Kings Lynn Subsidence

Kings Lynn Subsidence Re-opener and Price Control Deliverable Submission

Revision 1.0

30 March 2022

nationalgrid

Contents and Supporting Documents

Executive Summary 3
PCD Status 5
Background 6
Previous Remediation Work Carried Out 13
Investigation and Ongoing Monitoring 14
Findings and Status 16
Innovation 19
Implications for Long Term Network Capability Requirements 20
Supplementary Re-opener Reporting Requirements 21
PCD Costs 23

Document	File Name
[redacted] Report	NG-Asset-GT-KL-RO1-001-[redacted]
Drawing of Monitoring Point Locations	NG-Asset-GT-KL-RO1-002-Monitoring Point Locations
Site Photographs	NG-Asset-GT-KL-RO1-003-Photographs
[redacted] Fatigue Analysis Report	NG-Asset-GT-KL-RO1-004-[redacted] Fatigue Analysis
[redacted] Integrity Assessment Report	NG-Asset-GT-KL-RO1-005-[redacted] Integrity Assessment
[redacted] Removal of Pits Recommendation	NG-Asset-GT-KL-RO1-006-Removal of Pits
[redacted] Stress Analysis Report	NG-Asset-GT-KL-RO1-007-[redacted] Stress Analysis
Borehole Data Raw	NG-Asset-GT-KL-RO1-008-Borehole Data Raw
Borehole Data Interpreted	NG-Asset-GT-KL-RO1-009-Borehole Data Interpreted
Assurance Statement	NG-Asset-GT-KL-RO1-010-Assurance Statement

Executive Summary

This document together with its appendices and attached supporting information comprises National Grid Gas Transmission's (NGGT) submission pursuant to the Gas Transporter Licence Special Condition 3.12, Kings Lynn Subsidence Re-opener and Price Control Deliverable (PCD). Intrusive site works and analytical modelling undertaken with baseline allowances have concluded there is no longer a subsidence driver. In light of these circumstances this is a proportionate submission to close this PCD. No major project investment is proposed at this time and no re-opener allowance is requested.

National Grid Gas Transmission (NGGT) submitted a request for funding to rebuild the bi-directional pipework arrangement at Kings Lynn compressor site as part of their 2019 Business Plan. Ofgem's final determination was to fund the development of a reopener submission for this project by way of a PCD in the amount of £[redacted], to be submitted by the 31st March 2022 via Special Condition 3.12 in the Gas Transmission licence.

The Kings Lynn bi-directional area allows the compressor station to support the Bacton terminals entry and exit flows through the interconnectors to Europe and facilitates the connection to the National Transmission System (NTS), moving gas away from the South East when combined entry flows from the Bacton and Isle of Grain terminals exceeds local demand. Analysis of all Future Energy Scenarios (FES) suggest a long-term requirement for the bi-directional area which is critical for meeting customer's entry and export requirements allowing the UK (United Kingdom) to import and export gas with continental Europe and meet the UK's gas demand.

The subsidence issue at Kings Lynn was first identified in 2011 with various work having been carried out since then to quantify and mitigate the risk. Remedial work included excavation and removal of the concrete from the 50[1] Nominal Bore (NB) pipework allowing it to relevel, and installation of shallow land drainpipe. The quantification work included surveys, bore holes, laser scans, ground penetration radar and stress analyses. Given the strategic significance of the site; its criticality to UK gas flows; and the available data at the time, NGGT considered that there was a need for urgent remediation in the form of a major project to rebuild the bi-directional area to mitigate risks from the eventuality of the complete failure of the bi-directional area pipework.

In 2021, NGGT appointed [redacted] to undertake Front End Engineering Design (FEED) Engineering Justification study to facilitate NGGT's delivery of the PCD and address the specific questions posed by Ofgem in the Reopener Guidance. To undertake further stress analysis work, the 900NB pipework was excavated at strategic locations and monitoring rods were affixed to the buried pipework to facilitate greater accuracy with the surveys than had been achieved by the laser scans. A

[1] *Throughout this document, reference is made to 50NB and 900NB pipelines. These refer to the Nominal Bore diameter of the pipe; with 50NB being a 50mm Nominal Bore pipe and 900NB being a 900mm Nominal Bore pipe.*

search through the physical archives of construction records was undertaken and a prior assumption that the original 1970's valves were not on piled foundations (which had originated from secondary digital sources) was found to be erroneous. These key refinements were fed into an updated stress analysis study involving Finite Element Analysis (FEA) and fatigue analysis taking into account past and future operation out to 2050. During the extensive site surveys carried out at this time, a mains water leak was identified and rectified in August 2021, it is suspected that this was exacerbating the adverse ground conditions.

This refined modelling showed that all but one of the identified over stresses (on a 900NB equal tee) was resolved. The increased confidence in the findings together with the continuous operation and future safe operating life analysis has led NGGT to conclude that the perceived extent of the subsidence and associated integrity risks have therefore been reduced to manageable levels by this study. The monitoring rods, which have been affixed to the 900NB pipework, will remain in situ to facilitate ongoing monitoring. The most recent survey in December 2021 found negligible movement (≤2mm).

The work on the subsidence issue has delivered the ancillary benefit (albeit under the Network Innovation Allowance (NIA) funding mechanism) of furthering the technological readiness of geopolymer injection for ground stabilisation via a successful trial where subsided pipework was stabilised and, in some cases, relevelled at the Kings Lynn site.

NGGT's view is that the PCD has been partially delivered with alternative specification because the work to deliver the reopener submission was curtailed when it became apparent that the subsidence needs case driver for the project was no longer valid and this, of necessity, meant delivering an alternative specification. NGGT determined that incurring further costs in delivering the submission with a subsidence driver would not be in the interests of the consumer and sought guidance from Ofgem that, in accordance with NGGT's Gas Transmission Governance Code S.10.4, the investment can be closed where the needs case is no longer valid. Ofgem agreed this was acceptable and NGGT proceeded on the basis of a proportionate close-out submission.

The project to rebuild the bi-directional area would have addressed outstanding asset health issues concerning valve seal rates; cathodic protection survey findings of potential coating failures; corrosion and refurbishment of actuators. We are conscious the resolution of these issues is interdependent with considerations of the Kings Lynn emissions FOSR/reopener event and/or the Asset Health re-opener and future RIIO-3 plan. We will continue discussions with Ofgem about the best way to take forward a coherent investment strategy for Kings Lynn site under the RIIO-2 framework of regulatory instruments and ensure we deliver our network capability and reliability levels required from the gas transmission network.

The forecast cost to completion for the work undertaken on this PCD (including direct costs of NG (National Grid) personnel and cost of services outsourced to [redacted]) is £[redacted]m in 18/19 price base. NGGT's expectation is that the unused portion of the

£[redacted]m baseline allowance will be returned to consumers through the operation of licence condition Part D Assessment of Price Control Deliverable.

PCD Status

NGGT received baseline allowances in the amount of £[redacted]m in the 21/22 Regulatory year to deliver the Kings Lynn subsidence Price Control Deliverable (PCD) on 31/03/2022, this is termed KLSAt in the Price Control Financial Model.

The PCD is a new mechanism as part of the RIIO-2 framework and provides a price control allowance which is linked to the delivery of outputs specified in the licence. It provides for the possible adjustment of the level and timing of allowances in the event the output is not delivered, not delivered to the specification required, or delivered late.

In December 2021, when it became apparent that the subsidence needs case was no longer the driver or urgency for the investment, NGGT sought guidance from Ofgem on our proposal to close the investment because the needs case was no longer valid, in line with S.10.4 of the Gas Transmission Governance Code, and not submit a Reopener submission requesting further allowances.

In a bilateral meeting on 20th December 2021, NGGT advised Ofgem that, according to the draft [redacted] report, there was no longer a subsidence needs case for the major project to rebuild the bi-directional area and suggested closing down the project; curtailing further spend; and delivering an abbreviated submission to bring the PCD to a conclusion. This is in keeping with the licence condition requirement that a re-opener submission should take account of any allowed expenditure, which can be avoided. There was some uncertainty on both sides how to proceed with the return of the unspent portion of the allowance, which NGGT forecast to be approximately £[redacted], so a further meeting was agreed upon to allow Ofgem to discuss internally.

In a second meeting on 25th January 2022, NGGT advised Ofgem that project spend had been curtailed and our view was that the PCD had been partially delivered with an alternative specification because we had proceeded with delivery up to the point where we believed that further spend would not be in the best interests of consumers which meant the output would, necessarily, be to a different specification from that in the licence.

Ofgem reaffirmed the proportionality principle with respect to PCD assessment, so NGGT proceeded on the basis of a submission proportional to the spend and avoiding further costs, forecasting that the KLSRAt term in the licence would be approximately £[redacted]. The submission of the basic PCD report in July 2022 will finalise spent costs and allow precise assessment of the KLSRAt term.

Background

Description of site

Kings Lynn compressor station sits on National Transmission System (NTS) Feeder 2. Feeder 2 runs from Bacton beach terminal to the East of site, through The Midlands to Dyffryn-Clydach in South Wales. The section of Feeder 2 passing through the Kings Lynn area was constructed in 1967. The compressor station was connected to Feeder 2 in 1970. Connections to Feeders 4 and 27 were added as the network developed further.

The three feeders that pass through the bi-directional pipework arrangement at Kings Lynn constitute three out of five feeders fed from Bacton Terminal, as shown in Figure 1 below. All three of the feeders can be fed from Bacton, which is the largest entry and exit point in the UK. In the period running up to the RIIO-2 Business Plan submission, Bacton had, at times, provided up to 39% of the UK's gas need. On earlier occasions it had provided up to 30% of the system demand. Feeders 4 and 27 are unable to flow directly through the site without passing through the bi-directional pipework arrangement.

The current bi-directional area has evolved, over decades, with changing network conditions. It was developed from an earlier, more simplistic compressor station/feeder connection arrangement, typical elsewhere on the network.

The first 27, or so, years of operation required for Kings Lynn compressor to move gas from East to West, pumping the gas away from Bacton towards other parts of the network and critical hubs around Wisbech and Peterborough. The original configuration was uni-directional only.

The original compressor station/feeder connection arrangement was redesigned and re-engineered, becoming operational in something akin to its current bi-directional area configuration in 1998. This was necessary as Interconnector UK (IUK) facility had been constructed at Bacton Terminal. The IUK facility was designed with 4 large compressor drives to accept gas from the NTS and compress it for conveyance, in an undersea pipeline, to the IUK reception facility in Zeebrugge (Belgium).

From the outset, the IUK facility has been the largest single point load on the NTS. Subsequent upgrades have seen the IUK import capacity grow at Bacton. An additional Interconnector, the Balgzand Bacton Line (BBL), was commissioned at Bacton in 2006.

Within a period overlapping the construction, early operation, and development of these interconnectors, the ability to supply gas from the UK Continental Shelf (UKCS) has diminished significantly. The ability to connect Bacton to significant gas supply and distribution sources, elsewhere in the UK, is heavily impacted by the required safety and operability of major connection facilities within the network. Kings Lynn is one such facility.

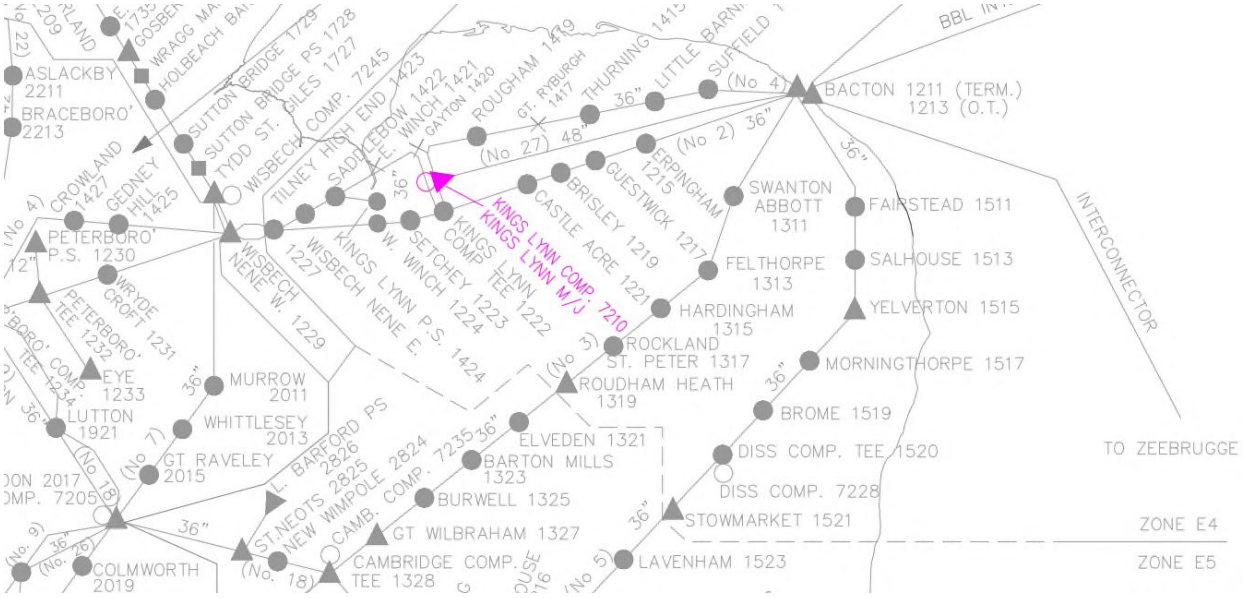

Figure 1 Kings Lynn National Transmission System (NTS) location

RIIO-2 Business Plan summary

NGGT submitted a request for funding to rebuild the bi-directional pipework arrangement at Kings Lynn compressor site driven by a subsidence needs case as part of our 2019 Business Plan.

Ofgem's final determination allowed funding to develop a reopener submission for this project by way of a PCD in the amount of £[redacted].

The investment justification was compiled based upon the available evidence at the time and a series of working assumptions. In the Business Plan submission, National Grid stated:

'The bi-directional area has been affected by ground movement caused by subsidence and pipework is subject to unacceptable levels of stress with deformation of pipework and some instances of small gas escapes.'

The available evidence and working assumptions are described further in *NG-Asset-GT-KL-RO1-001-*[redacted] and consisted of:

Visual observation of movement

Movement of small bore (50NB) pipework was readily identifiable to the naked eye. Noticeable deformation of some sections of 50NB pipe were apparent.[2]

Similarly, actuator cabinet supports, and bases were readily identifiable as having subsided.[3]

[2] NG-Asset-GT-KL-RO1-001-[redacted], p. 12
[3] Ibid, p.12

A sample of the visual indications can be seen in photos 1-3.

Photo 1 Water logging in part of bi-directional and evidence of 50NB pipe subsidence (Winter 18/19)

Photo 2 Evidence of subsided 50NB pipework and similar pipe support subsidence (Winter 18/19)

Photo 3 50NB pipe support subsidence compared to original height (Winter 18/19)

More site photographs can be found in *NG-Asset-GT-KL-RO1-003-Photographs*.

Visual observation ground water logging

The ground water table at the Kings Lynn bi-directional area was frequently noted to be in a state of visible pooling. A submersible pump had been installed in one of the small pipework pits in the bi-directional area. This was an attempt to keep the pit clear to permit routine inspection of some small sections of pipework. The high water table was considered to be a contributing factor in ground settlement issue for the 50NB pipework; this having been experienced on other sites in the past.[4] (Detailed analyses and results are presented in *NG-Asset-GT-KL-RO1-006-Removal of Pits*.)

Initial pipe stress calculations (50NB pipework)

The site operations team raised initial concerns regarding the visible position of some pipework in the bi-directional area through routine maintenance inspections. This matter was listed in the National Grid Plant Status system (PSI ref: 271396) and was reviewed with assistance from the Civil Engineer, for matters of ground movement, and the Pipeline Engineer for the associated stress considerations.

In order to better quantify the potential stresses and reasons for ground movement, the Asset Engineering team initiated two pieces of work:

1) [redacted] Engineering pipeline stress calculations
2) Ground and groundwater investigations ([redacted] Ltd)

[4] NG-Asset-GT-KL-RO1-006-Removal of Pits, p.13

[redacted] **Engineering pipeline stress calculations**

[redacted] Engineering were engaged to undertake initial pipeline stress calculations for deformed 50NB pipework. [redacted] Engineering report (9496: 24/10/2016) advises the following:

'The calculations of stress are based on site measurements of the inclination of above-ground small bore pipework only. These were recorded on the thirty offtakes during a site visit on 15th September 2016. A beam model was used to estimate the bending moment at the weldolet[5] connection to the 900mm pipelines. Stresses are calculated following the procedure in IGE/TD/12 and compared to the code limit stresses.'

A primary consideration for the stresses imposed on the 50NB pipework is associated with the stiffness of the ground conditions. Higher moments are developed in the lower stiffness soils because less load is transferred into the soil. For upper bound soil, the moment developed at the weldolet is negligible, signifying that the load is predominantly transferred into the soil.

[redacted] Engineering conclusion highlighted the following key points:

- Calculations of IGE/TD/12 code stresses at the connections of the 50mm diameter offtakes indicate significant loads may be present.
- The magnitudes of predicted stresses depend on the condition of the soil and the depth of the connection to the buried 900mm diameter pipelines.
- Potentially up to 27 of the 30 offtakes could be experiencing significant loads with lower bound soil conditions.

The report also recommended the following actions:

- Establish depth of cover on pipeline.
- The condition of the soil in the bi-directional pipework area should be established.

[redacted] Engineering further advised that if the presence of stresses that exceed IGE/TD/12 limits was substantiated by measurements of soil depth and condition, it would be recommended to consider:

- More detailed calculation of the performance of the offtake connection points by three-dimensional finite element analysis.
- Relieving the loads by uncovering the buried sections of the 50NB pipework and re-establishing support to the pipework at the original elevation, or at a higher elevation than currently exists at site.

[5] *A Weldolet is a branch butt weld connection fitting that is adhered to outlet pipe to minimizes stress concentrations, providing overall reinforcement.*

Ground and groundwater investigations [redacted] Ltd)

As the first part of the strategy to determine the cause of 50NB pipework deformation, and ultimately to prevent further deformation, National Grid appointed [redacted] Ltd ([redacted]) to undertake an initial site assessment of pipe bedding material, ground and groundwater conditions. This included a desktop review of available information and a site visit by [redacted] Engineers. The review of available information uncovered three ground investigation reports, which showed that ground conditions across the site were variable. Each of the reports reviewed referred to borehole location plans; however, none of the documentation received included these plans. Therefore, the geology at specific locations across the site could not be identified and the ground conditions at the location of the bi-directional upgrade pipework remained unknown.

From observations and available documentation, [redacted] considered that the main cause of ground settlement and subsequent pipe deformation is likely to be weak ground exacerbated by saturated conditions and the susceptibility of the ground to liquefaction as a consequence of vibration. This results in considerably reduced ground strength. [redacted] went on to speculate that this is compounded by liquefaction of the bedding sand around the pipes, caused by vibration of the pipework, which reduces the ground strength further.

Note: Pipework vibration can be a feature of the gas flow within the pipeline under normal operating conditions.

Further stress analysis

The intervention proposed in the Business Plan was also supported by another stress assessment conducted as part of an initial options development activity in the National AGI Renovation Campaign (NARC) programme.

This included a limited stress analysis of the bi-directional area carried out by [redacted]. By this stage, the [redacted] ground conditions report was available. Since all pipework was buried, and in operational service, a series of assumptions remained necessary to develop the stress calculations.

The practices associated with both series of stress calculations were thought to be conservative, at the time. However, no additional information was available to permit a quantifiable alternative stress calculation.

Point cloud laser scan surveys

A series of three point cloud laser scan surveys had been conducted during RIIO-1 as part of the NARC Programme. At the time, this technology was a new development being used by National Grid and some of its design contractor base.

The initial baseline point cloud survey was compared with two further surveys and appeared to be indicating movement of actuators on the large diameter 900NB

pipework. The actuators are mechanically coupled to the valves. The valves, in-turn, are directly welded to the 900NB pipework.

The indication of apparent movement of the actuators was taken as a proxy to infer movement of the 900NB pipeline. All pipework and valves are buried, with only limited valve stem extensions, actuators, and some 50NB pipework visible at ground level.

Operational and safety responsibilities

The information available by late 2018 suggested that additional work was required on pipework at Kings Lynn, primarily to relieve stresses on the 50NB pipework, with an intent to better substantiate likely stresses and potential failure modes associated with the 900NB pipework. Using a working assumption based upon the available evidence, though mindful of the lack of some of the necessary dataset, a primary consideration was a potential for pipeline failure. The design codes employed generally have a considerable design margin ensuring that NTS pipeline loss of containment through stress mechanisms tend to be classified as Low Probability/High Impact events.

As a Gas Transporter, National Grid has an obligation to act as a prudent and responsible operator of its asset base. Failure concerns, potential risk to site staff and members of the public, environmental risk of large gas release, operational risk, and impact on Bacton entry and exit capability were key considerations in the development of a bi-directional area funding application.

Those stresses that could be readily addressed, on 50NB pipework, were remediated by works starting late 2018 – see the following section.

Previous Remediation Work Carried Out

Some remedial intervention work was undertaken during RIIO-1 to relieve stresses on the 50NB pipework. This work included:

- In 2019 excavation of the bi-directional area to a depth of circa 60cm to remove stresses associated with settled soil over-burden. The excavations were extended to permit removal of shallow concrete pipe support bases where these were surrounding 50NB pipework or where these had settled in the water-logged ground leaving 50NB pipe un-supported.

- The excavation of topsoil combined with the removal of the shallow concrete pipe support bases permitted the 50NB pipe to relax to its originally installed position and orientation. These interventions significantly improved the visible condition of the 50NB pipework. It should be noted that overburden removal and allowing small diameter pipework to resettle is not an uncommon practice to address settlement of these smaller pipeline diameters.

- Rectification of minor gas leaks associated with above works.

- Installation of shallow land drainage, at a depth of 30cm – 60cm, and tie-in to the site drainage system to improve water run-off from the bi-directional area.

- Re-instatement of bi-directional area to finished level.

The remediation work undertaken in RIIO-1 did not address the issues associated with the potential over-stresses associated with the 900NB pipework. This work was commenced in 2021 and is summarised in the Investigations and Ongoing Monitoring section of this document.

Photographs showing 50NB pipe movement, key to the National Grid considerations for further investigations on the 900NB pipework, can be viewed in Photographs 1 to 3 of this document.

Investigation and Ongoing Monitoring

This section describes the work undertaken since 1 April 2021 under the auspices of the RIIO-2 Kings Lynn Subsidence Re-opener and Price Control Deliverable.

During 2021 National Grid engaged contractors to undertake further investigation works as part of the Optioneering Study for proposals on the Kings Lynn bi-directional area. In addition, National Grid undertook a data review and managed to successfully retrieve additional construction records. The 2021 works consisted of:

- Excavation of 900NB pipe in specific locations to expose pipe crown – 34 locations.[6]

- Attachment of fixed measurement point to pipe crown to permit detailed survey of the pipe location – 11 locations.[7]

- Detailed measurement of pipe position using a Total Station[8] measuring device. A new position baseline was established on 29th July 2021 with a re-measurement, undertaken on 10th December 2021. A negligible difference in height was detected at all permanently installed monitoring locations.

- Data mine and recovery: examine and review all available documents, photographs, records, and drawings stored in the site library, and additional document storage area. Key information in this respect was the recovery, of the original piling records associated with the original site build.

- [redacted] collated new additional information from activities above to produce an accurate model of the bi-directional area (to allow stress analysis).

- Generation of limited options for the bi-directional area interventions.

- Undertake Close Interval Protection Study (CIPS) and Direct Current Voltage Gradient (DCVG) surveys to provide intelligence on the level of Cathodic Protection (CP) afforded the localised area on the pipeline.

- [redacted] undertake stress analysis, Finite Element Analysis and run fatigue calculations on bi-directional pipework model.[9]

[6] NG-Asset-GT-KL-RO1-002-Monitoring Point Locations, p.1
[7] Ibid, p.1
[8] *A total station is an optical surveying instrument that uses electronics to calculate angles and distances. It combines the functions of a theodolite with that of a transit level and electronic distance meter (EDM).*
[9] NG-Asset-GT-KL-RO1-004-[redacted]; NG-Asset-GT-KL-RO1-005-[redacted]; NG-Asset-GT-KL-RO1-007-[redacted]

- Engage Power Mechanical to survey 20 actuators and produce condition survey and recommendations.

- Hold two-day Formal Process Safety Assessment (FPSA) meetings under guise of HAZID and HAZOP studies to determine the associated safety implications of options under considerations.

- Produce price estimates and programme options under consideration. Note: Market impact associated with the COVID-19 pandemic restricted some of the available pricing routes. As an alternative, National Grid staff undertook an internal, and necessarily limited, costing assessment of the developing options. The costs tolerances are commensurate with the Options only phase of development, and, as stated, have not been subjected to external market review.

- Clean ditch adjacent to bi-directional area, investigate water leak, locate leak and repair.

The collation of data from the earlier assumptions was essential and has permitted the worst-case assumptions considered in Pipeline stress calculations to be normalised to the conditions now known.

A singular remaining stress exception, likely to be reduced to acceptable tolerances, requires additional excavation to retrieve metal samples to permit material analysis and recalculation of the stress. This matter is highlighted as part of the residual risk following close out of this project – it is to be listed on National Grid defect recording system.

Ongoing monitoring

The recovery of piling information for both major phases of work in the bi-directional area, coupled with revised data and associated reports indicates that there is no active subsidence affecting pipework that is of current concern to National Grid.

The additional stress analysis work has down rated all but one of the remaining stress exceptions. National Grid Asset Lifecycle Engineering Team have committed to undertake additional measurements in a specific structural Integrity monitoring scope to ensure that the area remains stable.[10]

The National Grid Civil Engineer has recommended that the preponderance of available evidence suggests this monitoring arrangement should be sufficient to conclude the assets remain stable.

[10] NG-Asset-GT-KL-RO1-001-[redacted], Chapter 14.3

Findings and Status

Since 1 April 2021 NGGT has spent approximately £0.6m to date on investigation, assessment, analyses and remedial work with final costs to be reconciled at closure.

In March 2021, NGGT instructed [redacted] to complete a FEED Engineering Justification Study covering asset health condition assessment of the bi-directional pipework area at the site, further stress and fatigue analysis studies and optioneering for identified potential solutions.[11]

Monitoring rods have been installed at strategic locations facilitating surveying prisms, giving accurate measurement of pipe positions. Detailed measurements were taken of the pipe position using a Total Station measuring device. A new position baseline was established on 29th July 2021 with a re-measurement, undertaken on 10th December 2021. A negligible difference in height was detected at all permanently installed monitoring locations.

During excavation of 900NB pipe in specific locations, to expose pipe crown, the opportunity was taken to undertake a limited visual examination of pipe coatings. These were found to be in generally good condition.

During data mine and recovery, the early 1970s site build piling records were recovered. One of the assumptions made in earlier stress analysis considered secondary digital data sources. The lack of original (paper) records and subsequent reliance on secondary digital sources suggested a lack of piling in some part to the bi-directional area. This drove some considerations around potential stress, that are directly related to soil stiffness assumptions.

During discussions with the designers, following the discovery of piling records for the differing phase of works at Kings Lynn over the years, some dialogue was undertaken on the indication provided by earlier Point Cloud Surveys. National Grid were advised that there is some level of interpretation necessary when using comparative Point Cloud Surveys overlaid upon one another. The introduction of the fixed monitoring points and the use of a Total Station has now alleviated these variations and is considered a major learning point in the use of this technology.

The initial lack of original build records is likely a result of changing formats for data sources over the 6 decades since the records were originally produced. Whilst some original build records are retrievable for sites finding a full set of primary records is not always possible.

The completion of Close Interval Protection Study (CIPS) and Direct Current Voltage Gradient (DCVG) surveys has generated findings that will be considered under normal Asset Health investment processes[12].

[redacted] undertook stress analysis, Finite Element Analysis and ran fatigue calculations on bi-directional pipework model. This permitted generation of a refined model of the current area to complete a comprehensive stress

[11] NG-Asset-GT-KL-RO1-001-[redacted]
[12] NG-Asset-GT-KL-RO1-001-[redacted], Chapter 2.4.4

analysis study up to the year 2050[13]. Initial results showed a number of potential over-stresses; all but one was resolved by detailed finite element analysis of the identified fittings. The singular over stress will be entered into the National Grid defect system for consideration under normal Asset Health investment processes.

A limited series of options for bi-directional area interventions was produced. A two-day Formal Process Safety Assessment (FPSA) meeting under guise of HAZID and HAZOP studies, was undertake. This considered the safety implications of options under considerations at that time. These implications will be considered when developing any potential future investments for Kings Lynn bi-directional area.

The following table summarises the options considered in the [redacted] report.[14]:

Option no.	Description	Brief summary
0	Do Nothing.	Option 0 involves no replacement or refurbishment of any of the equipment / assets within the bi-directional area.
1a	Minor In-Situ Remediation	Option 1A considers replacement of 721001 valve and actuator and maintains or refurbishes other 900NB valves in situ. A deviation from current design standards would be required for installation of the new valve.
1b	Major In-Situ Remediation	Option 1B considers replacement of the four original 1972 vintage 900NB valves in the bi-directional area. A deviation from current design standards would be required for installation since this option does not consider revised layout of the bi-directional area.
2a	Specification Compliant Re-build In-situ	Option 2A considers replacement of the pipework in the bi-directional area. The arrangement is a like for like replacement with no increase in capacity or flexibility. Modern design code compliance necessitates revised layout in the existing area. Significant challenging civil foundation design would be required for this option due to the change in footprint, the existing piled foundations will no longer line up with the new pipework. It is likely that new piled foundations would be required. A lengthy construction timeframe and associated network outage widow is considered likely with this option.
2b	Re-build In-Situ (as per current arrangement)	Option 2B considers replacement of the pipework in the bi-directional area. Similar to Option 2a, the arrangement is a like for like replacement with no increase in capacity or flexibility. Unlike option 2a, the equipment layout would be considered using the current design code non-compliances. Design code deviations would therefore be required. A lengthy construction timeframe and associated network outage widow is also considered likely with this option.
3	Re-build in New Location	Option 3 considers rebuild of the entire bi-directional arrangement on another area of the site with interconnecting pipework to Feeders 2, 4 and 27. The new design would provide full compliance with current design codes. In addition, other opportunistic considerations for future proofing would be considered. These may include, but not limited to: - Revised pipe sizing requirements - Alterations to network operability and flexibility - Network and compressor separation/isolation requirements

[13] NG-Asset-GT-KL-RO1-004-[redacted], p.14 onwards
[14] NG-Asset-GT-KL-RO1-001[redacted], Chapter 6

The [redacted] report concludes, superficially, that Option 3 appears to offer more process safety benefits than the other options. This recommendation was developed following related considerations of buildability/ process safety/ system operability and flexibility. National Grid need to consider the linkage of Asset Health issues at Kings Lynn in wider context of other investment considerations at the same site in such a manner to generate a well-informed site-wide intervention.

A condition survey of 20 actuators was undertaken by the Original Equipment manufacturer (OEM) in October 2021[15]. Their recommendations are generally overhaul work and will be considered under normal Asset Health investment processes.

National Grid staff undertook an internal, and necessarily limited, costing assessment of the developing options to avoid further costs at this stage, which would be driven by a different needs case. The costs are in a very early stage of development and have not been subject to further maturation as spend was curtailed prior to this being completed, as stated, they have also not been subjected to external market review. These are advised in the [redacted] report[16].

Water was found to be leaking from the ground in an area North of the bi-directional area. This was excavated, the leak located and repaired. It is unclear if this may have been contributing to increased water table in recent times since this was discovered after the land drainage was installed in 2019. There is no further action resulting from this finding.[17]

[15] NG-Asset-GT-KL-RO1-001-[redacted], p.19
[16] NG-Asset-GT-KL-RO1-001-[redacted] Chapter 7
[17] NG-Asset-GT-KL-RO1-001-[redacted] Chapter 2.4.3

Innovation

Consideration for an innovative underpinning technique

In 2018, the National AGI Renovation Campaign (NARC) had started a process of options development for site. This included the need to validate the needs case driver. During options development, a consideration was given to how National Grid might find an alternative approach to underpinning the bi-directional area should the subsidence needs case be apparent.

A technology employed in other industries was considered: Geopolymer resin injection.[18]

Should the 900NB pipework be found to have subsided to limits that were beyond allowable tolerances, the working suggestion was that geopolymer resin may be injected into the surrounding soil structure to:

1) Stabilise and arrest any further subsidence.
2) Attempt to re-position pipework to a level commensurate with original design parameters.

An innovative project to investigate the use of geopolymer resin injection methods on National Grid Gas sites for ground stabilisation and pipework relevelling was initiated in June 2020 and completed in March 2021.

The project comprised a comprehensive review of geopolymer injection technology including a desktop technology review, and a site trial on decommissioned gas pipework, to assess its effectiveness at stabilising and relevelling gas pipework.

Results from the assessments showed that:

1) The technology will be suitable for adoption on gas transmission assets.
2) The technology would result in a net CO2 saving compared to a number of conventional cement-based grouting solutions.
3) The technology's ability to relevel pipework.

[18] For further detail see: NG-Asset-GT-KL-RO1-001-[redacted], Chapter 12.2

Implications for Long Term Network Capability Requirements

During investigations to undertake an intervention based upon a subsidence needs case driver, a series of considerations were discussed that are typical of early options development. These included:

- Physical flow requirements for site (now and future).
- Network operability needs.
- Consideration of new options in context of current design codes and safety considerations.
- Consideration of known asset health issues and potentially dormant asset health issues that require consideration in future compressor FEED studies.

Two Formal Process Safety Assessment (FPSA) meetings were undertaken to determine the associated safety implications of options under considerations. This was an initial conceptual level only study. A full FPSA (longer duration) process requires to follow when project needs case driver is fully validated and the detailed design is underway.

The limited study undertaken so far has highlighted some issues that have been documented for future intervention development for Kings Lynn Bi-directional Area.

The matters fall into the following categories:

- Emerging Asset Health issues and compliance of any developed solution to current design requirements.
- Existing Asset Health issues and buildability on a live network where 3 Feeders converge.
- Network operability and flexibility associated with isolation of Kings Lynn Compressor Station from the 3 National Transmission Feeders; this being particularly impacted by physical isolation requirements.
- Network capacity requirements associated and compliance with pipeline design codes.

By the time these studies were undertaken, the subsidence needs case driver appeared to be diminishing.

It should be noted that had the rebuild of the Kings Lynn bi-directional area been completed as set out in the EJP, the interconnectivity, operability and resilience of the network would have been a Conceptual Design consideration taking into account longer term capability requirements and asset health priorities.

The studies were pursued no further to balance expenditure against the perceived benefit of a diminishing needs case driver.

Based on the longer term requirements, a robust conceptual design will be required to develop these matters further in preparation to address.

Supplementary Re-opener Reporting Requirements

In Ofgem's "Price Control Deliverable Reporting Requirements and Methodology Document" published in March 2021, Ofgem posed the following questions under "Kings Lynn Subsidence FOSR Guidance – SpC 3.12 King's Lynn subsidence Reopener and Price Control Deliverable (KLSt)":

Requirement	Response
Quantify the rate of deterioration and the probability of failure to demonstrate the need for a major investment rather than mere ongoing monitoring.	The work to quantify the rate of deterioration and probability of failure was undertaken by [redacted] and [redacted]. As detailed in the "Findings and Status" section, this included excavation to enable the affixing of monitoring rods to the 900NB pipework; detailed measurements using a Total station measuring device; visual examination of pipe coatings; a search through the physical construction archives; Close Interval Protection Studies; Direct Current Voltage Gradient Studies; Finite element analysis; stress and fatigue calculations and safe operating life analysis. These exhaustive studies together with the remediation work including the excavation and relevelling of the small-bore pipework; the installation of the shallow drainpipe and the remediation of the mains water leak led Premtech to conclude that given that there was no "rate of deterioration" which differed from that applicable to the broader asset class in the National Transmission System. Given that only one stress exception remained (which has been entered into the National Grid defect system for consideration under normal Asset Health investment processes), it was concluded that no integrity risks remained that would need treatment over and above NGGT's standard asset health/risk management practices. NGGT informed Ofgem of its intention to curtail project spend in line with S.10.4 of the Gas Transmission Governance Code, concluding that further work to quantify residual risks would not be an efficient spend of allowance or in the interests of the consumer.
Demonstrate a thorough optioneering process to address the risks posed by the current Kings Lynn bi-directional pipework, including reference to the probability of failure. All options considered must have a cost estimate built to an equivalent accuracy to allow a fair comparison to be made.	NGGT instructed [redacted] to deliver a Front-End Engineering and Design (FEED) study to facilitate NGGT's delivery of the Reopener submission specified in the licence. This was to include a full optioneering study to allow NGGT to select the optimal solution to remediate the issues at the Kings Lynn bi-directional area. The exhaustive studies, remediation and findings detailed in the "Background"; "Previous Remediation Work Carried Out"; "Investigation and Monitoring" and "Findings and Status" sections of this report led to the conclusion in December 2021 that the subsidence needs case no longer supported the Reopener Submission, so NGGT sought sanction from Ofgem to follow internal processes and close down the project. This meant curtailing further project spend as it was no longer an efficient use of allowances or in the interests of the consumer. The option costs are, therefore, in a very early stage of maturity; have not been the validated via market-based "price discovery" and were not progressed further due to project spend being curtailed, but have been included in the [redacted] report supporting document for completeness.

Use updated FES and Network Capability modelled flows in the CBAs.	The sensitivity analysis of the costs and benefits to the Future Energy Scenarios and network capability modelling was to be undertaken once the costs were at the required level of maturity for a Reopener submission requesting incremental allowances. With the emergent conclusion that the subsidence needs case was no longer supportive of the Reopener Submission, and Ofgem sanction sought for early project close-out it was agreed that further work, absent the subsidence needs case driver, was neither in the interests of the consumer nor an efficient use of allowances.
Include consideration of the probability of failure of the Kings Lynn bi-directional pipework.	See the first two responses in this table above.
The CBA must also consider all key drivers of investment including safety and environmental risks and clearly set out any assumptions.	The incremental studies to quantify these risks and assumptions so that they could be fed into the CBA were in process when sanction was sought for early project close-down, in the interests of consumers and efficient spend of allowances, due to the subsidence needs case driver no longer supporting the delivery of the Reopener Submission. This work comprised HAZID, HAZOP and FPSA studies. Although the incremental analysis NGGT was undertaking was truncated, these studies fed into the optioneering work which [redacted] completed and were critical in supporting their superficial conclusion that remediation in situ may not be possible due to safety, buildability, and system operability considerations.
Provide an updated breakdown of the capital costs and associated risk, project management, and other such contingencies in line with the RIIO-T2 EJP guidance, and provide the basis of any calculations and key assumptions	The option costs are in a very early stage of maturity and were not progressed further as project spend was curtailed after the subsidence needs case was no longer supportive of Reopener Submission and due to considerations of efficient spend of allowances and the best interests of consumers, but have been included in the [redacted] report supporting document for completeness.

PCD Costs

The table below details the costs anticipated with the completion of this project in 2018/2018 price base.

Item description	Cost in 18/19 price base (£)
NG staff cost – direct cost associated with project management coordination and compiling information	[redacted]
Professional services costs associated with project management coordination and compiling information	0
Contractor costs (this will make up the majority cost)	[redacted]
Materials	0
Miscellaneous	[redacted]
Total (based on February 2022 forecast)	[redacted]

Below shows a list of investigations and ongoing works completed:

- Excavation of 900NB pipe in specific locations to expose pipe crown – 34 locations.
- Attachment of fixed measurement point to pipe crown to permit detailed survey of the pipe location – 11 locations.[19]
- Detailed measurement of pipe position using a Total Station measuring device. A new position baseline was established on 29th July 2021 with a re-measurement, undertaken on 10th December 2021. A negligible difference in height was detected at all permanently installed monitoring locations.
- Data mine and recovery: examine and review all available documents, photographs, records, and drawings stored in the site library, and additional document storage area. Key information in this respect was the recovery, of the original piling records associated with the original site build.
- [redacted] collated new additional information from activities above to produce an accurate model of the bi-directional area (to allow stress analysis).
- Generation of limited options for the bi-directional area interventions.
- Undertake Close Interval Protection Study (CIPS) and Direct Current Voltage Gradient (DCVG) surveys to provide intelligence on the level of Cathodic Protection (CP) afforded the localised area on the pipeline.
- [redacted] Ltd undertake stress analysis, Finite Element Analysis and run fatigue calculations on bi-directional pipework model.

[19]NG-Asset-GT-KL-RO1-002-Monitoring Point Locations

- Engage Power Mechanical to survey 20 actuators and produce condition survey and recommendations.

- Hold two-day Formal Process Safety Assessment (FPSA) meetings under guise of HAZID and HAZOP studies to determine the associated safety implications of options under considerations.

- Produce price estimates and programme options under consideration. Note: Market impact associated with the COVID-19 pandemic restricted some of the available pricing routes. As an alternative, National Grid staff undertook an internal, and necessarily limited, costing assessment of the developing options. The costs tolerances are commensurate with the Options only phase of development, and, as stated, have not been subjected to external market review.

- Clean ditch adjacent to bi-directional area, investigate water leak, locate leak and repair.