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Report: [redacted]-R0713-21

KINGS LYNN COMPRESSOR STATION – PROPOSED REMOVAL OF THREE PITS ON FEEDER 2 - IGE/TD/12 STRESS ANALYSIS

Confidential *Restricted to* [redacted]

[redacted]

[redacted]

[redacted]

CUSTOMER	**CUSTOMER CONTACT**	**CUSTOMER ADDRESS**	**CUSTOMER REF: NO.**
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Revision	**Date**	**Author Signature**	**Verifier Signature**	**Approver Signature**	**Status**

[redacted]

REVISION STATUS INDEX							
SUMMARY OF CHANGES	**SECTION NUMBER**	**REVISIONS**					
		1	**2**	**3**	**4**	**5**	**6**
Including additional assessment with engineered backfill after removal of pits.		**X**					
900mm x 50mm weldolet exception removed at node 6160.		**X**					

Executive Summary

National Grid owns and operates Kings Lynn Compressor Station in Norfolk. At a part of the site, in the area of the bi-directional pipework, associated with the compressors, there is visible evidence of changes to the ground elevation, suggesting differential settlement. A previous study, AFAA-R0706-21, was undertaken to assess the effects of the settlement to the abnormal sustained and shakedown criteria of IGE/TD/12. A small quantity of code exceptions were identified during the study which are to be further investigated.

Kings Lynn compressor station was commissioned in 1971 and over the years has been subject to significant modifications, concerning both piping arrangement and operating conditions; most notably the installation of the bi-directional pipework in 1998 and pigging loop in 2003. During the modifications sections of 200mm venting pipework and 300mm regulator pipework were installed in inspection pits. As part of potential site upgrade and remediation works National Grid propose to demolish three pits and backfill the pipework with native soil.

National Grid have therefore requested that a pipe stress study be undertaken to confirm that the proposed modifications of the removal of the pits are acceptable and do not unduly overstress the piping to what the existing stress levels are.

The purpose of the analysis is to:

- Report the stress levels including the proposed modifications in accordance with the requirements of IGE/TD/12 using the guidance provided in T/SP/PW/13.
- Report any existing exceptions which are exacerbated by the proposed modifications.
- Report any exceptions on the existing pipework that were not present in the existing state.

Conclusions

1. Stress analyses have been undertaken to consider the effects of demolishing and backfilling the pits in the bi-directional area at Kings Lynn compressor station. Cohesive soils have been considered with lower and upper bound soil properties.

2. IGE/TD/12 code stress analyses have been undertaken of the existing and proposed configuration.

3. There are six fittings exceeding the IGE/TD/12 sustained criterion.

    i. At three locations, concerning two different fitting types, the predicted code stress is exacerbated by the proposed modifications.

    ii. It may be possible to show acceptability of the fittings by undertaking a more detailed design-by-analysis assessment involving the finite element method.

[redacted]

4. There are fourteen fittings exceeding the IGE/TD/12 shakedown criterion.
    i. At six locations, concerning three different fitting types, the predicted code stress is exacerbated by the proposed modifications.
    ii. It may be possible to show acceptability of the fittings by undertaking a more detailed design-by-analysis assessment involving the finite element method.
5. Fatigue assessments considering: the existing configuration, the removal of all three pits and the removal of Pit-2 and Pit-3 has been undertaken and reported in [redacted]-R0711-21. A summary of the results are provide in Table17 and Table 18.
    i. National Grid to confirm which pits, if any, are to be removed.
6. The removal of Pit-1 has an adverse effect on the pre-existing stress levels
7. An additional study has been performed considering removing Pits 2 and 3 only. It is shown that if these two pits are removed they do not have an adverse effect on the magnitude of the pre-existing code stress exceptions or introduce new exceptions.

Recommendations

National Grid to review the stress and fatigue implications on removing all three pits or alternatively just consider removing Pit-2 and Pit-3 only, which do not increase the existing stress levels.

National Grid to confirm which pits on Feeder 2 are to be removed, if any, so that the appropriate forces and moments from the piping stress models can be extracted and used in the Stage 2 finite element modelling programme of work.

CONTENTS

[redacted]

1 INTRODUCTION

National Grid owns and operates Kings Lynn Compressor Station in Norfolk. At a part of the site, in the area of the bi-directional pipework, associated with the compressors, there is visible evidence of changes to the ground elevation, suggesting differential settlement. A previous study, AFAA-R0706-21 [1], was undertaken to assess the effects of the settlement to the abnormal sustained and shakedown criteria of IGE/TD/12 [2]. A small quantity of code exceptions were identified during the study which are to be further investigated.

Kings Lynn compressor station was commissioned in 1971 and over the years has been subject to significant modifications, concerning both piping arrangement and operating conditions; most notably the installation of the bi-directional pipework in 1998 and pigging loop in 2003. During the modifications sections of 200mm venting pipework and 300mm regulator pipework were installed in inspection pits. As part of potential site upgrade and remediation works National Grid propose to demolish three pits and backfill the pipework with native soil at the locations shown in Figure 1.

National Grid have therefore requested that a pipe stress study be undertaken to confirm that the proposed modifications of the removal of the pits are acceptable and do not unduly overstress the piping to what the existing stress levels are.

1.1 Purpose

- Report the stress levels including the proposed modifications in accordance with the requirements of IGE/TD/12 using the guidance provided in T/SP/PW/13.
- Report any existing exceptions which are exacerbated by the proposed modifications.
- Report any exceptions on the existing pipework that were not present in the existing state.

1.2 Scope

The location of the bi-directional pipework and pits is shown in Figure 1.

[redacted]

MODELLING

1.3 Drawings

In addition to the referenced national, international and National Grid standards, the following drawings and material take-offs have been provided and used where necessary.

Drawing Number	Issue	Title
[redacted]		
[redacted]-GEN-7210-0010	E	Kings Lynn Compressor Station General Arrangement Trial Hole Locations
Navisworks Model		Kings Lynn – As-Built – 5-8-21.nwd
Navisworks Model		Kings Lynn – PC – 5-8-21.nwd
[redacted]		
CPEL-1238-DW01	1	General Arrangement
405000-MMD-LOT3-ZZ-DR-C-0001	E	NARC 3 Kings Lynn Compressor Station Lot 3 – Isolation Valves Civil General Arrangement
405000-MMD-LOT3-ZZ-DR-C-0002	D	NARC 3 Kings Lynn Compressor Station Lot 3 – Isolation Valves Isometric View
405000-MMD-LOT3-ZZ-DR-C-0003	D	NARC 3 Kings Lynn Compressor Station Lot 3 – Isolation Valves Foundation Details
405000-MMD-LOT3-ZZ-DR-C-0004	E	NARC 3 Kings Lynn Compressor Station Lot 3 – Isolation Valves Foundation Details Sections A & B
405000-MMD-LOT3-ZZ-DR-M-0001	F	NARC 3 Kings Lynn Compressor Station Lot 3 – Isolation Valves Mechanical General Arrangement
[redacted]		
	2	Kings Lynn Compressor Station Design Basis Report
M478/BE/39/01/4025/001	1	Kings Lynn Compressor Station Stress Analysis
AU/M/KIN/4001	C	Bi-Directional Pipework Line Diagram
AU/M/KIN/4003	A	Regulator Pipework Details Feeder No.4
AU/M/KIN/4004	C	Regulator Pipework Details Feeder No.2
AU/M/KIN/4005	B	Power Gas Supply Details
AU/M/KIN/4006	B	No.2 Feeder Valve Bridle Pipework Details
AU/M/KIN/4007	B	No.4 Feeder Valve Bridle Pipework Details
AU/M/KIN/4008	B	Instrumentation – No.2 Feeder

[redacted]

Drawing Number	Issue	Title
AU/M/KIN/4012	B	900NB Pipework Details
AU/M/KIN/4013	B	Instrumentation – No.4 Feeder
AU/M/KIN/4016	A	Outstation Gas Supply Details
Method Statement No.23		Preparatory Works to Allow Access for Piling Operation
[redacted]		
Factual Report	0	Ground Investigation Factual Report
[redacted]		
J17-577-003R-Rev0	0	Initial Site Assessment
[redacted] **Limited**		
C8594		Report on a Ground Investigation at King's Lynn Compressor Station Near East Winch King's Lynn Norfolk
[redacted]		
M830/BE/67/00/2020/914	B	Kings Lynn Compressor Stress Analysis Report
M830/BE/68/00/2020/020	F	Revised As-built Issue
The Gas Council		
BGHP/SC/1353		King's Lynn Compressor Link Twin 36" Pipelines
[redacted]		
Cert No. 25573		900mm x 300mm Sweepolet Test Certificate
[redacted]		
Sheet No. 3394		900mm 1.5D 90° Bends Dimensional Report
No. 9161		300MM 1.5D 90° Bends Material Test Certificate
[redacted] **Ltd**		

[redacted]

Drawing Number	Issue	Title
2021-06-09 11-38		Piping General Arrangement Scrubber Area
2021-06-09 11-58		Details of Valve Supports
GC/L11/2/19		Piping General Arrangement Scrubber Area
GC/L11/2/20		Piping General Arrangement Of Station Valves
GC/L11/4/01		Civil Engineering Key Plan
GC/L11/4/9		Scrubber Supports Including Piles
BG/L20/1/3	B	Layout of Compressor Station
BG/L20/1/24	N	Arrangement of Pipework
0195/3/1001	M	Arrangement of Pipework

1.4 Navisworks Model & Software

[redacted] have provided a Navisworks CAD model of the site in the as-built and current configuration. The files have been developed from an automated survey of the site, Above Ordnance Datum (AOD) survey and as-built drawings.

The files have been used to aid in developing models suitable for analysis using CAESAR II v12[3]. This version of the software assesses pipework code compliance according to IGE/TD/12 (Edition 2, 2003), and is approved by National Grid for this purpose.

1.5 CAESAR II Models Created

The following models have been created including the proposed modifications.

- KL_CLAY_FF_01_PITS.C2
- KL_CLAY_RF_01_PITS.C2
- KL_FIRM_CLAY_FF_01_PITS.C2
- KL_FIRM_CLAY_RF_01_PITS.C2

The following models have been created of the as-built layout to permit a stress comparison with the models above.

- KL_CLAY_FF_01.C2
- KL_CLAY_RF_01.C2
- KL_FIRM_CLAY_FF_01.C2
- KL_ FIRM_CLAY_RF_01.C2

[redacted]

2 INPUT DATA

2.1 General

The site has been subject to several modifications over the past 50 years. Notably significant modifications were made circa 1998, to include the bi-directional functionality to the site. The pigging loop and associated tie-in pipework was installed circa 2003.

More recently minor alterations have been undertaken to include two new 900mm ball valves on Feeder 2. Figure 2 shows the general arrangement of the bi-directional area and the era in which the pipework was installed.

Details for pipework has been taken from the supplied drawings and applicable standards from the era of construction.

2.2 Materials

Materials are generally to the requirements of API 5L. For the analysis the API-5L equivalent materials, built into the CAESAR II material database, have been used.

The Specified Minimum Yield Stress (SMYS) and Specified Minimum Ultimate Tensile Strength (SMUTS) values, for the materials under the API-5L specifications, are shown for comparison in Table 1.

2.3 Pipework & Fittings

2.3.1 Pipe

Details of the pipework modelled for the assessment are shown in Table 2.

Details for pipework installed as part of the original construction, Circa 1970, is taken from historic drawings and BG/PS/DAT6 (1977) [4].

Details for pipework installed circa 1998 and 2003 is taken from historic drawings and BG/PS/DAT6 (1988) [5].

Details for pipework installed in 2019 is taken from TS/SP/DAT/6 [6].

2.3.2 Tees

Details of the tees modelled for the assessment are shown in Table 3.

For tees installed circa 1970, conservative diameter, wall thickness and material information was taken from 1972 edition of GC/PS/T1 [7].

For tees installed circa 1998 and 2003, conservative diameter, wall thickness and material information was taken from 1993 edition of T1 [8].

2.3.3 Bends

Details of the bends modelled for the assessment are shown in Table 4.

[redacted]

For bends installed circa 1970, conservative diameter, wall thickness and material information was taken from the 1973 edition of PS/B1 [9].

For bends installed circa 1998 and 2003, conservative diameter, wall thickness and material information was taken from the 1993 edition of B7 [10] and B4 [11].

2.3.4 Welding Fittings

For weldolets/weldoflanges Appendix 4.10 of TD/12 requires certain geometry validity limits to be met, which allows for more accurate calculation of stress concentration factors (SCFs). These dimensions have been chosen to meet the validity limits using data available from weldolet/weldoflange manufacturers.

Welding fittings installed circa 1970 are assumed to satisfy the requirements of T/SP/F1 [12] (1971)

Welding fittings installed circa 1998 and 2003 are assumed to satisfy the requirements of T/SP/F1 [13] (1993).

Details of the modelled fittings are provided in Table 5.

2.3.5 Reducers

Data for reducers installed circa 1998 has been taken from the 1990 edition of PS/F3 [14].

Details of the modelled fittings are provided in Table 6.

2.3.6 Rigid Weights

The weights of rigid elements such as valves and flanges are taken as those in the CAESAR II internal database and manufacturer catalogues.

2.4 Loading Conditions

Within CAESAR II a series of pressures, temperatures and other loads may be applied to each element. These individual loads are then combined into a series of loadcases describing the operation of the facility over its lifetime. These include loadcases to enable sustained, abnormal sustained, shakedown and fatigue assessments to be undertaken and assessed to the requirements of IGE/TD/12.

A loadcase table was created based upon the below pressure and temperature values, in accordance with the guidance of IGE/TD/12. The loadcase table as entered into CAESAR II is shown in Table 9.

2.4.1 Pressures

The following design pressures for the parts of the site were provided in Ref. [15]

- MIP 79.5 barg

[redacted]

2.4.2 Temperatures

2.4.2.1 Operating Temperatures

Taking guidance from T/SP/PW/13[16] and the supplied drawings, the following temperatures have been used;

- Above ground maximum and minimum temperatures of +50°C and -20°C, respectively.

Forward Flow (Kings Lynn to Bacton)

For forward flow the following temperatures have been used:

- An assumed minimum below ground temperature of 5°C.
- Maximum below ground, suction and discharge, flow temperature of 15°C and 47°C respectively [17].
- Minimum below ground suction temperature of 8°C [18].
- Assumed minimum below ground discharge temperature of 37°C, to produce a temperature swing of 10°C from the maximum.

Reverse Flow (Bacton to Kings Lynn)

For reverse flow the following temperatures have been used:

- An assumed minimum below ground temperature of 5°C.
- Maximum below ground, suction and discharge, flow temperature of 18°C and 47°C respectively [17].
- Minimum below ground suction temperature of 8°C [18].
- Assumed minimum below ground discharge temperature of 37°C, to produce a temperature swing of 10°C from the maximum.

The temperatures as applied to the models are shown in Figure 3 to Figure 5.

Temperatures and pressures used for the analyses are provided in Table 7 and Table 8.

2.5 Boundary Conditions

2.5.1 Buried Pipe Modelling

Soil restraint is modelled as a series of bi-linear springs. The CAESAR II soil modeller allows input of different values in the axial, lateral, upward and downward directions. The bi-linear springs consist of a spring, of constant stiffness, which gives a restive load that increases linearly with increasing displacement and an ultimate load cut-off point beyond which no further resistive load is transferred to the pipe regardless of displacement.

[redacted]

For this analysis the soil restraint has been calculated using the American Lifelines Alliance[19] methodology built into CAESAR II. This is in accordance with the recommendations in IGE/TD/12.

Historic boreholes have been provided for Kings Lynn Compressor Station, the locations of which are shown in 7Appendix A. At the depths considered, the boreholes indicate the ground varies between fine to medium sand and soft to stiff clay. In view of this the models have been analysed using conservative lower bound and upper bound soil restraint.
The lower bound analysis is based on the assumption that soil behaves as a soft clay, whilst the upper bound analysis is based on the assumption that soil behaves as a firm clay, where these two soil types are defined in NEN 3650[20]..

For the lower bound soil restraint, the water table is conservatively assumed to be at the surface and for the upper bound soil restraint the water table is assumed to be below the pipe.

The original buried piping is assumed to be coal tar coated and an appropriate coating coefficient of friction has been used in the soil modelling.

The soil properties used are shown in Table 10, whilst the information as entered into CAESAR II is shown in Table 11.

2.5.2 Supports

Sliding supports on the 300mm NB above ground regulator pipework have a PTFE lining. These supports have been modelled as +Y restraint and coefficient of friction of 0.12[21].

Adjustable supports on the 50mm NB above ground pipework have been modelled as Y with Guide and a coefficient of friction of 0.12.

The ten 900mm NB valves in the bi-directional area are installed on concrete piled supports. The piled support bases, installed circa 1998, have a neoprene lining, and the same has been assumed for the support bases installed circa 1970. The supports have been modelled as +Y restraint and coefficient of friction of 0.2 [22].

Similarly, the remaining below ground supports have been modelled as +Y support and coefficient of friction of 0.2.

There are several pits, associated with Feeder 2, in the bi-directional area, as shown in Figure 1. It is assumed the pit wall will have been lined with Neoprene or similar, therefore the pit-wall transition has been modelled as Y with Guide restraint and coefficient of friction of 0.2.

[redacted]

3 IGE/TD/12 ASSESSMENTS

3.1 Normal Sustained

The normal sustained loadcase assessment addresses the effects of primary loadings such as the dead weight of the pipework, fittings, valves and soil loadings together with the full design pressure. It addresses those loadings that may cause failure due to global plastic collapse. Thermal loadings (other than long range thermal effects with elastic follow up) are treated as secondary in a TD/12 analysis and are not assessed for this failure mode.

The maximum predicted von Mises equivalent stress (S_S) for each component is evaluated for the primary loadings and checked against the normal sustained criterion specified in TD/12.

The facility is in a Type 'R' area, and hence the design factor is 0.67. The normal sustained acceptance criterion for such pipework is given by:

$$S_s = 0.80MYS \quad if\ \frac{SMYS}{SUTS} \leq 0.74 \qquad [1]$$

or

$$S_s = 0.34SMYS \quad if\ \frac{SMYS}{SUTS} > 0.74 \qquad [2]$$

where S_S is the calculated von Mises equivalent stress, SMYS is the Specified Minimum Yield Strength and SUTS is the Specified Ultimate Tensile Strength.

3.2 Shakedown

When part of a structure is initially loaded beyond its elastic limit, local plasticity can occur. Upon removal of the load a self-equilibrating residual stress can remain. Subsequent applications of loads of the same magnitude will eventually produce an elastic response if shakedown is achieved. If shakedown is not achieved, failure by incremental plastic collapse, otherwise known as "ratchetting", will occur under repeated cyclic loading. The shakedown analysis calculates the maximum allowable range of stresses before ratchetting occurs. To obtain these, a series of loadcases are run for both zero and design pressures at the minimum and maximum thermal conditions.

The differences (the self-weight and any prescribed forces cancel out) between all of the aforementioned loadcases are considered in turn, and a von Mises equivalent stress range, S_{VM}, is calculated using these differences. The TD/12 shakedown acceptance criterion requires the calculated equivalent stress range should not exceed S_{PR}, which is given by

$$S_{PR} = \frac{K_{SD}(S_Y + S_{YT})}{2} \qquad [3]$$

where K_{SD} is the shakedown factor of the material, which is 1.8 for carbon steel.

In the above, S_Y is taken to be equal to SMYS at room temperature and S_{YT} is taken to be equal to SMYS at maximum temperature.

[redacted]

3.3 Fatigue

A fatigue assessment considering past and future usage has been undertaken in [redacted]-R0711-21 [23].

4 RESULTS

Occurrences of stress that exceed the TD/12 allowable values are termed 'exceptions'. Where a component has an exception for both the lower and upper bound analyses then the greater exception is said to 'bound' the lesser.

4.1 Normal Sustained

There are six fittings with code stress exceeding the TD/12 normal sustained allowable stress criterion. A brief summary of the exceptions is provided below, there are;

- Three exceptions on 900mm x 200mm sweepolets
  - At Node 15040 the code stress exception is exacerbated by the proposed modifications. The sweepolet is in close proximity to Pit-1 and Pit-2 and therefore it is unknown if the removal of both or just one pit is having a detrimental effect.
- Three exceptions on 900mm x 300mm sweepolets.
  - At two locations (Node 10590 and Node 15920) the code stress is exacerbated by the proposed modifications at Pit-1.

Details of the exceptions are provided in Table 13 and locations are shown in Figure 6 to Figure 9.

For locations where an increase in stress is predicted due to the proposed modifications it is recommended a more detailed assessment is undertaken to better understand the level and distribution of stress in the fitting.

4.2 Shakedown

There are fourteen fittings exceeding the TD/12 shakedown allowable stress criterion. A brief summary of the of exceptions is shown below, there are;

- Five exceptions on 900mm x 200mm sweepolets.
  - At Node 15040 the code stress exception is exacerbated by the proposed modifications. The sweepolet is in close proximity to Pit-1 and Pit-2 and therefore it is unknown if the removal of both or just one pit is having a detrimental effect.
- Five exceptions on 900mm x 300mm sweepolets.
  - The code stress at three of the sweepolets is exacerbated by the proposed modifications at Pit-1.
- Four exceptions on 900mm x 900mm equal tees.

- The code stress at two of the tees is exacerbated by the proposed modifications at Pit-1.
- The code stress at one of the tees (node 15070) is also exacerbated by the proposed modifications. The tee is in close proximity to Pit-1 and Pit-2 and therefore it is unknown if the removal of both or just one pit is having a detrimental effect.

Details of the exceptions, are provided in Table 14 and their locations are provided in Figure 6 to Figure 9. Where exceptions are observed for multiple loadcases per fitting, only the most onerous loadcase has been reported.

4.3 Fatigue

A detailed fatigue assessment has been undertaken considering the removal of the three pits in [redacted]-R0711-21.

A summary of the results have been reproduced in Table 17 and Table 18.

4.4 Removal of Pit-2 and Pit-3 Only

Due to the close proximity of Pit-1 to Pit-2 a further study has been undertaken to better understand the influence of each pit by considering the removal of Pit-2 and Pit-3 only. The results of the study are detailed in Appendix B.

It is shown that removal of Pit-2 and Pit-3, only, has a negligible effect on the: predicted code stress for both sustained and shakedown assessment; and the predicted future fatigue usage.

4.5 Summary of Results

For some locations the removal of all three pits increases existing stress exception levels or introduces new stress exceptions where currently none exist. Table 15 to Table 17 show the highest observed stress level per fitting type for the sustained, shakedown and fatigue assessment, respectively. It may be possible to show acceptability of the fittings by undertaking a more detailed design-by-analysis assessment involving the finite element method.

Due to the close proximity of Pit-1 to Pit-2 a further study has been undertaken to better understand the influence of each pit by considering the removal of Pit-2 and Pit-3 only. It is shown that the proposed modification does not have an adverse effect on pre-existing code stress exceptions or introduce new exceptions.

[redacted]

5 CONCLUSIONS

1. Stress analyses have been undertaken to consider the effects of demolishing and backfilling the pits in the bi-directional area at Kings Lynn compressor station. Cohesive soils have been considered with lower and upper bound soil properties.

2. IGE/TD/12 code stress analyses have been undertaken of the existing and proposed configuration.

3. There are six fittings exceeding the IGE/TD/12 sustained criterion.

    iii. At three locations, concerning two different fitting types, the predicted code stress is exacerbated by the proposed modifications.

    iv. It may be possible to show acceptability of the fittings by undertaking a more detailed design-by-analysis assessment involving the finite element method.

4. There are fourteen fittings exceeding the IGE/TD/12 shakedown criterion.

    iii. At six locations, concerning three different fitting types, the predicted code stress is exacerbated by the proposed modifications.

    iv. It may be possible to show acceptability of the fittings by undertaking a more detailed design-by-analysis assessment involving the finite element method.

5. Fatigue assessments considering: the existing configuration, the removal of all three pits and the removal of Pit-2 and Pit-3 has been undertaken and reported in [redacted]-R0711-21. A summary of the results are provide in Table17 and Table 18.

    i. National Grid to confirm which pits, if any, are to be removed.

6. The removal of Pit-1 has an adverse effect on the pre-existing stress levels

7. An additional study has been performed considering removing Pits 2 and 3 only. It is shown that if these two pits are removed they do not have an adverse effect on the magnitude of the pre-existing code stress exceptions or introduce new exceptions.

6 RECOMMENDATIONS

National Grid to review the stress implications on removing all three pits or alternatively just consider removing Pits 2 and 3 only which do not increase the existing stress levels.

National Grid to confirm which pits on Feeder 2 are to be removed, if any, so that the appropriate forces and moments from the piping stress models can be extracted and used in the Stage 2 finite element modelling programme of work.

7 REFERENCES

1. [redacted]-R0706-21, 'Kings Lynn Compressor Station – Integrity Assessment of Bi-directional Pipework Affected by Ground Subsidence', 13/09/21.

[redacted]

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3. CAESAR II v12.00.01.0015 (Build 210109).
4. BGC/PS/DAT6, Standard Sizes of Carbon and Carbon Maganese Steel Pipe for Operating Pressures Greater than 7 Bar, 1977.
5. BGC/PS/DAT6, Standard Sizes of Carbon and Carbon Maganese Steel Pipe for Operating Pressures Greater than 7 Bar, 1988.
6. TS/SP/DAT/6, Specification for Standard Sizes of Carbon and Carbon Manganese Steel Pipe for Operating Pressures Greater Than 7 bar, National Grid, February 2015.
7. BGC/PS/T1, Specification for Forged Tees 450mm Nominal Size and Above Operating at Pressures of 7 to 70 bar, March 1972.
8. BGC/PS/T1, Specification for Carbon and Carbon Manganese Steel Tees Equal to or Greater than 450mm Nominal Size Produced from Plate for Operating Pressures Greater than 7 bar, February 1993.
9. BGS/PS/B1, Specification for Forged Bends 457mm Diameter and Above Operating at Pressures of 7 to 70 bar, June 1973.
10. B7, Specification for Carbon and Carbon Manganese Steel Bends Equal to or Greater than 450mm Nominal Size for Operating Pressures Greater than 7 bar, February 1993.
11. B4, Specification for Carbon and Carbon Manganese Steel Bends 50mm to 400mm Inclusive Nominal Size Produced from Seamless Pipe for Operating Pressures Greater than 7 bar, February 1993.
12. BGPS/F1, Specification for Steel Forging for Flanges and Brancholets, January 1971.
13. F1, Specification for Carbon and Carbon Manganese Steel Forgings and Forged Components for Operating Pressures Greater than 7 bar, February 1993.
14. PS/F3, Specification for Carbon and Carbon Manganese Steel Reducers 50mm to 1050mm Nominal Size for Operating Pressures Above 7 bar, September 1990.
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16. T/SP/PW/13, Specification for Carrying Out Pipework Stress Analysis to the Requirements of IGE/TD/12, National Grid, September 2011.
17. [redacted] Utilities, ‘Kings Lynn Compressor Station Stress Analysis Rev 1’, September 1999.
18. Email from [redacted], ‘NARC - Stress Info’, 16/08/2018.
19. Guidelines for the Design of Buried Steel Pipe, American Lifelines Alliance.

[redacted]

20. NEN3650-1+C1:2017, Requirements for Pipeline Systems, Nederlands Normalisatie Institute.
21. Datasheet for PTFE Slide Bearing. Fluorocarbon Company Ltd, Caxton Hill, Hertford.
22. RR031, Development of design guidance for neoprene lined clamps for offshore application, MSL Engineering Ltd for HSE, 2002.
23. [redacted]-R0711-21, 'Kings Lynn Compressor Station - IGE/TD/12 Fatigue Analysis of Bi-directional Area Piping', 13/10/21.

[redacted]

24. TABLES

Steel Name	SMYS (MPa)	SUTS (MPa)
B	241	413
X42	289	413
X46	317	434
X52	358	455
X56	386	449
X60	413	516
X65	448	530

Table 1 – Materials

Installation Date (Year)	Nominal Diameter (mm)	Outside Diameter (mm)	Wall Thickness (mm)	Specification	Strength Grade
1970	900	914.4	15.9	Ref. [Gel 2003 Stress]	X60
2003	900 (Proxy Pipe)	914.4	19.1	Ref. [Gel 2003 Stress]	X60
2003	900 (AGI Pipe)	914.4	15.9	Ref. [Gel 2003 Stress]	X65
1998	300	323.9	9.5	Ref. [Gel 2003 Stress]	X46
2003	200	219.1	8.2	Ref. [Gel 2003 Stress]	X42
1998/2003	50	60.3	5.5	Historic Drawings	B

Table 2 – Details of Pipe

Installation Date (Year)	Pressure Rating (barg)	Nominal Diameter (mm)	Outside Diameter (Header/Branch) (mm)	Wall Thickness on the Tee (Header/Branch) (mm)	Spec.	Strength Grade
1998 / 2003	103	900 x 900	970.6 / 970.6	44 / 44	BGC/PS/T1 (1993)	X56
1998	80	900 x 900	956.6 / 956.6	37 / 37	BGC/PS/T1 (1993)	X56
1970	-	900 x 900	945.2 / 945.2	31.3 / 31.3	BGC/PS/T1 (1972)	X56
2003	-	200 x 200	229.5 / 229.5	13.4 / 13.4	BGC/PS/T2 (1993)	X42
1998 / 2003	-	50 x 50	60.3 / 60.3	5.5 / 5.5	BG/PS/T2 (1993)	B

Table 3 – Details of Tees

Installation Date (Year)	Nominal Diameter (mm)	Radius	Fitting Wall Thickness (mm)	Spec.	Strength Grade
1970	900	3D	17.5	BG/PS/B1 (1973)	X60
2003	900	3D	17.5	BG/PS/B7 (1993)	X65
2003	900	3D	21	BG/PS/B7 (1993)	X60

[redacted]

1998	900	1.5D	19.9	BG/PS/B7 (1993)	X65
2003	900	1.5D	19.9	BG/PS/B7 (1993)	X65
1998	300	1.5D	10.7	BG/PS/B4 (1993)	X52
2003	200	1.5D	10.5	BG/PS/B4 (1993)	X42
1998	50	1.5D	5.5	BG/PS/B4 (1993)	B
2003	50	1.5D	5.5	BG/PS/B4 (1993)	B

Table 4 – Details of Bends

Installation Date (Year)	Nominal Diameter (mm)	Type	Spec.	Strength Grade
1998	900 X 300	Sweepolet	BGC/PS/F1 (1993)	X65
2003	900 x 200	Sweepolet	BGC/PS/F1 (1993)	X65
1998	900 x 50	Weldolet	BGC/PS/F1 (1993)	X60
1998 / 2003	600 x 50	Weldolet	BGC/PS/F1 (1993)	X65

Table 5 – Details of Forged Branch Connections

Nominal Diameter, D_1 (mm)	Nominal Diameter, D_2 (mm)	Wall Thickness, T_1 (mm)	Wall Thickness, T_2 (mm)	Type	Grade	Length	α (°)	R_1	R_2
300	250	9.5	8.74	Concentric	X46	203	11.8	30	30

Table 6 – Details of Reducers

CAESARII Designation	Description	Temperature (°C)			
		Suction		Discharge	
		Above Ground	Below Ground	Above Ground	Below Ground
T1	Max Temp, no flow	50	15	50	15
T2	Min Temp, no flow	-20	5	-20	5
T3	Max Temp, flow	50	15	50	47
T4	Min Temp, flow	-20	8	-20	37
CAESAR II Designation	**Description**			**Pressures (barg)**	
P1	MIP (SOL)			79.5	

Table 7 – Temperature and Pressure Table – Forward Flow (KL to Bacton)

[redacted]

CAESARII Designation	Description	Temperature (°C)			
		Suction		Discharge	
		Above Ground	Below Ground	Above Ground	Below Ground
T1	Max Temp, no flow	50	15	50	15
T2	Min Temp, no flow	-20	5	-20	5
T3	Max Temp, flow	50	18	50	47
T4	Min Temp, flow	-20	8	-20	37
CAESAR II Designation	**Description**	**Pressures (barg)**			
P1	MIP (SOL)	79.5			

Table 8 – Temperature and Pressure Table – Reverse Flow (Bacton to KL)

Case	Combination		Identifier
	As-built	Current Configuration	
L1	W+T1	W+D1+T1	OPE
L2	W+T2	W+D1+T2	OPE
L3	W+T1+P1	W+D1+T1+P1	OPE
L4	W+T5+P1	W+D1+T3+P1	OPE
L5	W+T6	W+D1+T4	OPE
L6	W+P1	W+D1+P1	SUS
L7	L1-L2	L1-L2	EXP
L8	L3-L2	L3-L2	EXP
L9	L4-L2	L4-L2	EXP
L10	L5-L2	L5-L2	EXP
L11	L6-L2	L6-L2	EXP
L12	L3-L1	L3-L1	EXP
L13	L3-L4	L3-L4	EXP
L14	L3-L5	L3-L5	EXP
L15	L3-L6	L3-L6	EXP
L16	L1-L4	L1-L4	EXP
L17	L4-L5	L4-L5	EXP
L18	L4-L6	L4-L6	EXP
L19	L5-L1	L5-L1	EXP
L20	L5-L6	L5-L6	EXP
L21	L1-L6	L1-L6	EXP

Table 9- Loadcase Combinations for CAESAR II

Soil Type	Effective Density (kg/m^3)	Effective Cohesion c' (kN/m^2)

[redacted]

Soft Clay	427	25
Firm Clay	2039	200

Table 10 – Soil Strength Parameters

LOWER	
GAMMA PRIME – EFFECTIVE SOIL DENSITY (kg/cu.m.)	427
H – BURIED DEPTH TO TOP OF PIPE (mm.)	Varies
C – SOIL COHESION OF BACKFILL (N./sq.mm.)	0.025
ALPHA – ADHESION FACTOR (CALCULATED IF OMITTED)	
dT – YIELD DISP FACTOR, AXIAL (mm.)	10
dP – YIELD DISP FACTOR, LAT, MAX MULTIPLE OF D	0.15
dQu – YIELD DISP FACTOR, UPWARD, MULTIPLE OF H	0.2
dQu – YIELD DISP FACTOR, UP, MAX MULTIPLE OF D	0.2
dQd – YIELD DISP FACTOR, DOWN, MULTIPLE OF D	0.2
THERMAL EXPANSION COEFFICIENT xE-6 (L/L/deg C)	11.2131
TEMPERATURE CHANGE, Install-Operating (deg C)	5

Table 11 – CAESAR II Soil Input, Soft Clay Based Soil

LOWER	
GAMMA PRIME – EFFECTIVE SOIL DENSITY (kg/cu.m.)	2039
H – BURIED DEPTH TO TOP OF PIPE (mm.)	Varies
C – SOIL COHESION OF BACKFILL (N./sq.mm.)	0.2
ALPHA – ADHESION FACTOR (CALCULATED IF OMITTED)	
dT – YIELD DISP FACTOR, AXIAL (mm.)	7.5
dP – YIELD DISP FACTOR, LAT, MAX MULTIPLE OF D	0.1
dQu – YIELD DISP FACTOR, UPWARD, MULTIPLE OF H	0.1
dQu – YIELD DISP FACTOR, UP, MAX MULTIPLE OF D	0.2
dQd – YIELD DISP FACTOR, DOWN, MULTIPLE OF D	0.2
THERMAL EXPANSION COEFFICIENT xE-6 (L/L/deg C)	11.2131
TEMPERATURE CHANGE, Install-Operating (deg C)	

Table 12 – CAESAR II Soil Input, Firm Clay Based Soil

[redacted]

Node	Pit Association*	Fitting	Code Stress Ratio (%)			
			Soft Clay		Firm Clay	
			Existing	Proposed	Existing	Proposed
410	n/a	900 x 200 Sweepolet	-	-	111	110.8
15040	Pit 1 & Pit-2		-	-	149.48	156.63* / 99.98**
15990	Pit-3		164.88	89.70	240.66	164.14 / 111.84**
5810	n/a	900 x 300 Sweepolet	-	-	104.56	104.51
15090	Pit-1		94.87	105.65*	94.61	157.86* / 112.52**
15920	Pit-1		99.70	100.27*	101.73	102.59* / 102.52**

Table 13 – Sustained Exceptions – (See Figures 7 to 9 for Fitting Location)

** Code stress exacerbated by proposed modifications*
***Loose sand backfill used after removal of pits.*
See Figure 1 for pit locations

[redacted]

Node	Pit Association	Fitting	Code Stress Ratio (%)							
			Soft Clay				Firm Clay			
			Forward Flow		Reverse Flow		Forward Flow		Reverse Flow	
			Existing	Proposed	Existing	Proposed	Existing	Proposed	Existing	Proposed
410	n/a	900 x 200 Sweepolet	104.72	104.13	122.62	122.25	125.95	124.76	173.04	171.89
480	n/a		108.95	109.42	137.21	131.11	119.24	114.95	150.79	150.45
1480	n/a		-	-	100.04	100.33	-	-	-	-
15040	Pit-1 & Pit-2		111.88	123.96*	103.64	113.01*	229.35	235.15* / 155.28**	156.24	166.07* / 125.57**
15990	Pit-3		164.47	117.30	237.4	140.61	207.92	158.74 / 126.49**	357.9	246.85 / 172.91**
5810	n/a	900 x 300 Sweepolet	108.48	108.42	108.26	108.02	130.14	130.39	131.68	132.06
6070	n/a		120.3	107.91	125.8	108.31	132.66	131.78	137.38	136.95 / 136.95**
15090	Pit-1		125.65	166.85*	113.90	126.52*	127.33	243.19* / 165.64**	112.97	157.39* / 125.57**
15760	Pit-1		127.09	132.96*	134.94	140.32*	135.88	139.83* / 139.89**	134.87	138.03 / 137.71**
15920	Pit-1		152.82	153.93*	153.91	154.83*	163.45	165.56* / 165.42**	159.05	160.57 / 160.16**
1220	n/a	900 x 900 Tee	-	-	-	-	103.0	102.99	-	-
15220	Pit-1		127.13	101.85	108.41	92.93	107.19	105.65 / 92.09**	-	-
15350	n/a		94.07	100.46*	-	-	102.87	100.46 / 92.09**	103.7	101.89 / 101.82**
15880	Pit-1		104.05	93.75	-	-	100.16	105.39* / 105.73**	-	-

Table 14 – Worst Case Shakedown Exceptions – (See Figures 9 and 10 for Fitting Location)

**Code stress exacerbated by proposed modifications*
***code stress when using loose sand backfill after removal of pits*
See Figure 1 for pit locations

Wall Thickness	Soil Type	Node	Fitting	Code Stress Ratio (%)	
				Existing	Proposed
15.9	Firm Clay	15990	900 x 200 Sweepolet	240.66	164.14 / 111.84**
15.9	Firm Clay	15090	900 x 300 Sweepolet	94.61	157.86* / 112.52**

Table 15 – Fittings Recommended for Finite Element Analysis – Sustained Exceptions – Firm Clay

***code stress when using loose sand backfill after removal of pits*

Wall Thickness	Soil Type	Flow	Loadcase	Node	Fitting	Code Stress Ratio (%)	
						Existing	Proposed
15.9	Firm Clay	Forward	9 (EXP)	15990	900 x 200 Sweepolet	357.9	246.85 / 172.91
15.9	Firm Clay	Forward	9 (EXP)	15090	900 x 300 Sweepolet	127.33	243.19* / 165.64**

Table 16 – Fittings Recommended for Finite Element Analysis – Shakedown Exceptions

***code stress when using loose sand backfill after removal of pits*

Node	Fitting Type	Soft Clay					
		Case-1			Case-2		
		Existing	Pits Removed		Existing	Pits Removed	
			Pit-1,2 & 3	Pit-2 & 3		Pit-1,2 & 3	Pit-2 & 3
15990	900 x 200 Sweepolet	2.96	2.35*	2.35*	9.18	3.14	3.13*
480	900 x 300 Sweepolet	-	-	-	1.02	1.02	1.02

Table 17 – Fatigue Results Summary – Soft Clay

*lowest predicted fatigue usage
See Report: AFAA-R0711-21 for details.

Node	Fitting Type	Firm Clay					
		Case-1			Case-2		
		Existing	Pits Removed		Existing	Pits Removed	
			Pit-1,2 & 3	Pit-2 & 3		Pit-1,2 & 3	Pit-2 & 3
6070	900 x 50 Weldolet	-	-	-	1.16	1.16	1.16
6220		1.41	1.41	1.41	1.46	1.46	1.46
6180	900 x 900 Tee	-	-	-	1	1	1
15990	900 x 200 Sweepolet	15.36	12.82*	12.83	46.64	21.22 / 14.18**	21.28
15040		1.23	1.27	1.23*	2.61	2.9	2.61*
410		-	-	-	3.06	3.06	3.06
480		-	-	-	1.79	1.79	1.79
15920	900 x 300 Sweepolet	-	-	-	1.05	1.11	1.04*

Table 18 – Fatigue Results Summary – Firm Clay

*lowest predicted fatigue usage
**code stress when using loose sand backfill after removal of pits

See Report: [redacted]-R0711-21 for details.

[redacted]

FIGURES

Figure 1 – Location of Bi-directional Area and Pits

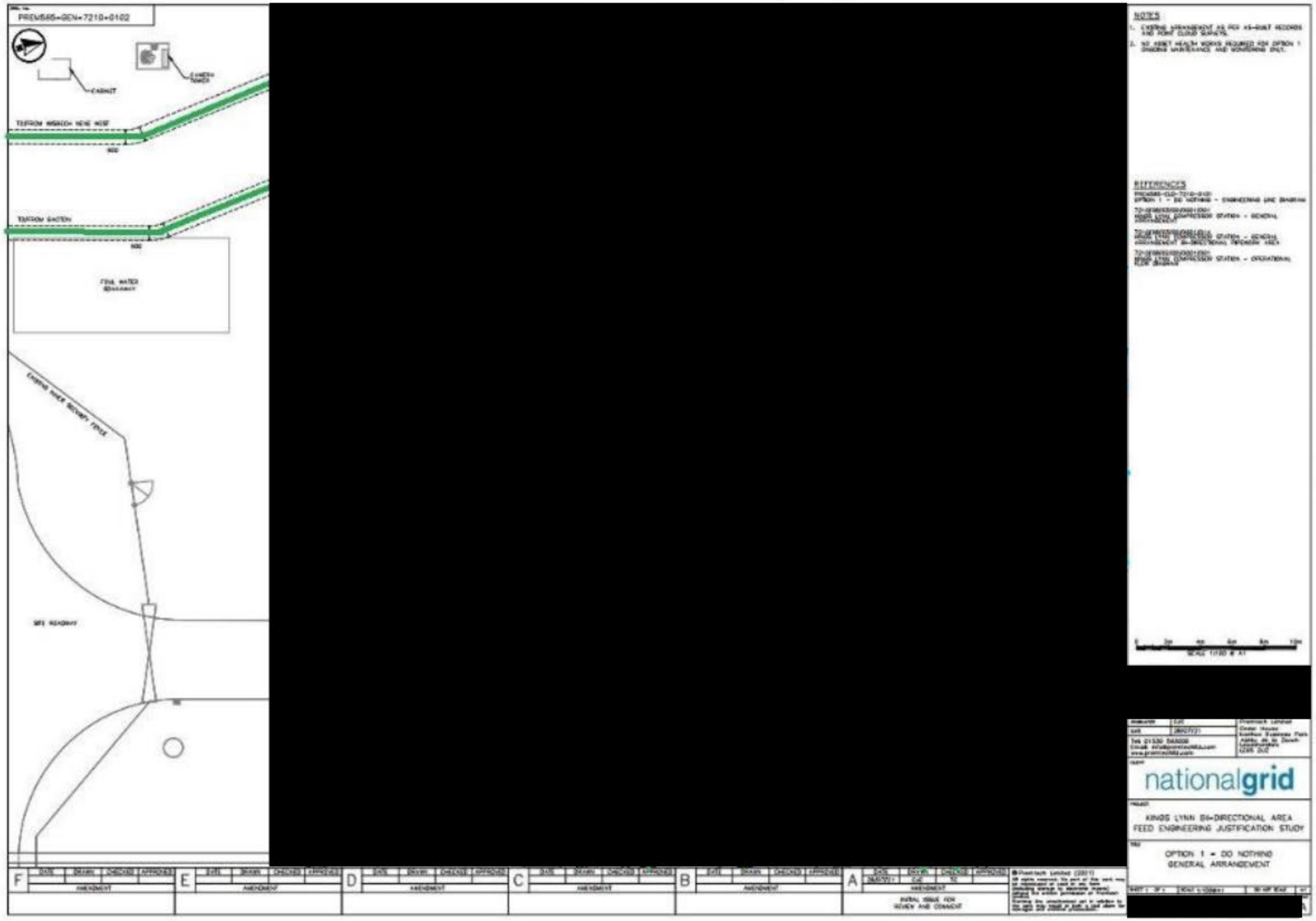

Figure 2 – General Arrangement and Construction Year

	T1	T2
	50	-20
	15	5

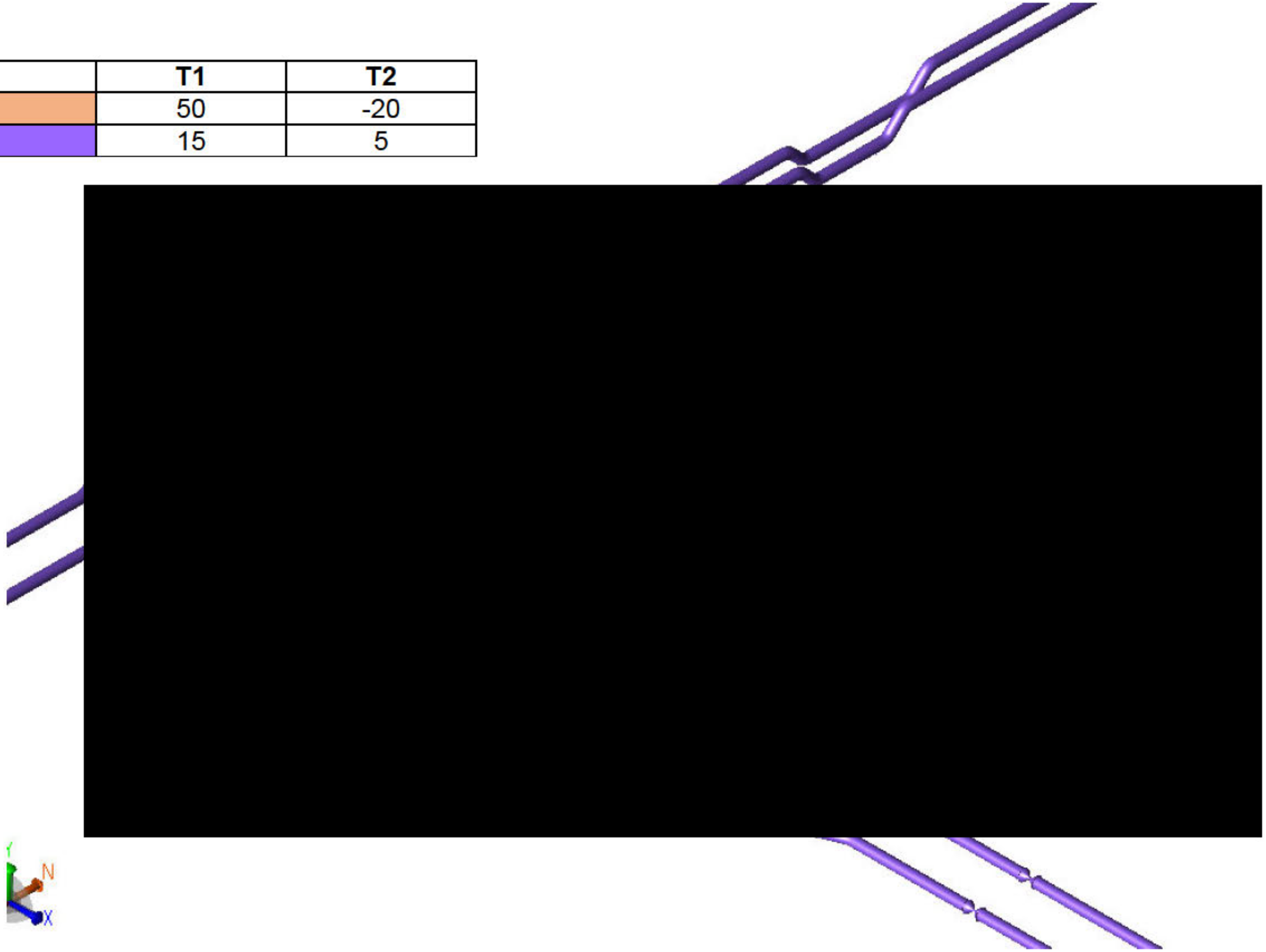

Figure 3 – Temperatures

	T3	T4
	15	8
	47	37
	50	-20

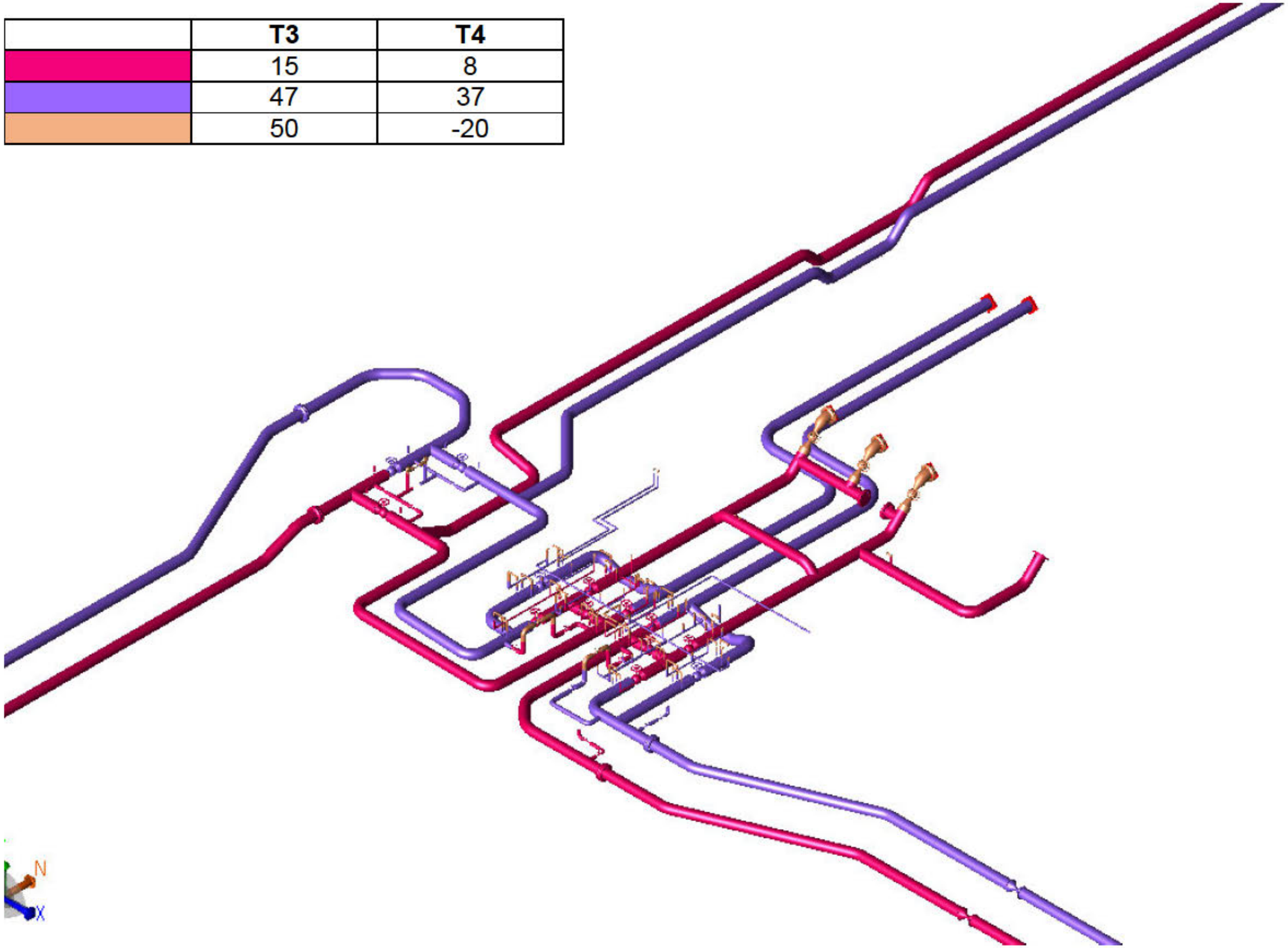

Figure 4 – Temperatures Cont'd (Forward Flow)

[redacted]

	T3	T4
	50	-20
	18	8
	47	37

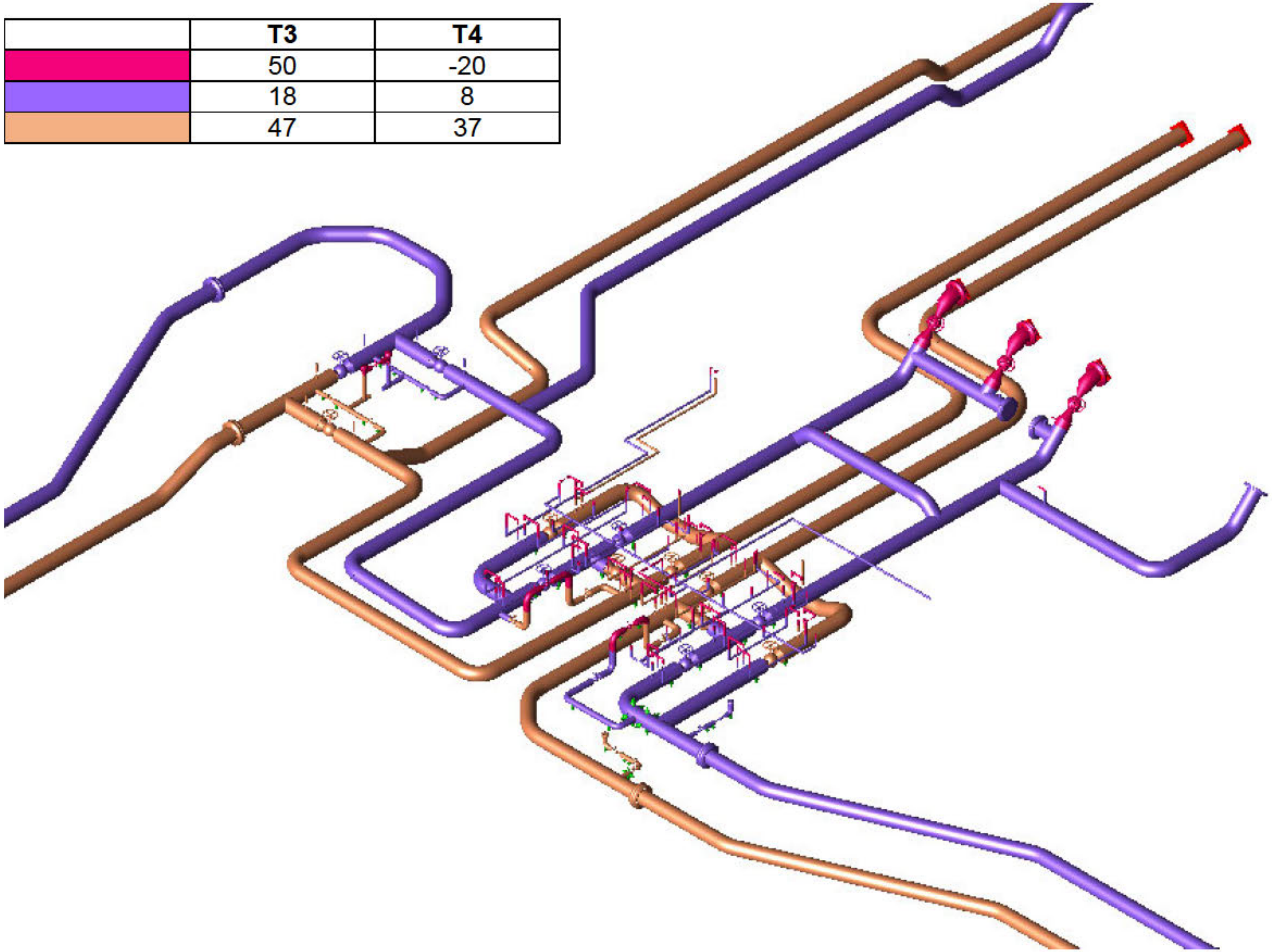

Figure 5 – Temperatures Cont'd (Reverse Flow)

Figure 6 – Stress Exception Locations

[redacted]

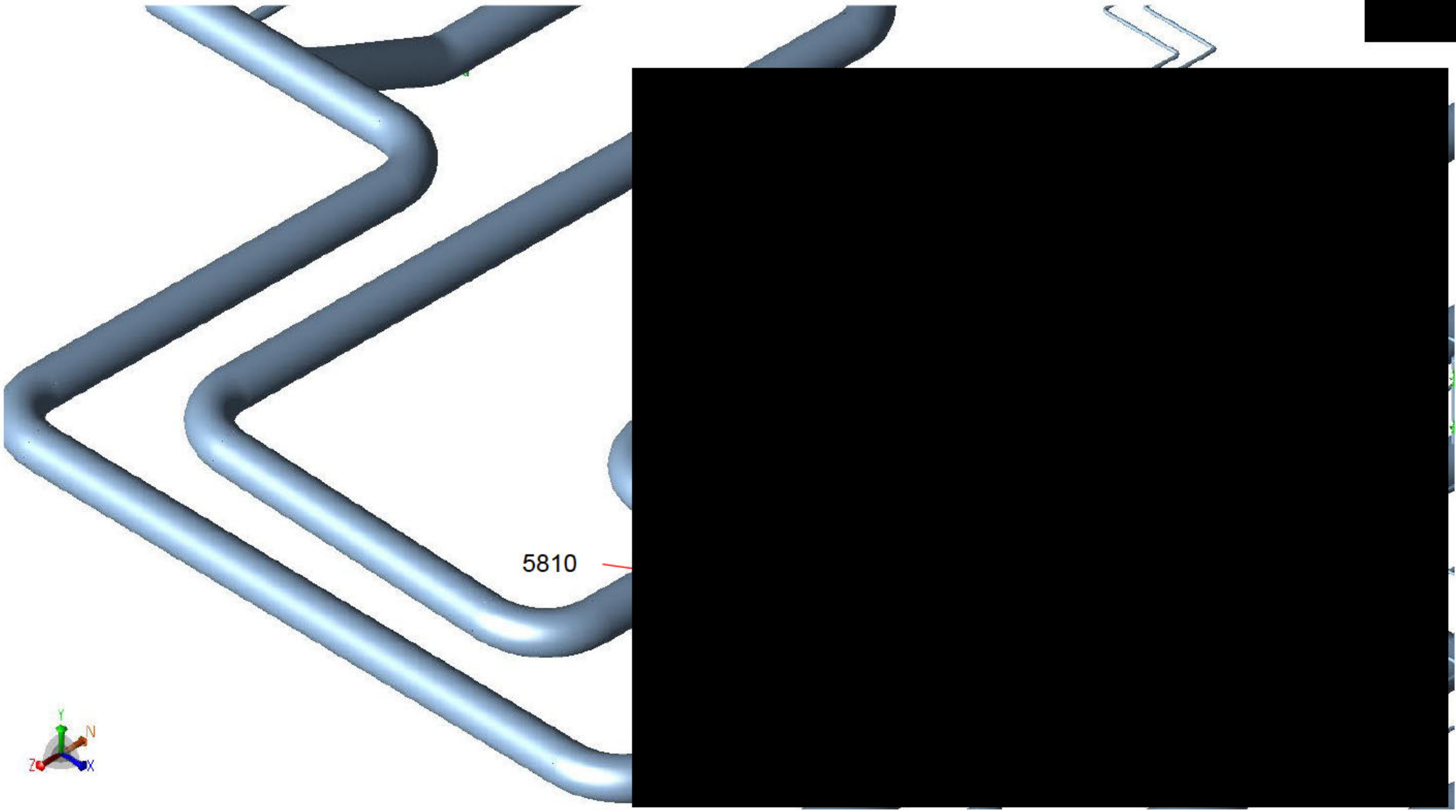

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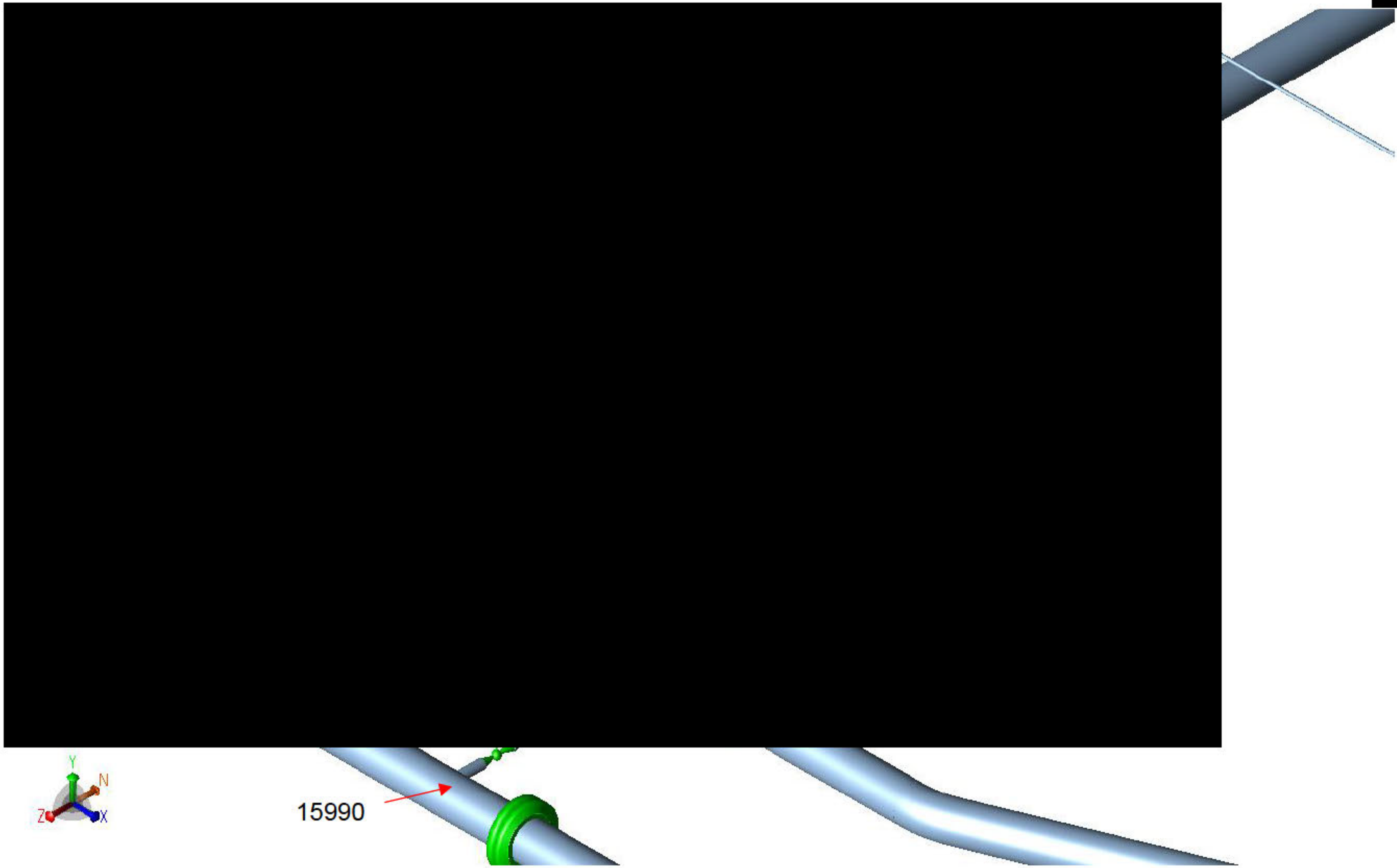
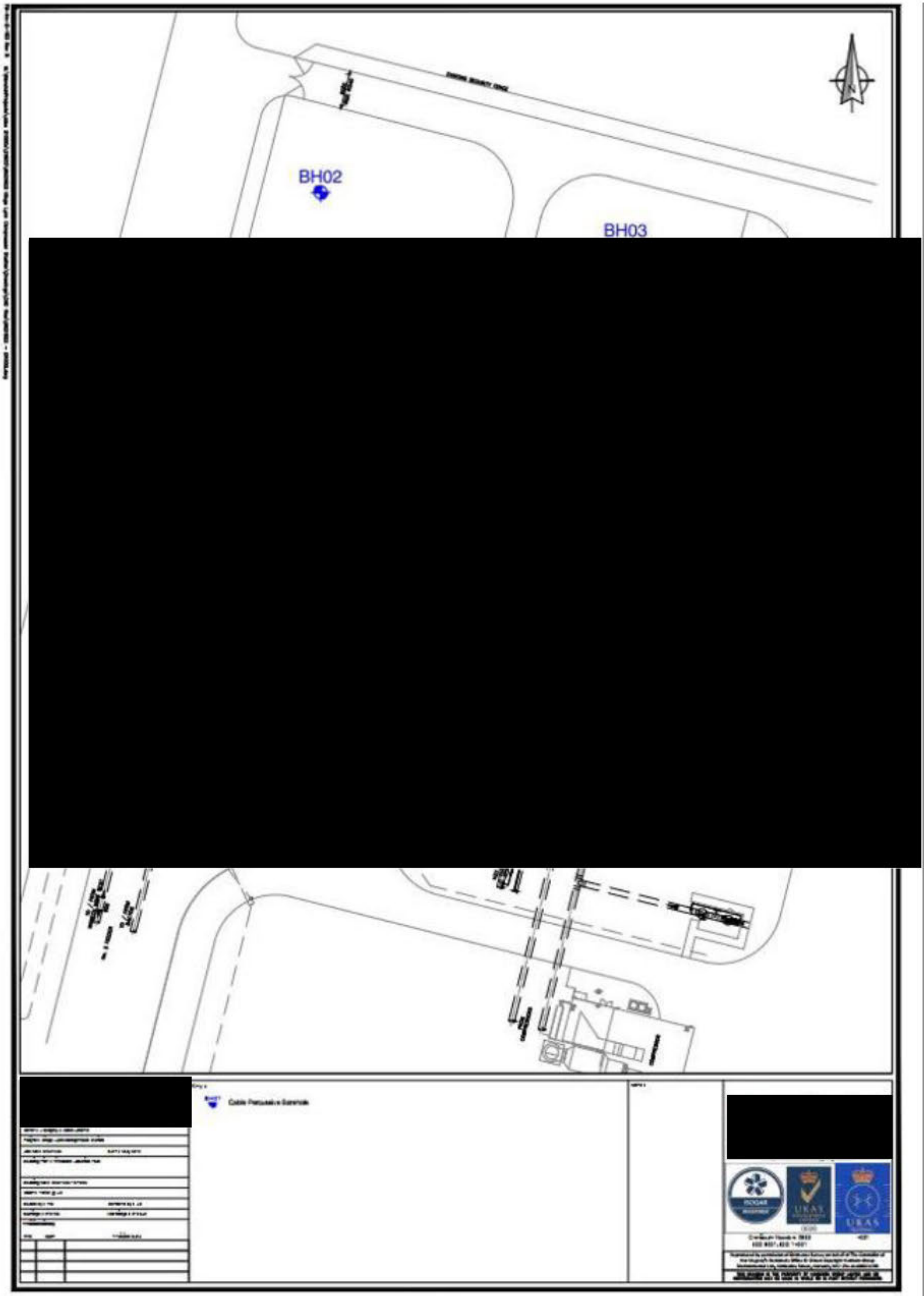
Figure 7 – Stress Exception Locations Cont'd



<u>Figure 8 – Stress Exception Locations Cont'd</u>

Figure 9 – Stress Exception Locations Cont'd

APPENDIX A HISTORIC BOREHOLES



[redacted]	**Rotary Borehole Record**	**BH01A**	Sheet 1 of 6

Project ID: GN21822	[redacted]	E: 572076.00	N: 316205.00
Location: King's Lynn Compressor Station		Date: 24/05/2018 - 31/05/2018	
	Plant used: Comacchio MC405	SPT Hammer Serial No: ADP04 (ER: 62%)	

Geology Description

Depth (m)	Geology Description
0.50	TOPSOIL (Dark brown slightly silty gravelly fine to coarse SAND. Gravel is angular to subrounded fine to coarse flint. Occasional rootlets present).
1.25	Dark grey clayey gravelly fine to coarse SAND. Gravel is angular to subrounded fine to coarse flint. Occasional pockets of black decaying organic matter with faint organic odour.
1.90	Light yellowish brown clayey gravelly fine to coarse SAND. Gravel is angular to subangular fine and medium flint.
2.00	Soft grey mottled brown sandy CLAY with rare gravel of subrounded fine and medium flint.
	Soft to firm black mottled dark grey silty CLAY with occasional gravel of subrounded fine flint. Slight organic odour present. *From 2.80m: Occasional fine to coarse gravel-sized fossil shell fragments and whole shells.* *At 3.70m: Rare coarse gravel-sized whole shell.* *From 4.60m to 5.00m: Locally frequent coarse sand-sized and fine gravel-sized shell and shell fragments.* *From 5.50m: Becoming firm.* *From 6.00m: Locally frequent fine and medium gravel-sized shell fragments.* *From 6.25m: Locally frequent fine to coarse gravel-sized fossil shell fragments.* *From 7.50m: Becoming firm to stiff. Fossil shell fragments becoming rare.* *From 8.00m: Locally frequent fine and medium sand-sized fossil shell fragments.* *At 8.80m: 150mm open subhorizontal fracture. Drilling-induced.* *At 9.10m: 100mm open subhorizontal fissure.*

Core recovery

Run	T.C.R. (%)	S.C.R. (%)	R.Q.D. (%)
6.50 - 7.50	33	0	0
7.50 - 9.00	50	50	0
9.00 -	86	86	0

Sample / In-Situ Test Information

Type	Depth	Results / Remarks	Date - Depth (m) Casing (Water)
B1	0.10		
ES1	0.10		
B2	0.60		
ES2	0.60		
B3	1.10		
ES3	1.10		
SPT(S)	1.20	N=9 (2,2/2,2,2,3)	- (Dry)
D1	1.20		
D2	1.80		
SPT(S)	2.00	N=9 (1,1/2,1,3,3)	2.00 (0.00)
B4	2.00 - 2.50		
D3	2.20		
D4	2.80 - 3.00		
SPT(S)	3.00	N=11 (2,1/2,3,3,3)	3.00 (0.00)
D5	3.50		
U1	4.00 - 4.60		
D6	5.00		
SPT(S)	5.50	N=10 (1,2/2,2,3,3)	5.50 (0.00)
B5	6.00 - 6.50		
D7	6.00		
SPT(S)	6.50	N=20 (3,3/4,5,5,6)	6.50 (0.00)
U2	8.40 - 8.70		
SPT(S)	9.00	N=17 (3,3/4,4,5,4)	6.50 (0.00)
D8	9.00		
D9	10.00		

Hole Diameter by Depth

Depth Base (m)	Diameter (mm)
6.50	146
51.00	116

Casing Diameter by Depth

Depth Base (m)	Diameter (mm)
6.50	150

Drilling Flush Details

Depth (m)	Type	Return (%)
6.50 - 7.50	WATER	100
7.50 - 9.00	WATER	100
9.00 - 10.50	WATER	60

Water Strike

Date	Strike Depth (m)	Depth Sealed (m)	Casing Depth (m)	Time Elapsed (mins)	Standing Level (m)	Remarks
						No groundwater encountered

Remarks:

1. Inspection pit GL to 1.20m.
2. Installations: Pipe1: 50mm standpipe GL to 8.00m plain, 8.00m to 50.00m slotted, fitted with gas tap and bung. Pipe2: 50mm standpipe GL to 1.00m plain, 1.00m to 6.00m slotted, fitted with gas tap and bung. Both installed in flush cover.
3. Backfill: GL to 0.50m concrete, 0.50m to 1.00m bentonite, 1.00m to 6.00m gravel, 6.000m to 9.00m bentonite, 9.00m to 51.00m gravel.
4. 0.33hrs standing time: Waiting for Murphy's to clear hole. 24/05/18. 5. 0.75hrs dayworks: Additional set up time 24/05/18.
6. 0.83hrs dayworks: Mixing mud into tank 29/05/18. 7. 0.5hrs dayworks: Mixing mud into tank 29/05/18.
8. 1hr standing time: Waiting for permit 30/05/18. 9. 1hr dayworks: Cleaning out tanks and mixing mud 30/05/18.
10. 1hr dayworks: Cleaning out tanks 30/05/18. 11. 2.5hrs standing time: Waiting for installation details 31/05/18.
12. 1hr dayworks: Clearing spoil 31/05/18.

[redacted]

Drilled by: [redacted]	Logged by: JE	Checked by: JA	Fm-Hn-R-3870-Rev D

[redacted]

Rotary Borehole Record

BH02 — Sheet 1 of 6

Project ID: GN21822	[redacted]	E: 572081.83	N: 316300.54
Location: King's Lynn Compressor Station		Date: 17/05/2018 - 24/05/2018	
	Plant used: Comacchio MC405	SPT Hammer Serial No: ADP04 (ER: 62%)	

Geology Description	Depth (m)
MADE GROUND (Multicoloured GRAVEL with high cobble content. Gravel is subangular to subrounded medium and coarse flint. Cobbles are flint).	0.05
MADE GROUND (Brown slightly silty slightly gravelly fine to coarse SAND. Gravel is subangular to subrounded fine to coarse flint and concrete).	0.90
MADE GROUND (Dark grey to dark brown slightly silty gravelly fine to coarse SAND with pockets of black fine to coarse sand. Gravel is angular to subrounded fine to coarse flint. Hydrocarbon odour present). *From 1.20m to 1.50m: Drilling flush cuttings.*	1.30
Light brown mottled brown slightly clayey fine to coarse SAND with rare gravel of subrounded fine and medium flint.	1.60
Medium dense becoming dense grey slightly silty fine to coarse SAND with occasional gravel of subrounded fine flint. *From 1.80m to 1.90m: Sand becoming locally medium and coarse with rare gravel of subangular medium flint.* *From 4.50m: Becoming slightly gravelly .Gravel is black subangular to subrounded fine and medium flint.*	4.90
Dark grey and brown slightly gravelly silty sandy CLAY. Gravel is subrounded fine and medium flint.	5.00
Soft dark grey slightly sandy silty CLAY with occasional gravel of fine and medium fossil shell fragments. Slight organic odour present. *From 5.00m to 5.10m: Becoming locally very gravelly.* *From 5.60m: Becoming locally silty fine and medium sand.* *From 5.90m: Becoming locally very sandy.*	6.00
Firm to stiff grey silty CLAY with occasional gravel of fine to coarse fossil shell and fossil shell fragments. *From 8.50m: Gravel becoming rare fossil shell fragments.* *From 9.00m: Becoming occasionally mottled black.*	

TCR (%)	SCR (%)	RQD (%)
100	80	0
73	67	0
[illegible]	[illegible]	0

Type	Depth	Results / Remarks	Date - Depth (m) Casing (Water)
B1	0.20		
ES1	0.20		
B2	0.60		
ES2	0.90		
B3	1.00		
SPT(S)	1.20	N=23 (2,3/5,6,6,6)	- (Dry)
ES3	1.30		
D1	1.40		
SPT(S)	2.00	N=32 (3,5/7,8,9,8)	2.00 (2.00)
B4	2.00 - 3.00		
D2	2.00		
SPT(S)	3.00	N=45 (4,7/11,11,11,12)	3.00 (0.00)
B5	3.50 - 4.00		
SPT(S)	4.00	N=60 (3,5/7,11,15,17)	4.00 (0.00)
D3	4.50		
D4	4.90 - 5.00		
SPT(S)	5.00	N=9 (2,2/2,2,3,2)	5.00 (0.00)
B6	5.50 - 5.90		
D5	5.90 - 6.00		
U1	6.00 - 6.60		
U2	7.00 - 7.30		
HV01	7.40		
SPT(S)	7.50	N=20 (3,3/5,4,5,6)	6.00 (0.00)
D6	7.50		
HV02	8.00		
D7	8.60		
U3	8.70 - 9.00		
D8	9.00 - 9.10		
HV03	10.00		

Hole Diameter by Depth

Depth Base (m)	Diameter (mm)
6.00	146
51.00	116

Drilling Flush Details

Depth (m)	Type	Return (%)
6.60 - 7.50	WATER	100
7.50 - 9.00	WATER	90
9.00 - 10.50	WATER	40

Water Strike

Date	Strike Depth (m)	Depth Sealed (m)	Casing Depth (m)	Time Elapsed (mins)	Standing Level (m)	Remarks
17-05-2018	1.30					Seepage

Casing Diameter by Depth

Depth Base (m)	Diameter (mm)
6.00	150

[redacted]

Remarks:

1. Inspection pit GL to 1.20m.
2. Backfill: GL to 51.30m bentonite.
3. 1hr dayworks: Additional set up time 17/05/18.
4. 1hr dayworks: Pulled geobore and flushed more casing in 18/05/18.
5. 0.33hrs dayworks: Flush casing to 12.00m 21/05/18.
6. 0.67hrs dayworks: Flush geobore back to 12.00m 21/05/18.
7. 0.83hrs dayworks: Mixing mud into tank 21/05/18.
8. 1hr dayworks: Cleaning out tanks and mixing mud 22/05/18.

Drilled by: [redacted] | Logged by: JE | Checked by: JA | Fm-Hn-R-1070-Rev D

[redacted]

Rotary Borehole Record

BH03

Sheet 1 of 6

Project ID:	GN21822	[redacted]	E: 572130.02 N: 316292.03
Location:	King's Lynn Compressor Station		Date: 08/05/2018 - 16/05/2018
		Plant used: Comacchio MC405	SPT Hammer Serial No: ADP04 (ER: 62%)

Geology Description

Geology Description	Depth (m)
TOPSOIL (Dark brown slightly gravelly CLAY. Gravel is angular to subrounded fine to coarse flint).	0.20
MADE GROUND (Dark brown mottled brown slightly sandy gravelly CLAY. Gravel is angular to rounded fine to coarse flint. Occasional cobbles of rounded flint).	0.40 / 0.60
MADE GROUND (Dark brown mottled brown and black slightly clayey gravelly fine to coarse SAND. Gravel is angular to subrounded fine to medium flint. Slight hydrocarbon odour present).	1.20
Light brown mottled brown slightly clayey gravelly fine to coarse SAND. Gravel is angular to subrounded fine to medium flint.	1.80
Medium dense brown slightly gravelly fine to coarse SAND. Gravel is subrounded fine flint. *From 1.60m: Becoming silty.*	
Grey very clayey fine to medium SAND.	2.50
Firm black mottled grey silty CLAY with occasional medium sand-sized fossil shell fragments. *From 2.70m to 3.20m: Drilling flush cuttings. From 3.40m: Becoming firm to stiff. From 3.50m: Fossil shell fragments becoming frequent and fine to medium gravel-sized. From 3.80m to 3.90m: Band of locally grey silty fine to medium sand. From 4.10m: Rare coarse gravel-sized fossilised wood fragments. From 4.20m: Rare grey silty fine to medium sand. From 6.00m: Becoming stiff and dark grey with occasional fine to medium gravel-sized fossil shell fragments. From 7.75m to 7.80m: Open fissuring approx. 3mm and medium spaced. From 8.00m: Becoming locally firm. From 8.50m: Fossil shell fragments becoming occasional. From 9.00m: Rare coarse gravel-sized whole fossil shells.*	

Core recovery

Run	TCR (%)	SCR (%)	RQD (%)
6.00 - 7.50	40	40	40
7.50 - 9.00	89	89	81
9.00 - 10.00	100	100	100

Sample / In-Situ Test Information

Type	Depth	Results / Remarks	Date - Depth (m) Casing (Water)
B1	0.20 - 0.40		
ES1	0.30		
B2	0.50 - 0.60		
ES2	0.55		
B3	0.70 - 1.00		
ES3	0.80		
D1	1.00		
SPT(S)	1.20	N=19 (3,4/4,6,5,4)	- (1.00) 08/05/2018 - 1.20 - (1.20) 09/05/2018 - 1.20 - (1.00)
B4	2.00 - 2.50		
D2	2.00		
SPT(S)	2.70	N=11 (1,1/2,3,3,3)	2.70 (1.00)
D3	3.00		
D4	3.50		
D5	4.20		
U1	4.30 - 4.80		
D6	5.00		
B5	5.50 - 6.00		
SPT(S)	6.00	N=16 (2,2/3,4,4,5)	6.00 (0.00)
D7	6.00		09/05/2018 - 6.00 6.00 (1.00) 10/05/2018 - 6.00 6.00 (1.00)
U2	7.30 - 7.50		
SPT(S)	7.50	N=20 (2,2/4,5,5,6)	6.00 (1.00)
D8	7.80		
HV01	8.00		
HV02	8.80		
D9	9.00		
U3	9.00 - 9.30		
HV03	9.50		
D10	10.00		

Installation & Backfill: [redacted]

Hole Diameter by Depth

Depth Base (m)	Diameter (mm)
6.00	146
51.00	116

Casing Diameter by Depth

Depth Base (m)	Diameter (mm)
6.00	150

Drilling Flush Details

Depth (m)	Type	Return (%)
6.00 - 7.50	WATER	100
7.50 - 9.00	WATER	100
9.00 - 10.50	WATER	100

Water Strike

Date	Strike Depth (m)	Depth Sealed (m)	Casing Depth (m)	Time Elapsed (mins)	Standing Level (m)	Remarks
08-05-2018	1.00					Seepage

[redacted]

Remarks:

1. Inspection pit GL to 1.20m. 2. Backfill: GL to 51.38m bentonite.
3. 2.33hrs standing time: Inductions 08/05/18. 4. 2hrs dayworks: Additional set up time 08/05/18.
5. 1hrs standing time: Waiting to start drilling 09/05/18. 6. 0.5hrs dayworks: Collecting water 09/05/18.
7. 0.75hrs dayworks: Collecting water 09/05/18. 8. 2hrs standing time: Waiting for kit 09/05/18.
9. 1hr standing time: Waiting to start drilling 10/05/18.
10. 2.5hrs dayworks: Change flush in tanks and borehole and clean out tanks 10/05/18.
11. 1hr dayworks: Pumping water out of skip and IBC 11/05/18. 12. 1.5hrs dayworks: Mixing mud into tank 14/05/18.
13. 1hr dayworks: Mixing mud into tank 14/05/18. 14. 0.5hrs standing time: Waiting for permit 15/05/18.
15. 1hr standing time: Waiting to replacing hydraulic hose 15/05/18. 16. 1hr dayworks: Travel to Pirtek to fix hose 16/05/18.
17. 1.5hrs dayworks: Travel back to site to fit new hose 16/05/18. 18. 1hr standing time: Waiting for installation details 16/05/18.
19. 1hr dayworks: Moving kit to next position 16/05/18.

Drilled by: [redacted]	Logged by: JE	Checked by: JA	Fm-Hn-R-3870-Rev D

APPENDIX B REMOVAL OF PIT-2 AND PIT-3 ONLY

Previous analyses, detailed in the main section of this report, considered the removal of all three pits, Pit-1, Pit-2 and Pit-3 (See Figure 1 for pit locations), at Kings Lynn. It was shown that this resulted in both positive and detrimental effects to the observed stress levels on fittings in the region of the proposed modifications.

Due to the close proximity of Pit-1 to Pit-2 an additional assessment has been undertaken, to better understand the influence of each pit, by considering the removal of Pit-2 and Pit-3 only. The results of the study is presented in the below.

B.1 MODELS

- KL_CLAY_FF_02_PITS.C2
- KL_CLAY_RF_02_PITS.C2
- KL_FIRM_CLAY_FF_02_PITS.C2
- KL_FIRM_CLAY_RF_02_PITS.C2

B.2 RESULTS

B.2.1 **Normal Sustained**

There are five fittings with code stress exceeding the TD/12 normal sustained allowable stress criterion. A brief summary of the exceptions is provided below, there are;

- Three exceptions on 900mm x 200mm sweepolets
    - There is negligible difference between the code stress in the existing and modified configuration.
- Two exceptions on 900mm x 300mm sweepolets.
    - The exceptions are not exacerbated by the proposed modifications.

Details of the exceptions are provided in Table B1 and locations are shown in Figure 6 to Figure 9.

7.2 Shakedown

There are fourteen fittings exceeding the TD/12 shakedown allowable stress criterion. A brief summary of the of exceptions is shown below, there are;

- Five exceptions on 900mm x 200mm sweepolets.
    - At four locations there is negligible difference between the code stress in the existing and modified configuration.
    - At Node 15990 the modifications significantly reduce the current code stress exception.
- Five exceptions on 900mm x 300mm sweepolets.
    - There is negligible difference between the code stress in the existing and modified configuration.
- Four exceptions on 900mm x 900mm equal tees.
    - There is negligible difference between the code stress in the existing and modified configuration.

Details of the exceptions, are provided in B2 and their locations are provided in Figure 6 to Figure 9. Where exceptions are observed for multiple loadcases per fitting, only the most onerous loadcase has been reported.

Node	Pit Association*	Fitting	Code Stress Ratio (%)			
			Lower Bound		Upper Bound	
			Existing	Proposed	Existing	Proposed
410	n/a	900 x 200 Sweepolet	-	-	111	111
15040	Pit 1 & Pit-2		-	-	149.48	150.19
15990	Pit-3		164.88	89.54	240.66	164.4
5810	n/a	900 x 300 Sweepolet	-	-	104.56	104.56
15090	Pit-1		-	-	-	-
15920	Pit-1		-	-	101.73	101.69

Table B1 – Sustained Exceptions – (See Figures 7 to 9 for Fitting Location)

[redacted]

Node	Pit Association	Fitting	Code Stress Ratio (%)							
			Lower Bound				Upper Bound			
			Forward Flow		Reverse Flow		Forward Flow		Reverse Flow	
			Existing	Proposed	Existing	Proposed	Existing	Proposed	Existing	Proposed
410	n/a	900 x 200 Sweepolet	104.72	104.73	122.62	122.63	125.95	125.95	173.04	173.57
480	n/a		108.95	108.95	137.21	137.21	119.24	119.24	150.79	151.23
1480	n/a		-	-	100.04	100.03	-	-	-	-
15040	Pit-1 & Pit-2		111.88	113.29	103.64	104.58	229.35	230.12	156.24	157.3
15990	Pit-3		164.47	117.12	237.4	140.46	207.92	158.92	357.9	247.24
5810	n/a	900 x 300 Sweepolet	108.48	108.48	108.26	108.26	130.14	130.14	131.68	131.81
6070	n/a		120.3	120.29	125.8	125.79	132.66	132.66	137.38	137.83
15090	Pit-1		125.65	125.46	113.90	114.12	127.33	127.15	112.97	112.9
15760	Pit-1		127.09	127.13	134.94	135.07	135.88	135.81	134.87	134.81
15920	Pit-1		152.82	152.82	153.91	153.93	163.45	163.39	159.05	158.93
1220	n/a	900 x 900 Tee	-	-	-	-	103.0	103	-	-
15070	Pit-1 & Pit-2		-	-	-	-	-	-	-	-
15220	Pit-1		127.13	127.16	108.41	108.45	107.19	107.12	-	-
15350	n/a		-	-	-	-	102.87	102.86	103.7	103.7
15880	Pit-1		104.05	104.07	-	-	100.16	100.19	-	-

Table B2 – Worst Case Shakedown Exceptions – (See Figures 9 and 10 for Fitting Location)