3 SOIL / PIPELINE INTERACTION ANALYSIS (SPIA)

The circumferential and longitudinal stresses in the gas pipeline, due to internal pressure, soil overburden and settlement loading, have been estimated using commercially available software Ple4Win [/11/]. The stresses induced in the gas pipeline are estimated using an elastic stress analysis approach by modelling the gas pipeline as a circular ring cross-section and supported on an elastic foundation. Further details regarding the modelling inputs are provided in the sub-sections below.

3.1 Modelling Methodology

3.1.1 Pipeline Geometry

The Barrow to Ulverston Pipeline has been modelled as a predominantly straight section of pipeline. The pipeline exits the above ground installation, followed by a 90° horizontal bend and then runs parallel to the embankment for approximately 750m. There is another 90° horizontal bend, followed by an over and underbend to drop the pipeline elevation beneath the canal. The model boundaries have been assumed as the AGI (model start) and an arbitrary distance underneath the canal (model end). The modelled bends were assumed to have a wall thickness and outer diameter the same as that of the adjacent pipe sections and all bends were considered to have a minimum bend radius of 3 times the outer diameter in accordance with IGEM/TD/1 [/12/].

The pipeline was modelled with an outer diameter 323.9mm, a wall thickness of 9.52mm. A wall thickness manufacturing under tolerance of 12.5% was applied as per Cadent Specification T/SP/DAT/6 [/13/].

The ground level along the pipeline length has been assumed to be constant for modelling purposes and the pipe level (i.e. cover depth) has been taken from the original strip map Drg. No. 100/154 [/14/] and updated Drg. No. 53074 (see Appendix B). The settlement displacements, recorded in 2007 / 2008, have also been taken from Drg. No. 53074.

3.1.2 Pipeline Material Properties

The pipeline was modelled using a material grade with a Specified Minimum Yield Strength (SMYS) of 317N/mm^2. The pipeline is modelled with elastic material properties in accordance with T/SP/GM/1 [/15/]. Table 3-1 summarises the material properties for steel considered in this assessment.

Table 3-1 Elastic material properties for steel

Properties	Value
Material Grade	X46
Elastic Modulus	210,000 N/mm^2
Poisson’s Ratio	0.3
SMYS	317 N/mm^2

3.1.3 Soil Restraint Properties

Based upon the information in Section 2.3, the pipeline is buried within made up ground that consists of firm clay. As site specific investigations have been undertaken, only one cohesive soil type has been modelled within Ple4Win.

The soil restraint characteristics were modelled using the built-in “Soil Wizard” module within Ple4Win, which uses the recognised Dutch Standard NEN 3650 [/16/] to determine the mechanical properties of the soil and hence the restraint properties.

3.1.4 Boundary Conditions

Boundary conditions at the pipeline ends were modelled as 'Infinite' and 'Open'. 'Infinite' considers that the pipeline has no restraints at the boundary and will also model a half-infinite section of pipe at this location to dissipate the effects of end boundary conditions. 'Open' considers that the pipeline has no obstructions to gas flow at the boundary (such as closed valves) i.e. no end pressure thrust.

3.1.5 Settlement Profiles

Two settlement cases have been considered – these are shown within Figure 9-1. The first (S1) utilised the drawings provided by Cadent and were based upon the ground level changes measured in 2007/2008 as part of the inspections (see Appendix B).

The second settlement profile (S2) is based upon a topographical survey and a ground penetrating radar (GPR) survey (to determine the depth of cover to the pipe) undertaken as part of the current project. Even though similar, settlement profile S2 is considered to be more accurate as ground and pipeline cover depths have been measured at more regular intervals (approximately every 10m). and both profiles have therefore been considered within the assessment.

Due to some limitations in the previous survey data and access constraints, assumptions had to be made on the ground movement magnitudes at the section beneath the canal and the adjacent bends. This has been based upon the historical rates of movement at this location and the previous survey.

Due to the spacing between pipeline survey points, a curve smoothing exercise was undertaken to minimise any stress peaks that may be due to the 20 – 30m spacing between measurements (see Figure 9-2).

The calculated settlements of the pipeline have been applied in the "Z" direction (vertical) only, as no information is available on lateral pipeline movement. However, when comparing the current pipeline survey to the as-built information, the predominant ground movement appears to be in the vertical direction.

3.1.6 Loads and Load Case Table

The following loads have been considered within this assessment:

1. Maximum Operational Pressure (MOP)

   The High Pressure (HP) pipeline transports natural gas at MOP of 17.2 barg; therefore, an internal pressure of 17.2 bar is considered in this SPIA. The maximum incidental pressure (MIP) has not been used in this instance as this section of pipeline is regulated, such that a constant pressure is maintained.

   The hydrotest pressure has been taken as 103.5 bar in accordance with the TD/1 report [/9/].

2. Soil dead weight (D)

   The HP pipeline is approximately 1.2m below the ground level where it runs parellel to the canal embankment. The soil overburden has been modelled in Ple4Win using the conditions outlined within Section 2.3.

3. Excavation (E) – weld inspections and installation of strain gauges

   Eight excavations were undertaken on the pipeline in 2008 to carry out an inspection of selected welds and to also install strain gauges at select locations. An "excavation" case has therefore been considered where the pipe is exposed at each of the eight excavation locations. The excavations have been modelled as 8 No. 3m free-spans, centred around the weld locations.

The locations of the excavations have been inferred from the weld inspection locations in Appendix C.

4. Temperature (ΔT)

   A temperature change of -15°C and +15°C has been considered. This was used for reference and to assist in calibrating the model.

5. Settlement (S)

   The settlement cases, S1 and S2, as per Section 3.1.5 above.

Using the above loads, the load cases considered are outlined in the table below.

Table 3-2 Load cases for Assessment

Load Case	Load Case Combination	Load Case Description
L1	D	As-built condition
L2	D + Hydrotest	Hydrotest pressure
L3	D + MIP + S1	Settlement prior to weld investigations
L4	D + MIP + S1 + E	Excavations for weld inspection
L5	D + MIP + S1**	Burial following excavation
L6	D + MIP + S2	Current estimated settlement
L7*	D + MIP + S2 + ΔT	Settlement + 15°C temperature change
L8*	D + MIP + S2 - ΔT	Settlement - 15°C temperature change

**These load cases were used for reference only, to understand the effects of temperature change on the model and to support model calibration.*

***It is assumed that the ground movement profile is the same as Load Case 3 however, the stress / displacement change from the free-span excavations is now included (although small) following re-burial of the pipe.*

3.2 Performance Acceptance Criteria

Performance acceptance limits for the pipeline have been based upon the requirements for high pressure steel pipelines detailed within specification T/SP/GM/1. The assessment considers the acceptable limit for von Mises equivalent stress, which is 90% of the SMYS.

The pipeline is subjected to T/PM/P/18 (P/18). For pipelines subject to P/18, the performance criteria for acceptable total longitudinal stress are based upon the axial stresses induced during the hydrotest, which for the Ulverston to Barrow Gas Pipeline is a pressure of 103.5 bar. This provides an axial stress during hydrotest of 52.7N/mm^2.

Additional performance acceptance criteria are applicable for the pipeline, as determined within the 2008 report by DNV GL (then Advantica) [/1/]. This outlined the following revised limits to be used for the longitudinal tensile stresses, based upon weld inspections and fracture mechanics assessments:

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

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

These longitudinal stress values are to be applied as the current acceptable limits for this section of pipeline and will be used to advise recommendations for residual risk control.

Therefore, based upon the above, the limits to be applied are shown within Table 3-3.

Table 3-3 Revised Performance Acceptance Criteria

Parameter	Limit Value
Von Mises Equivalent Stress (90% SMYS)	285 N/mm^2
Total Longitudinal/Axial Stress (Lower Bound)	50 N/mm^2
Total Longitudinal/Axial Stress (Upper Bound)	100 N/mm^2

NB: Ovalisation and cyclic loading fatigue from surface loading has not been considered within this assessment, as this is beyond the scope of this report.

4 RESULTS

Based on the available inputs and modelling assumptions discussed on this report, the maximum axial stresses are shown in Table 4-1 for selected load cases to show the change in stresses on the pipeline through its lifetime.

The full stress profiles for von Mises equivalent stress and axial stress are shown for settlement prior to weld excavations (load case L3) and the current settlement profile (load case L6). It should be noted that the predicted stresses around and after the bend at chainage 725m are considered to be influenced by the low quality of information in this area and the boundary conditions assumed in the model. Hence, these stresses are not considered to be indicative of actual stresses in the pipeline.

Table 4-1 Maximum predicted stresses for the pipeline

Load Case	Max Von Mises Stress (N/mm^2)	Max Axial Stress (N/mm^2)	50 N/mm^2 Limit	100 N/mm^2 Limit
As-built condition (L1) *c. 1975*	19.5	6.2	PASS	PASS
Settlement prior to weld investigations (L3)	114.7	100.0	FAIL	FAIL
Excavations for weld inspection (L4) *c. 2008*	114.7	100.0	FAIL	FAIL
Current estimated settlement (L6)	94.1	107.8	FAIL	FAIL

The peak stresses for L3 and L4 occur around chainage 630m along the embankment from the bridge just outside of the AGI (shown within Figure 9-3 and Figure 9-4). Upon inspection it can be seen that the excavations had a negligible effect on the maximum stresses on the pipe.

For the current settlement cases (L6, L7, L8) the peak stresses occur at chainage of 170m from the bridge (although similar to those around chainage 570 – 600 m). L6 is shown within Figure 9-5 and Figure 9-6

It can be seen that the maximum predicted stresses have increased with settlement increase. For L3, only three stress peaks were found to exceed the lower bound 50N/mm^2 limit; however, for L6, up to 15 No. peaks exceed the same lower bound limit (discounting those peaks caused by boundary conditions). The upper bound limit is exceeded at chainage 170m.

Figure 9-6 shows the approximate locations of the strain gauges on the pipeline in relation to the peak stresses. The two strain gauge locations approximately align with two of the predicted stress peaks. This suggests that the strain gauges do appear to be located within the higher zones of settlement induced bending stress.

Recent strain gauge readings were reported in DNV GL Report 118HYXV2-7 [/7/]. For the strain gauges at chainage 170m the stress measurement was 86.4N/mm^2 and at chainage 570m the stress measurement was 128.2N/mm^2. A comparison of the predicted stresses at the strain gauge locations is shown in Table 4-2.

Table 4-2 Predicted stresses at the strain gauge locations

Chainage (m)	Strain Gauge Reading (N/mm^2)	Settlement Case, L3 (N/mm^2)	Current Settlement, L6 (N/mm^2)
170	86.4	13.5	107.8
570	128.2	14.1	92.6

It can be seen in Table 4-2 that the predicted stresses are significantly lower for L3, but show some correlation to the strain gauges in L6, although the stresses at 570m chainage within the model are lower than expected – this is most likely due to the smoothing of the ground movement profile. It should be noted that in L3, no settlement measurements were available at the strain gauge locations. The adjacent upstream and downstream settlement measurements at both locations were relatively similar, hence the pipeline was subjected to minimal bending in this location (according to the measurements). For L6, the predicted stresses are similar at chainage 170m and 570m.

5 DISCUSSION

5.1 Current Scenario

The results of the analyses suggest that the pipeline is currently operating above the previously established axial stress limits. This is supported by the strain gauge results (Table 4-2) and the pipe has been operating above these recommended axial limits since 2008. Plots showing the longitudinal stresses at the strain gauges are shown within Figure 9-7, taken from the March 2018 [/6/] report.

It should also be noted that 5 No. epoxy shells were previously installed on the pipeline during the weld inspection and strain gauge installation works in 2008 [/1/]. These epoxy shells may align with some of the locations of peak stress, and as such remediate the stress issues in these locations. However, this will not counter any stress increases at the welds where there are no shells installed – this is a possibility due to the potential number of peak locations.

Figure 9-6 shows that the areas in which the strain gauges were previously installed are within the key stress zones, as the rate of curvature of the settlement profile in these areas is greatest. This is similar to the previous assessments undertaken in 2008.

Considerations should be made to the conditions of the bends where the pipeline runs underneath the canal. These bends may have been subjected to settlement at this location in the past, although the limited available previous data suggests that the movement is not of the same magnitude as the adjacent settlement profile. However, it is recommended that inspection and residual stress measurements are made in this area to ensure that excessive bending stresses are not apparent.

5.1.1 Limitations

The accuracy of the settlement must be considered when reviewing the outputs of the assessment. The ground levels were monitored as part of the previous movement monitoring regime; however, the pipeline displacement was never measured. Therefore, a conservative assumption had to be made that the pipeline is subjected to the same movement – it must be noted that no lateral movement has been recorded as part of the previous surveys. Additionally, where the pipe geometry runs underneath the canal, there is no information on the current, or the previous positions of the pipeline in this area. Therefore, its stress condition in this area can only be estimated using SPIA and making the assumption that the magnitude of settlement reduces with depth and that the bed of the canal is stable.

This assessment has also not accounted for any surface loading on the embankment. As noted during site visits, despite the weight limits for the embankment, the access route is being utilised by vehicles of any weight up to a modern tractor, which can be in the region of 12T. As well as potentially contributing to the ongoing settlement of the embankment, this could induce additional surface loading and thus circumferential and longitudinal stresses into the pipeline. This will need to be considered when reviewing the life of the pipeline.

5.2 Estimation of Allowable Settlement Increase

Although global ground movement of the embankment is considered unlikely, additional ground movement profiles were assessed within Ple4Win to understand the pipeline behaviour and thus the stress response, should future ground movements occur. Based upon the historical survey profiles, the overall settlement profile does not change, but rather the magnitude increases at two key locations. Utilising the current smoothed ground movement profile, future ground movement events were assumed by increasing the magnitude of settlement by 100% (approximately double), 150%, 175% and 200% (approximately triple).

Depending on the remediation option utilised (see Section 5.3), different limits may be applicable to the existing pipeline. Should the pipeline essentially no longer be susceptible to P/18 or stress corrosion cracking (i.e. through inspection and repair), then normal GM/1 limits could be applied. Therefore, the maximum von Mises equivalent stresses and the membrane stresses have been assessed. These have been summarised within the tables below.

Table 5-1 Maximum von Mises Equivalent Stress due to Settlement

Settlement	Limit N/mm²	Value N/mm²	% of Limit	Pass/Fail
+100%	285.3	175.2	61.4	PASS
+150%		217.8	76.3	PASS
+175%		239.7	84.0	PASS
+200%		263.6	92.4	PASS

Table 5-2 maximum Membrane Stress due to Settlement

Settlement	Limit N/mm²	Value N/mm²	% of Limit	Pass/Fail
+100%	253.6	179.6	70.8	PASS
+150%		222.4	87.7	PASS
+175%		244.5	96.4	PASS
+200%		268.2	105.8	FAIL

It can be seen in the tables above that the limiting criterion for the pipeline, should no other restrictions apply, is membrane stress. This is due to bending stress becoming the primary stress component.

Considering the above, an overall increase in the magnitude of the current settlement profile of 175% - an increase of approximately 1800mm at the trough of the current profile at chainage 550 - 600m - would put the pipeline at the limit of the GM/1 criterion.

It should be noted that an increase in localised settlement such as from a localised slip or other event, the overall magnitude of settlement required would reduce, as the radius of curvature due to pipe displacement would be smaller and thus bending stresses would be higher.

Ongoing monitoring of the embankment would need to be undertaken to measure these values and to ensure that the assumptions are correct.

Consideration of the bends at the canal crossing needs to be made. The lack of information reduces the confidence of the life of the bends in comparison to the straight section of pipe. Therefore, the bends should be inspected as part of any further asset life extension preparations.

It should be noted that ongoing use of the embankment by vehicles has not been considered within this assessment.

5.3 Remediation Options

Based upon the assessments within this report, the following options can be considered when extending the life of the pipeline:

1. Do Nothing – pipeline and embankment in its current state (short term action).
2. Phased pipeline remediation – inspect worst case areas and fit epoxy shells where required (short – medium term action).
3. Pipeline remediation – inspect all welds and fit epoxy repair sleeves where required (medium term action).
4. Pipeline and embankment remediation – stabilise the embankment and undertake either phased or full inspection and epoxy repair (long term action).
5. Diversion of the at-risk section of pipeline.

5.3.1 Do Nothing

Ongoing monitoring of the pipeline with no remediation is not an option that should be considered. Based on the previous integrity assessment of the pipeline, 50% of the welds that were inspected had evidence of SCC. This ratio may not be strictly applicable to the rest of the pipeline, as there could be more than 50% of the total welds in this section requiring remediation.

Although it could be noted that there have not been any additional failures on this pipeline since the repairs were installed, ongoing ground movements would subject the pipeline and its welds to stresses not previously encountered - it should be noted that the axial stress due to hydrotest would have been in the region of 52.7N/mm^2, lower than what sections of the pipeline currently encounter.

The current predicted longitudinal stresses and the latest strain gauge readings taken in March 2018 [/6/] suggest that the pipeline continues to operate over the previously established upper 100N/mm^2 limit for longitudinal stress and therefore has done since 2008. Further ground movements would increase these stresses and thus the potential risk of loss of containment.

Consideration can be made to previous weld repairs undertaken as part of the work in 2008. However, the condition of the welds due to SCC outside of these areas are unknown.

Restricting the management of the pipeline to monitoring only is not recommended going forward.

5.3.2 Pipeline Remediation

Remediation of the pipeline, whether undertaken as one or multiple work phases would increase the resilience of the pipeline. The limitations due to SCC around the welds can be mitigated, such that the membrane stress would become the limiting factor as discussed in Section 5.2.

As discussed, should embankment remediation not be undertaken, future movements cannot be eliminated. Should future movements occur, the limiting increase in settlement magnitude at pipeline level from current would be in the region of 1800mm at chainage 550 – 600m; this is based upon the current profile. More onerous movement profiles could reduce this value.

5.3.3 Embankment Remediation

Remediation to stabilise the embankment and minimise / prevent ongoing settlement issues would prevent the increase in bending stresses in the pipeline. Therefore, only the welds that have been currently identified as being at risk due to current stress levels would need to be inspected and repaired as necessary. Ongoing monitoring of the embankment would be recommended in order to capture any unforeseen movements or events.

This option is of course dependant on the mechanism of movement and whether it can be controlled. There will remain a risk from third party interaction with the embankment, such as ongoing repair works to the road surface and road surface loading from vehicles. The condition of the inside bank of the canal is also important, such as to prevent any leaks through the embankment (as has happened previously), which would cause localised movements.

5.3.4 Diversion

Diversion of the affected section of pipeline to a route outside of the towpath would mitigate against the current hazards relating to the condition of the pipeline within the embankment and will result in a section of pipeline that is to P/2 standards. A new route would also lift the pipeline out of the current easement within the embankment and would provide easier access for maintenance in the future, should it be needed.

This option would be dependent on available rights of way around the existing embankment. Any diversions that are undertaken will need to ensure that the supply to GSK on the south side of the canal is not interrupted.

A number of diversion options have been raised previously as part of previous studies. These are included within the accompanying DNV GL Optioneering Report [/17/].

Diversion is recommended should no remediation of the existing pipeline or embankment be undertaken.

6 CONCLUSIONS

Based upon the available information, assumptions stated, and the analyses presented within this report, the following conclusions can be drawn:

1. The current pipeline displacement profile is a function of two forms of ground movement, which are inducing bending stresses on the pipeline: subsidence along the embankment length and localised slope instability at discrete locations along the embankment.
2. Based on the available pipe level data the axial stresses in the pipeline are predicted to exceed the upper bound 100 N/mm^2 performance acceptance criteria determined within the previous 2008 works.
3. The maximum predicted axial stress on the pipeline is 107.8 N/mm^2.
4. The stresses within the pipeline will increase should further movement of the embankment occur in the future.
5. The section of the pipeline within the embankment needs to be diverted or remediation works undertaken to mitigate the current and future risks to the pipeline.

7 RECOMMENDATIONS

Based upon the analyses and discussions presented within the report, the following recommendations are provided:

1. Remediation or diversion of the pipeline should be undertaken to reduce the risk from stress corrosion cracking and extend asset life.
2. Regular ground movement surveys should be undertaken at least annually to capture any ongoing settlement of the embankment, until remediation or diversion of the pipeline is completed. The position of the pipeline should be included within these surveys.
3. Dialogue should be maintained with the embankment owner / maintainer to ensure that any works undertaken are captured and that any developments that could suggest the pipeline's integrity is at risk are known.
4. Consideration of the bends at the canal crossing needs to be made. The bends should be inspected (potentially through the use of residual stress measurements) as part of any further asset life extension preparations.

8 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. 9562, "The 300mm Barrow to Whasset pipeline. Summary of analysis and results of Ulverston canal strain gauges." GL Noble Denton, 17th Dec 2009

/3/ Technical Note No. 10219, "The 300mm Barrow to Whasset pipeline. Summary of analysis and results of Ulverston canal strain gauges." GL Noble Denton, 7th April 2010

/4/ 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

/5/ Document No. 1130U1T9-1, "Ulverston to Barrow HP Pipeline. Strain Measurement Summary." Rev A., DNV GL, 1st Sept 2017.

/6/ Document No. 118HYXV2-7, "Ulverston to Barrow HP Pipeline. Strain Measurement Summary." Rev A., DNV GL, 30th March 2018

/7/ Document No. 119H8FGN-6, "Ulverston Canal, Geotechnical Investigation Report." Rev A., DNV GL, November 2018.

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/9/ Report No. 16538, "IGE/TD/1 Report, Ulverston – Barrow Pipeline (1091) including: Glaxo Supply (1084)". Rev 1., DNV GL, 31st December 2015.

/10/ T/PM/P/18, "Management Procedure for: Working on pipelines Containing Defective Girth Welds or Girth Welds of Unknown Quality." National Grid, April 2013.

/11/ Ple4Win v4.5.0, ©2018 Expert Design Systems, Geestbrugweg 44, 2281 CM Rijswijk, The Netherlands.

/12/ IGEM/TD/1, "Steel Pipelines and Associated Installations for High Pressure Gas Transmission." Ed.5, Communication 1789, Institution of Gas Engineers and Managers (IGEM), July 2016.

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/15/ T/SP/GM/1, "Specification for: The Protection of Pipelines from Ground Movement and External Loading. External Loading on Steel Pipelines and Buried Piping at Installations." National Grid, June 2014.

/16/ NEN 3650+A1, "Requirements for pipeline systems, Part 1 – General and Part 2 – Steel", Nederlands Normalisatie-instituut (NEN), 2007.

/17/ Document No. 119H8FGN-8, "Ulverston Canal, Optioneering Report." Rev A., DNV GL, December 2018.

9 FIGURES

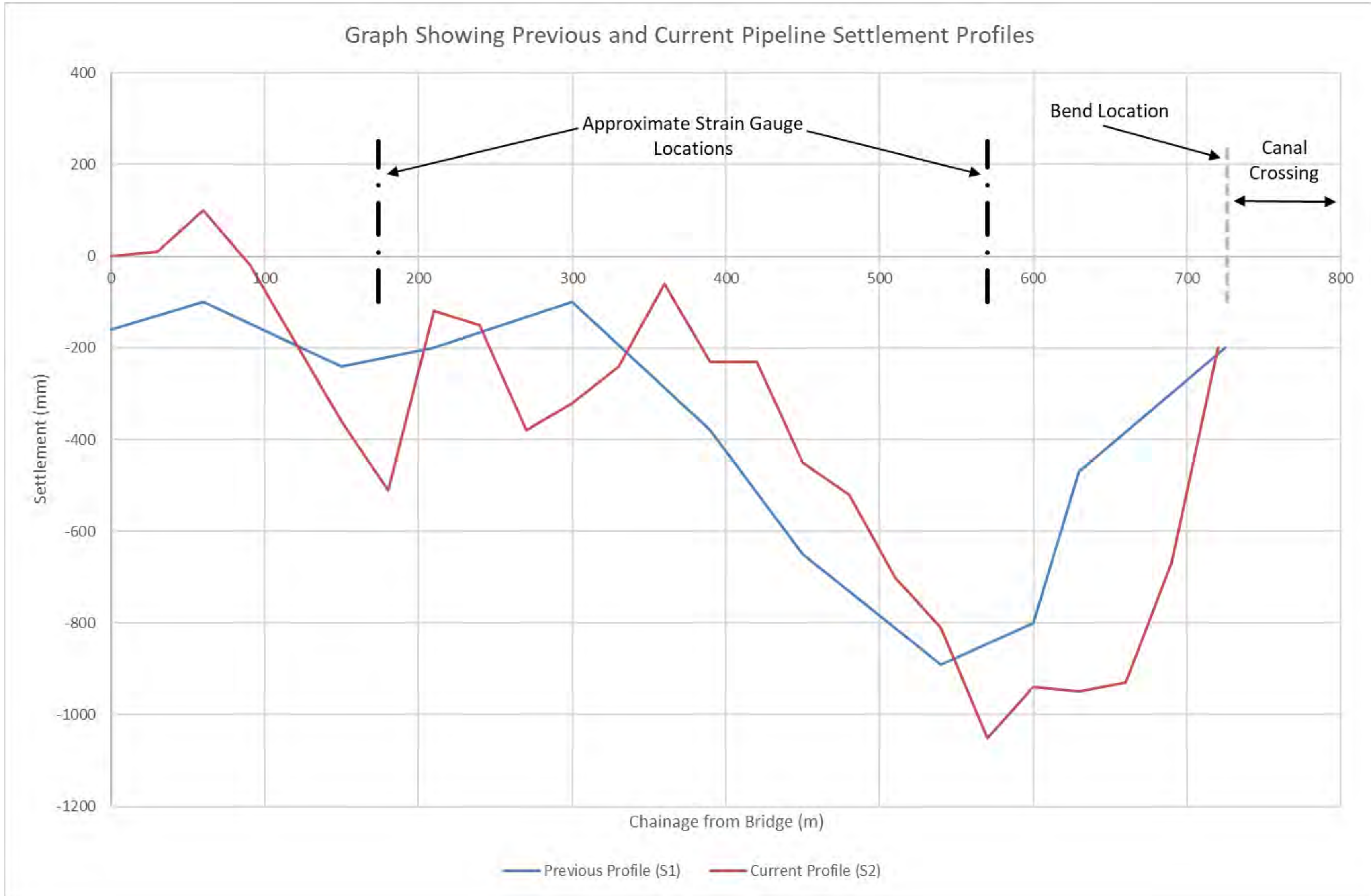


Figure 9-1 Graph showing survey pipeline settlement profiles for the previous profile (S1) and the current profile (S2)

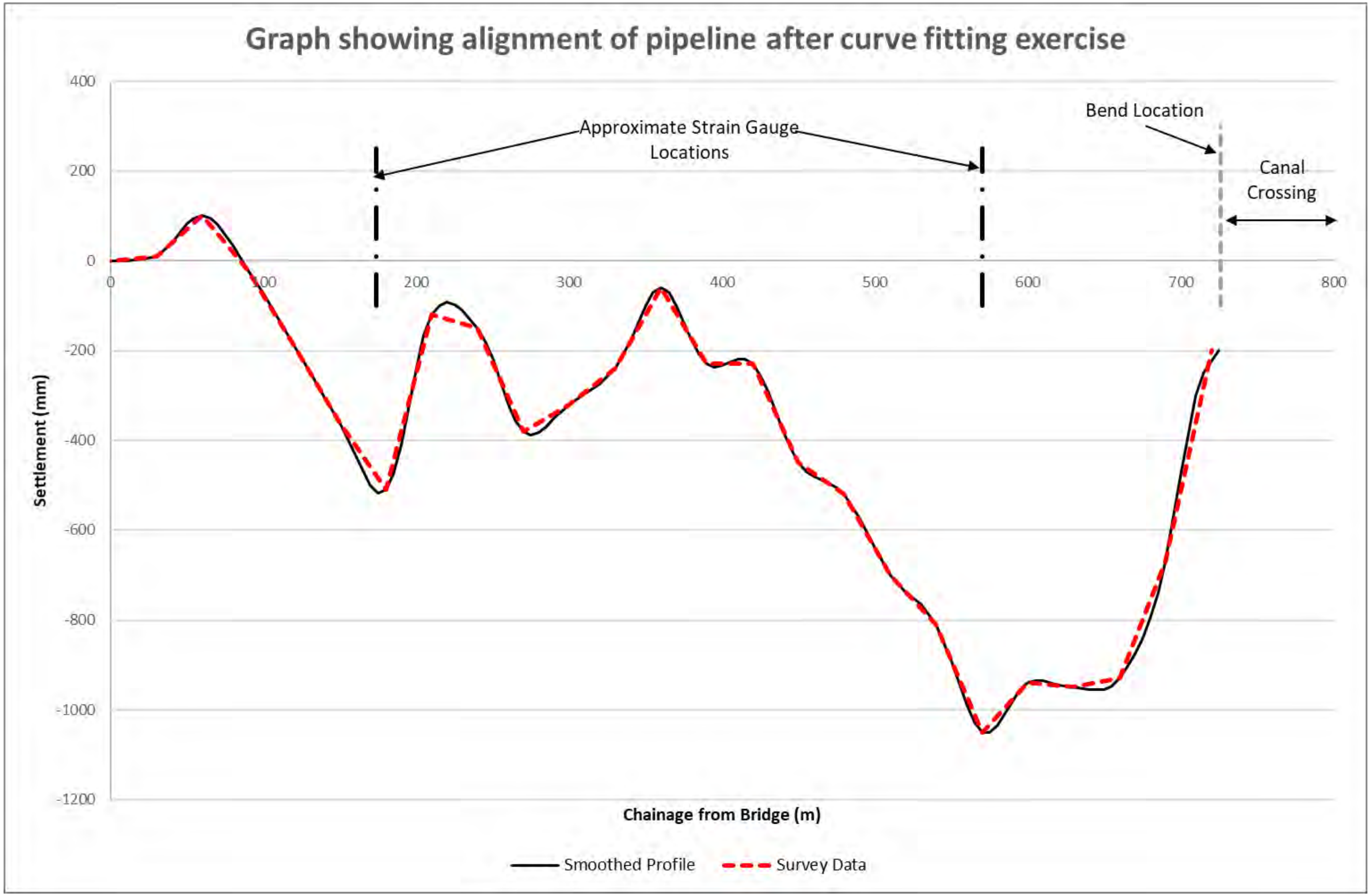


Figure 9-2 Graph showing settlement profile of pipeline after curve fitting exercise.

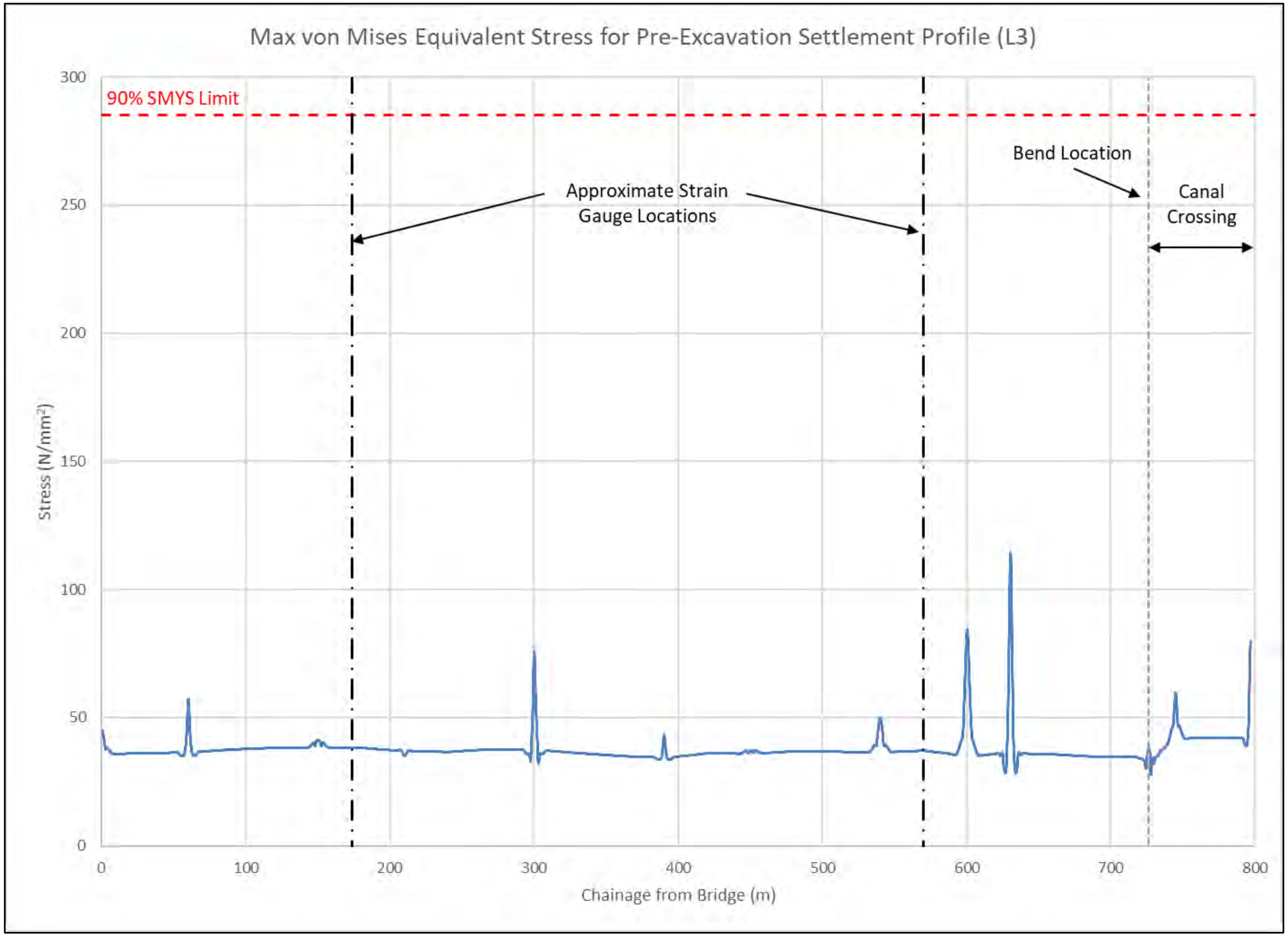


Figure 9-3 Maximum von Mises equivalent stress for load case 3

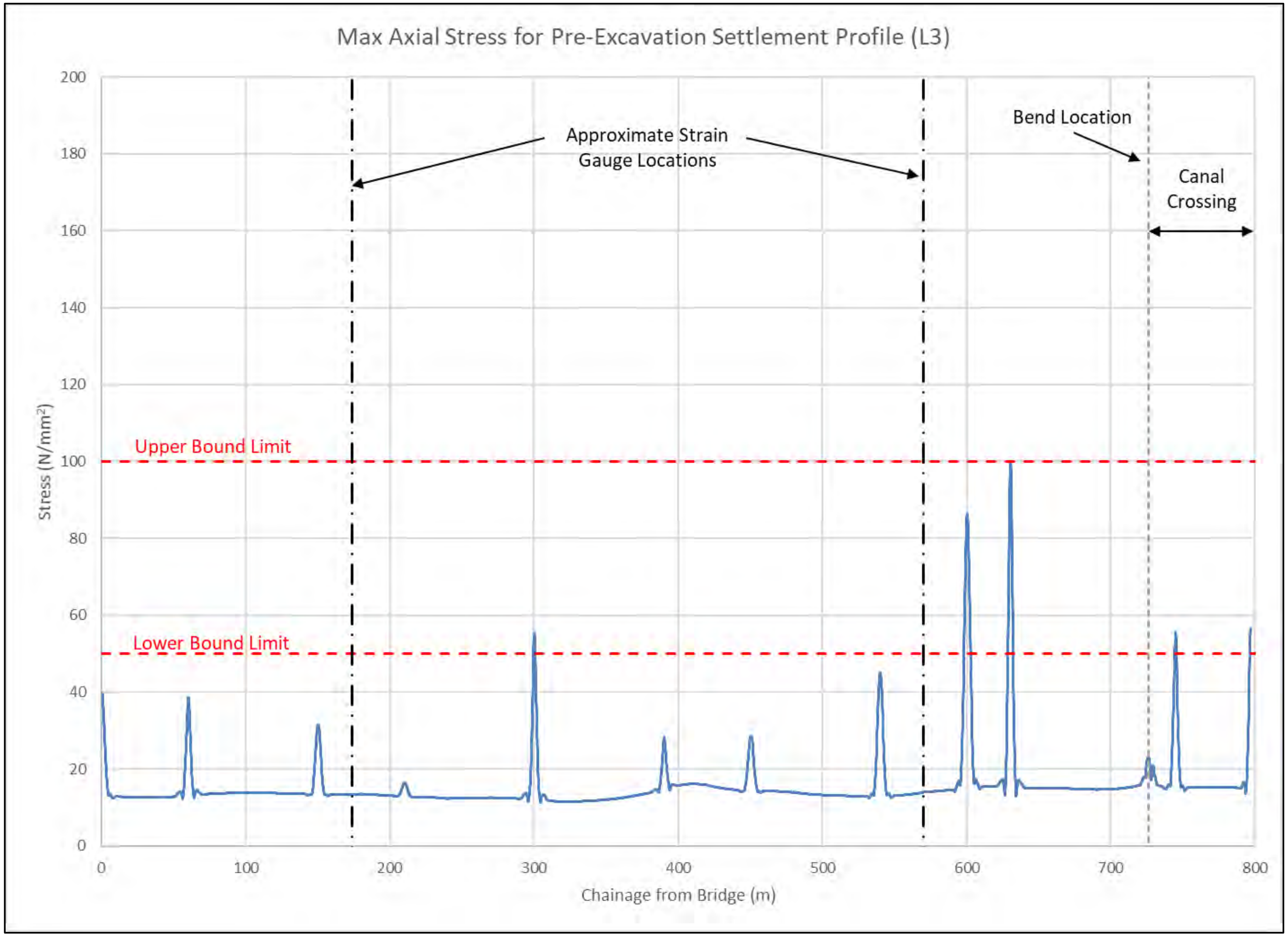


Figure 9-4 Maximum axial stress for load case 3

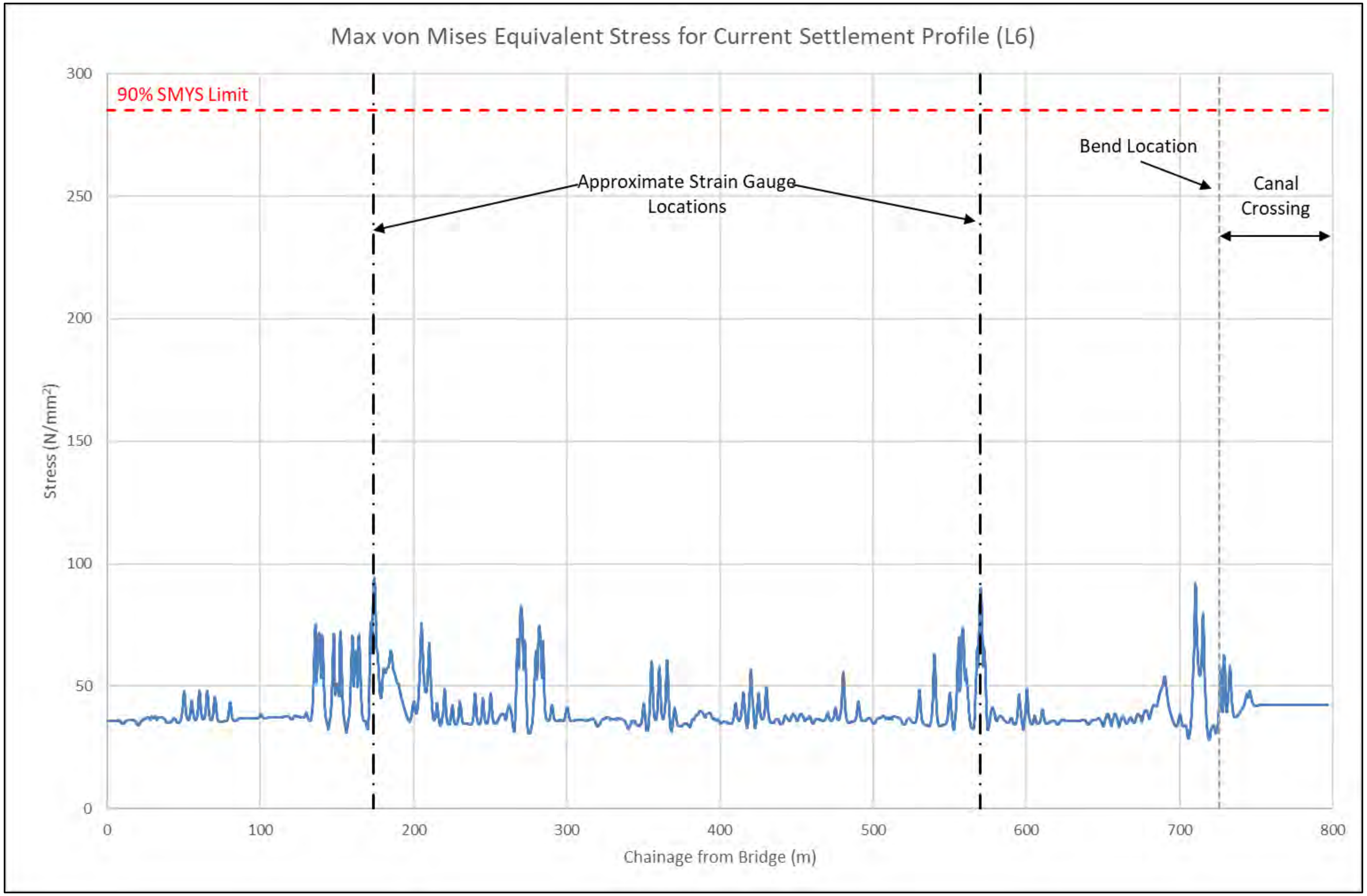


Figure 9-5 Maximum von Mises equivalent stress for load case 6

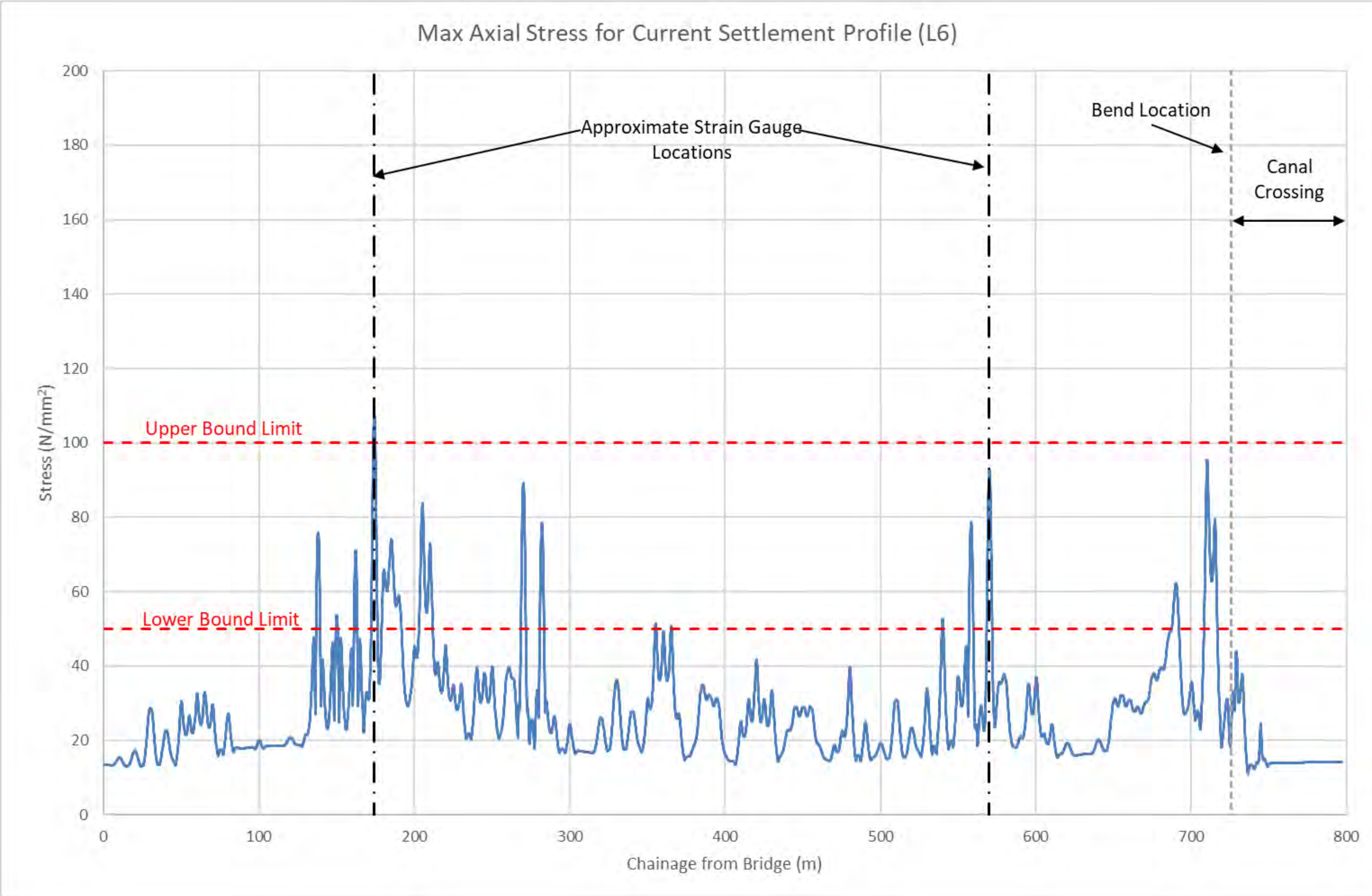
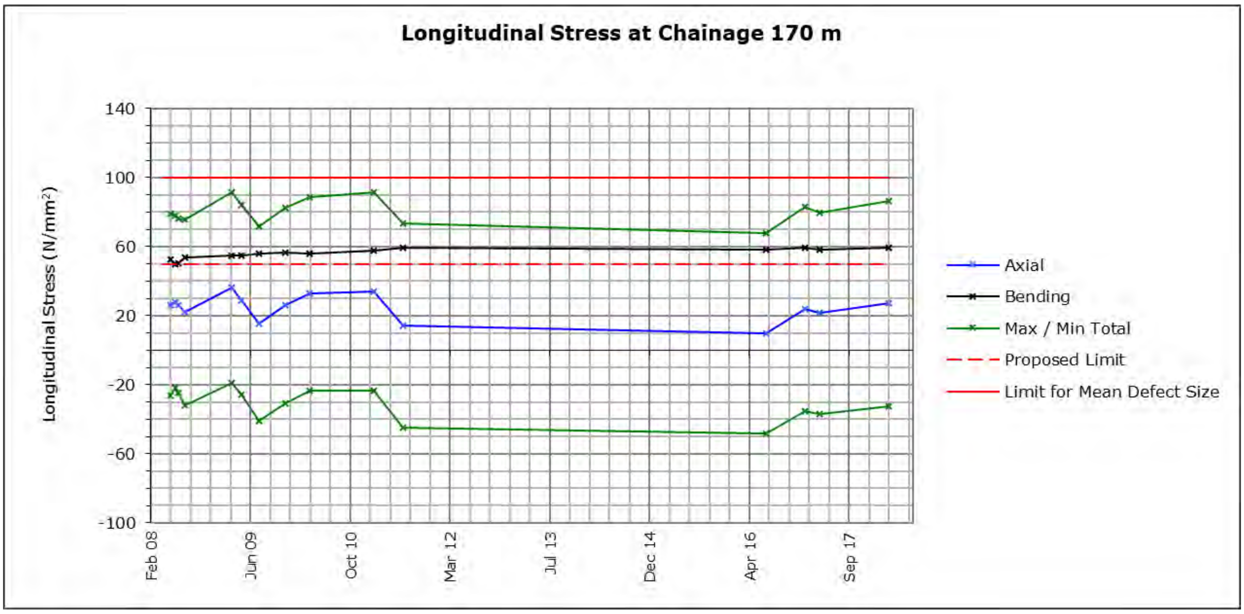


Figure 9-6 Maximum axial stress for load case 6



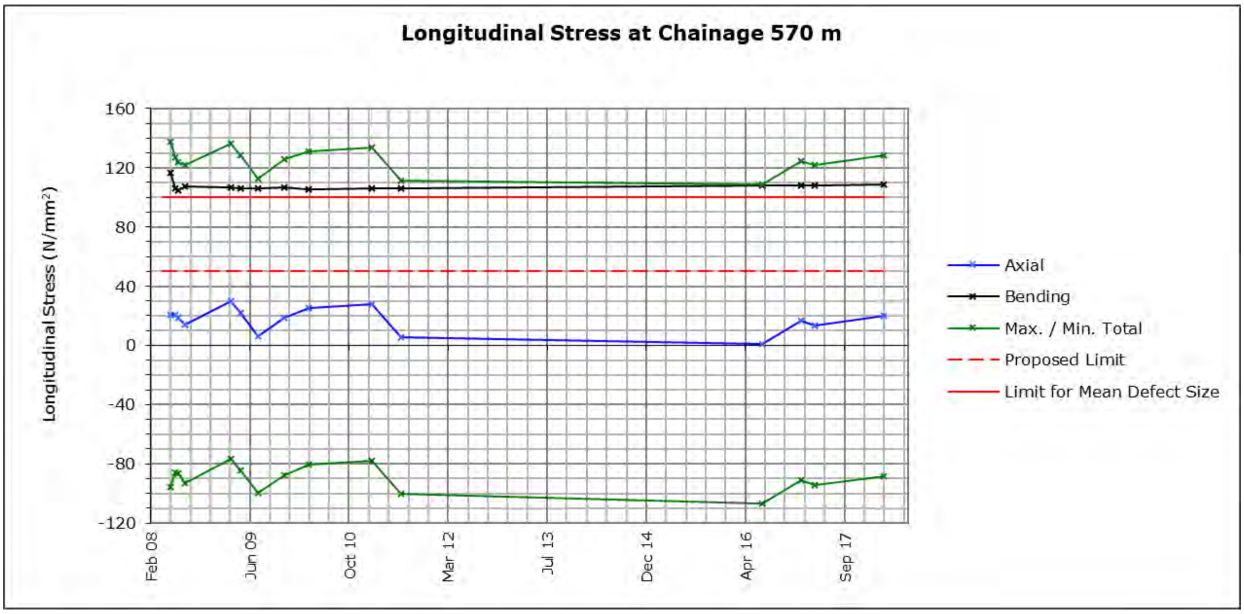


Figure 9-7 Pipeline Longitudinal Stresses at Strain Gauges Since Installation

APPENDIX A
Site Location and Asset Maps

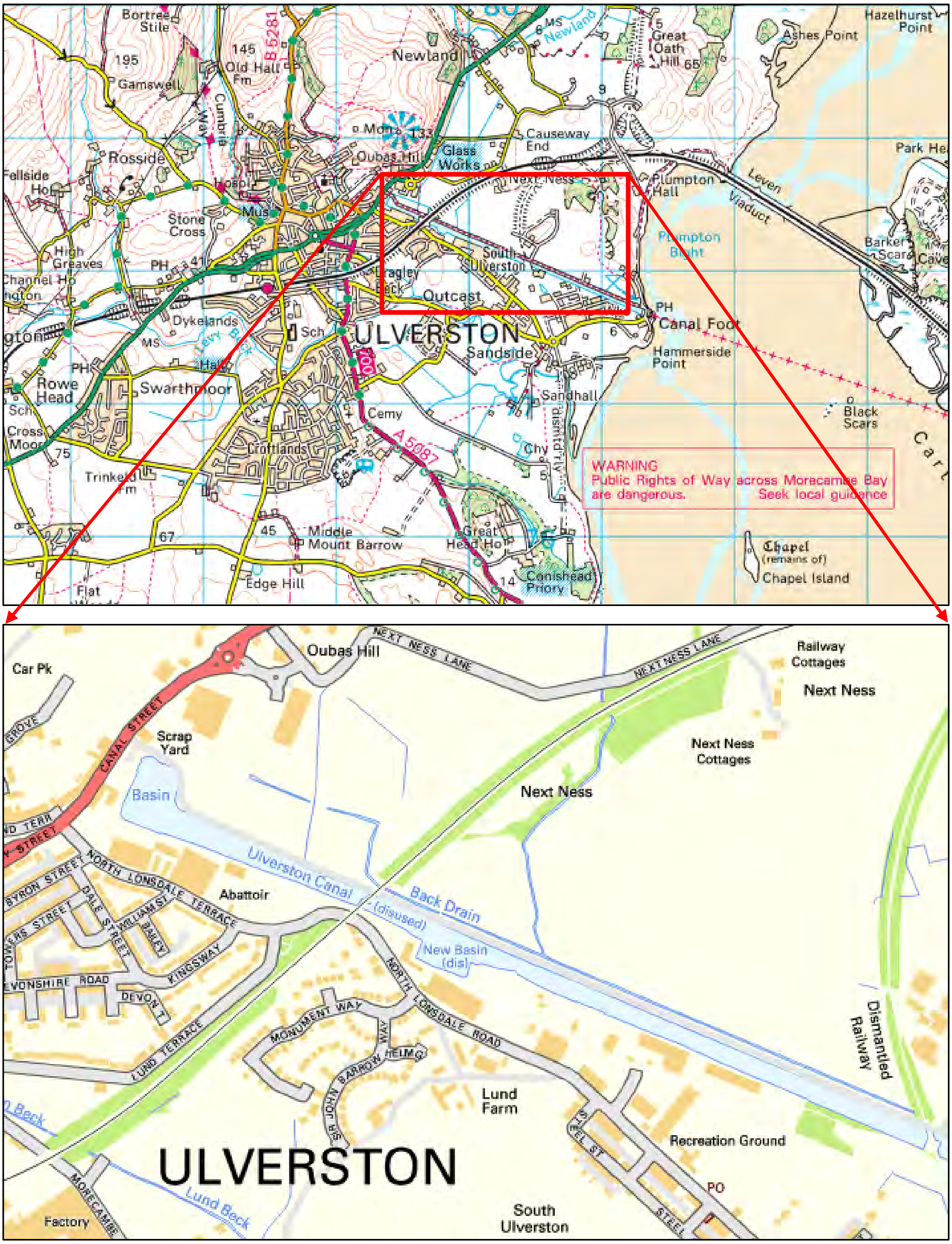
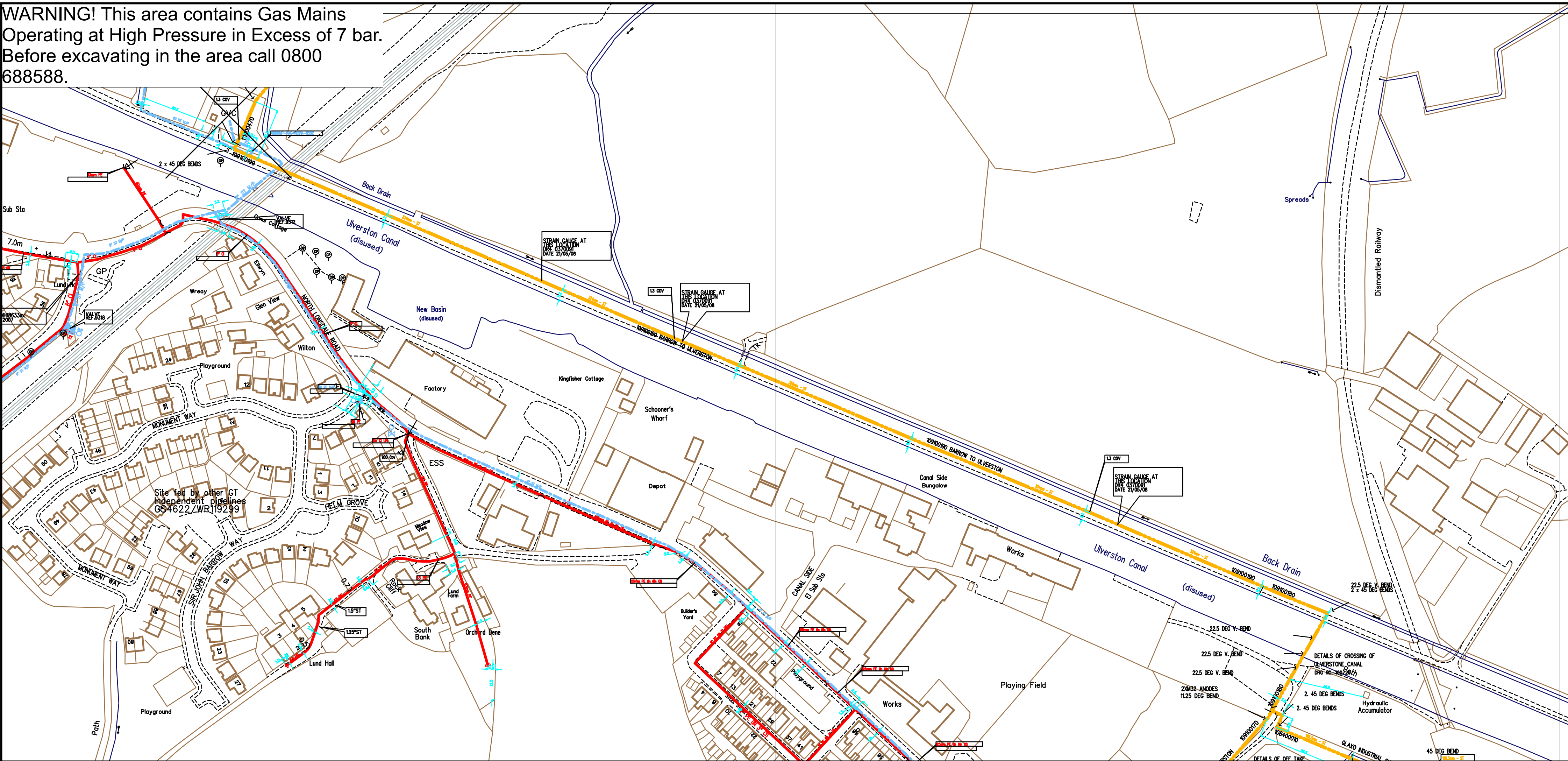


Figure A - 1: Site location Plan

Contains OS data © Crown copyright and database rights (2018)

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

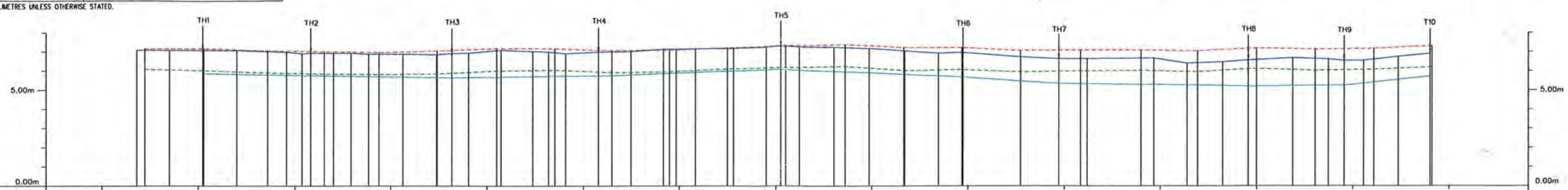
Local Machine

APPENDIX B

Drawing 53074: 2008 Chainage and Updated Pipeline Levels

Drg No: | Site: | Title:

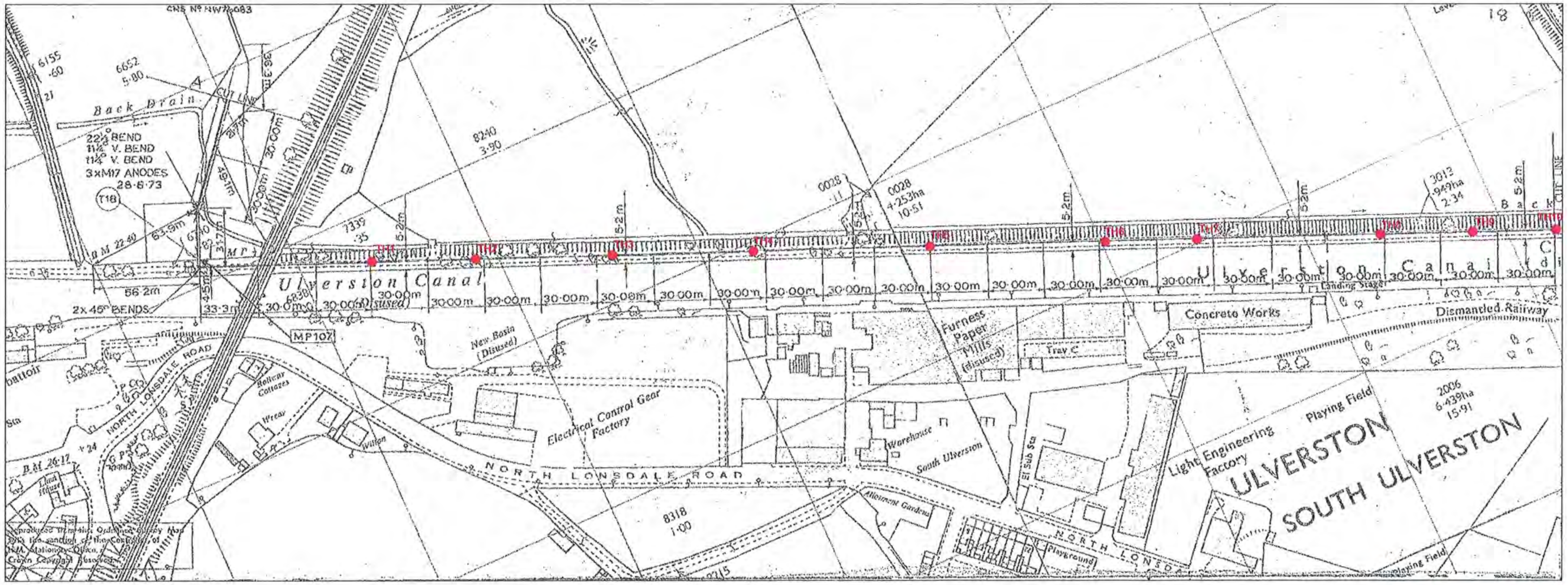
DO NOT SCALE. IF IN DOUBT ASK. ALL DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE STATED.



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, 5.23, 6.23, 6.02, 6.07, 5.97, 6.01, 6.03, 5.95, 6.13, 6.05, 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

NATIONAL GRID PLC
UK DISTRIBUTION - NETWORK STRATEGY
BLOCK 4 - AREA 6
BRICK KILN STREET
HINCKLEY
LEICESTER
LE10 ONE
TEL: (01455) 251111

Site: BARROW-WHASSET 12" HP GAS PIPELINE

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

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

Drg No: 53074 | Revision:

A1

APPENDIX C

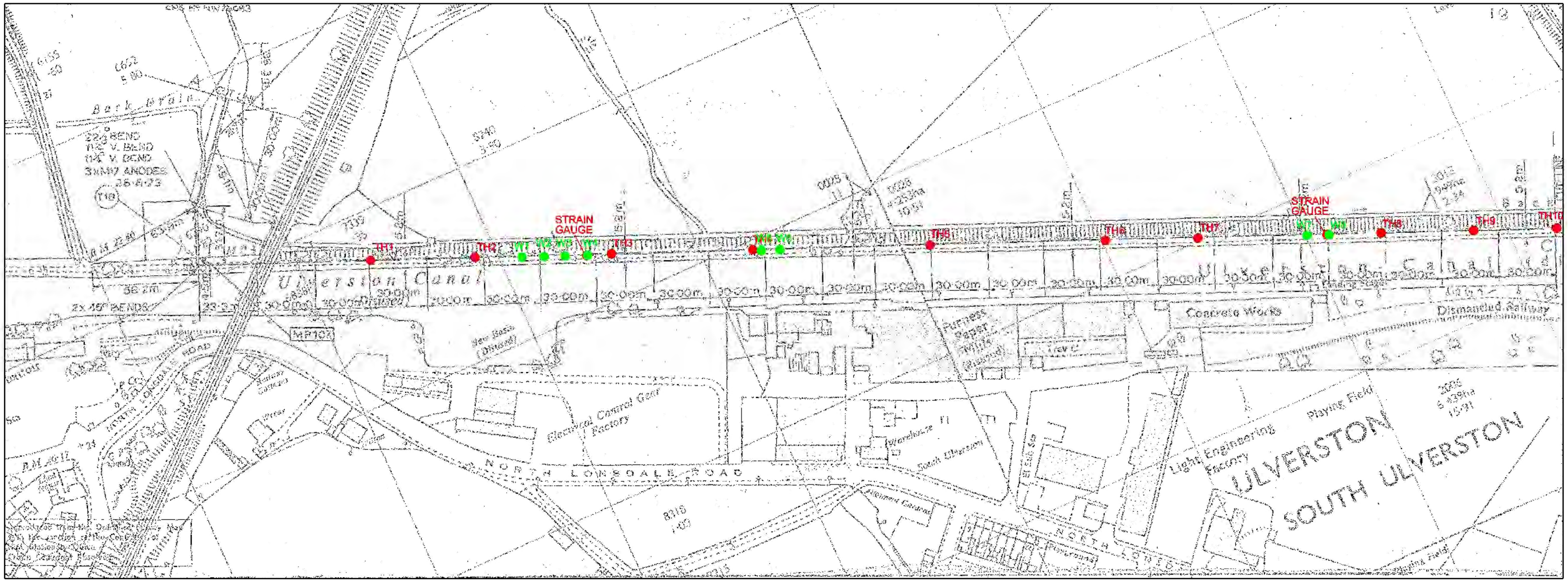
Trial Hole and Weld Inspection Locations

Drawing referenced from 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

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



● (green)	Girth Weld Inspection
● (red)	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

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DNV GL is a global quality assurance and risk management company. Driven by our purpose of safeguarding life, property and the environment, we enable our customers to advance the safety and sustainability of their business. We provide classification, technical assurance, software and independent expert advisory services to the maritime, oil & gas, power and renewables industries. We also provide certification, supply chain and data management services to customers across a wide range of industries. Operating in more than 100 countries, our experts are dedicated to helping customers make the world safer, smarter and greener.