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KINGS LYNN COMPRESSOR STATION – IGE/TD/12 FATIGUE ANALYSIS OF BI-DIRECTIONAL AREA PIPING

Confidential *Restricted to,* [redacted]
[redacted]

[redacted]

[redacted]

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REVISION STATUS INDEX

SUMMARY OF CHANGES	SECTION NUMBER	REVISIONS					
		1	**2**	**3**	**4**	**5**	**6**
Includes results for removal of all pits and backfill with soft fill (only updated results table so far).		**X**					
900mm x 50mm (6160) weldolet exception removed		**X**					

[redacted]

Executive Summary

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. National Grid hope to achieve continued operation of the bi-directional area up to 2050 and have requested a fatigue study be undertaken to consider both past and future usage, giving due consideration to the modifications stated.

Pressure and temperature cycling data for the site have been provided from July 2015 to August 2021, which is to be used for predicting past and future fatigue usage from 1998 to 2050. In the absence of site operating conditions pre-installation of the bi-directional area it is proposed to consider Industry Best Practice operating conditions, in accordance with IGE/TD/12, when considering fatigue usage from 1971 to 1998.

The purpose of this study is to:

- Perform a rainflow-counting analysis to determine the number of discrete pressure and temperature cycles between 2015 and 2021, for forward and reverse flow operation.
- Create piping models to consider the significant piping arrangement changes between 1971 and 2003.
- Perform a fatigue assessment of the site to the requirements of IGE/TD/12 taking into account past and future operation to 2050.
- Identify which fittings, if any, would be at risk of failing by fatigue.

The purpose of this report is to describe the analysis that was undertaken, to set out the conclusions and to make any recommendations as is necessary.

Conclusions

1. National Grid have provided temperature and pressure data recorded at Kings Lynn compressor station between 2015 and 2021.
    i. The data has been censored to remove negative pressures.
    ii. The temperature data has not been utilised due to numerous occurrences of unrealistic sub-zero and >50°C readings.
2. A Rainflow-counting analysis has been undertaken of the censored pressure data to determine the number of discrete pressure cycles for the loadcase pressure ranges recommended in IGE/TD/12.
3. Piping stress models have been created to capture the significant piping arrangement modifications from 1971 to 2021.
4. Fatigue analyses have been assessed to consider both non-factored and factored (factor of 10 on actual cycles) fatigue usage when considering future operation.

5. IGE/TD/12 fatigue analyses have been undertaken to determine the cumulative fatigue usage since commissioning to 2050.
6. For the existing piping arrangement, with non-factored fatigue usage, there are four fatigue code stress exceptions located at two 900mm x 50mm weldolets and two 900mm x 200mm sweepolets.
    i. The highest fatigue exception is 15.36 at a 900mm x 200mm sweepolet located at Node 15990.
7. For the existing piping arrangement with factored fatigue usage there are eight fatigue code stress exceptions, the exceptions are located at:
    - two 900mm x 50mm weldolets,
    - four 900mm x 200mm sweepolets,
    - one 900mm x 900mm tee, and
    - one 900mm x 300mm sweepolet.

    i. The highest fatigue exception is 46.64 at a 900mm x 200mm sweepolet located at Node 15990.
8. Whilst the fatigue usage values appear high it should be borne in mind that they are proportional to the cube of the stress ranges. It follows that it may be possible to show acceptability of the fittings by undertaking a more detailed design-by-analysis assessment involving the finite element method to remove the conservatism from the stress concentration factors.
9. National Grid have also requested a fatigue study to be performed considering the removal of three pits on Feeder 2. These results are reported in Appendix B. For the models considering the proposed removal of the pits on Feeder 2.
    i. The same fatigue exceptions remain; however the maximum fatigue usage at Node 15990 reduces to 21.22.
    ii. The fatigue usage at two sweepolets is marginally exacerbated by the removal of all three pits.
10. An additional assessment has been undertaken to consider the effects of removing Pit-2 and Pit-3 only.
    i. The predicted fatigue usage is either lower or remains unchanged from that observed in the existing configuration.
    ii. A summary of all assessments considered herein is provided in Table 14 and Table 15 for soft and firm soil properties respectively.

[redacted]

Recommendations

National Grid to advise which pits, if any, on Feeder 2 are to be removed and the forces and moments from the appropriate models should be used in the Stage-2 assessment.

National Grid to advise if the pits on Feeder 2 are to be removed and the forces and moments from the appropriate models should be used in the Stage 2 assessment.

[redacted]

CONTENTS

1 INTRODUCTION

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. National Grid hope to achieve continued operation of the bi-directional area up to 2050 and have requested a fatigue study be undertaken to consider both past and future usage, giving due consideration to the modifications stated.

Pressure and temperature cycling data for the site has been provided from July 2015 to August 2021, which is to be used for predicting past and future fatigue usage from 1998 to 2050. In the absence of site operating conditions pre-installation of the bi-directional area it is proposed to consider Industry Best Practice operating conditions, in accordance with IGE/TD/12, when considering fatigue usage from 1971 to 1998.

1.1 Purpose

The purpose of this study is to:

- Perform a Rainflow-counting analysis to determine the number of discrete pressure and temperature cycles between 2015 and 2021, for forward and reverse flow operation.
- Construct piping models to consider the significant piping arrangement changes between 1971 and 2003.
- Perform a fatigue assessment of the site to the requirements of IGE/TD/12 taking into account past and future operation to 2050.
- Identify which fittings, if any, would be at risk of failing by fatigue.

The purpose of this report is to describe the analysis that was undertaken, to set out the conclusions and to make any recommendations as is necessary.

1.2 Scope

The extent of the pipework consider for the fatigue assessment at Kings Lynn compressor station, including location of pits, is shown in Figure 1.

2 MODELLING

2.1 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**
National Grid		
20210810 Kings Lynn Compressor.xlsx		Kings Lynn Pressure and Temperature Cycling Data – 2015 to 2021

2.2 CAESAR II Models

Pipe stress models have been created using CAESAR II v12 [2]. 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

The following piping models have been created of the site in 1971.

Models: Period 1971-1998

- 1971_FIRM_CLAY.C2
- 1971_SOFT_CLAY.C2

The following models have been created including addition of the bi-directional area in 1998.

Models: Period 1998-2003

- 1998_FF_FIRM_CLAY.C2
- 1998_FF_SOFT_CLAY.C2
- 1998_RF_FIRM_CLAY.C2
- 1998_RF_SOFT_CLAY.C2

The following models have been created including addition of the pigging loop in 2003.

Models: Period 2003-2021

- 2003-2021_FF_FIRM_CLAY.C2
- 2003-2021_FF_SOFT_CLAY.C2
- 2003-2021_RF_FIRM_CLAY.C2
- 2003-2021_RF_SOFT_CLAY.C2

Models: Period 2021-2050 (No safety factor)

- 2021-2050_FF_FIRM_CLAY.C2
- 2021-2050_FF_SOFT_CLAY.C2
- 2021-2050_RF_FIRM_CLAY.C2
- 2021-2050_RF_SOFT_CLAY.C2

Models: 2021-2050: (Safety Factor of 10 on future cycles)

National Grid have requested an additional assessment case be considered, assuming a safety factor of 10 applied to the future operating cycles, from 2021 to 2050[10]. to account for uncertainty of the site operating conditions. The following models have been created assuming a safety factor of 10 applied to the future operating cycles, from 2021 to 2050.

- 2021-2050_x10_FF_FIRM_CLAY.C2
- 2021-2050_x10_FF_SOFT_CLAY.C2
- 2021-2050_x10_RF_FIRM_CLAY.C2
- 2021-2050_x10_RF_SOFT_CLAY.C2

3 INPUT DATA

Piping and fitting input data is as per that reported in [redacted]-R0706-21-01 [3].

4 OPERATING CONDITIONS

IGE/TD/12 contains a list of loadcases and required number of cycles to be considered for a fatigue assessment. However, it only provides guidance for the pressure and temperature ranges which the loadcases should consider.

Where site specific data is not available loadcases are assessed assuming Industry Best Practice pressure and temperature ranges, as shown in Table 3 and Table 4.

National Grid have provided pressure and temperature data recorded from July 2015 to August 2021 [4], and it is assumed the operating conditions at the site have not changed since installation of the bi-directional area in 1998. It is therefore proposed to use the supplied operating data when considering fatigue usage from installation of the bi-directional area to the target design life (2050).

Figure 2 and Figure 3 show the recorded pressure data readings between 2015 and 2021 for forward and reverse flow operation, respectively. It can be seen there are periods of time for which negative pressure was recorded. These are assumed to be reading errors and have therefore been amended to 0 barg, as shown in Figure 4 and Figure 5 for forward and reverse flow operation, respectively.

The data also included temperature readings ranging from -30°C to +58°C, which have been deemed unreliable. Consequently, the temperature reading data has not been used and site specific temperatures provided in [redacted]-R0706-21 have been considered, as outlined in the following section.

4.1 Operating Temperatures

Taking guidance from IGE/TD/12 and T/SP/PW/13[5] the following temperatures have been used;

- Above ground maximum and minimum design 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 [6].
- Minimum below ground suction temperature of 8°C [7].
- Assumed minimum below ground discharge temperature of 37°C, to produce a temperature swing of 10°C from the maximum, as per industry best practice.

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 [6].
- Minimum below ground suction temperature of 8°C [7].
- Assumed minimum below ground discharge temperature of 37°C, to produce a temperature swing of 10°C from the maximum, as per industry best practice.

4.2 Operating Pressures

To satisfy the pressure ranges to be considered the following pressures have been applied:

- MIP – 79.5 barg
- MOP – 75 barg
- Compressor Operating – 60 barg
- Winter Demand Pressure – 69 barg

- Summer Demand Pressure – 70 barg

Temperatures and pressures used for the analyses are provided in Table 1 and Table 2.

4.3 Fatigue Cycles

The number of fatigue cycles for each construction phase is outlined below.

4.3.1 Period 1971 to 1998

From the original construction date to installation of the bi-directional area is 27 years. The fatigue cases and corresponding required number of cycles, as per IGE/TD/12, for this time period are provided in Table 4.

4.3.2 Period 1998 to 2050

4.3.2.1 Case-1 (No Factoring of Cycles)

It is assumed the operating conditions of the site remain unchanged since installation of the bi-directional area in 1998. It is therefore proposed to use the pressure cycling data provided in Ref. [4] to determine the fatigue usage from 1998 to 2050.

The rainflow-counting method has been used to count the number of discrete pressure cycles for the pressure ranges shown in Table 3 and Table 4 for forward and reverse flow, respectively.

To consider the changes to the site piping arrangement since installation of the bi-directional area the required number of cycles have been separated into the time periods: 1998 to 2003; 2003 to 2021 and 2021 to 2050. The number of fatigue cycles considered, and model identifiers, are provided in Table 5.

4.3.2.2 Case-2 (Factoring of Cycles)

To account for uncertainty of the future site operating conditions National Grid have requested an additional assessment case be considered, assuming a safety factor of 10 applied to the future operating cycles, from 2021 to 2050[10]. The number of fatigue cycles considered, and model identifiers, are provided in Table 6.

4.4 Loadcases

Using the pressure, temperature and cycling conditions outlined above a loadcase table was created in accordance with the guidance of IGE/TD/12. The loadcase table as entered into CAESAR II is shown in Table 5 and Table 6 for the two cases respectively.

5 BURIED PIPE MODELLING

For this analysis the soil restraint has been calculated using the American Lifelines Alliance[8] 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 0. 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[9].

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 soil properties used are shown in Table 7, whilst the information as entered into CAESAR II is shown in Table 8 and Table 9.

6 FATIGUE CRITERION

The fatigue analysis considers variations in the principal stresses over the life of the installation due to normal expected operation. The fatigue life considers the variation of the pressure and temperature loads from a notional starting point. Therefore, the calculated stresses represent ranges and are used with the appropriate fatigue class curve to evaluate the allowable number of cycles. This is performed for each of the fatigue duties and a Miner's Law summation is performed to determine the cumulative fatigue damage, which should not exceed unity.

The 'target' design life of the site is set at 2050.

The maximum permitted number of cycles, N, for a corresponding peak stress range, S_R, is given by:

$$N = \frac{A}{S_R{}^m}, \qquad [1]$$

where S_R is the maximum principal stress range.

Values for the constants m and A appearing in the above expression are provided in TD/12 for various classes of weld, which relate different component types.

For variable pressure cycling, the total fatigue damage (D_f) is then calculated using the Miner's Law summation for the periods of construction and operation and is given by the following;

$$D_f = \sum\left[\frac{n_i}{N_i}\right]_{1971-1998} + \sum\left[\frac{n_i}{N_i}\right]_{1998-2003} + \sum\left[\frac{n_i}{N_i}\right]_{2003-2021} + \sum\left[\frac{n_i}{N_i}\right]_{2021-2050} \qquad [2]$$

Where n_i is the actual number of cycles and N_i is the maximum permitted number of cycles for a given pressure fluctuation. For Case 2, n is increased by factor of 10 for the 2021-2050 period of operation.

For an acceptable fatigue life, the total fatigue damage (D_f) should be less than unity.

7 RESULTS

Occurrences of fatigue damage that exceed unity are termed ‘exceptions’. Results are provided from original commissioning (1971) to the various periods of construction phases and future operation showing how the fatigue damage accrues over time.

7.1 Period 1971 to 1998

Considering fatigue cycling from 1971 to 1998, the predicted usage is greater than unity at three locations. A summary of the exceptions is shown below:

- 900mm x 50mm weldolet (Node 6160).
- 900mm x 50mm weldolet (Node 6220).
- 900mm x 200mm sweepolet (Node 15990).

The maximum fatigue usage is 9.21 (at Node 15990) for the model with firm clay soil properties.

7.2 Period 1971 to 2003

Considering fatigue cycling from 1971 to 2003, the predict usage is greater than unity at three locations. A summary of the exceptions is shown below:

- 900mm x 50mm weldolet (Node 6160).
- 900mm x 50mm weldolet (Node 6220).
- 900mm x 200mm sweepolet (Node 15990).

The maximum fatigue usage is 9.75 (at Node 15990) for the model with firm clay soil properties.

7.3 Period 1971 to 2021

Considering fatigue cycling from 1971 to 2021, the predict usage is greater than unity at four locations. A summary of the exceptions is shown below:

- 900mm x 50mm weldolet (Node 6160).
- 900mm x 50mm weldolet (Node 6220).
- 900mm x 200mm sweepolet (Node 15990).
- 900mm x 200mm sweepolet (Node 15040).

The maximum fatigue usage is 11.89 (at Node 15990) for the model with firm clay soil properties.

7.4 Period 1971 to 2050

7.4.1 Case-1 (No Factoring of Cycles)

Considering fatigue cycling from 1971 to 2050, the predict usage is greater than unity at four locations. A summary of the exceptions is shown below:

- 900mm x 50mm weldolet (Node 6160).
- 900mm x 50mm weldolet (Node 6220).
- 900mm x 200mm sweepolet (Node 15990).
- 900mm x 200mm sweepolet (Node 15040).

The maximum fatigue usage is 15.36 (at Node 15990) for the model with firm clay soil properties.

The locations of the fatigue exceptions are shown in Figure 9 and details are provided in Table 10 and Table 11.

7.4.2 Case-2 (Factoring of Cycles)

For the Case-2 assessment, whereby the number of fatigue cycles for 2021 to 2050 have been increased by a factor of 10 to take into account uncertainty in future operation, the predict usage is greater than unity at nine locations. A summary of the exceptions is shown below:

- 900mm x 50mm weldolet (Node 6160)
- 900mm x 50mm weldolet (Node 6220)
- 900mm x 50mm weldolet (Node 15920)
- 900mm x 200mm weldolet (Node 410)
- 900mm x 200mm weldolet (Node 480)
- 900mm x 200mm sweepolet (Node 15990)
- 900mm x 200mm sweepolet (Node 15040)
- 900mm x 300mm sweepolet (Node 6070)
- 900mm x 900mm Tee (Node 6180)

The maximum fatigue usage is 46.64 (at Node 15990) for the model with firm clay soil properties.

The locations of the fatigue exceptions are shown in Figure 9 and details are provided in Table 12 and Table 13.

8 PROPOSED REMOVAL OF PITS ON FEEDER 2 PIPING

National Grid have requested that an additional assessment be considered whereby the three remaining pits located on the Feeder 2 piping are demolished and back-filled with native soil. Details of the effect of the proposed removal of the pits on Feeder 2 are provided in Appendix B.

Comparing the results for Case-1 (non-factored fatigue usage from 2021 to 2050) it can be seen the removal of the pits has a beneficial effect on a 900mm x 200mm sweepolet (node 15990). Whist the fatigue usage at a 900mm x 200mm sweepolet (node 15040) is marginally exacerbated by the proposed modifications.

Comparing the results of Case-2 (fatigue usage factored from 2021 to 2050) it can be seen the removal of the pits has a beneficial effect on a 900mm x 200mm sweepolet (node 15990). Whilst the fatigue usage at a 900mm x 200mm sweepolet (node 15040) and 900mm x 50mm weldolet (node 15920) is marginally exacerbated.

In light of the results discussed above, and in an attempt to better understand the influence of each pit, an additional study has been undertaken to consider the effects of removing Pit-2 and Pit-3 only. The results of the study are presented in Appendix C.

It is shown that the predicted fatigue usage is either lower or remains the same as that predicted for the existing piping arrangement. A summary of the results for all assessments considered herein are provided in Table 14 and Table 15 for soft and firm clay soil properties, respectively.

National Grid are to advise if the pits on Feeder 2 are to be removed and the forces and moments from the appropriate models should be used in the Stage-2 assessment.

9 SUMMARY OF FATIGUE RESULTS

Whilst the fatigue usage values appear high it should be borne in mind that they are proportional to the cube of the stress ranges. It follows that it may be possible to show acceptability of the fittings by undertaking a more detailed design-by-analysis assessment involving the finite element method to remove the conservatism from the stress concentration factors.

Fittings of the same type and size were identified as having code stress exceptions in report [redacted]-R0706-21, which require resolution. It is therefore recommended the exceptions identified herein are included in the scope of works for the Stage-2 programme of work.

The fittings

[redacted]

10 CONCLUSIONS

1. National Grid have provided temperature and pressure data recorded at Kings Lynn compressor station between 2015 and 2021.
    i. The data has been censored to remove negative pressures.
    ii. The temperature data has not been utilised due to numerous occurrences of unrealistic sub-zero and >50°C readings.
2. A Rainflow-counting analysis has been undertaken of the censored pressure data to determine the number of discrete pressure cycles for the loadcase pressure ranges recommended in IGE/TD/12.
3. Piping stress models have been created to capture the significant piping arrangement modifications from 1971 to 2021.
4. Fatigue analyses have been assessed to consider both non-factored and factored (factor of 10 on actual cycles) fatigue usage when considering future operation.
5. IGE/TD/12 fatigue analyses have been undertaken to determine the cumulative fatigue usage since commissioning to 2050.
6. For the existing piping arrangement, with non-factored fatigue usage, there are four fatigue code stress exceptions located at two 900mm x 50mm weldolets and two 900mm x 200mm sweepolets.
    i. The highest fatigue exception is 15.36 at a 900mm x 200mm sweepolet located at Node 15990.
7. For the existing piping arrangement with factored fatigue usage there are eight fatigue code stress exceptions, the exceptions are located at:
    - two 900mm x 50mm weldolets,
    - four 900mm x 200mm sweepolets,
    - one 900mm x 900mm tee, and
    - one 900mm x 300mm sweepolet.

    i. The highest fatigue exception is 46.64 at a 900mm x 200mm sweepolet located at Node 15990.
8. Whilst the fatigue usage values appear high it should be borne in mind that they are proportional to the cube of the stress ranges. It follows that it may be possible to show acceptability of the fittings by undertaking a more detailed design-by-analysis assessment involving the finite element method to remove the conservatism from the stress concentration factors.
9. National Grid have also requested a fatigue study to be performed considering the removal of three pits on Feeder 2. These results are reported in Appendix B. For the models considering the proposed removal of the pits on Feeder 2.

   i. The same fatigue exceptions remain; however the maximum fatigue usage at Node 15990 reduces to 21.22.

   ii. The fatigue usage at two sweepolets is marginally exacerbated by the removal of all three pits.

10. An additional assessment has been undertaken to consider the effects of removing Pit-2 and Pit-3 only.

   i. The predicted fatigue usage is either lower or remains unchanged from that observed in the existing configuration.

   ii. A summary of all assessments considered herein is provided in Table 14 and Table 15 for soft and firm soil properties respectively.

11 RECOMMENDATIONS

For the fittings which exceed the IGE/TD/12 fatigue assessment criterion it is recommended a more detailed finite element analysis is undertaken to better understand the level and distribution of stress in the fitting.

Fittings of the same type and size were identified as having code stress exceptions in report [redacted]-R0706-21, which require resolution. It is therefore recommended the exceptions identified herein are included in the scope of works for the Stage-2 programme of work.

National Grid to advise which pits, if any, on Feeder 2 are to be removed and the forces and moments from the appropriate models should be used in the Stage-2 assessment.

12 REFERENCES

1. IGE/TD/12 Edition 2, Reprint with Amendments, Communication 1757, 2012, Pipework Stress Analysis for Gas Industry Plant, Institution of Gas Engineers & Managers.
2. CAESAR II v12 SP1 12.00.01.0015, (Build 210109).
3. [redacted]-R0706-21, 'Kings Lynn Compressor Station – Integrity Assessment of Bi-directional Pipework Affected by Ground Subsidence', 13/09/21.
4. Email from [redacted], 'Kings Lynn bi-directional area – historical flow records', Tue 10/08/2021 15:39.
5. T/SP/PW/13, Specification for Carrying Out Pipework Stress Analysis to the Requirements of IGE/TD/12, National Grid, September 2011.
6. [redacted], 'Kings Lynn Compressor Station Stress Analysis Rev 1', September 1999.
7. Email from [redacted], 'NARC - Stress Info', 16/08/2018.
8. Guidelines for the Design of Buried Steel Pipe, American Lifelines Alliance.

9. NEN3650-1+C1:2017, Requirements for Pipeline Systems, Nederlands Normalisatie Institute.

10. Technical Query Form, 'Kings Lynn Bi-directional Area – Fatigue Analysis Cycles', 01/10/2021.

TABLES

CAESARII Designation	Description	Temperature (°C)			
		Suction		Discharge	
		Above Ground	Below Ground	Above Ground	Below Ground
T1	Max, no flow	50	15	50	15
T2	Max Winter	25	15	25	47
T3	Min, no flow	-20	5	-20	5
T4	Min Winter, flow	-20	8	-20	37
T5	Min Summer, flow	10	8	10	37

CAESARII Designation	Description	Pressure (barg)
P1	MIP	79.5
P2	MOP	75
P3	Compressor Operating	60
P4	Winter Demand	69
P5	Summer Demand	70

Table 1 – Temperature and Pressure Table – Forward Flow (KL to Bacton)

CAESARII Designation	Description	Temperature (°C)			
		Suction		Discharge	
		Above Ground	Below Ground	Above Ground	Below Ground
T1	Max, no flow	50	18	50	47
T2	Max Winter	25	18	25	47
T3	Min, no flow	-20	5	-20	5
T4	Min Winter, flow	-20	8	-20	37
T5	Min Summer, flow	10	8	10	37

CAESARII Designation	Description	Pressure (barg)
P1	MIP	79.5
P2	MOP	75
P3	Compressor Operating	60
P4	Winter Demand	69
P5	Summer Demand	70

Table 2 – Temperature and Pressure Table – Reverse Flow (Bacton to KL)

[redacted]

IGE/TD/12 Loadcase	Pressure (bar)	Pressure Range (barg)	Temperature (°C)					
			Suction		Discharge		Operating Status	
			Above Ground	Below Ground	Above Ground	Below Ground		TD/12 Assessment
6a	79.5	79.5	50	15	50	47	Fault conditions	Fatigue Analysis
6b	0		Tie-in					
7a	75	75	50	15	50	47	Annual commissioning and decommissioning	
7b	0		Tie-in					
8a	75	15	25	15	25	47	Compressor station operation*	
8b	60		-20	5	-20	5		
9a	75	6	25	15	25	47	Winter diurnal*	
9b	69		-20	8	-20	37		
10a	75	5	50	15	50	47	Summer diurnal*	
10b	70		10	8	10	37		

Table 3 – Loadcase Table – Forward Flow (KL to Bacton)

*Industry Best Practice pressure range

IGE/TD/12 Loadcase	Pressure (bar)	Pressure Range (barg)	Temperature (°C)						
			Suction		Discharge		Operating Status	TD/12 No. of Cycles	
			Above Ground	Below Ground	Above Ground	Below Ground			TD/12 Assessment
6a	79.5	79.5	50	18	50	47	Fault conditions	5 [4]*	Fatigue Analysis
6b	0		Tie-in						
7a	75	75	50	18	50	47	Annual commissioning and decommissioning	40 [27]*	
7b	0		Tie-in						
8a	75	15	25	18	25	47	Compressor station operation	1000 [675]*	
8b	60		-20	5	-20	5			
9a	75	6	25	18	25	47	Winter diurnal	8000 [5400]*	
9b	69		-20	8	-20	37			
10a	75	5	50	18	50	47	Summer diurnal	6000 [4050]*	
10b	70		10	8	10	37			

Table 4 – Loadcase Table – Reverse Flow (Bacton to KL)

*Fatigue usage from 1971 to 1998

Case	Combination	Identifier	Number of Cycles							
			IGE/TD/12		Rainflow-counting					
			Models: 1971-1998*		Models: 1998-2003*		Models: 2003-2021*		Models: 2021-2050*	
			Forward Flow	Reverse Flow	Forward Flow	Reverse Flow	Forward Flow	Reverse Flow	Forward Flow	Reverse Flow
L1	W+T1+P1	OPE		<u>Caesar II Models:</u> 1971_SOFT_CLAY 1971_FIRM_CLAY	<u>Caesar II Models:</u> 1998_FF_SOFT_CLAY 1998_FF_FIRM_CLAY	<u>Caesar II Models:</u> 1998_RF_SOFT_CLAY 1998_RF_FIRM_CLAY	<u>Caesar II Models:</u> 2003_FF_SOFT_CLAY 2003_FF_FIRM_CLAY	<u>Caesar II Models:</u> 2003_RF_SOFT_CLAY 2003_RF_FIRM_CLAY	<u>Caesar II Models:</u> 2021-2050_FF_SOFT_CLAY 2021-2050_FF_FIRM_CLAY	<u>Caesar II Models:</u> 2021-2050_RF_SOFT_CLAY 2021-2050_RF_FIRM_CLAY
L2	W	OPE								
L3	W+T1+P2	OPE								
L4	W+T2+P2	OPE								
L5	W+T3+P3	OPE								
L6	W+T4+P4	OPE								
L7	W+T5+P5	OPE								
L8	L1-L2	FAT	0	4	0	0	4	4	2	2
L9	L3-L2	FAT	0	27	1	2	12	22	7	13
L10	L4-L5	FAT	0	675	5	53	46	502	29	310
L11	L4-L6	FAT	0	5400	31	81	294	765	181	472
L12	L3-L7	FAT	0	4050	139	265	1310	2495	809	1539

<u>Table 5- Loadcase Combinations for CAESAR II – Existing Piping Arrangement – Case-1</u>

*See Section 2.2 for applicable models

Case	Combination	Identifier	Number of Cycles							
			IGE/TD/12		Rainflow-counting					
			Models: 1971-1998*		Models: 1998-2003*		Models: 2003-2021*		Models: 2021-2050*	
			Forward Flow	Reverse Flow	Forward Flow	Reverse Flow	Forward Flow	Reverse Flow	Forward Flow	Reverse Flow
L1	W+T1+P1	OPE		<u>Caesar II Models:</u> 1971_SOFT_CLAY 1971_FIRM_CLAY	<u>Caesar II Models:</u> 1998_FF_SOFT_CLAY 1998_FF_FIRM_CLAY	<u>Caesar II Models:</u> 1998_RF_SOFT_CLAY 1998_RF_FIRM_CLAY	<u>Caesar II Models:</u> 2003_FF_SOFT_CLAY 2003_FF_FIRM_CLAY	<u>Caesar II Models:</u> 2003_RF_SOFT_CLAY 2003_RF_FIRM_CLAY	<u>Caesar II Models:</u> 2021-2050_X10_FF_SOFT_CLAY 2021-2050_X10_FF_FIRM_CLAY	<u>Caesar II Models:</u> 2021-2050_X10_RF_SOFT_CLAY 2021-2050_X10_RF_FIRM_CLAY
L2	W	OPE								
L3	W+T1+P2	OPE								
L4	W+T2+P2	OPE								
L5	W+T3+P3	OPE								
L6	W+T4+P4	OPE								
L7	W+T5+P5	OPE								
L8	L1-L2	FAT	0	4	0	0	4	4	20	20
L9	L3-L2	FAT	0	27	1	2	12	22	70	1320
L10	L4-L5	FAT	0	675	5	53	46	502	290	3100
L11	L4-L6	FAT	0	5400	31	81	294	765	1810	4720
L12	L3-L7	FAT	0	4050	139	265	1310	2495	8090	15390

<u>Table 6- Loadcase Combinations for CAESAR II – Existing Piping Arrangement – Case-2</u>

*See Section 2.2 for applicable models

Soil Type	Effective Density (kg/m^3)	Effective Cohesion c' (kN/m^2)
Cohesive – Lower Bound	427	25
Cohesive – Upper Bound	2039	200

Table 7 – Soil Strength Parameters

LOWER	
GAMMA PRIME – EFFECTIVE SOIL DENSITY (kg/cu.m.)	1427
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)	

Table 8 – CAESAR II Soil Input, Soft Clay (Lower Bound)

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 9 – CAESAR II Soil Input, Firm Clay (Upper Bound

Node	Fitting Type	Fatigue Usage							
		1971 to 1998	1998 to 2003		2003 to 2021		2021 to 2050		Cumulative Fatigue Damage (D_f)
		Reverse Flow	Reverse Flow	Forward Flow	Reverse Flow	Forward Flow	Reverse Flow	Forward Flow	
15990	900x200 Sweepolet	1.74	0.1	0	0.42	0.01	0.68	0.01	2.96

Table 10 – Fatigue Exceptions – Soft Clay – Case-1

Node		Fatigue Usage							
		1971 to 1998	1998 to 2003		2003 to 2021		2021 to 2050		Cumulative Fatigue Damage (D_f)
		Reverse Flow	Reverse Flow	Forward Flow	Reverse Flow	Forward Flow	Reverse Flow	Forward Flow	
6220	900x50 Weldolet	1.35	0.06	0	0	0	0	0	1.41
15990	900x200 Sweepolet	9.21	0.53	0.01	2.12	0.02	3.44	0.03	15.36
15040		0.97	0.01	0.01	0.07	0.02	0.11	0.04	1.23

Table 11 – Fatigue Exceptions – Firm Clay – Case-1

Node	Fitting Type	Fatigue Usage							
		1971 to 1998	1998 to 2003		2003 to 2021		2021 to 2050		

		Reverse Flow	Reverse Flow	Forward Flow	Reverse Flow	Forward Flow	Reverse Flow	Forward Flow	Cumulative Fatigue Damage (D_f)
15990	900x200 Sweepolet	1.74	0.1	0	0.42	0.02	6.79	0.11	9.18
480		0	0	0	0.06	0	0.92	0.04	1.02

Table 12 – Fatigue Exceptions – Soft Clay – Case-2

Node	Fitting Type	Fatigue Usage							
		1971 to 1998	1998 to 2003		2003 to 2021		2021 to 2050		Cumulative Fatigue Damage (D_f)
		Reverse Flow	Reverse Flow	Forward Flow	Reverse Flow	Forward Flow	Reverse Flow	Forward Flow	
6220	900x50 Weldolet	1.35	0.06	0	0	0	0.04	0.01	1.46
15920		0	0.01	0	0.05	0.01	0.87	0.11	1.05
6180	900 x 900 Tee	0.82	0.03	0	0.01	0	0.12	0.02	1
15990	900x200 Sweepolet	9.21	0.53	0.01	2.12	0.02	34.43	0.32	46.64
15040		0.97	0.01	0.01	0.07	0.02	1.1	0.43	2.61
410		0	0	0	0.17	0	2.84	0.05	3.06
480		0	0	0	0.1	0	1.66	0.03	1.79
6070	900 x 300 Sweepolet	0	0.06	0	0.06	0	0.97	0.07	1.16

Table 13 – Fatigue Exceptions – Firm Clay – Case-2

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	900x200 Sweepolet	2.96	2.35*	2.35*	9.18	3.14	3.13*
480		-	-	-	1.02	1.02	1.02

Table 14 – Results Summary – Soft Clay

*lowest predicted fatigue usage

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
6220	900 x 50 Weldolet	1.41	1.41	1.41	1.46	1.46	1.46
15920		-	-	-	1.05	1.11	1.04*
6180	900 x 900 Tee	-	-	-	1	1	1
15990	900 x 200 Sweepolet	15.36	12.82*	12.83	46.64	21.22*	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
6070	900 x 300 Sweepoplet	-	-	-	1.16	1.16	1.16

Table 15 – Results Summary – Firm Clay

*lowest predicted fatigue usage

[redacted]

[redacted]

FIGURES

[redacted]

Figure 1 – Location of Bi-directional Area

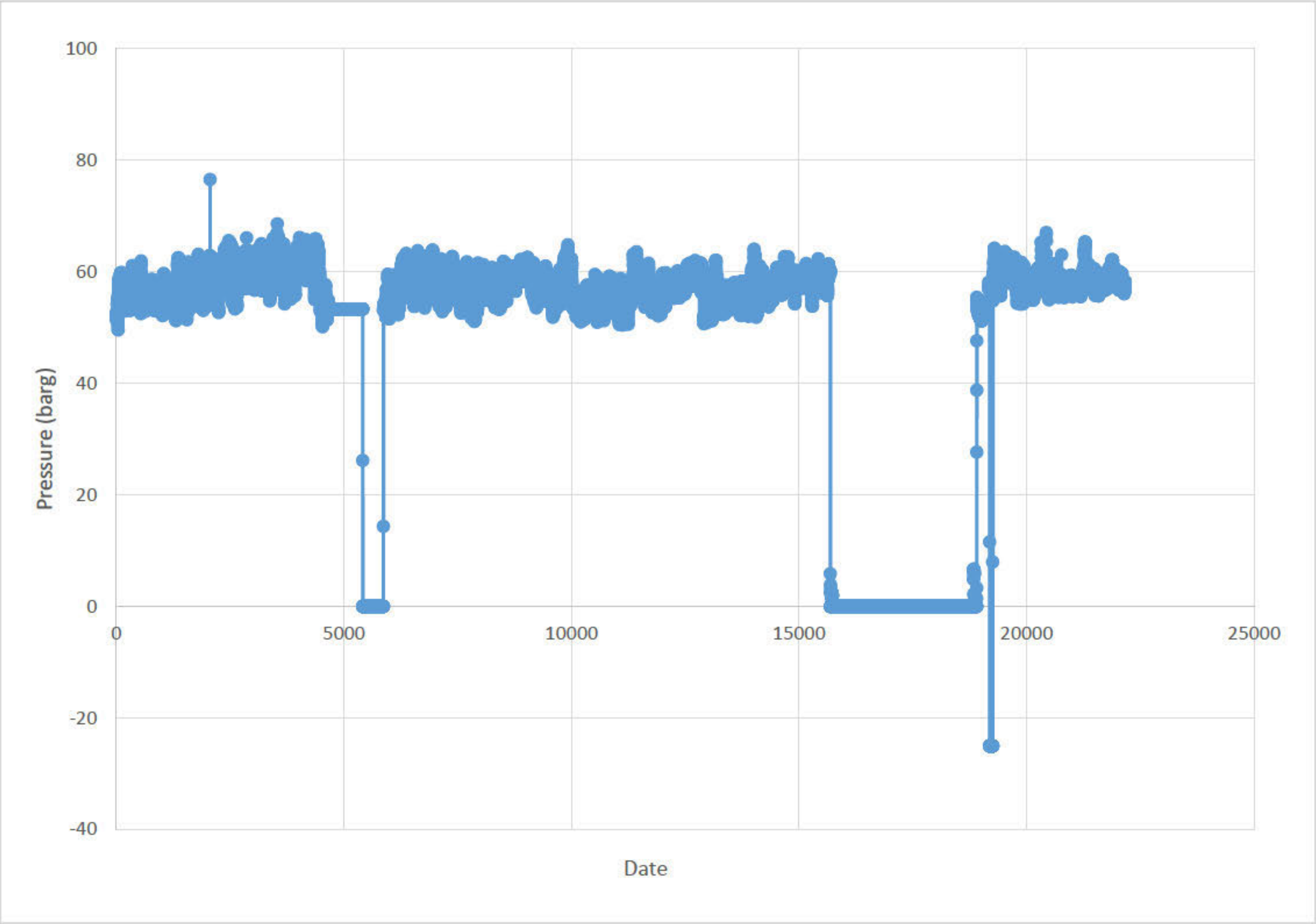

Figure 2 – Recorded Pressure Data from August 2015 to August 2021 – Forward Flow

[redacted]

[redacted]

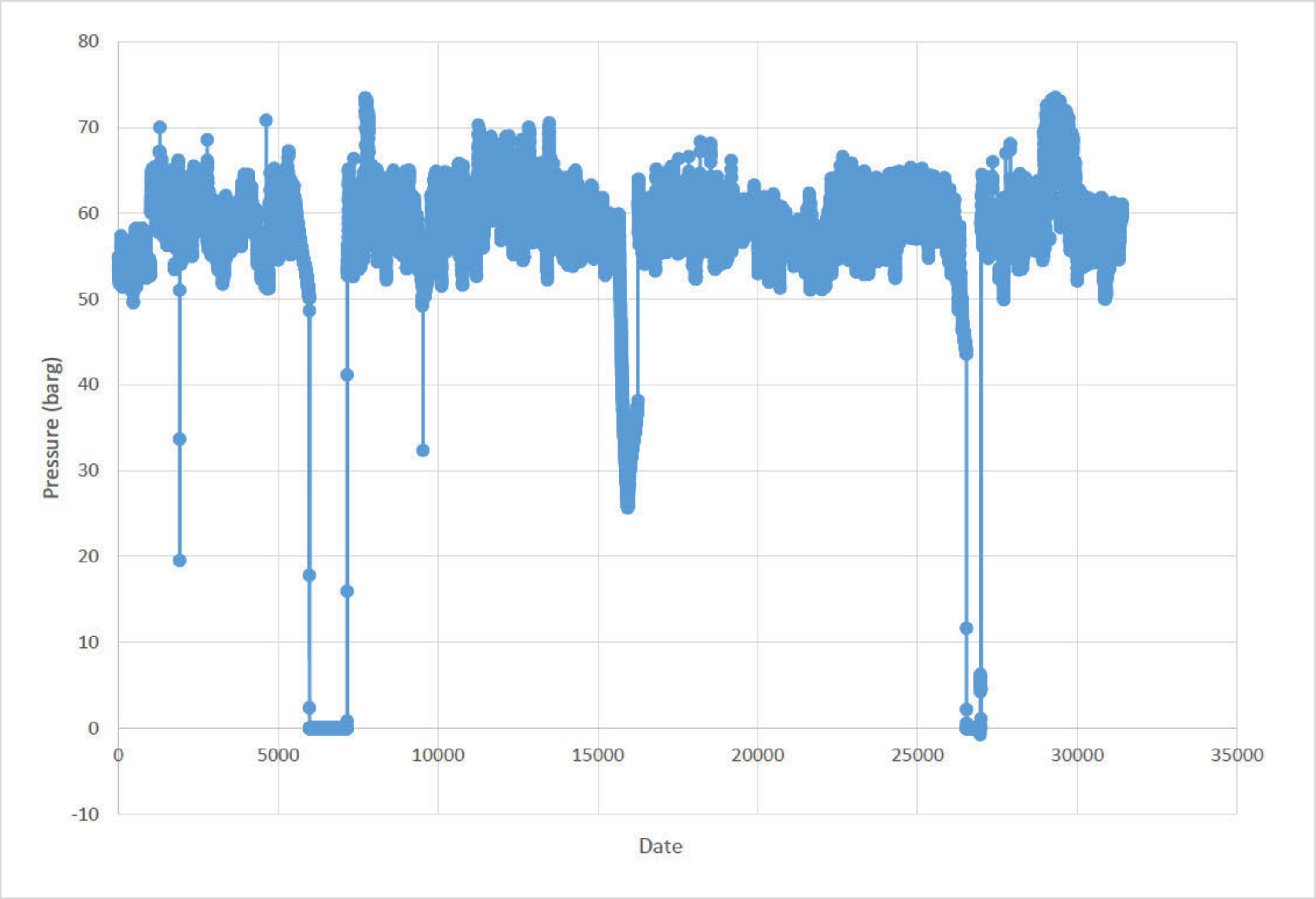

Figure 3 – Recorded Pressure Data from July 2015 to April 2021 – Reverse Flow

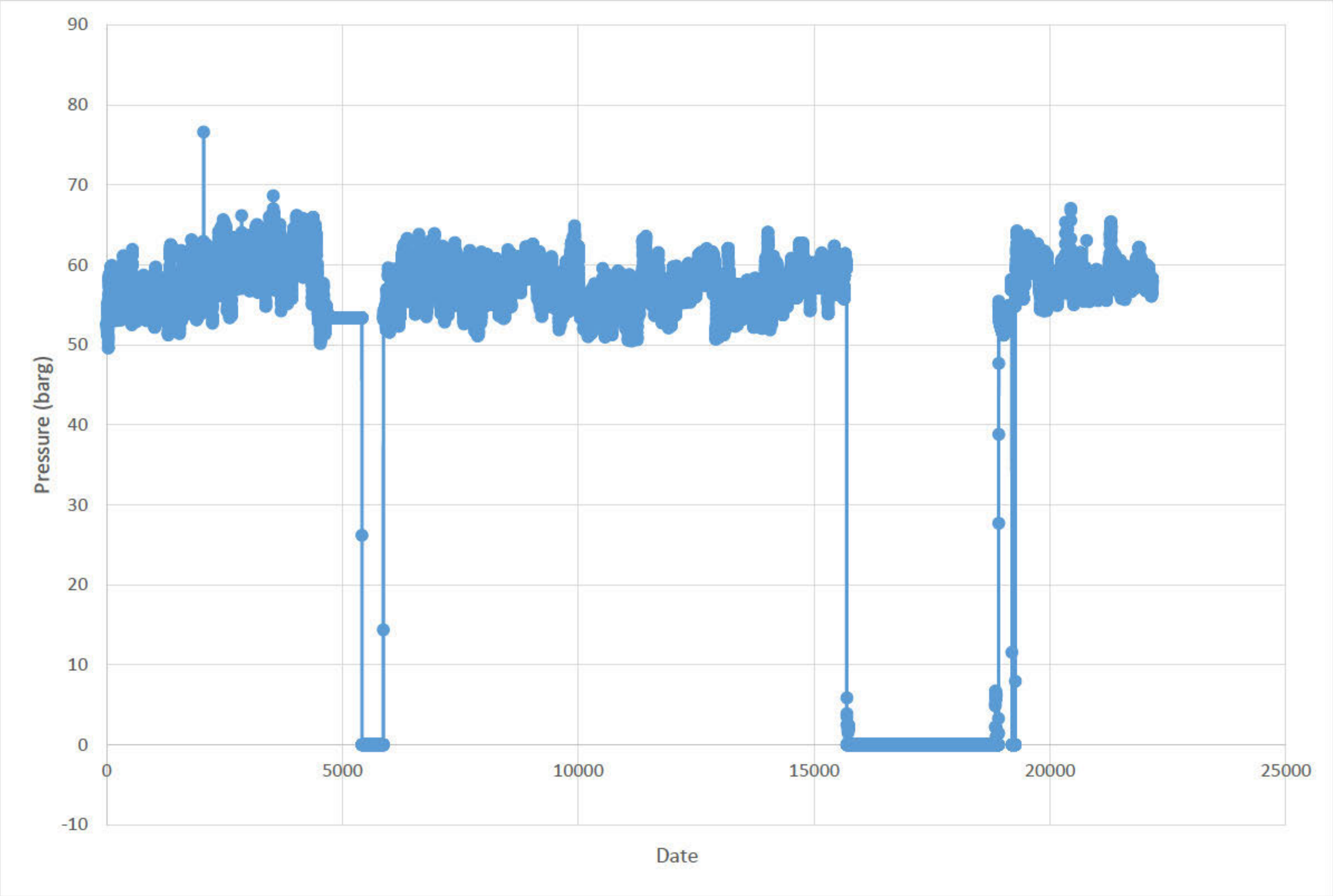

Figure 4 – Censored Pressure Data from August 2015 to August 2021 – Forward Flow

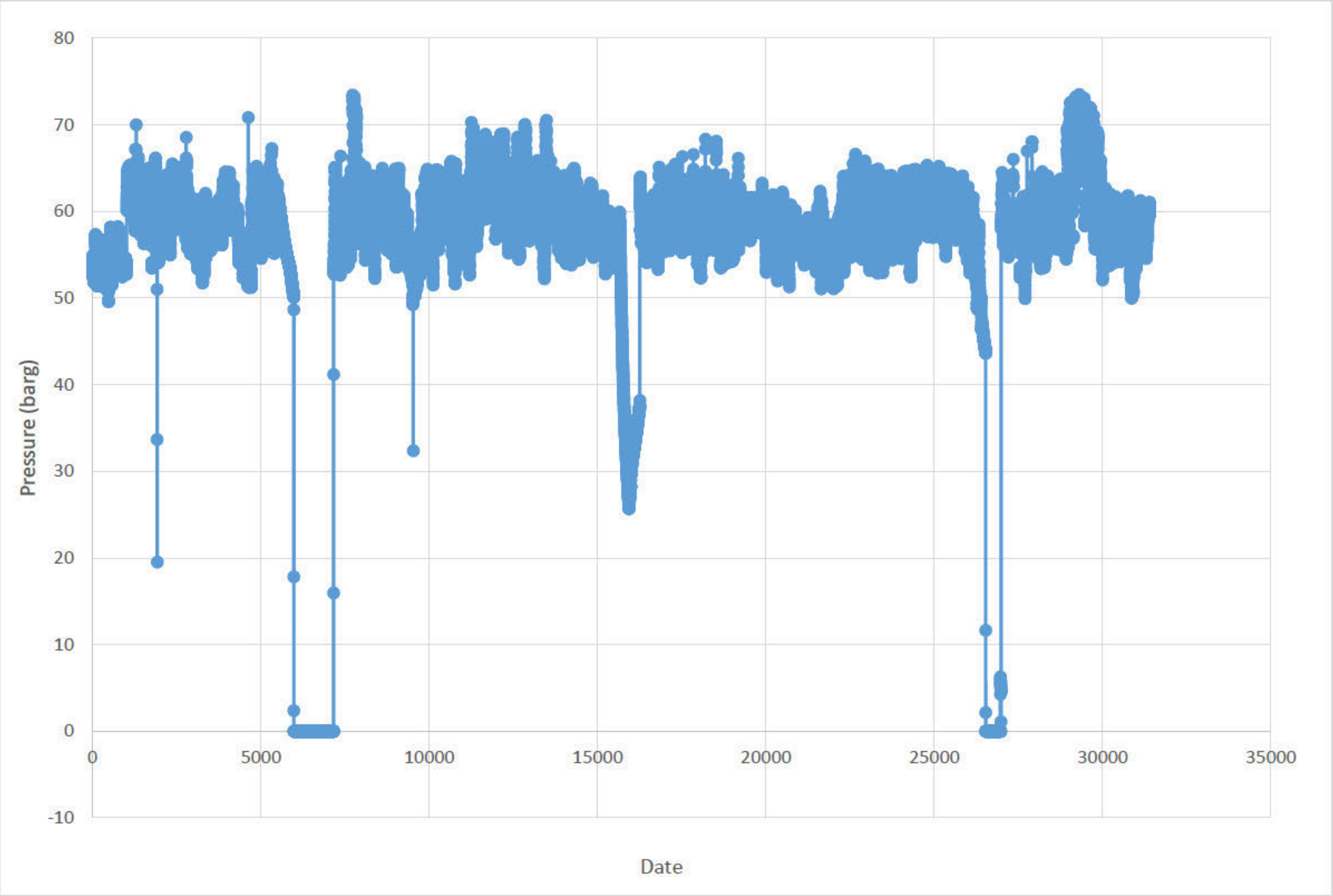

Figure 5 – Censored Pressure Data from July 2015 to April 2021 – Reverse Flow

[redacted]

Figure 6 – Fatigue Exception Locations

[redacted]

[redacted]

Figure 7 – Fatigue Exception Locations Cont'd

[redacted]

HISTORIC BOREHOLES

[redacted]

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Rotary Borehole Record

BH01A

Sheet 1 of 6

[redacted]

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)
TOPSOIL (Dark brown slightly silty gravelly fine to coarse SAND. Gravel is angular to subrounded fine to coarse flint. Occasional rootlets present).	0.50
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.	1.25
Light yellowish brown clayey gravelly fine to coarse SAND. Gravel is angular to subangular fine and medium flint.	1.90
Soft grey mottled brown sandy CLAY with rare gravel of subrounded fine and medium flint.	2.00
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.*	

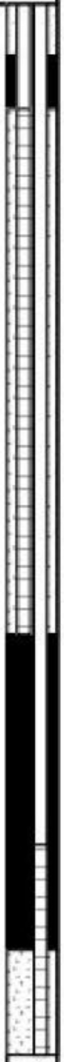
Elevation (mAOD)

T.C.R. (%)	S.C.R. (%)	R.Q.D. (%)
13	0	0
50	50	0
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		

Installation & Backfill



Hole Diameter by Depth		Drilling Flush Details		
Depth Base (m)	Diameter (mm)	Depth (m)	Type	Return (%)
6.50	146	6.50 - 7.50	WATER	100
51.00	116	7.50 - 9.00	WATER	100
		9.00 - 10.50	WATER	60

Casing Diameter by Depth	
Depth Base (m)	Diameter (mm)
6.50	150

Water Strike

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

[redacted]

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.

Logged by: JE	Checked by: JA	Fm-Hn-R-3870-Rev D

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Rotary Borehole Record

BH02

Sheet 1 of 6

[redacted]

Project ID:	GN21822	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%)	

[redacted]

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.*	1.20 1.60
Light brown mottled brown slightly clayey fine to coarse SAND with rare gravel of subrounded fine and medium flint.	
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.*	

T.C.R. (%)	S.C.R. (%)	R.Q.D. (%)
100	80	0
75	67	0
[illegible]	[illegible]	0

Type	Depth	Results / Remarks	Date - Depth (m) Casing (Water)	Installation & Backfill
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=50 (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 (3,2/5,4,5,6)	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	60

Casing Diameter by Depth

Depth Base (m)	Diameter (mm)
6.00	150

Water Strike

Date	Strike Depth (m)	Depth Sealed (m)	Casing Depth (m)	Time Elapsed (mins)	Standing Level (m)	Remarks
17-05-2018	1.20					Seepage

[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.

Logged by: JE | Checked by: JA | Fm-Hn-R-3070-Rev D

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Rotary Borehole Record

BH03

Sheet 1 of 6

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

Geology Description	Legend	Depth (m)	Elevation (mAOD)
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	
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).		0.60	
Light brown mottled brown slightly clayey gravelly fine to coarse SAND. Gravel is angular to subrounded fine to medium flint.		1.20	
Medium dense brown slightly gravelly fine to coarse SAND. Gravel is subrounded fine flint. *From 1.60m: Becoming silty.*		1.80	
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.*			

T.C.R. (%)	S.C.R. (%)	R.Q.D. (%)
40	40	40
89	89	61
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	4.20 - 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	7.20 - 7.50		
SPT(S)	7.50	N=20 (2,3/4,5,5,6)	6.00 (1.00)
D8	7.80		
HV01	8.00		
HV02	8.80		
D9	9.00		
U3	9.00 - 9.20		
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

[redacted]

Water Strike

Date	Strike Depth (m)	Depth Sealed (m)	Casing Depth (m)	Time Elapsed (mins)	Standing Level (m)	Remarks
09-05-2018	1.00					Seepage

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.

Logged by: JE	Checked by: JA	Frm-Ho-R-3870-Rev D

[redacted]

PROPOSED REMOVAL OF PITS ON FEEDER 2 PIPING

There are currently three pits located on the Feeder 2 piping (as shown in Figure 1) which National Grid are considering demolishing and backfilling with native soil.

The following CAESARII piping models have been created to consider the fatigue usage from 2021 to 2050 with the pits removed.

- 2021-2050_FF_FIRM_CLAY_NO_PITS.C2
- 2021-2050_FF_SOFT_CLAY_NO_PITS.C2
- 2021-2050_RF_FIRM_CLAY_NO_PITS.C2
- 2021-2050_RF_SOFT_CLAY_NO_PITS.C2

- 2021-2050_X10_FF_FIRM_CLAY_NO_PITS.C2
- 2021-2050_X10_RF_FIRM_CLAY_NO_PITS.C2
- 2021-2050_X10_FF_SOFT_CLAY_NO_PITS.C2
- 2021-2050_X10_RF_SOFT_CLAY_NO_PITS.C2

The number of fatigue cycles considered, and model identifiers are provided in Table B1 and Table B2 for the un-factored and factored fatigue cycles, respectively.

CASE-1 (NON-FACTORED FATIGUE USAGE)

Considering fatigue cycling from 1971 to 2050, the predict usage is greater than unity at four locations. A summary of the exceptions is shown below:

- 900mm x 50mm weldolet (Node 6160).
- 900mm x 50mm weldolet (Node 6220).
- 900mm x 200mm sweepolet (Node 15990).
- 900mm x 200mm sweepolet (Node 15040).

The maximum fatigue usage is 12.82 (at Node 15990) for the model with firm clay soil properties.

The locations of the fatigue exceptions are shown in Figure 9 and details are provided in Table B3 and Table B4.

CASE-2 (FACTORED FATIGUE USAGE)

For the Case-2 assessment, whereby the number of fatigue cycles for 2021 to 2050 have been factored, the predict usage is greater than unity at nine locations. A summary of the exceptions is shown below:

- 900mm x 50mm weldolet (Node 6070)

[redacted]

- 900mm x 50mm weldolet (Node 6160)
- 900mm x 50mm weldolet (Node 6220)
- 900mm x 200mm weldolet (Node 410)
- 900mm x 200mm weldolet (Node 480)
- 900mm x 200mm sweepolet (Node 15990)
- 900mm x 200mm sweepolet (Node 15040)
- 900mm x 300mm Sweepolet (Node 15920)
- 900mm x 900mm Tee (Node 6180)

The maximum fatigue usage is 21.22 (at Node 15990) for the model with firm clay soil properties.

The locations of the fatigue exceptions are shown in Figure 9 and details are provided in Table B5 and Table B6.

Comparing the results for Case-1 (non-factored fatigue usage from 2021 to 2050) it can be seen the removal of the pits has a beneficial effect on the two 900mm x 200mm sweepolets located in the region of Pit-2 and Pit-3.

Comparing the results of Case-2 (fatigue usage factored from 2021 to 2050) it can be seen the removal of the pits has both a beneficial and detrimental effect on the predicted fatigue usage for different regions of the site. Specifically, the fatigue usage at Node 15990 reduces from 46.64 to 21.22. However, an exception is introduced on a 900mm x 300mm sweepolet, at Node 15920. The exception is most likely due to the removal of Pit-1.

Case	Combination	Identifier	Number of Cycles							
			IGE/TD/12		Rainflow-counting					
			Models: 1971-1998*		Models: 1998-2003*		Models: 2003-2021*		Models: 2021-2050*	
			Forward Flow	Reverse Flow	Forward Flow	Reverse Flow	Forward Flow	Reverse Flow	Forward Flow	Reverse Flow
L1	W+T1+P1	OPE		Caesar II Models: 1971_SOFT_CLAY 1971_FIRM_CLAY	Caesar II Models: 1998_FF_SOFT_CLAY 1998_FF_FIRM_CLAY	Caesar II Models: 1998_RF_SOFT_CLAY 1998_RF_FIRM_CLAY	Caesar II Models: 2003_FF_SOFT_CLAY 2003_FF_FIRM_CLAY	Caesar II Models: 2003_RF_SOFT_CLAY 2003_RF_FIRM_CLAY	Caesar II Models: 2021-2050_FF_SOFT_CLAY_NO_PITS 2021-2050_FF_FIRM_CLAY_NO_PITS	Caesar II Models: 2021-2050_RF_SOFT_CLAY_NO_PITS 2021-2050_RF_FIRM_CLAY_NO_PITS
L2	W	OPE								
L3	W+T1+P2	OPE								
L4	W+T2+P2	OPE								
L5	W+T3+P3	OPE								
L6	W+T4+P4	OPE								
L7	W+T5+P5	OPE								
L8	L1-L2	FAT	0	4	0	0	4	4	2	2
L9	L3-L2	FAT	0	27	1	2	12	22	7	13
L10	L4-L5	FAT	0	675	5	53	46	502	29	310
L11	L4-L6	FAT	0	5400	31	81	294	765	181	472
L12	L3-L7	FAT	0	4050	139	265	1310	2495	809	1539

Table B1 - Loadcase Combinations for CAESAR II – Pits Removed – Case-1

*See Section 2.2 for applicable models

Case	Combination	Identifier	Number of Cycles							
			IGE/TD/12		Rainflow-counting					
			Models: 1971-1998*		Models: 1998-2003*		Models: 2003-2021*		Models: 2021-2050*	
			Forward Flow	Reverse Flow	Forward Flow	Reverse Flow	Forward Flow	Reverse Flow	Forward Flow	Reverse Flow
L1	W+T1+P1	OPE		<u>Caesar II Models:</u> 1971_SOFT_CLAY 1971_FIRM_CLAY	<u>Caesar II Models:</u> 1998_FF_SOFT_CLAY 1998_FF_FIRM_CLAY	<u>Caesar II Models:</u> 1998_RF_SOFT_CLAY 1998_RF_FIRM_CLAY	<u>Caesar II Models:</u> 2003_FF_SOFT_CLAY 2003_FF_FIRM_CLAY	<u>Caesar II Models:</u> 2003_RF_SOFT_CLAY 2003_RF_FIRM_CLAY	<u>Caesar II Models:</u> 2021-2050_X10_FF_SOFT_CLAY_NO_PITS 2021-2050_X10_FF_FIRM_CLAY_NO_PITS	<u>Caesar II Models:</u> 2021-2050_X10_RF_SOFT_CLAY_NO_PITS 2021-2050_X10_RF_FIRM_CLAY_NO_PITS
L2	W	OPE								
L3	W+T1+P2	OPE								
L4	W+T2+P2	OPE								
L5	W+T3+P3	OPE								
L6	W+T4+P4	OPE								
L7	W+T5+P5	OPE								
L8	L1-L2	FAT	0	4	0	0	4	4	20	20
L9	L3-L2	FAT	0	27	1	2	12	22	70	1320
L10	L4-L5	FAT	0	675	5	53	46	502	290	3100
L11	L4-L6	FAT	0	5400	31	81	294	765	1810	4720
L12	L3-L7	FAT	0	4050	139	265	1310	2495	8090	15390

<u>Table B2- Loadcase Combinations for CAESAR II – Pits Removed – Case-2</u>

[redacted]

Node	Fitting Type	Fatigue Usage							
		1971 to 1998	1998 to 2003		2003 to 2021		2021 to 2050		Cumulative Fatigue Damage (D_f)
		Reverse Flow	Reverse Flow	Forward Flow	Reverse Flow	Forward Flow	Reverse Flow	Forward Flow	
6160	900x50 Weldolet	0.89	0.04	0	0.04	0	0.06	0.01	1.04
15990*	900x200 Sweepolet	1.74	0.1	0	0.42	0.01	0.08	0	2.35

Table B3 – Fatigue Exceptions – Soft Clay – Pits Removed – Case-1

**fatigue exception reduced by removal of pits

Node	Fitting Type	Fatigue Usage							
		1971 to 1998	1998 to 2003		2003 to 2021		2021 to 2050		Cumulative Fatigue Damage (D_f)
		Reverse Flow	Reverse Flow	Forward Flow	Reverse Flow	Forward Flow	Reverse Flow	Forward Flow	
6160	900x50 Weldolet	3.66	0.13	0	0.08	0.01	0.14	0.01	4.03
6220		1.35	0.06	0	0	0	0	0	1.41
15990**	900x200 Sweepolet	9.21	0.53	0.01	2.12	0.02	0.92	0.01	12.82
15040*		0.97	0.01	0.01	0.07	0.02	0.14	0.05	1.27

Table B4 – Fatigue Exceptions – Firm Clay - Pits Removed – Case-1

*fatigue exception exacerbated by removal of pits
**fatigue exception reduced by removal of pits

Node	Fitting Type	Fatigue Usage							
		1971 to 1998	1998 to 2003		2003 to 2021		2021 to 2050		Cumulative Fatigue Damage (D_f)
		Reverse Flow	Reverse Flow	Forward Flow	Reverse Flow	Forward Flow	Reverse Flow	Forward Flow	
6160	900x50 Weldolet	0.89	0.04	0	0.04	0	0.6	0.07	1.64
15990*	900x200 Sweepolet	1.74	0.1	0	0.42	0.01	0.84	0.03	3.14
480		0	0	0	0.06	0	0.92	0.04	1.02

Table B5 – Fatigue Exceptions – Soft Clay – Pits Removed – Case-2

*fatigue exception reduced by removal of pits

[redacted]

Node	Fitting Type	Fatigue Usage							
		1971 to 1998	1998 to 2003		2003 to 2021		2021 to 2050		Cumulative Fatigue Damage (D_f)
		Reverse Flow	Reverse Flow	Forward Flow	Reverse Flow	Forward Flow	Reverse Flow	Forward Flow	
6160	900x50 Weldolet	3.66	0.13	0	0.08	0.01	1.38	0.12	5.38
6220		1.35	0.06	0	0	0	0.04	0.01	1.46
15920*		0	0.01	0	0.05	0.01	0.93	0.11	1.11
6180	900 x 900 Tee	0.82	0.03	0	0.01	0	0.12	0.02	1
15990**	900x200 Sweepolet	9.21	0.53	0.01	2.12	0.02	9.23/2.25***	0.1/0.04***	21.22/14.18***
15040*		0.97	0.01	0.01	0.07	0.02	1.37	0.48	2.9
410		0	0	0	0.17	0	2.84	0.05	3.06
480		0	0	0	0.1	0	1.66	0.03	1.79
6070	900x300 Sweepolet	0	0.06	0	0.06	0	0.97	0.07	1.16

Table B6 – Fatigue Exceptions – Firm Clay - Pits Removed – Case-2

*fatigue exception exacerbated by removal of pits
**fatigue exception reduced by removal of pits
***Loose sand backfill after removal of pits

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 fatigue usage 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.

.1 MODELS

- 2021-2050_FF_FIRM_CLAY_NO_PITS2.C2
- 2021-2050_FF_SOFT_CLAY_NO_PITS2.C2
- 2021-2050_RF_FIRM_CLAY_NO_PITS2.C2
- 2021-2050_RF_SOFT_CLAY_NO_PITS2.C2

- 2021-2050_X10_FF_FIRM_CLAY_NO_PITS2.C2
- 2021-2050_X10_RF_FIRM_CLAY_NO_PITS2.C2
- 2021-2050_X10_FF_SOFT_CLAY_NO_PITS2.C2
- 2021-2050_X10_RF_SOFT_CLAY_NO_PITS2.C2

The number of fatigue cycles considered, and model identifiers are provided in Table C1 and Table C2 for the un-factored and factored fatigue cycles, respectively.

CASE-1 (NON-FACTORED FATIGUE USAGE)

Considering fatigue cycling from 1971 to 2050, the predict usage is greater than unity at four locations. A summary of the exceptions is shown below:

- 900mm x 50mm weldolet (Node 6160).
- 900mm x 50mm weldolet (Node 6220).
- 900mm x 200mm sweepolet (Node 15990).
- 900mm x 200mm sweepolet (Node 15040).

The maximum fatigue usage is 12.83 (at Node 15990) for the model with firm clay soil properties.

The locations of the fatigue exceptions are shown in Figure 9 and details are provided in Table C3 and Table C4.

CASE-2 (FACTORED FATIGUE USAGE)

For the Case-2 assessment, whereby the number of fatigue cycles for 2021 to 2050 have been factored, the predict usage is greater than unity at nine locations. A summary of the exceptions is shown below:

- 900mm x 50mm weldolet (Node 6070)
- 900mm x 50mm weldolet (Node 6160)
- 900mm x 50mm weldolet (Node 6220)
- 900mm x 200mm weldolet (Node 410)
- 900mm x 200mm weldolet (Node 480)
- 900mm x 200mm sweepolet (Node 15990)
- 900mm x 200mm sweepolet (Node 15040)
- 900mm x 300mm Sweepolet (Node 15920)
- 900mm x 900mm Tee (Node 6180)

The maximum fatigue usage is 21.28 (at Node 15990) for the model with firm clay soil properties.

The locations of the fatigue exceptions are shown in Figure 9 and details are provided in Table B5 and Table B6.

Comparing the results for Case-1 (non-factored fatigue usage from 2021 to 2050) it can be seen the removal of the pits has a beneficial effect on the two 900mm x 200mm sweepolet at node 15990.

Comparing the results of Case-2 (fatigue usage factored from 2021 to 2050) it can be seen the removal of the pits has a beneficial effect on the predicted fatigue usage at node 15990 whilst all other locations remain unaffected.

Case	Combination	Identifier	Number of Cycles							
			IGE/TD/12		Rainflow-counting					
			Models: 1971-1998*		Models: 1998-2003*		Models: 2003-2021*		Models: 2021-2050*	
			Forward Flow	Reverse Flow	Forward Flow	Reverse Flow	Forward Flow	Reverse Flow	Forward Flow	Reverse Flow
L1	W+T1+P1	OPE		Caesar II Models: 1971_SOFT_CLAY 1971_FIRM_CLAY	Caesar II Models: 1998_FF_SOFT_CLAY 1998_FF_FIRM_CLAY	Caesar II Models: 1998_RF_SOFT_CLAY 1998_RF_FIRM_CLAY	Caesar II Models: 2003_FF_SOFT_CLAY 2003_FF_FIRM_CLAY	Caesar II Models: 2003_RF_SOFT_CLAY 2003_RF_FIRM_CLAY	Caesar II Models: 2021-2050_FF_SOFT_CLAY_NO_PITS2 2021-2050_FF_FIRM_CLAY_NO_PITS2	Caesar II Models: 2021-2050_RF_SOFT_CLAY_NO_PITS2 2021-2050_RF_FIRM_CLAY_NO_PITS2
L2	W	OPE								
L3	W+T1+P2	OPE								
L4	W+T2+P2	OPE								
L5	W+T3+P3	OPE								
L6	W+T4+P4	OPE								
L7	W+T5+P5	OPE								
L8	L1-L2	FAT	0	4	0	0	4	4	2	2
L9	L3-L2	FAT	0	27	1	2	12	22	7	13
L10	L4-L5	FAT	0	675	5	53	46	502	29	310
L11	L4-L6	FAT	0	5400	31	81	294	765	181	472
L12	L3-L7	FAT	0	4050	139	265	1310	2495	809	1539

Table C1 - Loadcase Combinations for CAESAR II – Pits Removed – Case-1

*See Section 2.2 for applicable models

Case	Combination	Identifier	Number of Cycles							
			IGE/TD/12		Rainflow-counting					
			Models: 1971-1998*		Models: 1998-2003*		Models: 2003-2021*		Models: 2021-2050*	
			Forward Flow	Reverse Flow	Forward Flow	Reverse Flow	Forward Flow	Reverse Flow	Forward Flow	Reverse Flow
L1	W+T1+P1	OPE		Caesar II Models: 1971_SOFT_CLAY 1971_FIRM_CLAY	Caesar II Models: 1998_FF_SOFT_CLAY 1998_FF_FIRM_CLAY	Caesar II Models: 1998_RF_SOFT_CLAY 1998_RF_FIRM_CLAY	Caesar II Models: 2003_FF_SOFT_CLAY 2003_FF_FIRM_CLAY	Caesar II Models: 2003_RF_SOFT_CLAY 2003_RF_FIRM_CLAY	Caesar II Models: 2021-2050_X10_FF_SOFT_CLAY_NO_PITS2 2021-2050_X10_FF_FIRM_CLAY_NO_PITS2	Caesar II Models: 2021-2050_X10_RF_SOFT_CLAY_NO_PITS2 2021-2050_X10_RF_FIRM_CLAY_NO_PITS2
L2	W	OPE								
L3	W+T1+P2	OPE								
L4	W+T2+P2	OPE								
L5	W+T3+P3	OPE								
L6	W+T4+P4	OPE								
L7	W+T5+P5	OPE								
L8	L1-L2	FAT	0	4	0	0	4	4	20	20
L9	L3-L2	FAT	0	27	1	2	12	22	70	1320
L10	L4-L5	FAT	0	675	5	53	46	502	290	3100
L11	L4-L6	FAT	0	5400	31	81	294	765	1810	4720
L12	L3-L7	FAT	0	4050	139	265	1310	2495	8090	15390

Table C2- Loadcase Combinations for CAESAR II – Pits Removed – Case-2

Node	Fitting Type	Fatigue Usage							
		1971 to 1998	1998 to 2003		2003 to 2021		2021 to 2050		Cumulative Fatigue Damage (D_f)
		Reverse Flow	Reverse Flow	Forward Flow	Reverse Flow	Forward Flow	Reverse Flow	Forward Flow	
6160	900x50 Weldolet	0.89	0.04	0	0.04	0	0.06	0.01	1.04
15990*	900x200 Sweepolet	1.74	0.1	0	0.42	0.01	0.08	0	2.35

Table C3 – Fatigue Exceptions – Soft Clay – Pit-2 & Pit-3 Removed – Case-1

*fatigue exception reduced by removal of pits

Node	Fitting Type	Fatigue Usage							
		1971 to 1998	1998 to 2003		2003 to 2021		2021 to 2050		Cumulative Fatigue Damage (D_f)
		Reverse Flow	Reverse Flow	Forward Flow	Reverse Flow	Forward Flow	Reverse Flow	Forward Flow	
6160	900x50 Weldolet	3.66	0.13	0	0.08	0.01	0.14	0.01	4.03
6220		1.35	0.06	0	0	0	0	0	1.41
15990*	900x200 Sweepolet	9.21	0.53	0.01	2.12	0.02	0.93	0.01	12.83
15040		0.97	0.01	0.01	0.07	0.02	0.11	0.04	1.23

Table C4 – Fatigue Exceptions – Firm Clay - Pits Removed – Case-1

*fatigue exception reduced by removal of pits

Node	Fitting Type	Fatigue Usage							
		1971 to 1998	1998 to 2003		2003 to 2021		2021 to 2050		Cumulative Fatigue Damage (D_f)
		Reverse Flow	Reverse Flow	Forward Flow	Reverse Flow	Forward Flow	Reverse Flow	Forward Flow	
6160*	900x50 Weldolet	0.89	0.04	0	0.04	0	0.6	0.07	1.64
15990*	900x200 Sweepolet	1.74	0.1	0	0.42	0.01	0.83	0.03	3.13
480		0	0	0	0.06	0	0.92	0.04	1.02

Table C5 – Fatigue Exceptions – Soft Clay – Pits Removed – Case-2

*fatigue exception reduced by removal of pits

Node	Fitting Type	Fatigue Usage							
		1971 to 1998	1998 to 2003		2003 to 2021		2021 to 2050		Cumulative Fatigue Damage (D_f)
		Reverse Flow	Reverse Flow	Forward Flow	Reverse Flow	Forward Flow	Reverse Flow	Forward Flow	
6160	900x50 Weldolet	3.66	0.13	0	0.08	0.01	1.38	0.12	5.38
6220		1.35	0.06	0	0	0	0.04	0.01	1.46
6180	900 x 900 Tee	0.82	0.03	0	0.01	0	0.12	0.02	1
15990**	900x200 Sweepolet	9.21	0.53	0.01	2.12	0.02	9.23	0.1	21.28
15040		0.97	0.01	0.01	0.07	0.02	1.11	0.42	2.61
410		0	0	0	0.17	0	2.84	0.05	3.06
480		0	0	0	0.1	0	1.66	0.03	1.79
6070	900x300 Sweepolet	0	0.06	0	0.06	0	0.97	0.07	1.16
15920		0	0.01	0	0.05	0.01	0.86	0.11	1.04

Table C6 – Fatigue Exceptions – Firm Clay - Pits Removed – Case-2

**fatigue exception reduced by removal of pits