[redacted]

Document: Ground Investigation Interpretative Re[redacted]

Project: National AGI Renovation Campaign
(2018) Kings Lynn Compressor Statio[redacted]

Reference No.: GN21822_GI_Interpretative

Date: August 2018

Prepared for: [redacted] Limited

Engineer: [redacted]

[redacted]

A division of Harrison Group Environmental Ltd.

[redacted] LIMITED

Document: **Ground Investigation Interpretative Report**

Project: **National AGI Renovation Campaign Batch 2 (2018) Kings Lynn Compressor Station**

Reference No.: **GN21822_GI_Interpretative**

Date: **August 2018**

Prepared For: [redacted] **Limited**

Engineer: [redacted]

REPORT STATUS:

Revision	Comments	Prepared By	Approved By	Issued By	Audited By
0	Draft for initial information	INIT JE SIGN COMMENTS DATE 10/08/18	INIT SW SIGN COMMENTS DATE 10/08/18	INIT JE SIGN COMMENTS DATE 10/08/18	INIT SW SIGN COMMENTS DATE 10/08/18
		INIT SIGN COMMENTS DATE	INIT SIGN COMMENTS DATE	INIT SIGN COMMENTS DATE	INIT SIGN COMMENTS DATE
		INIT SIGN COMMENTS DATE	INIT SIGN COMMENTS DATE	INIT SIGN COMMENTS DATE	INIT SIGN COMMENTS DATE
		INIT SIGN COMMENTS DATE	INIT SIGN COMMENTS DATE	INIT SIGN COMMENTS DATE	INIT SIGN COMMENTS DATE

CONTENTS

FOREWORD

General Conditions Relating To Site Investigation

This geotechnical investigation has been devised to generally comply with the relevant principles and requirements of BS EN 1997-1:2004, 'Eurocode 7: Geotechnical design - Part 1: General rules' and BS EN 1997-2:2007, 'Eurocode 7 - Geotechnical design - Part 2: Ground investigation and testing'.

Boring, sampling and field test procedures are undertaken in accordance with BS 5930:2015 'Code of Practice for Ground Investigations' and other applicable standards as referenced. Likewise in-situ and laboratory testing complies with BS1377:1990, 'Methods of Tests for Soils for Civil Engineering Purposes', unless stated otherwise in the text.

The groundwater conditions entered on the drilling records are those observed at the time of investigation. The normal rate of drilling does not necessarily permit the recording of an equilibrium water level for any one water strike. Moreover, groundwater levels are subject to seasonal variation or changes in local drainage conditions.

Some items of the investigation have been provided by third parties and whilst [redacted] have no reason to doubt the accuracy, the items relied on have not been verified. No responsibility can be accepted for errors within third party items presented in this report.

The opinions expressed in this report are based on the ground conditions revealed by the site works, together with an assessment of the site and of laboratory test results. Whilst opinions may be expressed relating to sub-soil conditions in parts of the site not investigated, for example between exploratory positions, these are only for guidance and no liability can be accepted for their accuracy.

This report is produced for the benefit of the client alone. No responsibility can be accepted for any consequences of this information being passed to a third party who may act upon its contents/recommendations.

This report is produced in accordance with the scope of [redacted] appointment and is subject to the terms of appointment. [redacted] accepts no liability for any use of this document other than by its client and only for the purposes, for which it was designed and produced. No responsibility can be accepted for any consequences of this information being passed to a third party who may act upon its contents/recommendations.

Any advice, opinions, or recommendations within this document should be read and relied upon only in the context of the document as a whole. The contents of this document are not to be construed as providing legal, business or tax advice or opinion.

GROUND INVESTIGATION INTERPRETATIVE REPORT

FOR

NATIONAL AGI RENOVATION CAMPAIGN BATCH 2 (2018)

KINGS LYNN COMPRESSOR STATION

1 TERMS OF REFERENCE

The work covered by this report was undertaken on behalf of [redacted] The investigation is in accordance with a specification by [redacted] (reference [redacted]322-SPC-7210-1000), dated 21st February 2018) and [redacted] [redacted] Environmental Limited's (HGE) quotation (GN21822 Q3 JE) dated 24th July 2018 with an emailed instruction to proceed from [redacted] dated 24th July. This stage of work follows on from the ground investigation carried out by HGE and should be read in conjunction with the ground investigation factual report prepared for [redacted] (reference GN21822 GI dated June 2018). The information in this report is to aid in the design of foundations for proposed works at the Kings Lynn Compressor Station.

The site location and the site boundary are shown on drawing GN21822-DR001. The centre of the area investigated can be identified by National Grid Reference 572125, 316225 and by examination of online resources, the elevation of the site is estimated at approximately 13-15m above Ordnance Datum (maOD).

2 BACKGROUND INFORMATION

2.1 Summary of Intrusive Ground investigation Works

In accordance with the specification document [redacted]322-SPC-7210-1000) documented by [redacted] Ltd the ground investigation included drilling rotary boreholes supplemented by hand dug pits, dynamically sampling through the variable superficial deposits followed by wireline Geobore S techniques through more competent strata along with associated in-situ testing.

Three rotary boreholes (BH01a to BH03) were drilled between the 08/05/18 and 31/05/18, using wireline Geobore S techniques to drill to a maximum depth of 51.0m in order to identify, sample and test the strata underlying the Kings Lynn Compressor Station. Dynamic sampling techniques with a diameter of 146mm were utilised to progress through the initial superficial deposits, generally to a depth of 6.0m.

On completion of borehole BH01a, dual groundwater monitoring standpipes were installed to depths of 6.0 and 50.0m. The other two boreholes were backfilled with bentonite grout. Details regarding the drilling and ground conditions encountered are included in the Ground Investigation Factual Report.

2.2 Groundwater Monitoring

Groundwater was not always noticed during drilling of the boreholes due to water being added to enable drilling through the granular soils. However, groundwater levels were subsequently measured in the monitoring wells installed and details of groundwater levels during drilling and subsequent monitoring have been summarised in table 2.2 below.

Exploratory Hole Location (Dual installation)	Depth groundwater encountered during drilling (m)	Groundwater Depth (m)/ Level (maOD) encountered during monitoring		
		Round 1 (03/07/2018)	Round 2	Round 3
BH01a 6m install	*	1.18	TBA	TBA
BH01a 50m install	*	1.36	TBA	TBA

Table 2.2: Summary of Groundwater levels during drilling & monitoring * Due to drilling methods depth of groundwater could not be determined.

2.3 Summary of Geotechnical Laboratory Testing

A summary of geotechnical laboratory testing undertaken on samples prepared from the cores obtained is provided in table 2.3 below.

Test Type and Reference (BS 1377: 1990 unless stated)	Strata	Depth (m)	Number of Results	Results (Range)	Results (Average)
Moisture content (Part 2:3.2)	River Terrace Deposits	0.7 - 3.0	3	14-21%	17.3%
	Made Ground	1.0	1	8.3%	8.3%
	Head Deposits	1.10	1	14%	14.0%
	Nar Valley Formation – Clay	2.0 - 12.0	14	19 - 49%	34.8%
	Nar Valley Formation – Freshwater Beds	23.0 - 26.4	2	25%	19.0%
	Varved Clay	24.9 - 50.50	18	22-25%	25.0%
Atterberg Limits (Part 2)	Nar Valley Formation - Clay	3.5 - 9.0	5	PL – 17 - 30% LL – 32 - 53% PI – 15 - 38% Modified PI - 15 - 38%	23.8%
	Nar Valley Formation – Freshwater Beds	23.0	1	N.P.	N.P.
	Varved Clay	27.50 - 50.50	7	PL – 15 - 17% LL – 33 - 37% PI – 17 - 20% Modified PI - 17 - 20%	PL 16.1% LL 34.4% PI 18.3% Modified PI 18.3%
Particle size distribution - wet sieving (Part 2, clause 9.2) **& Sedimentation by pipette** (Part 2, clause 9.4)	Head Deposits	1.10	1	Gravel 18.4% Sand 68.4% Fines 13.1%	Gravel 18.4% Sand 68.4% Fines 13.1%
	River Terrace Deposits	2.0 - 3.0	2	Gravel 0.0% Sand 52.7 – 53.3% Fines 2.8 – 32.8%	Gravel 1.7% Sand 80.6% Fines 17.8%
	Nar Valley Formation – Freshwater Beds	20.50 – 22.90	2	Gravel 0.1% Sand 18 – 24.9% Silt 59.2 – 64.4% Clay 15.8 – 17.5%	Gravel 0.1% Sand 21.5% Silt 61.8% Clay 16.7%
	Varved Clay	26.60	1	Gravel 0.0% Sand 11.6% Fines 88.4%	Gravel 0.0% Sand 11.6% Fines 88.4%
Soil pH – geochemical testing (BRE SD1 2005)	Head Deposits	1.20	1	8.5	-
	River Terrace Deposits	1.0 - 5.0	5	8.2 - 8.7	-
	Nar Valley Formation - Clay	2.2 - 15.0	6	6.5 - 8.0	-
	Nar Valley Formation - Freshwater	14.5 - 26.0	4	6.5 - 8.4	-
	Varved Clay	31.4 - 45.5	5	8.1 – 8.3	-
Water soluble sulphate content 2:1 aqueous extract (BRE SD1 2005)	Head Deposits	1.20	1	0.072 g/l	-
	River Terrace Deposits	1.0 - 5.0	5	0.014 - 0.34 g/l	-
	Nar Valley Formation - Clay	2.2 - 15.0	6	2.2 - 3.2 g/l	-
	Nar Valley Formation - Freshwater	14.5 - 26.0	4	0.13 - 0.46 g/l	-
	Varved Clay	31.4 - 45.5	5	0.10 – 0.26 g/l	-

Test Type and Reference (BS 1377: 1990 unless stated)	Strata	Depth (m)	Number of Results	Results (Range)	Results (Average)
Single stage UU triaxial compression test (Part 7, clause 8)	Nar Valley Formation - Clay	4.00 - 13.60	16	39 – 226 kPa	91.3kPa
	Varved Clay	27.70 - 50.45	25	75 – 210 kPa	123.1kPa
Incremental loading oedometer test	Nar Valley Formation - Clay	4.00 - 13.05	4	See results	
	Varved Clay	27.95 - 50.35	9	See results	

Table 2.3: Summary of Geotechnical testing

2.4 Proposed Construction

The purpose of the work was to undertake a ground investigation, focusing on geotechnical issues relating to the replacement of existing pipework with new arrangement at the Kings Lynn Compressor Station. We understand that the existing compressor station bi-directional area is showing signs of over-stressed pipework and differential settlement and that the work required of [redacted] will include the replacement of multiple ball valves and associated pipework. It is understood that the new ball valves will be supported by raft foundations supported by piling if found to be necessary. The raft levels will be at a depth of approximately 2.2m below finished ground level (subject to ground conditions encountered).

It has been advised from [redacted] that if required, approximate individual pile capacities would need to be in the order of 275kN if shallow (placed above the Lignite layer) or up to 700kN if deeper piles penetrating the Lignite layer were utilised.

Our assessment will consider the potential settlement of the ground based on typical loadings from various pieces of equipment and pipework planned to be added to the site. [redacted] drawings [redacted]341-GEN7210-1001 sheets 1-3) provided by [redacted] indicate the proposed modifications that will be undertaken across the site. Table 3.1 below summarises proposed pile loads at each location.

Base No.	Size (mm)	No. of Piles	Max. Load Per Pile (kN)	Drawing Number
1	3.5 x 1.5	2	250	1
2	3.5 x 1.5	2	250	1
3	3.5 x 1.5	2	250	1
4	3.5 x 1.5	2	250	2
5	3.5 x 2.5	2	400	2
6	3 x 1	2	50	2
7	3 x 7	6	400	2
8	3.5 x 1.5	2	250	2
9	6 x 4	4	600	2
10	6 x 4	4	650	2
11	4 x 4	4	150	2
12	4 x 4	4	150	2
13	12 x 4	6	200	2
14	15x5x4x4	12	700	2
15	3.5x1.5	2	250	3
16	3.5 x 1.5	2	250	3
17	3.5 x 1.5	2	250	3

Table 2.4: Summary of maximum proposed piles loads (kN)

3 GEOTECHNICAL ASSESSMENT

3.1 Geological Summary and Characteristic Values

The ground conditions were broadly as anticipated based upon the geological mapping sequence of the area. A paleo-valley was present across the site which suggested superficial deposits are deeper than the surrounding area. Made ground was present at surface of boreholes BH01a, BH02 and BH03 and was found to be present to a maximum depth of 1.3mbgl.

The underlying superficial deposits initially comprised of a medium dense slightly clayey slightly gravelly fine to coarse sand. This stratum was found to a maximum depth of 4.9mbgl in BH02 and is likely to represent River Terrace Deposits.

A soft becoming stiff silty clay with frequent fossil shell fragments was then proved to a maximum depth of 14.10m and is likely to represent the Nar Valley Formation - Clay formed in a marine depositional environment. BH01a and BH02 then encountered a band of Lignite (compressed peat) to a depth of between 15.4m and 16.5m, respectively. No recovery was obtained at the anticipated depth of this stratum in borehole BH03, although some granular material was retained within the split spoon of an SPT undertaken over the range, suggesting that the lignite might not be continuous over the site area.

Medium dense to very dense silty gravelly sand underlay the compressed peat beds to depths in the order of 25m to 26mbgl. This stratum is thought to represent the Nar Valley Formation Freshwater Beds – Sand & Gravel and contained layers of silt and gravel within the lower parts.

Underlying these materials, a firm to very stiff thinly laminated silty clay with laminations of silt and sand and with rare recordings of chalk gravel was proved to the base of the boreholes. This material is believed to represent Varved Clay associated with a glacial depositional environment.

The findings of the investigation have been considered and an assessment has been made regarding a generalised soil profile and associated characteristic geotechnical parameters for each of the strata as summarised in table 3.1 below. Typical idealised strata depths and thicknesses have been used, although it should be appreciated that some variability in the superficial soils exists. Characteristic geotechnical parameters have been derived for each of the strata based on the range of in-situ and laboratory testing results obtained, statistical analysis and review of typical published values for similar materials.

Table 3.2 shows the graphical summary deriving Cu shear strength values from SPT N_{60} data vs triaxial shear strength values. A factor of 5 has been calculated from the PI values taken from laboratory testing and applied to the SPT N_{60} data.

Geological Formation	Top of Strata (mbgl)	Bottom of Strata (m)	Soil Parameters			
			Parameter	Range	Characteristic Value	Comments
River Terrace Deposits	0.6	2.5	w (%)	14-21	17	Average laboratory derived value
			N_{60}	9-44	35	Average derived from SPT data
			Ø	29-39	34	Based of relationship between SPT and relative density (Peck et al)
Nar Valley Formation (Clay)	2.5	13.5	w (%)	25-49	35	Average laboratory derived value
			N_{60}	9-26	17	Average derived from SPT data
			Modified PI	15-38	24	Worst case laboratory derived value
			Cu (kN/m²)	39-230	91	Average laboratory derived data
			γ (kN/m³)	14-20	17	Average based on laboratory data between 10th and 90th percentile
			ρ_b (Mg/m³)	1.4-2.04	1.7	Average laboratory derived data
			Mv (MN/m²)	0.072-0.15	0.1	Average based on laboratory data between 10th and 90th percentile
			Cv (m²/year)	2.5-17	11	Average based on laboratory data between 10th and 90th percentile

Geological Formation	Top of Strata (mbgl)	Bottom of Strata (m)	Soil Parameters			
			Parameter	Range	Characteristic Value	Comments
Lignite - Nar Valley Formation - Freshwater Beds	13.5	15.0	w (%)	11	11	Based on single laboratory test
			N_{60}	50	50	Based on single SPT test
			ρ_b (Mg/m^3)	1.18	1.18	Based on single laboratory test
			UCS (MN/m^2)	1.57	1.57	Based on single laboratory test
			Is_{50} (MN/m^2)	0.09	0.09	Based on single laboratory test
Sand and Gravel - Nar Valley Formation - Freshwater Beds	15.0	24.8	w (%)	25	25	Based on single laboratory test
			N_{60}	26-52	39	Average derived from CPT data between 10th and 90th percentile
			Ø	35-41	38	Based on relationship between SPT and relative density (Peck et al)
Varved Clay	24.8	50.0	w (%)	22-25	24	Average laboratory derived value
			N_{60}	39-52	45	Average derived from SPT data
			Modified PI	17-20	18	Worst case laboratory derived value
			Cu (kN/m^2)	75-210	123	Average laboratory derived data
			γ (kN/m^3)	20-21	20	Average based on laboratory data between 10th and 90th percentile
			ρ_b (Mg/m^3)	2.03-2.11	2.07	Average laboratory derived data
			Mv (MN/m^2)	0.042-0.053	0.046	Average based on laboratory data between 10th and 90th percentile
			Cv (m^2/year)	11-19	16	Average based on laboratory data between 10th and 90th percentile

Table 3.1: Summary of geology and characteristic soil parameters.

<u>Key for the abbreviations used in table 3.1 above:</u>

w	Moisture content
γ	Bulk unit weight
ρ_b	Bulk density
ρ_d	Dry density
PI	Plasticity Index
N_{60}	Standardised SPT N value
Cu	Undrained shear strength
UCS	Uniaxial compressive strength
Is_{50}	Point Load Index
Ø	Angle of shearing resistance
Mv	Coefficient of volume compressibility
Cv	Coefficient of consolidation

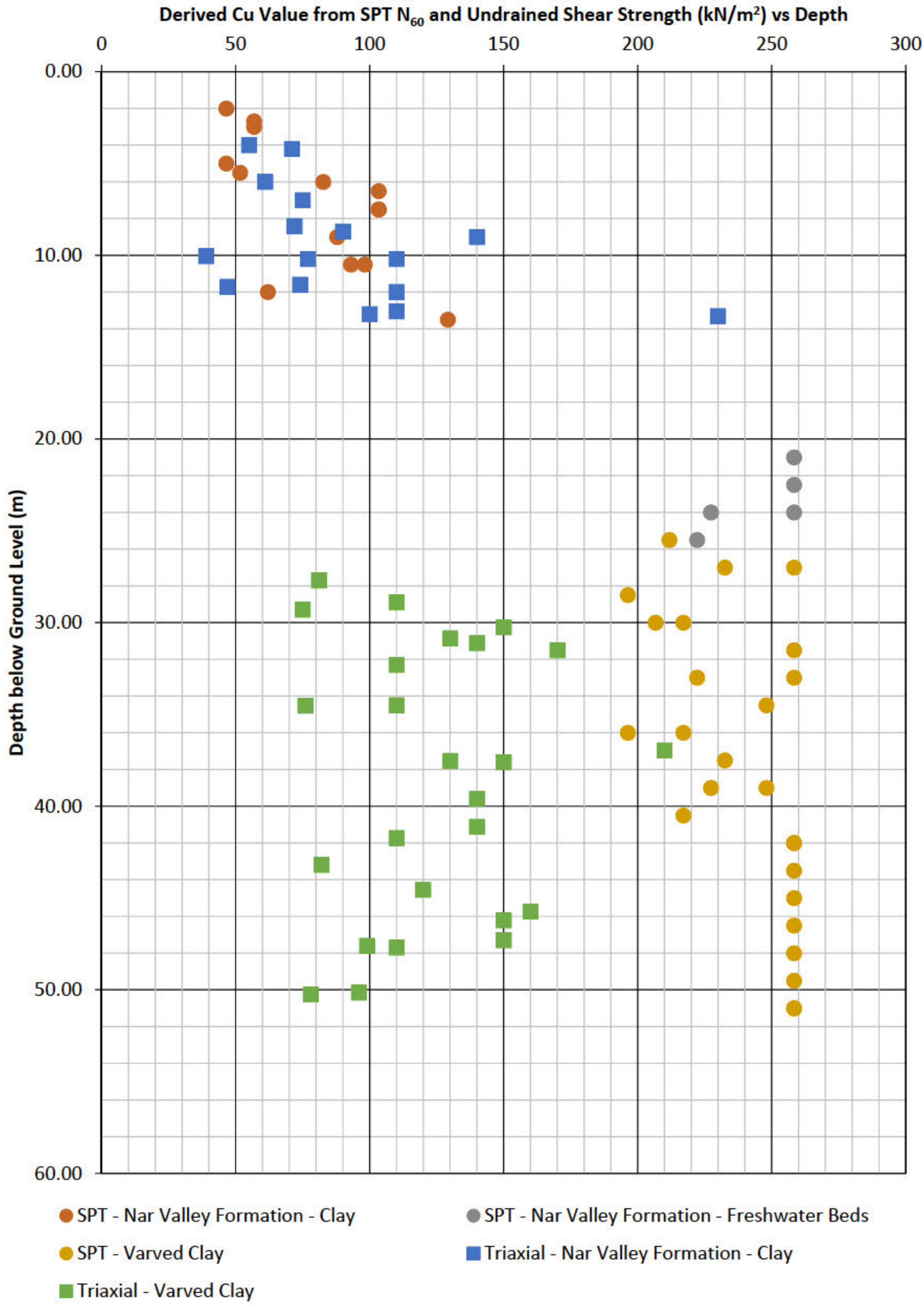


Table 3.2: Summary of Derived Cu values from SPT N_{60} and undrained shear strength (kN/m²) against depth below ground level

4 FOUNDATION ASSESSMENT

The proposed development will comprise a series of foundation bases which are required to support a number of new pipework valves and infrastructure within the Kings Lynn Compressor Station. From drawing [redacted]341-GEN-7210-1001, sheets 1 to 3 supplied by the client, the following foundations are currently proposed:

- 9no 3.5m x 1.5m, vertical load 500kN.
- 4no 4.0m x 4.0m, vertical load 1,000kN.
- 1no 7.0m x 3.0m, vertical load 2,400kN.
- 2no 6.0m x 4.0m, vertical load 2,800kN.
- 1no. 15.0m x 5.0m plus 4.0m x 4.0m, vertical load 8,400kN.

Due to the requirement to connect the proposed pipework to existing infrastructure already present within the compound, the primary concern with new foundations will be to limit differential settlement which will occur following construction. For the purposes of initial design it is assumed that any ongoing consolidation settlement of the existing infrastructure has essentially reduced close to zero. As such, any differential movement between the existing and proposed infrastructure will be as a result of settlement in the new foundations.

For cost reasons, a shallow foundation solution is the most attractive solution however, this will result in the risk of higher settlements occurring in the short to long term. The maximum allowable degree of settlement has not been indicated by the client at this stage. The alternative foundation solution which would result in a reduced magnitude of settlement would be through the use of piles. Proposed pile locations and spacing's are presented on drawing [redacted]341-GEN-7210-1001 and comprise anticipated maximum loads of 250kN, 400kN and 700kN.

Shallow pad/raft or piled foundations will be constructed in the shallow River Terrace Deposits and underlying Nar Valley Formation (clay, lignite and gravels). It is considered unlikely that the construction of piled foundations would need to penetrate into the Varved Clays which underlie the site at depths in excess of around 26mbgl.

Preliminary calculations have been undertaken to determine acceptability of such foundations with respect to bearing resistance and settlement in accordance with BS EN 1997-1 2004+A1:2013.

Groundwater may be encountered in shallow excavations (<1.5m depth) with an increased risk during the winter months. Deeper excavations will encounter groundwater as equilibrium levels have been recorded at approximately 1.36mbgl. Risk of groundwater inflows will exist where confined granular strata are encountered, particularly during piling operations. It should be appreciated that groundwater levels may fluctuate due to seasonal variation in rainfall.

4.1 Shallow Pad/Raft Foundation

Outline analysis carried out in accordance with Design Approach 1, Combination 1 shallow foundation. For the purposes of initial design, the assessment of Location 14 has been simplified to represent a rectangular base of equivalent area (91m^2) with overall dimensions of 15.0m x 6.07m. All other foundation bases have been assessed as required. For design purposes, ground conditions are assumed to be most closely represented by those encountered within BH3, which is located close to foundation location 06, 08 and 09, and within the area where the majority of foundations are proposed. In addition, ground conditions appear to be relatively consistent across the site with only relatively minor variations in the depths of stratum boundaries.

Foundations are assumed to be 1.0m thick and constructed at a depth of 1.0m bgl with the top of the foundation coincident with existing ground level. Proposed foundation loads have been calculated on the sum of maximum pile loads at each location as indicated on drawing [redacted]341-GEN-7210-1001.

Although there are a total of 17no foundations, there are 5no types requiring assessment for bearing capacity and settlement. The results of the analyses are presented in Table 4.1 below, with full results presented in the Appendix.

Foundation Type (Location)	Foundation Size (m)	Vertical Design Load (Horizontal Load)	Bearing Resistance [Rd] / Maximum Contact Stress [Vd] (kPa)	Estimated Settlement (mm)
A (01-06, 8, 15-16)	3.5m x 1.5m	500kN (100kN)	68.48 / 143.24 UNACCEPTABLE	8.9
B (11-13, 15)	4.0m x 4.0m	1000kN (100kN)	103.50 / 80.76 ACCEPTABLE	12.7
C (07)	7.0m x 3.0m	2,400kN (100kN)	106.38 / 132.54 UNACCEPTABLE	27.1
D (09-10)	6.0m x 4.0m	2,800kN (100kN)	117.29 / 133.78 UNACCEPTABLE	31.7
E (14)	15.0m x 5.0m plus 4.0m x 4.0m	8,400kN (100kN)	150.66 / 108.70 ACCEPTABLE	49.5

Table 4.1: Summary of shallow pad/raft foundation design assessed for bearing capacity and settlement

For three of the cases analysed (A, C & D), unacceptable bearing resistance has been determined in accordance with Design Approach 1. As such, should shallow foundations be required for the proposed development, the proposed foundation bases at these locations will need to be enlarged to reduce the magnitude of loads imposed on the underlying formation soils. However, it should be noted that increasing the size of dimensions may result in an increase in settlement.

With regard to settlement, for the analysed cases it is anticipated to range from between 8.9mm for the smaller, more lightly loaded foundations, up to a maximum of 49.5mm for the larger, more heavily loaded foundation at location 14.

Given the issue of unacceptable bearing resistance in some locations and anticipated settlement of up to 49.5mm, it is anticipated that assessment of a piled foundation solution should be undertaken, which is presented below.

Should shallow foundation be considered suitable it is recommended that detailed design should be carried out once actual design loads have been confirmed. The base of all foundations should be checked for the presence of loose or otherwise unsuitable soils and the formation would benefit from compaction which would help increase the density of any looser near surface soils that may be present. In addition, relict below ground structures/foundations should be removed from beneath areas of proposed new structures prior to construction.

4.2 Piled Foundations

Given the location of the proposed development and sensitivity of the surrounding compound infrastructure it has been assumed that the use of driven piles will not be acceptable due to the risk imposed by excessive ground vibration during installation. As such, should piles be utilised to support the proposed foundation bases, assessment has been undertaken based on the use of continuous flight auger (CFA) or bored piles.

Sensitivity assessment and analysis has been undertaken to determine the optimum pile diameter and depth. With the priority given to minimising settlement at the proposed loads it is considered that piles extending to a depth of 16.0m will provide the optimum performance. At 16m depth, the base of the pile will lie 1.0m into the very dense gravel of the Nar Valley Formation, which provides increased end bearing capacity at the base of the pile and also acts to minimise settlement which may occur within the overlying cohesive deposits and lignite of the Nar Valley Formation.

Based on a construction depth of 16.0mbgl, the three proposed pile loads have been analysed in accordance with Design Approach 1, Combination 1 & 2. The results are summarised in Table 4.2 below and the full calculations are presented in the Appendix.

Pile Diameter (m)	Pile Depth (m bgl)	Vertical Design Load (Horizontal Load)	Pile Bearing Resistance [Rc] / Ultimate Contact Force [Vd] (kPa)	Estimated Settlement (mm)
0.30	16.0	250kN (100kN)	774.94 / 264.70 ACCEPTABLE	0.9
0.30	16.0	400kN (100kN)	774.94 / 414.70 ACCEPTABLE	1.4
0.30	16.0	700kN (100kN)	774.94 / 714.70 ACCEPTABLE	2.4

Table 4.2: Summary of pile foundation design assessed for bearing resistance and settlement

Assessment of a 0.30m diameter CFA pile installed to a depth of 16.0m bgl has determined acceptable pile capacity for all proposed design loads. In addition, assessment of settlement has determined a maximum vertical displacement of 2.4mm for the highest vertical design load of 700kN.

4.3 Stability of Excavations

The short term stability of excavations within the made ground and shallow natural granular and cohesive soils is likely to be relatively poor, especially where River Terrace Deposits and Head Deposits are present. Excavations are likely to need battering back to a safe angle or positive support measures adopted.

Excavations that need to extend beneath the shallow groundwater table will be unstable and require dewatering and appropriate support.

Attention is drawn to the provisions of the Health and Safety at Work regulations, which state that the sides of any excavations should be inspected, and if required shall be fully supported or battered back to a safe angle, particularly where personnel are required to enter.

4.4 Foundation Concrete (Aggressive Chemical Environment)

Chemical laboratory testing of the shallow superficial deposits found soluble sulphates in concentrations of up to 0.34g/l with associated pH values varying between 8.2 and 8.7. 6no. tests were carried out in the Nar Valley Formation – Clay and found soluble sulphates in concentrations of up to 3.2g/l with associated pH values varying between 6.5 and 8.0. 4no. tests were carried out in the Nar Valley Formation – Freshwater Beds and found soluble sulphates in concentrations of up to 0.46g/l with associated pH values varying between 6.5 and 8.4. 5no. tests were carried out in the deeper Varved Clay material and found soluble sulphates in concentrations of up to 0.26g/l with associated pH values varying between 8.1 and 8.3.

For shallow foundations, results indicate that a design sulphate class of DS-1 and an ACEC class of AC-1 should be used for buried concrete in accordance with BRE Special Digest 1, "Concrete in aggressive ground". The digest described should be consulted prior to scheduling the permanent works as the specification must be applicable to the application. However, it is recommended to sample groundwater from the shallow installation to assess the classification against aggressive chemical environment.

Results from within the Nar Valley Formation - Clay indicate that a design sulphate class of DS-3 and ACEC class AC-3 should be used for piled foundations.

Report prepared by:

Jamie Etherington BSc (Hons) FGS
Geotechnical Engineer

Report checked by:

Stephen Williams BSc (Hons) FGS AIEMA
Managing Director

REFERENCES

BS1377:1990, 'Methods of Test for Soils for Civil Engineering Purposes'.

BS5930:2015, ‘Code of Practice for Ground Investigations’.

BS EN 1997-1:2004 +A1:2013, ‘Eurocode 7: Geotechnical Design - Part 1: General rules”.

BS EN 1997-2:2007, “Eurocode 7: Geotechnical Design - Part 2: Ground Investigation and Testing”.

BS EN ISO 14688-2:2004 Geotechnical investigation and testing. Identification and classification of soil. Principles for a classification.

BS EN ISO 22475-1:2006 & 22475-2/3:2011 Geotechnical investigation and testing. Sampling methods and groundwater measurements.

BS EN ISO 22476:2005+A1:2011 Geotechnical investigation and testing. Various.

Building Research Establishment, 2005. Special Digest 1:2005, ‘Concrete in Aggressive Ground’.

LIST OF APPENDICES

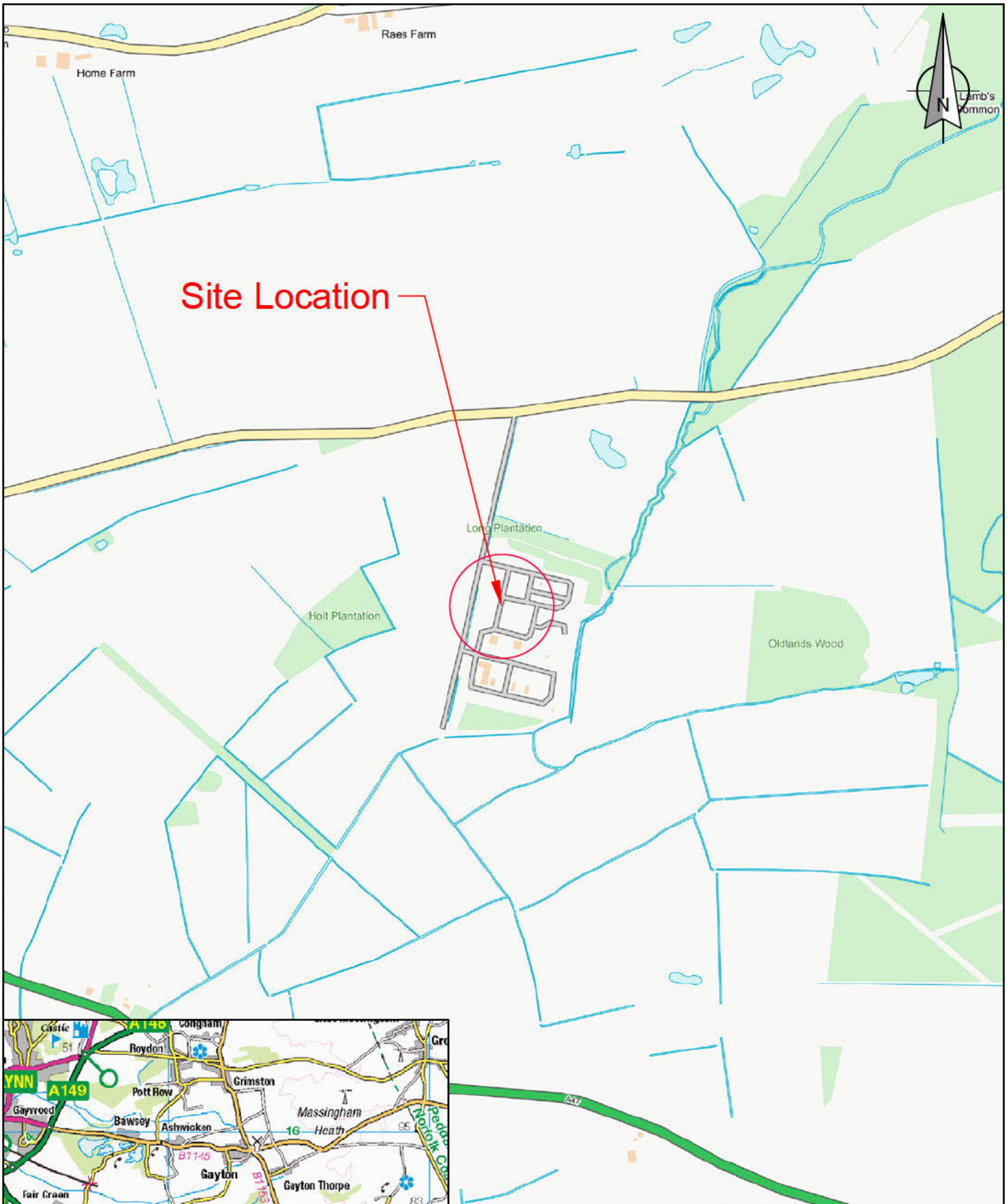
Drawings

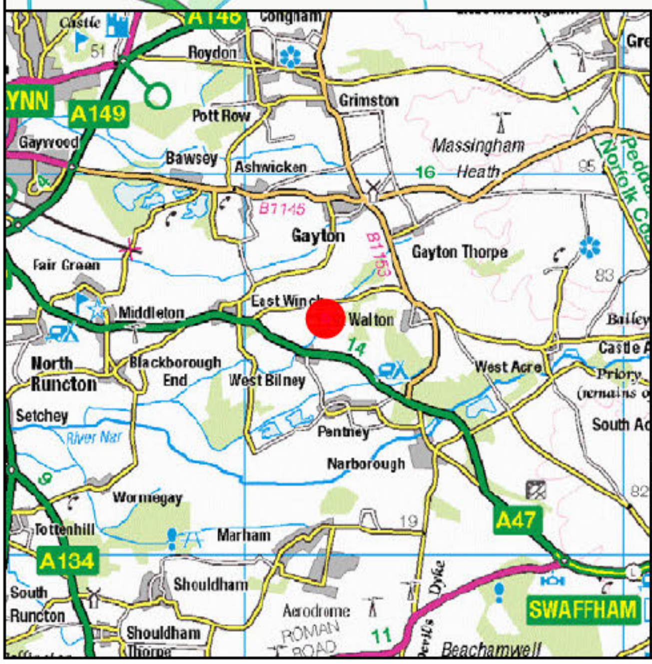
Site Location Plan	GN21822-DR001
Fieldwork Location Plan	GN21822-DR002
Preliminary Initial Pile Layout	[redacted]341-GEN-7210-10001 Sheet 1 (Rev B)
	[redacted]341-GEN-7210-10001 Sheet 2 (Rev B)
	[redacted]341-GEN-7210-10001 Sheet 3 (Rev B)

Calculations

Shallow Foundation Calculations	GN21822-Shallow_1-6&8-D01
	GN21822_Shallow_7-D01
	GN21822_Shallow_9-10D01
	GN21822_Shallow_500kN-D01
	GN21822_Shallow_2400kN-D01
	GN21822_Shallow_2800kN-D01
Pile Foundation Calculations	GN21822_Pile-0.30-250kPa
	GN21822_Pile-0.30-400kPa
	GN21822_Pile-0.30-700kPa

FM-Hn-D-104 Rev B N:\NorwichProjects\Jobs 21000s\21800\GN21822 Kings Lynn Compressor Station\Drawings\CAD files\GN21822 – DR001.dwg





[redacted]

[redacted]

Client : [redacted]

Project : Kings Lynn Compressor Station

Job No : GN21822	Date : May 2018
Drawing No : GN21822 - DR001	
Scale : 1:10000 @ A4	
Drawn by : RW	Checked by : JE
Eastings : 572100	Northings : 316240

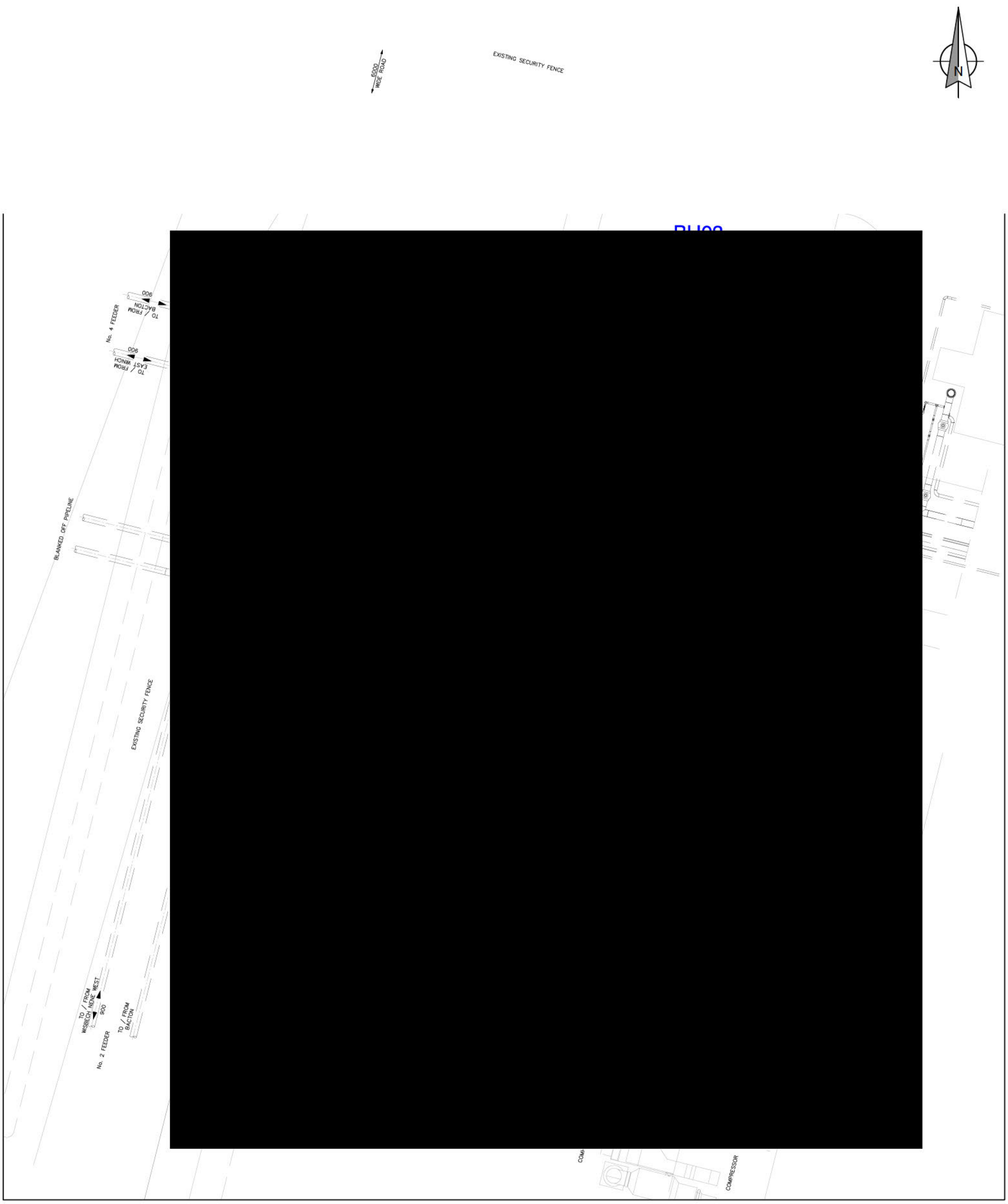
ISOQAR REGISTERED

UKAS MANAGEMENT SYSTEMS 0026

Certificate Number 5933
ISO 9001, ISO 14001

UKAS TESTING 4031

H:\Norwich\Projects\Jobs 21000s\21800\GN21822 Kings Lynn Compressor Station\Drawings\CAD files\GN21822 - DR002.dwg



[redacted]

Client : [redacted]	
Project : Kings Lynn Compressor Station	
Job No : GN21822	Date : May 2018
Drawing Title : Fieldwork Location Plan	
Drawing No : GN21822 - DR002	
Scale : 1:500 @ A3	
Drawn by : RW	Checked by : JE
Eastings : 572100	Northings : 316240

Revision history

Rev	Date	Revision Data

Key :

BH01 Cable Percussive Borehole

Notes :

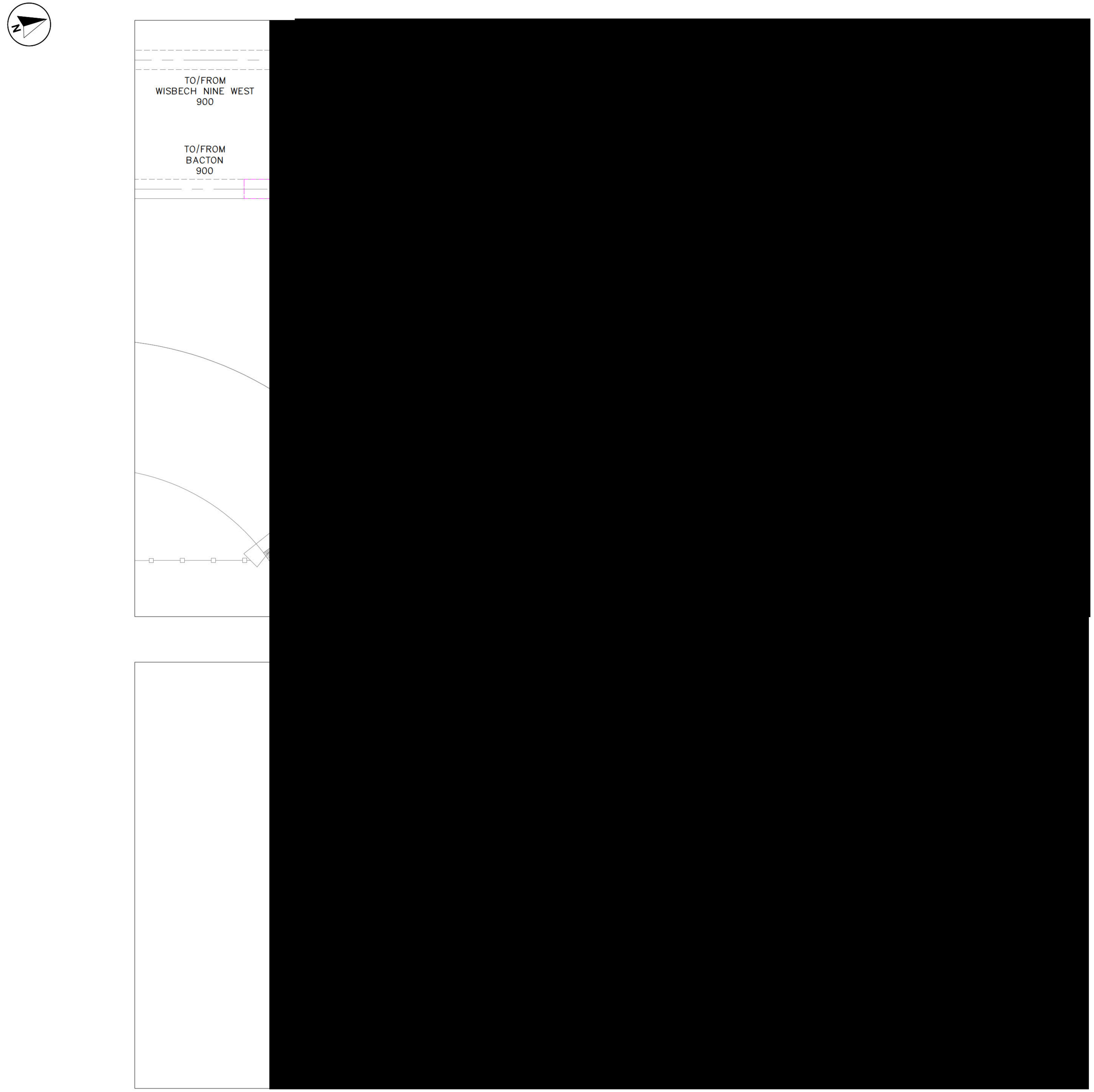
[redacted]

Certificate Number 5933
ISO 9001, ISO 14001

0026

4031

DRG. No.
[redacted]-GEN-7210-1001



[redacted]

FOR DRAWING CONTINUATION SEE SHEET 1

BASE No.	SIZE (m)	No. OF PILES	MAX. LOAD PER PILE (kN)
15	3.5x1.5	2	250
16	3.5x1.5	2	250

PILE LOADS ARE PRELIMINARY SAFE WORKING LOADS ONLY, BASED ON AN ESTIMATE OF POSSIBLE PERMANENT & VARIABLE LOADS FROM THE PIPELINES & EQUIPMENT (VALVES.... ETC)
ALL LOADS ARE UNFACTORED WITHOUT ANY ALLOWANCE FOR NEGATIVE SKIN FRICTION OR ANY OTHER GEOTECHNICAL LOADS.

BASE No.	SIZE (m)	No. OF PILES	MAX. LOAD PER PILE (kN)
17	3.5x1.5	2	250

DRAFT ISSUE FOR INFORMATION ONLY

NOTES

1. THE BEARING PILES ARE TO BE DESIGNED BY THE SPECIALIST PILING SUB-CONTRACTOR IN ACCORDANCE WITH THE RELEVANT EUROCODES.
2. FINAL AXIAL PILE CAPACITY SHOULD BE CALCULATED IN ACCORDANCE WITH BS EN 1997-1 (2004): CLAUSE 2.4.7.3.4.2 WHICH INVOKES DESIGN APPROACH 1.
3. THE STRUCTURES HAVE BEEN ASSUMED TO BE A GEOTECHNICAL CATEGORY 2 STRUCTURE WHICH APPLIES TO CONVENTIONAL STRUCTURES AND FOUNDATION WITH NO EXCEPTIONAL RISK OR LOADING CONDITIONS AS DETAILED IN BS EN 1997-1 (2004): CLAUSE 2.1, SUB-CLAUSE 18.
4. THE PILES ARE CONNECTED INTO PILE CAP GROUPS WHICH ARE RESTRAINED BY VIRTUAL TIE BEAMS BETWEEN THEM AND THEREFORE THE PILES ARE ASSUMED TO BE "FIXED" HEADED.
5. ESTIMATED VERTICAL LOADS SHOWN IN THE TABLES ARE THE TOTAL DUE TO PERMANENT AND VARIABLE ACTIONS UNFACTORED FOR ESTIMATION PURPOSES ONLY. NO TENSILE ACTIONS ARE EXPECTED TO BE APPLIED TO THE INDIVIDUAL PILES, HOWEVER THIS WILL BE CONFIRMED FOLLOWING THE MECHANICAL DETAIL ANALYSIS OF THE SUPPORTED PIPEWORK.
6. INDIVIDUAL PILES WILL BE SUBJECT TO HORIZONTAL ACTIONS FROM OPERATIONAL PROCEDURES. THESE FORCES WILL BE AVAILABLE ONCE THE PIPEWORK MECHANICAL DETAIL ANALYSIS HAS BEEN CARRIED OUT. AN ESTIMATED HORIZONTAL VARIABLE ACTION OF 15KN PER PILE SHOULD BE USED FOR ESTIMATION PURPOSES ONLY.
7. THE MAXIMUM PILE SETTLEMENT SHOULD BE NO MORE THAN 10mm AT DVL.
8. A MINIMUM OF 2 NO STATIC PILE TESTS SHOULD BE UNDERTAKEN. DYNAMIC PILE TESTS COULD ALSO BE USED TO VALIDATE THE PILES. IF DYNAMIC PILE TESTS ARE UNDERTAKEN THEN THEY MUST BE CORRELATED AGAINST A STATIC PILE TEST TO CHECK THAT THEY GIVE SIMILAR RESULTS. ALL PILES SHOULD BE SUBJECT TO INTEGRITY TESTS.
9. THE DESIGN OF THE PILING PLATFORM WILL BE THE RESPONSIBILITY OF THE PILING CONTRACTOR; THE PILING PLATFORM LEVEL WILL BE INDICATED ON THE DETAIL DESIGN DRAWINGS.

KEY

PHASE 1 PIPEWORK (ABOVE GROUND 2019).
PHASE 1 PIPEWORK (BELOW GROUND 2019).
EXISTING PIPEWORK.
NEW FEEDER (BELOW GROUND 2019)
PILE LOCATIONS
01 BASE NUMBERS

[redacted]

ORIGINATOR AW
DATE 05.07.18

[redacted]

CLIENT
nationalgrid

PROJECT
NATIONAL AGI RENOVATION CAMPAIGN (NARC) BATCH 2 (2018)

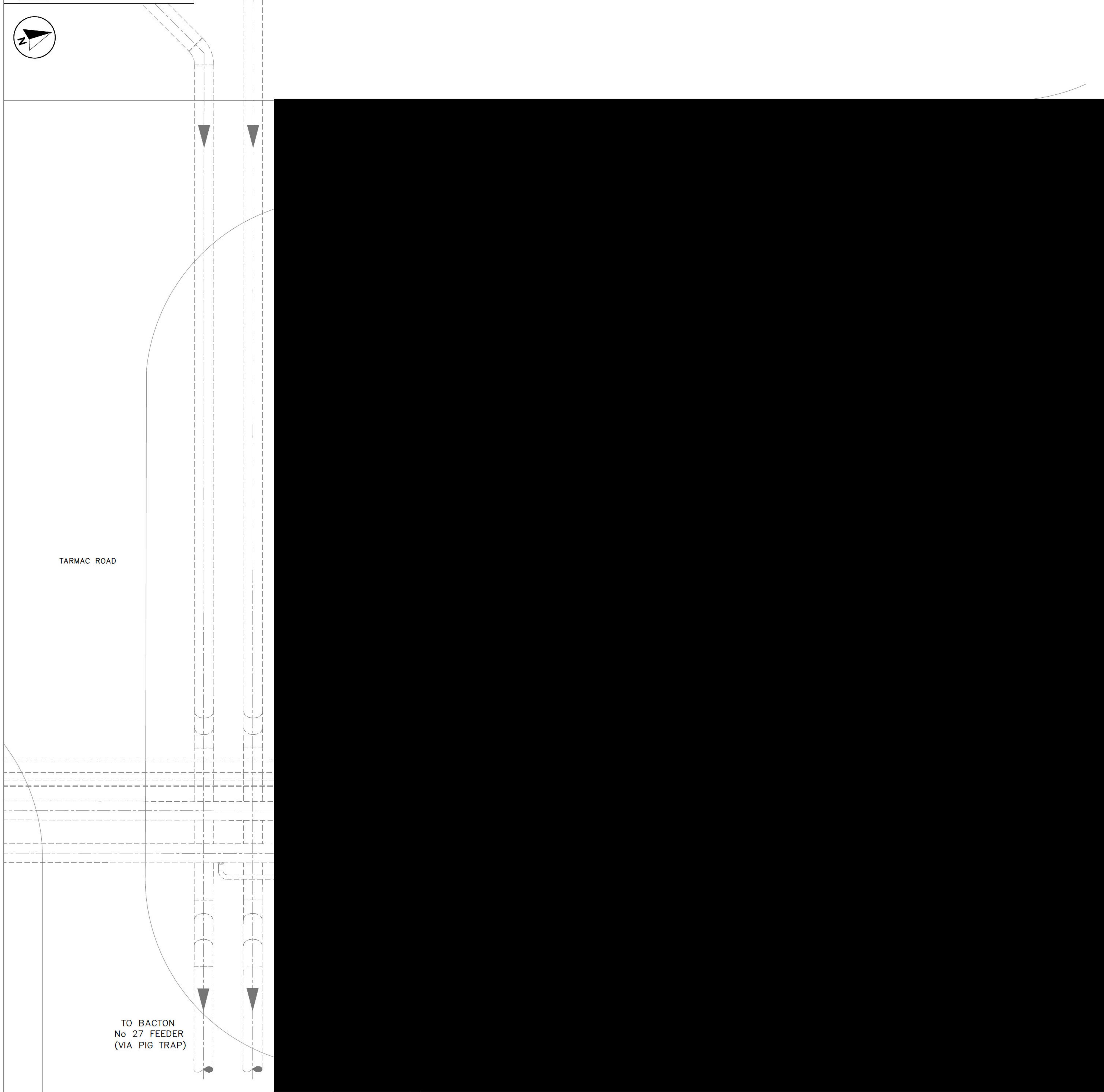
TITLE
KINGS LYNN COMPRESSOR STATION MODIFICATIONS PILING PROPOSALS

ISSUE	DATE	DRAWN	CHECKED	APPROVED	AMENDMENT
F					
E					
D					
C					
B	31.07.18	MS	GS	GS	NOTE ADDED
A	05.07.18	AW			INITIAL ISSUE FOR REVIEW AND COMMENT

SHEET 3 OF 3 | SCALE NTS | DO NOT SCALE | A1
DRG. No. [redacted]41-GEN-7210-1001 | ISSUE B

DRG. No.
[redacted]341-GEN-7210-1001

FOR DRAWING CONTINUATION SEE SHEET 1



[redacted]

BASE No.	SIZE (m)	No. OF PILES	MAX. LOAD PER PILE (kN)
04	3.5x1.5	2	250
05	3.5x1.5	2	250
06	3.5x1.5	2	250
07	3x7	6	400
08	3.5x1.5	2	250
[redacted]	[redacted]	[redacted]	700
[redacted]	[redacted]	[redacted]	700
[redacted]	[redacted]	[redacted]	250
[redacted]	[redacted]	[redacted]	250
[redacted]	[redacted]	[redacted]	250
[redacted]	[redacted]	[redacted]	700
[redacted]	[redacted]	[redacted]	250

[redacted]RELIMINARY SAFE WORKING
[redacted]D ON AN ESTIMATE OF
[redacted]NT & VARIABLE LOADS
[redacted]S & EQUIPMENT (VALVES....

[redacted] FACTORED WITHOUT ANY
[redacted]EGATIVE SKIN FRICTION OR
[redacted]HNICAL LOADS.

NOTES

1. THE BEARING PILES ARE TO BE DESIGNED BY THE SPECIALIST PILING SUB-CONTRACTOR IN ACCORDANCE WITH THE RELEVANT EUROCODES.
2. FINAL AXIAL PILE CAPACITY SHOULD BE CALCULATED IN ACCORDANCE WITH BS EN 1997-1 (2004): CLAUSE 2.4.7.3.4.2 WHICH INVOKES DESIGN APPROACH 1.
3. THE STRUCTURES HAVE BEEN ASSUMED TO BE A GEOTECHNICAL CATEGORY 2 STRUCTURE WHICH APPLIES TO CONVENTIONAL STRUCTURES AND FOUNDATION WITH NO EXCEPTIONAL RISK OR LOADING CONDITIONS AS DETAILED IN BS EN 1997-1 (2004): CLAUSE 2.1, SUB-CLAUSE 18.
4. THE PILES ARE CONNECTED INTO PILE CAP GROUPS WHICH ARE RESTRAINED BY VIRTUAL TIE BEAMS BETWEEN THEM AND THEREFORE THE PILES ARE ASSUMED TO BE "FIXED" HEADED.
5. ESTIMATED VERTICAL LOADS SHOWN IN THE TABLES ARE THE TOTAL DUE TO PERMANENT AND VARIABLE ACTIONS UNFACTORED FOR ESTIMATION PURPOSES ONLY. NO TENSILE ACTIONS ARE EXPECTED TO BE APPLIED TO THE INDIVIDUAL PILES, HOWEVER THIS WILL BE CONFIRMED FOLLOWING THE MECHANICAL DETAIL ANALYSIS OF THE SUPPORTED PIPEWORK.
6. INDIVIDUAL PILES WILL BE SUBJECT TO HORIZONTAL ACTIONS FROM OPERATIONAL PROCEDURES. THESE FORCES WILL BE AVAILABLE ONCE THE PIPEWORK MECHANICAL DETAIL ANALYSIS HAS BEEN CARRIED OUT. AN ESTIMATED HORIZONTAL VARIABLE ACTION OF 15KN PER PILE SHOULD BE USED FOR ESTIMATION PURPOSES ONLY.
7. THE MAXIMUM PILE SETTLEMENT SHOULD BE NO MORE THAN 10mm AT DVL.
8. A MINIMUM OF 2 NO STATIC PILE TESTS SHOULD BE UNDERTAKEN. DYNAMIC PILE TESTS COULD ALSO BE USED TO VALIDATE THE PILES. IF DYNAMIC PILE TESTS ARE UNDERTAKEN THEN THEY MUST BE CORRELATED AGAINST A STATIC PILE TEST TO CHECK THAT THEY GIVE SIMILAR RESULTS. ALL PILES SHOULD BE SUBJECT TO INTEGRITY TESTS.
9. THE DESIGN OF THE PILING PLATFORM WILL BE THE RESPONSIBILITY OF THE PILING CONTRACTOR; THE PILING PLATFORM LEVEL WILL BE INDICATED ON THE DETAIL DESIGN DRAWINGS.

KEY

- PHASE 1 PIPEWORK (ABOVE GROUND 2019).
- PHASE 1 PIPEWORK (BELOW GROUND 2019).
- EXISTING PIPEWORK.
- NEW FEEDER (BELOW GROUND 2019)
- PILE LOCATIONS
- 01 BASE NUMBERS

CO[redacted]

ORIGINATOR	AW
DATE	05.07.18

[redacted]

CLIENT
nationalgrid

PROJECT
NATIONAL AGI RENOVATION CAMPAIGN (NARC) BATCH 2 (2018)

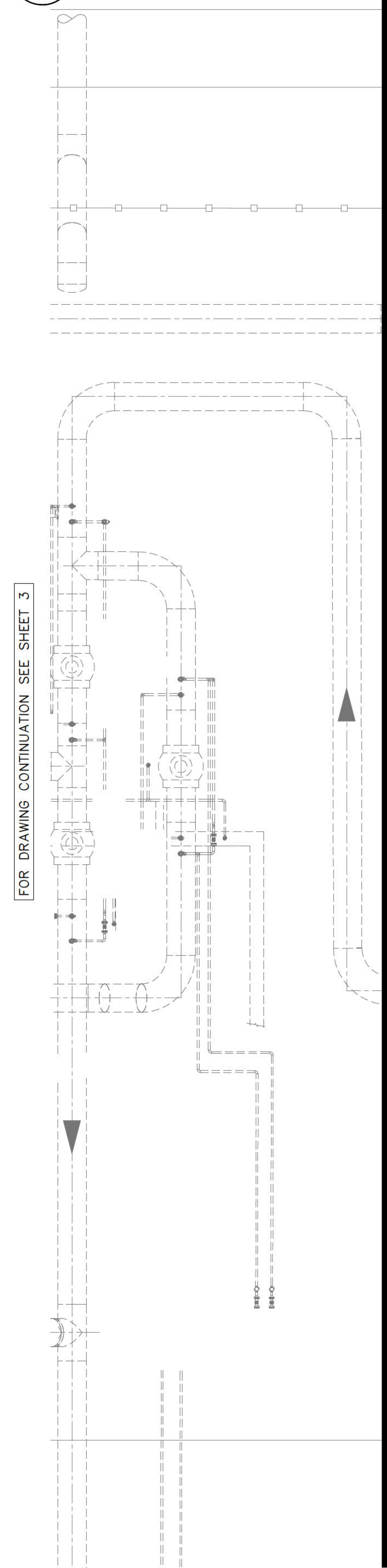
TITLE
KINGS LYNN COMPRESSOR STATION MODIFICATIONS PILING PROPOSALS

REV	DATE	DRAWN	CHECKED	APPROVED	AMENDMENT
F					
E					
D					
C					
B	31.07.18	MS	GS	GS	BASES AND PILES UPDATED, NOTE ADDED
A	05.07.18	AW			INITIAL ISSUE FOR REVIEW AND COMMENT

SHEET 2 OF 3 | SCALE NTS | DO NOT SCALE | A1

DRG. No. [redacted]41-GEN-7210-1001 | ISSUE B

DRG. No.
[redacted]41-GEN-7210-1001



[redacted]

	No. OF PILES	MAX. LOAD PER PILE (kN)
5	2	250
5	2	250
5	2	250

PILE LOADS ARE PRELIMINARY SAFE WORKING LOADS ONLY, BASED ON AN ESTIMATE OF POSSIBLE PERMANENT & VARIABLE LOADS FROM THE PIPELINES & EQUIPMENT (VALVES.... ETC)

ALL LOADS ARE UNFACTORED WITHOUT ANY ALLOWANCE FOR NEGATIVE SKIN FRICTION OR ANY OTHER GEOTECHNICAL LOADS.

POTENTIAL PIPELINE INSTRUMENTATION KIOSK (6mx4m) LOCATION

ROAD MODIFICATION

DRAFT ISSUE FOR INFORMATION ONLY

NOTES

1. THE BEARING PILES ARE TO BE DESIGNED BY THE SPECIALIST PILING SUB-CONTRACTOR IN ACCORDANCE WITH THE RELEVANT EUROCODES.
2. FINAL AXIAL PILE CAPACITY SHOULD BE CALCULATED IN ACCORDANCE WITH BS EN 1997-1 (2004): CLAUSE 2.4.7.3.4.2 WHICH INVOKES DESIGN APPROACH 1.
3. THE STRUCTURES HAVE BEEN ASSUMED TO BE A GEOTECHNICAL CATEGORY 2 STRUCTURE WHICH APPLIES TO CONVENTIONAL STRUCTURES AND FOUNDATION WITH NO EXCEPTIONAL RISK OR LOADING CONDITIONS AS DETAILED IN BS EN 1997-1 (2004): CLAUSE 2.1, SUB-CLAUSE 18.
4. THE PILES ARE CONNECTED INTO PILE CAP GROUPS WHICH ARE RESTRAINED BY VIRTUAL TIE BEAMS BETWEEN THEM AND THEREFORE THE PILES ARE ASSUMED TO BE "FIXED" HEADED.
5. ESTIMATED VERTICAL LOADS SHOWN IN THE TABLES ARE THE TOTAL DUE TO PERMANENT AND VARIABLE ACTIONS UNFACTORED FOR ESTIMATION PURPOSES ONLY. NO TENSILE ACTIONS ARE EXPECTED TO BE APPLIED TO THE INDIVIDUAL PILES, HOWEVER THIS WILL BE CONFIRMED FOLLOWING THE MECHANICAL DETAIL ANALYSIS OF THE SUPPORTED PIPEWORK.
6. INDIVIDUAL PILES WILL BE SUBJECT TO HORIZONTAL ACTIONS FROM OPERATIONAL PROCEDURES. THESE FORCES WILL BE AVAILABLE ONCE THE PIPEWORK MECHANICAL DETAIL ANALYSIS HAS BEEN CARRIED OUT. AN ESTIMATED HORIZONTAL VARIABLE ACTION OF 15KN PER PILE SHOULD BE USED FOR ESTIMATION PURPOSES ONLY.
7. THE MAXIMUM PILE SETTLEMENT SHOULD BE NO MORE THAN 10mm AT DVL.
8. A MINIMUM OF 2 NO STATIC PILE TESTS SHOULD BE UNDERTAKEN. DYNAMIC PILE TESTS COULD ALSO BE USED TO VALIDATE THE PILES. IF DYNAMIC PILE TESTS ARE UNDERTAKEN THEN THEY MUST BE CORRELATED AGAINST A STATIC PILE TEST TO CHECK THAT THEY GIVE SIMILAR RESULTS. ALL PILES SHOULD BE SUBJECT TO INTEGRITY TESTS.
9. THE DESIGN OF THE PILING PLATFORM WILL BE THE RESPONSIBILITY OF THE PILING CONTRACTOR; THE PILING PLATFORM LEVEL WILL BE INDICATED ON THE DETAIL DESIGN DRAWINGS.

KEY

PHASE 1 PIPEWORK (ABOVE GROUND 2019).
PHASE 1 PIPEWORK (BELOW GROUND 2019).
EXISTING PIPEWORK.
NEW FEEDER (BELOW GROUND 2019)
PILE LOCATIONS
01 BASE NUMBERS

[redacted]

ORIGINATOR	AW
DATE	05.07.18

[redacted]

CLIENT
nationalgrid

PROJECT
NATIONAL AGI RENOVATION CAMPAIGN (NARC) BATCH 2 (2018)

TITLE
KINGS LYNN COMPRESSOR STATION MODIFICATIONS PILING PROPOSALS

Rev	DATE	DRAWN	CHECKED	APPROVED	AMENDMENT
F					
E					
D					
C					
B	31.07.18	MS	GS	GS	NOTE ADDED
A	05.07.18	AW			INITIAL ISSUE FOR REVIEW AND COMMENT

SHEET 1 OF 3 SCALE NTS DO NOT SCALE A1
DRG. No. [redacted]41-GEN-7210-1001 ISSUE B

Spread footing verification

Input data

Project

Task : NARC Batch 2 2018 Foundation Design
Part : Locations 9-10
Description : Outline Pad Foundation Design
Customer : [redacted]
Author : [redacted]
Date : 07/08/2018
Project ID : Kings Lynn Compressor Station
Project number : GN21822

Settings

Standard - EN 1997 - DA1

Materials and standards

Concrete structures : EN 1992-1-1 (EC2)
Coefficients EN 1992-1-1 : standard

Settlement

Analysis method : Analysis using oedometric modulus
Restriction of influence zone : by percentage of Sigma,Or
Coeff. of restriction of influence zone : 10.0 [%]

Spread Footing

Analysis for drained conditions : EC 7-1 (EN 1997-1:2003)
Analysis of uplift : Standard
Allowable eccentricity : 0.333
Verification methodology : according to EN 1997
Design approach : 1 - reduction of actions and soil parameters

Partial factors on actions (A)									
Permanent design situation									
		Combination 1				Combination 2			
		Unfavourable		Favourable		Unfavourable		Favourable	
Permanent actions :	γ_G =	1.35	[–]	1.00	[–]	1.00	[–]	1.00	[–]

Partial factors for soil parameters (M)					
Permanent design situation					
		Combination 1		Combination 2	
Partial factor on internal friction :	γ_ϕ =	1.00	[–]	1.25	[–]
Partial factor on effective cohesion :	γ_c =	1.00	[–]	1.25	[–]
Partial factor on undrained shear strength :	γ_{cu} =	1.00	[–]	1.40	[–]
Partial factor on unconfined strength :	γ_v =	1.00	[–]	1.40	[–]

Basic soil parameters

No.	Name	Pattern	φ_{ef} [°]	c_{ef} [kPa]	γ [kN/m^3]	γ_{su} [kN/m^3]	δ [°]
1	Made Ground		21.00	0.00	16.00	6.00	
2	River Terrace Deposits		32.00	0.00	18.00	8.00	
3	Nar Valley (Clay)		24.00	0.00	19.10	9.10	

No.	Name	Pattern	φ_{ef} [°]	c_{ef} [kPa]	γ [kN/m3]	γ_{su} [kN/m3]	δ [°]
4	Nar Valley (Lignite)		12.00	500.00	11.80	1.80	
5	Nar Valley (Sand and Gravel)		38.00	0.00	20.00	10.00	
6	Varved Clay		24.00	5.00	20.00	10.00	

All soils are considered as cohesionless for at rest pressure analysis.

Soil parameters

Made Ground
Unit weight : γ = 16.00 kN/m3
Angle of internal friction : φ_{ef} = 21.00 °
Cohesion of soil : c_{ef} = 0.00 kPa
Oedometric modulus : E_{oed} = 4.00 MPa
Saturated unit weight : γ_{sat} = 16.00 kN/m3

River Terrace Deposits
Unit weight : γ = 18.00 kN/m3
Angle of internal friction : φ_{ef} = 32.00 °
Cohesion of soil : c_{ef} = 0.00 kPa
Oedometric modulus : E_{oed} = 30.00 MPa
Saturated unit weight : γ_{sat} = 18.00 kN/m3

Nar Valley (Clay)
Unit weight : γ = 19.10 kN/m3
Angle of internal friction : φ_{ef} = 24.00 °
Cohesion of soil : c_{ef} = 0.00 kPa
Oedometric modulus : E_{oed} = 8.00 MPa
Saturated unit weight : γ_{sat} = 19.10 kN/m3

Nar Valley (Lignite)
Unit weight : γ = 11.80 kN/m3
Angle of internal friction : φ_{ef} = 12.00 °
Cohesion of soil : c_{ef} = 500.00 kPa
Oedometric modulus : E_{oed} = 10.00 MPa
Saturated unit weight : γ_{sat} = 11.80 kN/m3

Nar Valley (Sand and Gravel)
Unit weight : γ = 20.00 kN/m3
Angle of internal friction : φ_{ef} = 38.00 °
Cohesion of soil : c_{ef} = 0.00 kPa
Oedometric modulus : E_{oed} = 200.00 MPa
Saturated unit weight : γ_{sat} = 20.00 kN/m3

Varved Clay
Unit weight : γ = 20.00 kN/m3
Angle of internal friction : φ_{ef} = 24.00 °
Cohesion of soil : c_{ef} = 5.00 kPa
Oedometric modulus : E_{oed} = 14.00 MPa

Saturated unit weight : γ_{sat} = 20.00 kN/m^3

Foundation

Foundation type: centric spread footing

Depth from original ground surface	h_z	=	1.00	m
Depth of footing bottom	d	=	1.00	m
Foundation thickness	t	=	1.00	m
Incl. of finished grade	s_1	=	0.00	°
Incl. of footing bottom	s_2	=	0.00	°

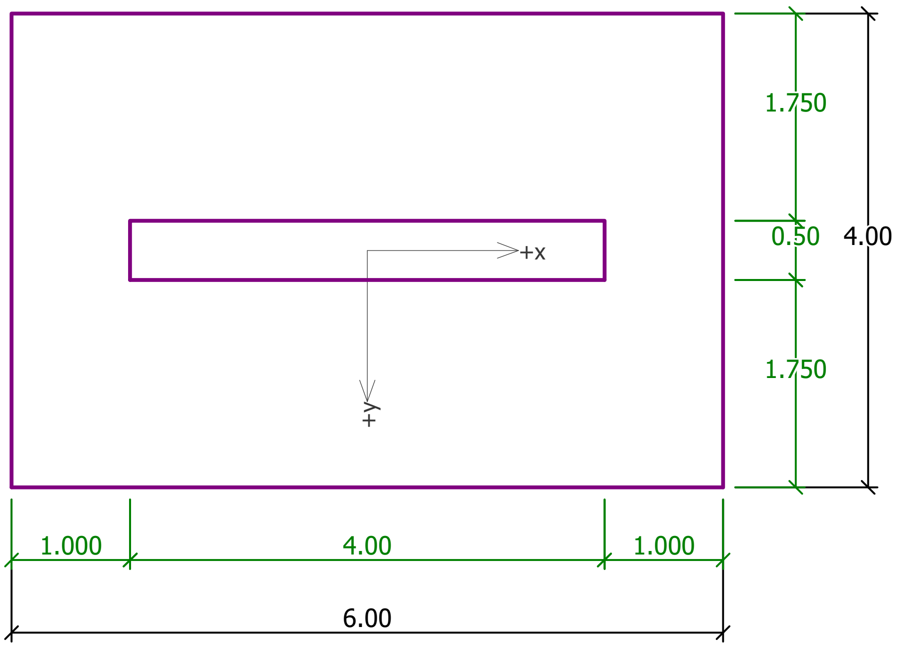
Unit weight of soil above foundation = 20.00 kN/m^3

Geometry of structure

Foundation type: centric spread footing

Spread footing length	x	=	6.00	m
Spread footing width	y	=	4.00	m
Column width in the direction of x	c_x	=	4.00	m
Column width in the direction of y	c_y	=	0.50	m
Spread footing volume		=	24.00	m^3

Name : Geometry | **Stage - analysis : 1 - 0**



Material of structure

Unit weight γ = 25.00 kN/m^3
Analysis of concrete structures carried out according to the standard EN 1992-1-1 (EC2).

Concrete : C 20/25

Cylinder compressive strength	f_{ck}	=	20.00	MPa
Tensile strength	f_{ctm}	=	2.20	MPa
Elasticity modulus	E_{cm}	=	30000.00	MPa

Longitudinal steel : B500

Yield strength f_{yk} = 500.00 MPa

Transverse steel: B500

Yield strength f_{yk} = 500.00 MPa

Geological profile and assigned soils

No.	Layer [m]	Assigned soil	Pattern
1	0.60	Made Ground	
2	1.90	River Terrace Deposits	
3	11.00	Nar Valley (Clay)	
4	1.50	Nar Valley (Lignite)	
5	9.80	Nar Valley (Sand and Gravel)	
6	17.20	Varved Clay	
7	8.00	Varved Clay	
8	-	Varved Clay	

Load

No.	Load		Name	Type	N [kN]	M_x [kNm]	M_y [kNm]	H_x [kN]	H_y [kN]
	new	change							
1	Yes		Load No. 1	Design	2800.00	0.00	0.00	0.00	100.00
2	Yes		Load No. 2	Service	2800.00	0.00	0.00	0.00	100.00

Ground water table

The ground water table is at a depth of 0.00 m from the original terrain.

Global settings

Type of analysis : analysis for drained conditions

Settings of the stage of construction

Design situation : permanent

Verification No. 1

Load case verification

Name	Self w. in favor	e_x [m]	e_y [m]	σ [kPa]	R_d [kPa]	Utilization [%]	Is satisfied
Load No. 1	Yes	0.00	-0.03	133.78	225.17	59.41	Yes
Load No. 1	No	0.00	-0.03	139.03	225.86	61.56	Yes
Load No. 2	Yes	0.00	-0.03	133.78	117.29	114.07	No
Load No. 2	No	0.00	-0.03	133.78	117.29	114.07	No

Analysis carried out with automatic selection of the most unfavourable load cases.

Computed weight of spread footing G = 360.00 kN
Computed weight of overburden Z = 0.00 kN

Vertical bearing capacity check

Shape of contact stress : rectangle

Most unfavorable load case No. 2. (Load No. 2)

Parameters of slip surface below foundation:
Depth of slip surface z_{sp} = 5.52 m
Length of slip surface l_{sp} = 15.63 m

Design bearing capacity of found.soil R_d = 117.29 kPa
Extreme contact stress σ = 133.78 kPa

Bearing capacity in the vertical direction is NOT SATISFACTORY

Verification of load eccentricity

Max. eccentricity in direction of base length e_x = 0.000<0.333
Max. eccentricity in direction of base width e_y = 0.008<0.333
Max. overall eccentricity e_t = 0.008<0.333

Eccentricity of load is SATISFACTORY

Horizontal bearing capacity check

Most unfavorable load case No. 2. (Load No. 2)

Earth resistance: at rest
Design magnitude of earth resistance S_{pd} = 6.68 kN

Horizontal bearing capacity R_{dh} = 1586.35 kN
Extreme horizontal force H = 100.00 kN

Bearing capacity in the horizontal direction is SATISFACTORY

Bearing capacity of foundation is NOT SATISFACTORY

Verification No. 1

Settlement and rotation of foundation - input data

Analysis carried out with automatic selection of the most unfavourable load cases.
Analysis carried out with accounting for coefficient κ_1 (influence of foundation depth).
Stress at the footing bottom considered from the finished grade.

Computed weight of spread footing G = 360.00 kN
Computed weight of overburden Z = 0.00 kN

Settlement and rotation of foundation - partial results

Layer No.	Origin [m]	End [m]	Thickness [m]	E_{def} [MPa]	σ_{or} [kPa]	$\Delta\sigma_z$ [kPa]	Settlement [mm]
1	1.00	1.05	0.05	1.75	7.00	124.81	0.21
2	1.05	1.10	0.05	1.75	7.40	124.43	0.21
3	1.10	1.15	0.05	1.75	7.80	123.35	0.21
4	1.15	1.20	0.05	1.75	8.20	121.40	0.20
5	1.20	1.25	0.05	1.75	8.60	118.67	0.20
6	1.25	1.30	0.05	1.75	9.00	115.37	0.19
7	1.30	1.40	0.10	1.75	9.60	109.81	0.37
8	1.40	1.50	0.10	1.75	10.40	102.32	0.34
9	1.50	1.60	0.10	1.75	11.20	95.29	0.32
10	1.60	1.70	0.10	1.75	12.00	89.01	0.30
11	1.70	1.80	0.10	1.75	12.80	83.54	0.28

Layer No.	Origin [m]	End [m]	Thickness [m]	E_{def} [MPa]	σ_{or} [kPa]	$\Delta\sigma_z$ [kPa]	Settlement [mm]
12	1.80	1.90	0.10	1.75	13.60	78.80	0.26
13	1.90	2.15	0.25	1.75	15.00	72.23	0.60
14	2.15	2.40	0.25	1.75	17.00	64.61	0.54
15	2.40	2.50	0.10	1.75	18.40	60.34	0.20
16	2.50	2.65	0.15	0.47	19.48	57.79	1.08
17	2.65	2.90	0.25	0.47	21.30	54.16	1.69
18	2.90	3.15	0.25	0.47	23.58	50.27	1.57
19	3.15	3.40	0.25	0.47	25.85	46.92	1.47
20	3.40	3.90	0.50	0.47	29.27	42.70	2.67
21	3.90	4.40	0.50	0.47	33.82	37.83	2.36
22	4.40	4.90	0.50	0.47	38.37	33.72	2.11
23	4.90	5.40	0.50	0.47	42.92	30.19	1.89
24	5.40	5.90	0.50	0.47	47.47	27.12	1.70
25	5.90	6.40	0.50	0.47	52.02	24.45	1.53
26	6.40	7.40	1.00	0.47	58.84	21.13	2.64
27	7.40	8.40	1.00	0.47	67.94	17.46	2.18
28	8.40	9.40	1.00	0.47	77.04	14.59	1.82
29	9.40	10.40	1.00	0.47	86.14	12.32	1.54
30	10.40	11.29	0.89	0.47	94.74	10.59	1.04

Settlement of mid point of edge x - 1 = 33.1 mm
Settlement of mid point of edge x - 2 = 32.2 mm
Settlement of mid point of edge y - 1 = 28.3 mm
Settlement of mid point of edge y - 2 = 28.3 mm
Settlement of foundation center point = 45.9 mm
Settlement of characteristic point = 31.7 mm

(1-max.compressed edge; 2-min.compressed edge)

Settlement and rotation of foundation - results

Foundation stiffness:
Computed weighted average modulus of deformation E_{def} = 0.92 MPa
Foundation in the longitudinal direction is rigid (k=150.92)
Foundation in the direction of width is rigid (k=509.36)

Verification of load eccentricity

Max. eccentricity in direction of base length e_x = 0.000<0.333
Max. eccentricity in direction of base width e_y = 0.008<0.333
Max. overall eccentricity e_t = 0.008<0.333

Eccentricity of load is SATISFACTORY

Overall settlement and rotation of foundation:
Foundation settlement = 31.7 mm
Depth of influence zone = 10.29 m

Rotation in direction of x = 0.000 (tan*1000); (3.4E-17 °)
Rotation in direction of y = 0.224 (tan*1000); (1.3E-02 °)

Spread footing verification

Input data

Project

Task : NARC Batch 2 2018 Foundation Design
Part : Location 7
Description : Outline Pad Foundation Design
Customer : [redacted]
Author : [redacted]
Date : 07/08/2018
Project ID : Kings Lynn Compressor Station
Project number : GN21822

Settings

Standard - EN 1997 - DA1

Materials and standards

Concrete structures : EN 1992-1-1 (EC2)
Coefficients EN 1992-1-1 : standard

Settlement

Analysis method : Analysis using oedometric modulus
Restriction of influence zone : by percentage of Sigma,Or
Coeff. of restriction of influence zone : 10.0 [%]

Spread Footing

Analysis for drained conditions : EC 7-1 (EN 1997-1:2003)
Analysis of uplift : Standard
Allowable eccentricity : 0.333
Verification methodology : according to EN 1997
Design approach : 1 - reduction of actions and soil parameters

Partial factors on actions (A)									
Permanent design situation									
		Combination 1				Combination 2			
		Unfavourable		Favourable		Unfavourable		Favourable	
Permanent actions :	γ_G =	1.35	[–]	1.00	[–]	1.00	[–]	1.00	[–]

Partial factors for soil parameters (M)					
Permanent design situation					
		Combination 1		Combination 2	
Partial factor on internal friction :	γ_ϕ =	1.00	[–]	1.25	[–]
Partial factor on effective cohesion :	γ_c =	1.00	[–]	1.25	[–]
Partial factor on undrained shear strength :	γ_{cu} =	1.00	[–]	1.40	[–]
Partial factor on unconfined strength :	γ_v =	1.00	[–]	1.40	[–]

Basic soil parameters

No.	Name	Pattern	φ_{ef} [°]	c_{ef} [kPa]	γ [kN/m^3]	γ_{su} [kN/m^3]	δ [°]
1	Made Ground		21.00	0.00	16.00	6.00	
2	River Terrace Deposits		32.00	0.00	18.00	8.00	
3	Nar Valley (Clay)		24.00	0.00	19.10	9.10	

No.	Name	Pattern	φ_{ef} [°]	c_{ef} [kPa]	γ [kN/m^3]	γ_{su} [kN/m^3]	δ [°]
4	Nar Valley (Lignite)		12.00	500.00	11.80	1.80	
5	Nar Valley (Sand and Gravel)		38.00	0.00	20.00	10.00	
6	Varved Clay		24.00	5.00	20.00	10.00	

All soils are considered as cohesionless for at rest pressure analysis.

Soil parameters

Made Ground
Unit weight : γ = 16.00 kN/m^3
Angle of internal friction : φ_{ef} = 21.00 °
Cohesion of soil : c_{ef} = 0.00 kPa
Oedometric modulus : E_{oed} = 4.00 MPa
Saturated unit weight : γ_{sat} = 16.00 kN/m^3

River Terrace Deposits
Unit weight : γ = 18.00 kN/m^3
Angle of internal friction : φ_{ef} = 32.00 °
Cohesion of soil : c_{ef} = 0.00 kPa
Oedometric modulus : E_{oed} = 30.00 MPa
Saturated unit weight : γ_{sat} = 18.00 kN/m^3

Nar Valley (Clay)
Unit weight : γ = 19.10 kN/m^3
Angle of internal friction : φ_{ef} = 24.00 °
Cohesion of soil : c_{ef} = 0.00 kPa
Oedometric modulus : E_{oed} = 8.00 MPa
Saturated unit weight : γ_{sat} = 19.10 kN/m^3

Nar Valley (Lignite)
Unit weight : γ = 11.80 kN/m^3
Angle of internal friction : φ_{ef} = 12.00 °
Cohesion of soil : c_{ef} = 500.00 kPa
Oedometric modulus : E_{oed} = 10.00 MPa
Saturated unit weight : γ_{sat} = 11.80 kN/m^3

Nar Valley (Sand and Gravel)
Unit weight : γ = 20.00 kN/m^3
Angle of internal friction : φ_{ef} = 38.00 °
Cohesion of soil : c_{ef} = 0.00 kPa
Oedometric modulus : E_{oed} = 200.00 MPa
Saturated unit weight : γ_{sat} = 20.00 kN/m^3

Varved Clay
Unit weight : γ = 20.00 kN/m^3
Angle of internal friction : φ_{ef} = 24.00 °
Cohesion of soil : c_{ef} = 5.00 kPa
Oedometric modulus : E_{oed} = 14.00 MPa

Saturated unit weight : γ_{sat} = 20.00 kN/m^3

Foundation

Foundation type: centric spread footing

Depth from original ground surface	h_z	=	1.00	m
Depth of footing bottom	d	=	1.00	m
Foundation thickness	t	=	1.00	m
Incl. of finished grade	s_1	=	0.00	°
Incl. of footing bottom	s_2	=	0.00	°

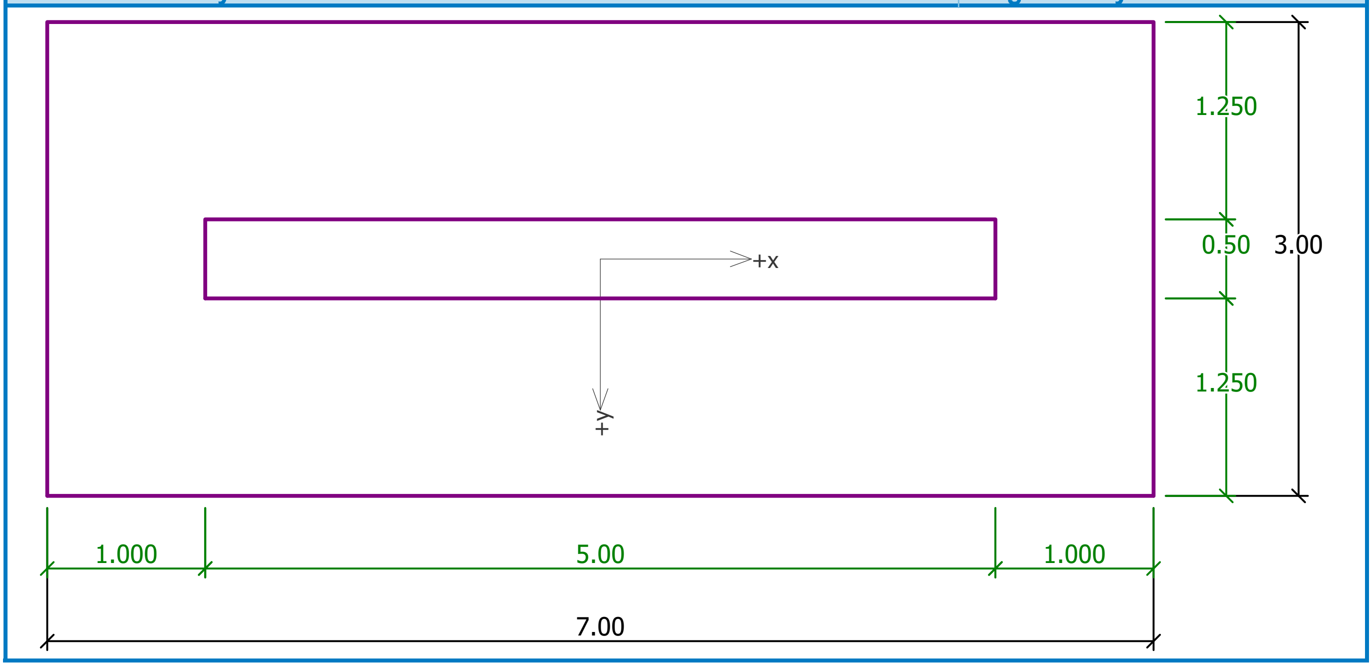
Unit weight of soil above foundation = 20.00 kN/m^3

Geometry of structure

Foundation type: centric spread footing

Spread footing length	x	=	7.00	m
Spread footing width	y	=	3.00	m
Column width in the direction of x	c_x	=	5.00	m
Column width in the direction of y	c_y	=	0.50	m
Spread footing volume		=	21.00	m^3

Name : Geometry **Stage - analysis : 1 - 0**



Material of structure

Unit weight γ = 25.00 kN/m^3
Analysis of concrete structures carried out according to the standard EN 1992-1-1 (EC2).

Concrete : C 20/25

Cylinder compressive strength	f_{ck}	=	20.00	MPa
Tensile strength	f_{ctm}	=	2.20	MPa
Elasticity modulus	E_{cm}	=	30000.00	MPa

Longitudinal steel : B500

Yield strength f_{yk} = 500.00 MPa

Transverse steel: B500

Yield strength f_{yk} = 500.00 MPa

Geological profile and assigned soils

No.	Layer [m]	Assigned soil	Pattern
1	0.60	Made Ground	
2	1.90	River Terrace Deposits	
3	11.00	Nar Valley (Clay)	
4	1.50	Nar Valley (Lignite)	
5	9.80	Nar Valley (Sand and Gravel)	
6	17.20	Varved Clay	
7	8.00	Varved Clay	
8	-	Varved Clay	

Load

No.	Load new	Load change	Name	Type	N [kN]	M_x [kNm]	M_y [kNm]	H_x [kN]	H_y [kN]
1	Yes		Load No. 1	Design	2400.00	0.00	0.00	0.00	100.00
2	Yes		Load No. 2	Service	2400.00	0.00	0.00	0.00	100.00

Ground water table

The ground water table is at a depth of 0.00 m from the original terrain.

Global settings

Type of analysis : analysis for drained conditions

Settings of the stage of construction

Design situation : permanent

Verification No. 1

Load case verification

Name	Self w. in favor	e_x [m]	e_y [m]	σ [kPa]	R_d [kPa]	Utilization [%]	Is satisfied
Load No. 1	Yes	0.00	-0.04	132.54	203.58	65.11	Yes
Load No. 1	No	0.00	-0.04	137.79	204.37	67.42	Yes
Load No. 2	Yes	0.00	-0.04	132.54	106.38	124.59	No
Load No. 2	No	0.00	-0.04	132.54	106.38	124.59	No

Analysis carried out with automatic selection of the most unfavourable load cases.

Computed weight of spread footing G = 315.00 kN
Computed weight of overburden Z = 0.00 kN

Vertical bearing capacity check

Shape of contact stress : rectangle

Most unfavorable load case No. 2. (Load No. 2)

Parameters of slip surface below foundation:
Depth of slip surface z_{sp} = 4.22 m
Length of slip surface l_{sp} = 12.03 m

Design bearing capacity of found.soil R_d = 106.38 kPa
Extreme contact stress σ = 132.54 kPa

Bearing capacity in the vertical direction is NOT SATISFACTORY

Verification of load eccentricity

Max. eccentricity in direction of base length e_x = 0.000<0.333
Max. eccentricity in direction of base width e_y = 0.012<0.333
Max. overall eccentricity e_t = 0.012<0.333

Eccentricity of load is SATISFACTORY

Horizontal bearing capacity check

Most unfavorable load case No. 2. (Load No. 2)

Earth resistance: at rest
Design magnitude of earth resistance S_{pd} = 5.01 kN

Horizontal bearing capacity R_{dh} = 1362.23 kN
Extreme horizontal force H = 100.00 kN

Bearing capacity in the horizontal direction is SATISFACTORY

Bearing capacity of foundation is NOT SATISFACTORY

Verification No. 1

Settlement and rotation of foundation - input data

Analysis carried out with automatic selection of the most unfavourable load cases.
Analysis carried out with accounting for coefficient κ_1 (influence of foundation depth).
Stress at the footing bottom considered from the finished grade.

Computed weight of spread footing G = 315.00 kN
Computed weight of overburden Z = 0.00 kN

Settlement and rotation of foundation - partial results

Layer No.	Origin [m]	End [m]	Thickness [m]	E_{def} [MPa]	σ_{or} [kPa]	$\Delta\sigma_z$ [kPa]	Settlement [mm]
1	1.00	1.05	0.05	1.75	7.00	122.38	0.20
2	1.05	1.10	0.05	1.75	7.40	121.68	0.20
3	1.10	1.15	0.05	1.75	7.80	119.84	0.20
4	1.15	1.20	0.05	1.75	8.20	116.84	0.19
5	1.20	1.25	0.05	1.75	8.60	113.09	0.19
6	1.25	1.30	0.05	1.75	9.00	108.99	0.18
7	1.30	1.40	0.10	1.75	9.60	102.88	0.34
8	1.40	1.50	0.10	1.75	10.40	95.28	0.32
9	1.50	1.60	0.10	1.75	11.20	88.62	0.30
10	1.60	1.70	0.10	1.75	12.00	82.87	0.28
11	1.70	1.80	0.10	1.75	12.80	77.91	0.26

Layer No.	Origin [m]	End [m]	Thickness [m]	E_{def} [MPa]	σ_{or} [kPa]	$\Delta\sigma_z$ [kPa]	Settlement [mm]
12	1.80	1.90	0.10	1.75	13.60	73.59	0.25
13	1.90	2.15	0.25	1.75	15.00	67.49	0.56
14	2.15	2.40	0.25	1.75	17.00	60.25	0.50
15	2.40	2.50	0.10	1.75	18.40	56.08	0.19
16	2.50	2.65	0.15	0.47	19.48	53.53	1.00
17	2.65	2.90	0.25	0.47	21.30	49.86	1.56
18	2.90	3.15	0.25	0.47	23.58	45.90	1.43
19	3.15	3.40	0.25	0.47	25.85	42.47	1.33
20	3.40	3.90	0.50	0.47	29.27	38.18	2.39
21	3.90	4.40	0.50	0.47	33.82	33.32	2.08
22	4.40	4.90	0.50	0.47	38.37	29.34	1.83
23	4.90	5.40	0.50	0.47	42.92	26.02	1.63
24	5.40	5.90	0.50	0.47	47.47	23.22	1.45
25	5.90	6.40	0.50	0.47	52.02	20.82	1.30
26	6.40	7.40	1.00	0.47	58.84	17.92	2.24
27	7.40	8.40	1.00	0.47	67.94	14.75	1.84
28	8.40	9.40	1.00	0.47	77.04	12.31	1.54
29	9.40	10.40	1.00	0.47	86.14	10.40	1.30
30	10.40	10.61	0.21	0.47	91.67	9.41	0.05

Settlement of mid point of edge x - 1 = 30.0 mm
Settlement of mid point of edge x - 2 = 29.0 mm
Settlement of mid point of edge y - 1 = 22.4 mm
Settlement of mid point of edge y - 2 = 22.4 mm
Settlement of foundation center point = 38.8 mm
Settlement of characteristic point = 27.1 mm

(1-max.compressed edge; 2-min.compressed edge)

Settlement and rotation of foundation - results

Foundation stiffness:
Computed weighted average modulus of deformation E_{def} = 0.95 MPa
Foundation in the longitudinal direction is rigid (k=91.98)
Foundation in the direction of width is rigid (k=1168.46)

Verification of load eccentricity

Max. eccentricity in direction of base length e_x = 0.000<0.333
Max. eccentricity in direction of base width e_y = 0.012<0.333
Max. overall eccentricity e_t = 0.012<0.333

Eccentricity of load is SATISFACTORY

Overall settlement and rotation of foundation:
Foundation settlement = 27.1 mm
Depth of influence zone = 9.61 m

Rotation in direction of x = 0.000 (tan*1000); (5.8E-17 °)
Rotation in direction of y = 0.326 (tan*1000); (1.9E-02 °)

Spread footing verification

Input data

Project

Task : NARC Batch 2 2018 Foundation Design
Part : Locations 1-6 & 8
Description : Outline Pad Foundation Design
Customer : [redacted]
Author : [redacted]
Date : 07/08/2018
Project ID : Kings Lynn Compressor Station
Project number : GN21822

Settings

Standard - EN 1997 - DA1

Materials and standards

Concrete structures : EN 1992-1-1 (EC2)
Coefficients EN 1992-1-1 : standard

Settlement

Analysis method : Analysis using oedometric modulus
Restriction of influence zone : by percentage of Sigma,Or
Coeff. of restriction of influence zone : 10.0 [%]

Spread Footing

Analysis for drained conditions : EC 7-1 (EN 1997-1:2003)
Analysis of uplift : Standard
Allowable eccentricity : 0.333
Verification methodology : according to EN 1997
Design approach : 1 - reduction of actions and soil parameters

Partial factors on actions (A)									
Permanent design situation									
		Combination 1				Combination 2			
		Unfavourable		Favourable		Unfavourable		Favourable	
Permanent actions :	γ_G =	1.35	[–]	1.00	[–]	1.00	[–]	1.00	[–]

Partial factors for soil parameters (M)					
Permanent design situation					
		Combination 1		Combination 2	
Partial factor on internal friction :	γ_ϕ =	1.00	[–]	1.25	[–]
Partial factor on effective cohesion :	γ_c =	1.00	[–]	1.25	[–]
Partial factor on undrained shear strength :	γ_{cu} =	1.00	[–]	1.40	[–]
Partial factor on unconfined strength :	γ_v =	1.00	[–]	1.40	[–]

Basic soil parameters

No.	Name	Pattern	φ_{ef} [°]	c_{ef} [kPa]	γ [kN/m³]	γ_{su} [kN/m³]	δ [°]
1	Made Ground		21.00	0.00	16.00	6.00	
2	River Terrace Deposits		32.00	0.00	18.00	8.00	
3	Nar Valley (Clay)		24.00	0.00	19.10	9.10	

No.	Name	Pattern	φ_{ef} [°]	c_{ef} [kPa]	γ [kN/m^3]	γ_{su} [kN/m^3]	δ [°]
4	Nar Valley (Lignite)		12.00	500.00	11.80	1.80	
5	Nar Valley (Sand and Gravel)		38.00	0.00	20.00	10.00	
6	Varved Clay		24.00	5.00	20.00	10.00	

All soils are considered as cohesionless for at rest pressure analysis.

Soil parameters

Made Ground
Unit weight : γ = 16.00 kN/m^3
Angle of internal friction : φ_{ef} = 21.00 °
Cohesion of soil : c_{ef} = 0.00 kPa
Oedometric modulus : E_{oed} = 4.00 MPa
Saturated unit weight : γ_{sat} = 16.00 kN/m^3

River Terrace Deposits
Unit weight : γ = 18.00 kN/m^3
Angle of internal friction : φ_{ef} = 32.00 °
Cohesion of soil : c_{ef} = 0.00 kPa
Oedometric modulus : E_{oed} = 30.00 MPa
Saturated unit weight : γ_{sat} = 18.00 kN/m^3

Nar Valley (Clay)
Unit weight : γ = 19.10 kN/m^3
Angle of internal friction : φ_{ef} = 24.00 °
Cohesion of soil : c_{ef} = 0.00 kPa
Oedometric modulus : E_{oed} = 8.00 MPa
Saturated unit weight : γ_{sat} = 19.10 kN/m^3

Nar Valley (Lignite)
Unit weight : γ = 11.80 kN/m^3
Angle of internal friction : φ_{ef} = 12.00 °
Cohesion of soil : c_{ef} = 500.00 kPa
Oedometric modulus : E_{oed} = 10.00 MPa
Saturated unit weight : γ_{sat} = 11.80 kN/m^3

Nar Valley (Sand and Gravel)
Unit weight : γ = 20.00 kN/m^3
Angle of internal friction : φ_{ef} = 38.00 °
Cohesion of soil : c_{ef} = 0.00 kPa
Oedometric modulus : E_{oed} = 200.00 MPa
Saturated unit weight : γ_{sat} = 20.00 kN/m^3

Varved Clay
Unit weight : γ = 20.00 kN/m^3
Angle of internal friction : φ_{ef} = 24.00 °
Cohesion of soil : c_{ef} = 5.00 kPa
Oedometric modulus : E_{oed} = 14.00 MPa

Saturated unit weight : γ_{sat} = 20.00 kN/m^3

Foundation

Foundation type: centric spread footing

Depth from original ground surface	h_z	=	1.00	m
Depth of footing bottom	d	=	1.00	m
Foundation thickness	t	=	1.00	m
Incl. of finished grade	s_1	=	0.00	°
Incl. of footing bottom	s_2	=	0.00	°

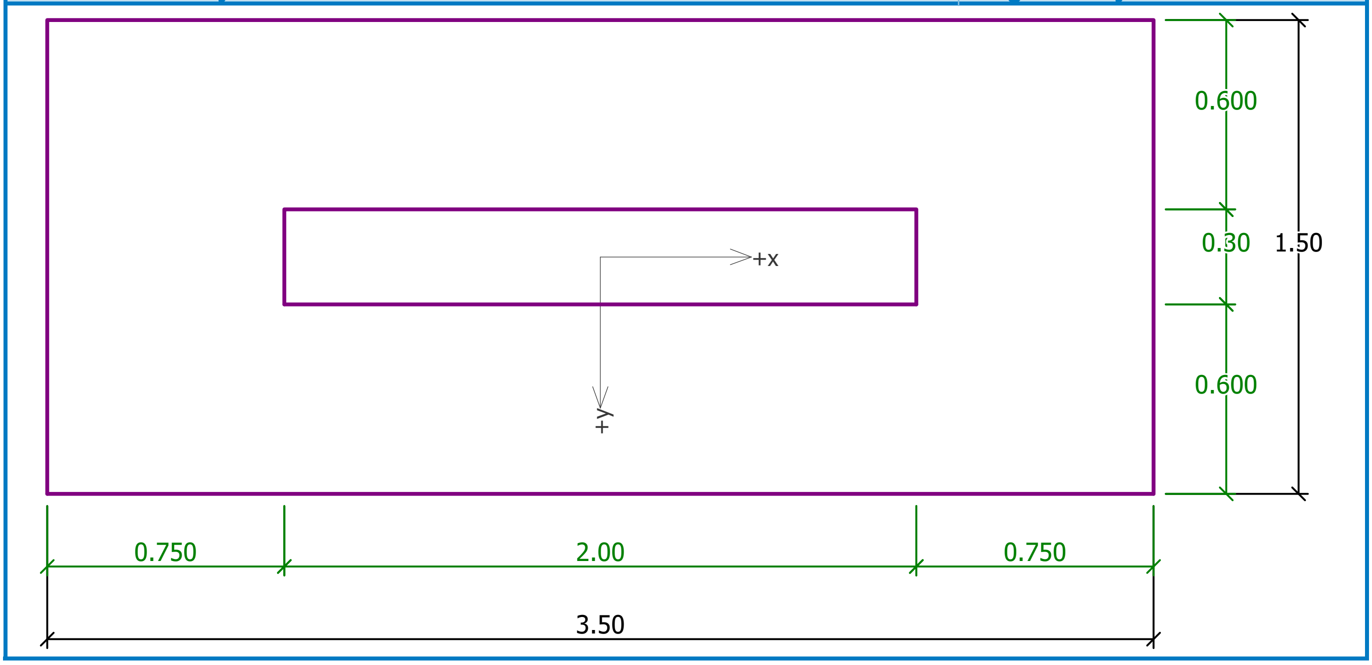
Unit weight of soil above foundation = 20.00 kN/m^3

Geometry of structure

Foundation type: centric spread footing

Spread footing length	x	=	3.50	m
Spread footing width	y	=	1.50	m
Column width in the direction of x	c_x	=	2.00	m
Column width in the direction of y	c_y	=	0.30	m
Spread footing volume		=	5.25	m^3

Name : Geometry | **Stage - analysis : 1 - 0**



Material of structure

Unit weight γ = 25.00 kN/m^3
Analysis of concrete structures carried out according to the standard EN 1992-1-1 (EC2).

Concrete : C 20/25

Cylinder compressive strength	f_{ck}	=	20.00	MPa
Tensile strength	f_{ctm}	=	2.20	MPa
Elasticity modulus	E_{cm}	=	30000.00	MPa

Longitudinal steel : B500
Yield strength f_{yk} = 500.00 MPa

Transverse steel: B500
Yield strength f_{yk} = 500.00 MPa

Geological profile and assigned soils

No.	Layer [m]	Assigned soil	Pattern
1	0.60	Made Ground	
2	1.90	River Terrace Deposits	
3	11.00	Nar Valley (Clay)	
4	1.50	Nar Valley (Lignite)	
5	9.80	Nar Valley (Sand and Gravel)	
6	17.20	Varved Clay	
7	8.00	Varved Clay	
8	-	Varved Clay	

Load

No.	Load		Name	Type	N [kN]	M_x [kNm]	M_y [kNm]	H_x [kN]	H_y [kN]
	new	change							
1	Yes		Load No. 1	Design	500.00	0.00	0.00	0.00	100.00
2	Yes		Load No. 2	Service	500.00	0.00	0.00	0.00	100.00

Ground water table

The ground water table is at a depth of 0.00 m from the original terrain.

Global settings

Type of analysis : analysis for drained conditions

Settings of the stage of construction

Design situation : permanent

Verification No. 1

Load case verification

Name	Self w. in favor	e_x [m]	e_y [m]	σ [kPa]	R_d [kPa]	Utilization [%]	Is satisfied
Load No. 1	Yes	0.00	-0.17	143.24	128.88	111.14	No
Load No. 1	No	0.00	-0.16	148.04	132.15	112.03	No
Load No. 2	Yes	0.00	-0.17	143.24	68.48	209.15	No
Load No. 2	No	0.00	-0.17	143.24	68.48	209.15	No

Analysis carried out with automatic selection of the most unfavourable load cases.

Computed weight of spread footing G = 78.75 kN
Computed weight of overburden Z = 0.00 kN

Vertical bearing capacity check

Shape of contact stress : rectangle

Most unfavorable load case No. 2. (Load No. 2)

Parameters of slip surface below foundation:
Depth of slip surface z_{sp} = 2.26 m
Length of slip surface l_{sp} = 6.68 m

Design bearing capacity of found.soil R_d = 68.48 kPa
Extreme contact stress σ = 143.24 kPa

Bearing capacity in the vertical direction is NOT SATISFACTORY

Verification of load eccentricity

Max. eccentricity in direction of base length e_x = 0.000<0.333
Max. eccentricity in direction of base width e_y = 0.115<0.333
Max. overall eccentricity e_t = 0.115<0.333

Eccentricity of load is SATISFACTORY

Horizontal bearing capacity check

Most unfavorable load case No. 2. (Load No. 2)

Earth resistance: at rest
Design magnitude of earth resistance S_{pd} = 2.51 kN

Horizontal bearing capacity R_{dh} = 291.82 kN
Extreme horizontal force H = 100.00 kN

Bearing capacity in the horizontal direction is SATISFACTORY

Bearing capacity of foundation is NOT SATISFACTORY

Verification No. 1

Settlement and rotation of foundation - input data

Analysis carried out with automatic selection of the most unfavourable load cases.
Analysis carried out with accounting for coefficient κ_1 (influence of foundation depth).
Stress at the footing bottom considered from the finished grade.

Computed weight of spread footing G = 78.75 kN
Computed weight of overburden Z = 0.00 kN

Settlement and rotation of foundation - partial results

Layer No.	Origin [m]	End [m]	Thickness [m]	E_{def} [MPa]	σ_{or} [kPa]	$\Delta\sigma_z$ [kPa]	Settlement [mm]
1	1.00	1.05	0.05	18.69	7.00	102.83	0.17
2	1.05	1.10	0.05	18.69	7.40	99.62	0.17
3	1.10	1.15	0.05	18.69	7.80	93.39	0.16
4	1.15	1.20	0.05	18.69	8.20	86.23	0.14
5	1.20	1.25	0.05	18.69	8.60	79.51	0.13
6	1.25	1.30	0.05	18.69	9.00	73.61	0.12
7	1.30	1.40	0.10	18.69	9.60	66.46	0.22
8	1.40	1.50	0.10	18.69	10.40	58.71	0.20
9	1.50	1.60	0.10	18.69	11.20	52.71	0.18
10	1.60	1.70	0.10	18.69	12.00	47.91	0.16
11	1.70	1.80	0.10	18.69	12.80	43.95	0.15

Layer No.	Origin [m]	End [m]	Thickness [m]	E_{def} [MPa]	σ_{or} [kPa]	$\Delta\sigma_z$ [kPa]	Settlement [mm]
12	1.80	1.90	0.10	18.69	13.60	40.60	0.14
13	1.90	2.15	0.25	18.69	15.00	35.99	0.30
14	2.15	2.40	0.25	18.69	17.00	30.61	0.26
15	2.40	2.50	0.10	18.69	18.40	27.57	0.09
16	2.50	2.65	0.15	0.47	19.48	25.76	0.48
17	2.65	2.90	0.25	0.47	21.30	23.19	0.72
18	2.90	3.15	0.25	0.47	23.58	20.50	0.64
19	3.15	3.40	0.25	0.47	25.85	18.25	0.57
20	3.40	3.90	0.50	0.47	29.27	15.60	0.98
21	3.90	4.40	0.50	0.47	33.82	12.76	0.80
22	4.40	4.90	0.50	0.47	38.37	10.60	0.66
23	4.90	5.40	0.50	0.47	42.92	8.93	0.56
24	5.40	5.90	0.50	0.47	47.47	7.60	0.48
25	5.90	6.40	0.50	0.47	52.02	6.54	0.41
26	6.40	6.67	0.27	0.47	55.54	5.87	0.05

Settlement of mid point of edge x - 1 = 10.8 mm
Settlement of mid point of edge x - 2 = 8.4 mm
Settlement of mid point of edge y - 1 = 7.5 mm
Settlement of mid point of edge y - 2 = 7.5 mm
Settlement of foundation center point = 12.0 mm
Settlement of characteristic point = 8.9 mm

(1-max.compressed edge; 2-min.compressed edge)

Settlement and rotation of foundation - results

Foundation stiffness:
Computed weighted average modulus of deformation E_{def} = 11.43 MPa
Foundation in the longitudinal direction is rigid (k=61.23)
Foundation in the direction of width is rigid (k=777.90)

Verification of load eccentricity

Max. eccentricity in direction of base length e_x = 0.000<0.333
Max. eccentricity in direction of base width e_y = 0.115<0.333
Max. overall eccentricity e_t = 0.115<0.333

Eccentricity of load is SATISFACTORY

Overall settlement and rotation of foundation:
Foundation settlement = 8.9 mm
Depth of influence zone = 5.67 m

Rotation in direction of x = 0.000 (tan*1000); (0.0E+00 °)
Rotation in direction of y = 1.630 (tan*1000); (9.3E-02 °)

Spread footing verification

Input data

Project

Task : NARC Batch 2 2018 Foundation Design
Part : Locations 9-10
Description : Outline Pad Foundation Design
Customer : [redacted]
Author : [redacted]
Date : 07/08/2018
Project ID : Kings Lynn Compressor Station
Project number : GN21822

Settings

Standard - EN 1997 - DA1

Materials and standards

Concrete structures : EN 1992-1-1 (EC2)
Coefficients EN 1992-1-1 : standard

Settlement

Analysis method : Analysis using oedometric modulus
Restriction of influence zone : by percentage of Sigma,Or
Coeff. of restriction of influence zone : 10.0 [%]

Spread Footing

Analysis for drained conditions : EC 7-1 (EN 1997-1:2003)
Analysis of uplift : Standard
Allowable eccentricity : 0.333
Verification methodology : according to EN 1997
Design approach : 1 - reduction of actions and soil parameters

Partial factors on actions (A)									
Permanent design situation									
		Combination 1				Combination 2			
		Unfavourable		Favourable		Unfavourable		Favourable	
Permanent actions :	γ_G =	1.35	[–]	1.00	[–]	1.00	[–]	1.00	[–]

Partial factors for soil parameters (M)					
Permanent design situation					
		Combination 1		Combination 2	
Partial factor on internal friction :	γ_ϕ =	1.00	[–]	1.25	[–]
Partial factor on effective cohesion :	γ_c =	1.00	[–]	1.25	[–]
Partial factor on undrained shear strength :	γ_{cu} =	1.00	[–]	1.40	[–]
Partial factor on unconfined strength :	γ_v =	1.00	[–]	1.40	[–]

Basic soil parameters

No.	Name	Pattern	φ_{ef} [°]	c_{ef} [kPa]	γ [kN/m^3]	γ_{su} [kN/m^3]	δ [°]
1	Made Ground		21.00	0.00	16.00	6.00	
2	River Terrace Deposits		32.00	0.00	18.00	8.00	
3	Nar Valley (Clay)		24.00	0.00	19.10	9.10	

No.	Name	Pattern	φ_{ef} [°]	c_{ef} [kPa]	γ [kN/m^3]	γ_{su} [kN/m^3]	δ [°]
4	Nar Valley (Lignite)		12.00	500.00	11.80	1.80	
5	Nar Valley (Sand and Gravel)		38.00	0.00	20.00	10.00	
6	Varved Clay		24.00	5.00	20.00	10.00	

All soils are considered as cohesionless for at rest pressure analysis.

Soil parameters

Made Ground
Unit weight : γ = 16.00 kN/m^3
Angle of internal friction : φ_{ef} = 21.00 °
Cohesion of soil : c_{ef} = 0.00 kPa
Oedometric modulus : E_{oed} = 4.00 MPa
Saturated unit weight : γ_{sat} = 16.00 kN/m^3

River Terrace Deposits
Unit weight : γ = 18.00 kN/m^3
Angle of internal friction : φ_{ef} = 32.00 °
Cohesion of soil : c_{ef} = 0.00 kPa
Oedometric modulus : E_{oed} = 30.00 MPa
Saturated unit weight : γ_{sat} = 18.00 kN/m^3

Nar Valley (Clay)
Unit weight : γ = 19.10 kN/m^3
Angle of internal friction : φ_{ef} = 24.00 °
Cohesion of soil : c_{ef} = 0.00 kPa
Oedometric modulus : E_{oed} = 8.00 MPa
Saturated unit weight : γ_{sat} = 19.10 kN/m^3

Nar Valley (Lignite)
Unit weight : γ = 11.80 kN/m^3
Angle of internal friction : φ_{ef} = 12.00 °
Cohesion of soil : c_{ef} = 500.00 kPa
Oedometric modulus : E_{oed} = 10.00 MPa
Saturated unit weight : γ_{sat} = 11.80 kN/m^3

Nar Valley (Sand and Gravel)
Unit weight : γ = 20.00 kN/m^3
Angle of internal friction : φ_{ef} = 38.00 °
Cohesion of soil : c_{ef} = 0.00 kPa
Oedometric modulus : E_{oed} = 200.00 MPa
Saturated unit weight : γ_{sat} = 20.00 kN/m^3

Varved Clay
Unit weight : γ = 20.00 kN/m^3
Angle of internal friction : φ_{ef} = 24.00 °
Cohesion of soil : c_{ef} = 5.00 kPa
Oedometric modulus : E_{oed} = 14.00 MPa

Saturated unit weight : γ_{sat} = 20.00 kN/m^3

Foundation

Foundation type: centric spread footing

Depth from original ground surface	h_z	=	1.00	m
Depth of footing bottom	d	=	1.00	m
Foundation thickness	t	=	1.00	m
Incl. of finished grade	s_1	=	0.00	°
Incl. of footing bottom	s_2	=	0.00	°

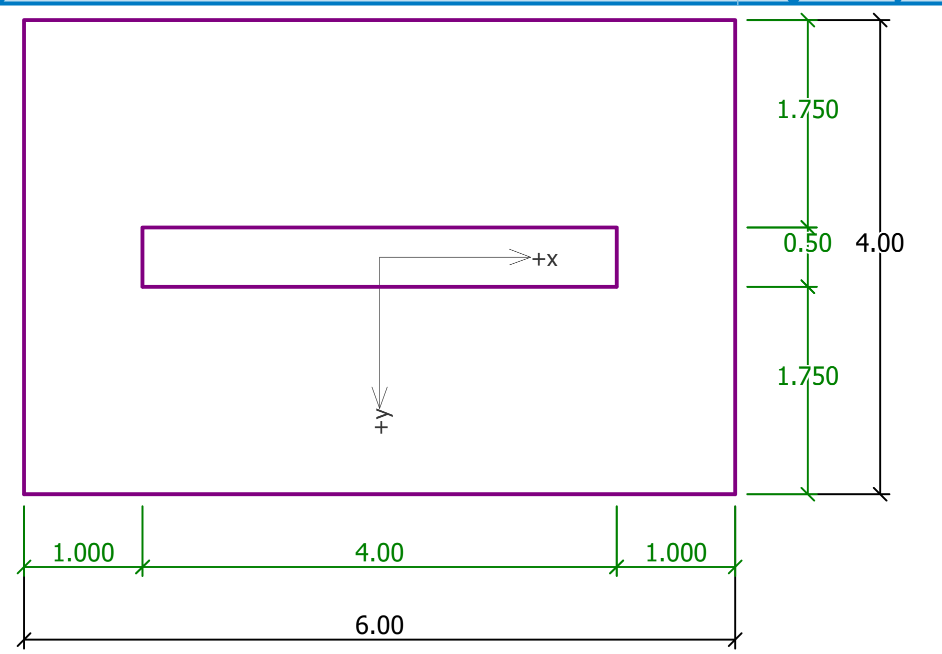
Unit weight of soil above foundation = 20.00 kN/m^3

Geometry of structure

Foundation type: centric spread footing

Spread footing length	x	=	6.00	m
Spread footing width	y	=	4.00	m
Column width in the direction of x	c_x	=	4.00	m
Column width in the direction of y	c_y	=	0.50	m
Spread footing volume		=	24.00	m^3

Name : Geometry **Stage - analysis : 1 - 0**



Material of structure

Unit weight γ = 25.00 kN/m^3
Analysis of concrete structures carried out according to the standard EN 1992-1-1 (EC2).

Concrete : C 20/25

Cylinder compressive strength	f_{ck}	=	20.00	MPa
Tensile strength	f_{ctm}	=	2.20	MPa
Elasticity modulus	E_{cm}	=	30000.00	MPa

Longitudinal steel : B500
Yield strength f_{yk} = 500.00 MPa

Transverse steel: B500
Yield strength f_{yk} = 500.00 MPa

Geological profile and assigned soils

No.	Layer [m]	Assigned soil	Pattern
1	0.60	Made Ground	
2	1.90	River Terrace Deposits	
3	11.00	Nar Valley (Clay)	
4	1.50	Nar Valley (Lignite)	
5	9.80	Nar Valley (Sand and Gravel)	
6	17.20	Varved Clay	
7	8.00	Varved Clay	
8	-	Varved Clay	

Load

No.	Load		Name	Type	N [kN]	M_x [kNm]	M_y [kNm]	H_x [kN]	H_y [kN]
	new	change							
1	Yes		Load No. 1	Design	2800.00	0.00	0.00	0.00	100.00
2	Yes		Load No. 2	Service	2800.00	0.00	0.00	0.00	100.00

Ground water table

The ground water table is at a depth of 0.00 m from the original terrain.

Global settings

Type of analysis : analysis for drained conditions

Settings of the stage of construction

Design situation : permanent

Verification No. 1

Load case verification

Name	Self w. in favor	e_x [m]	e_y [m]	σ [kPa]	R_d [kPa]	Utilization [%]	Is satisfied
Load No. 1	Yes	0.00	-0.03	133.78	225.17	59.41	Yes
Load No. 1	No	0.00	-0.03	139.03	225.86	61.56	Yes
Load No. 2	Yes	0.00	-0.03	133.78	117.29	114.07	No
Load No. 2	No	0.00	-0.03	133.78	117.29	114.07	No

Analysis carried out with automatic selection of the most unfavourable load cases.

Computed weight of spread footing G = 360.00 kN
Computed weight of overburden Z = 0.00 kN

Vertical bearing capacity check

Shape of contact stress : rectangle

Most unfavorable load case No. 2. (Load No. 2)

Parameters of slip surface below foundation:
Depth of slip surface z_{sp} = 5.52 m
Length of slip surface l_{sp} = 15.63 m

Design bearing capacity of found.soil R_d = 117.29 kPa
Extreme contact stress σ = 133.78 kPa

Bearing capacity in the vertical direction is NOT SATISFACTORY

Verification of load eccentricity

Max. eccentricity in direction of base length e_x = 0.000<0.333
Max. eccentricity in direction of base width e_y = 0.008<0.333
Max. overall eccentricity e_t = 0.008<0.333

Eccentricity of load is SATISFACTORY

Horizontal bearing capacity check

Most unfavorable load case No. 2. (Load No. 2)

Earth resistance: at rest
Design magnitude of earth resistance S_{pd} = 6.68 kN

Horizontal bearing capacity R_{dh} = 1586.35 kN
Extreme horizontal force H = 100.00 kN

Bearing capacity in the horizontal direction is SATISFACTORY

Bearing capacity of foundation is NOT SATISFACTORY

Verification No. 1

Settlement and rotation of foundation - input data

Analysis carried out with automatic selection of the most unfavourable load cases.
Analysis carried out with accounting for coefficient κ_1 (influence of foundation depth).
Stress at the footing bottom considered from the finished grade.

Computed weight of spread footing G = 360.00 kN
Computed weight of overburden Z = 0.00 kN

Settlement and rotation of foundation - partial results

Layer No.	Origin [m]	End [m]	Thickness [m]	E_{def} [MPa]	σ_{or} [kPa]	$\Delta\sigma_z$ [kPa]	Settlement [mm]
1	1.00	1.05	0.05	1.75	7.00	124.81	0.21
2	1.05	1.10	0.05	1.75	7.40	124.43	0.21
3	1.10	1.15	0.05	1.75	7.80	123.35	0.21
4	1.15	1.20	0.05	1.75	8.20	121.40	0.20
5	1.20	1.25	0.05	1.75	8.60	118.67	0.20
6	1.25	1.30	0.05	1.75	9.00	115.37	0.19
7	1.30	1.40	0.10	1.75	9.60	109.81	0.37
8	1.40	1.50	0.10	1.75	10.40	102.32	0.34
9	1.50	1.60	0.10	1.75	11.20	95.29	0.32
10	1.60	1.70	0.10	1.75	12.00	89.01	0.30
11	1.70	1.80	0.10	1.75	12.80	83.54	0.28

Layer No.	Origin [m]	End [m]	Thickness [m]	E_{def} [MPa]	σ_{or} [kPa]	$\Delta\sigma_z$ [kPa]	Settlement [mm]
12	1.80	1.90	0.10	1.75	13.60	78.80	0.26
13	1.90	2.15	0.25	1.75	15.00	72.23	0.60
14	2.15	2.40	0.25	1.75	17.00	64.61	0.54
15	2.40	2.50	0.10	1.75	18.40	60.34	0.20
16	2.50	2.65	0.15	0.47	19.48	57.79	1.08
17	2.65	2.90	0.25	0.47	21.30	54.16	1.69
18	2.90	3.15	0.25	0.47	23.58	50.27	1.57
19	3.15	3.40	0.25	0.47	25.85	46.92	1.47
20	3.40	3.90	0.50	0.47	29.27	42.70	2.67
21	3.90	4.40	0.50	0.47	33.82	37.83	2.36
22	4.40	4.90	0.50	0.47	38.37	33.72	2.11
23	4.90	5.40	0.50	0.47	42.92	30.19	1.89
24	5.40	5.90	0.50	0.47	47.47	27.12	1.70
25	5.90	6.40	0.50	0.47	52.02	24.45	1.53
26	6.40	7.40	1.00	0.47	58.84	21.13	2.64
27	7.40	8.40	1.00	0.47	67.94	17.46	2.18
28	8.40	9.40	1.00	0.47	77.04	14.59	1.82
29	9.40	10.40	1.00	0.47	86.14	12.32	1.54
30	10.40	11.29	0.89	0.47	94.74	10.59	1.04

Settlement of mid point of edge x - 1 = 33.1 mm
Settlement of mid point of edge x - 2 = 32.2 mm
Settlement of mid point of edge y - 1 = 28.3 mm
Settlement of mid point of edge y - 2 = 28.3 mm
Settlement of foundation center point = 45.9 mm
Settlement of characteristic point = 31.7 mm

(1-max.compressed edge; 2-min.compressed edge)

Settlement and rotation of foundation - results

Foundation stiffness:
Computed weighted average modulus of deformation E_{def} = 0.92 MPa
Foundation in the longitudinal direction is rigid (k=150.92)
Foundation in the direction of width is rigid (k=509.36)

Verification of load eccentricity

Max. eccentricity in direction of base length e_x = 0.000<0.333
Max. eccentricity in direction of base width e_y = 0.008<0.333
Max. overall eccentricity e_t = 0.008<0.333

Eccentricity of load is SATISFACTORY

Overall settlement and rotation of foundation:
Foundation settlement = 31.7 mm
Depth of influence zone = 10.29 m

Rotation in direction of x = 0.000 (tan*1000); (3.4E-17 °)
Rotation in direction of y = 0.224 (tan*1000); (1.3E-02 °)

Spread footing verification

Input data

Project

Task	:	NARC Batch 2 2018 Foundation Design
Part	:	Location 7
Description	:	Outline Pad Foundation Design
Customer	:	[redacted]
Author	:	[redacted]
Date	:	07/08/2018
Project ID	:	Kings Lynn Compressor Station
Project number	:	GN21822

Settings

Standard - EN 1997 - DA1

Materials and standards

Concrete structures :	EN 1992-1-1 (EC2)
Coefficients EN 1992-1-1 :	standard

Settlement

Analysis method :	Analysis using oedometric modulus
Restriction of influence zone :	by percentage of Sigma,Or
Coeff. of restriction of influence zone :	10.0 [%]

Spread Footing

Analysis for drained conditions :	EC 7-1 (EN 1997-1:2003)
Analysis of uplift :	Standard
Allowable eccentricity :	0.333
Verification methodology :	according to EN 1997
Design approach :	1 - reduction of actions and soil parameters

Partial factors on actions (A)

Permanent design situation

		Combination 1		Combination 2	
		Unfavourable	Favourable	Unfavourable	Favourable
Permanent actions :	γ_G =	1.35 [–]	1.00 [–]	1.00 [–]	1.00 [–]

Partial factors for soil parameters (M)

Permanent design situation

		Combination 1	Combination 2
Partial factor on internal friction :	γ_ϕ =	1.00 [–]	1.25 [–]
Partial factor on effective cohesion :	γ_c =	1.00 [–]	1.25 [–]
Partial factor on undrained shear strength :	γ_{cu} =	1.00 [–]	1.40 [–]
Partial factor on unconfined strength :	γ_v =	1.00 [–]	1.40 [–]

Basic soil parameters

No.	Name	Pattern	φ_{ef} [°]	c_{ef} [kPa]	γ [kN/m^3]	γ_{su} [kN/m^3]	δ [°]
1	Made Ground		21.00	0.00	16.00	6.00	
2	River Terrace Deposits		32.00	0.00	18.00	8.00	
3	Nar Valley (Clay)		24.00	0.00	19.10	9.10	

No.	Name	Pattern	φ_{ef} [°]	c_{ef} [kPa]	γ [kN/m^3]	γ_{su} [kN/m^3]	δ [°]
4	Nar Valley (Lignite)		12.00	500.00	11.80	1.80	
5	Nar Valley (Sand and Gravel)		38.00	0.00	20.00	10.00	
6	Varved Clay		24.00	5.00	20.00	10.00	

All soils are considered as cohesionless for at rest pressure analysis.

Soil parameters

Made Ground

Unit weight :	γ	=	16.00 kN/m^3
Angle of internal friction :	φ_{ef}	=	21.00 °
Cohesion of soil :	c_{ef}	=	0.00 kPa
Oedometric modulus :	E_{oed}	=	4.00 MPa
Saturated unit weight :	γ_{sat}	=	16.00 kN/m^3

River Terrace Deposits

Unit weight :	γ	=	18.00 kN/m^3
Angle of internal friction :	φ_{ef}	=	32.00 °
Cohesion of soil :	c_{ef}	=	0.00 kPa
Oedometric modulus :	E_{oed}	=	30.00 MPa
Saturated unit weight :	γ_{sat}	=	18.00 kN/m^3

Nar Valley (Clay)

Unit weight :	γ	=	19.10 kN/m^3
Angle of internal friction :	φ_{ef}	=	24.00 °
Cohesion of soil :	c_{ef}	=	0.00 kPa
Oedometric modulus :	E_{oed}	=	8.00 MPa
Saturated unit weight :	γ_{sat}	=	19.10 kN/m^3

Nar Valley (Lignite)

Unit weight :	γ	=	11.80 kN/m^3
Angle of internal friction :	φ_{ef}	=	12.00 °
Cohesion of soil :	c_{ef}	=	500.00 kPa
Oedometric modulus :	E_{oed}	=	10.00 MPa
Saturated unit weight :	γ_{sat}	=	11.80 kN/m^3

Nar Valley (Sand and Gravel)

Unit weight :	γ	=	20.00 kN/m^3
Angle of internal friction :	φ_{ef}	=	38.00 °
Cohesion of soil :	c_{ef}	=	0.00 kPa
Oedometric modulus :	E_{oed}	=	200.00 MPa
Saturated unit weight :	γ_{sat}	=	20.00 kN/m^3

Varved Clay

Unit weight :	γ	=	20.00 kN/m^3
Angle of internal friction :	φ_{ef}	=	24.00 °
Cohesion of soil :	c_{ef}	=	5.00 kPa
Oedometric modulus :	E_{oed}	=	14.00 MPa

Saturated unit weight : γ_{sat} = 20.00 kN/m^3

Foundation

Foundation type: centric spread footing

Depth from original ground surface	h_z	=	1.00	m
Depth of footing bottom	d	=	1.00	m
Foundation thickness	t	=	1.00	m
Incl. of finished grade	s_1	=	0.00	°
Incl. of footing bottom	s_2	=	0.00	°

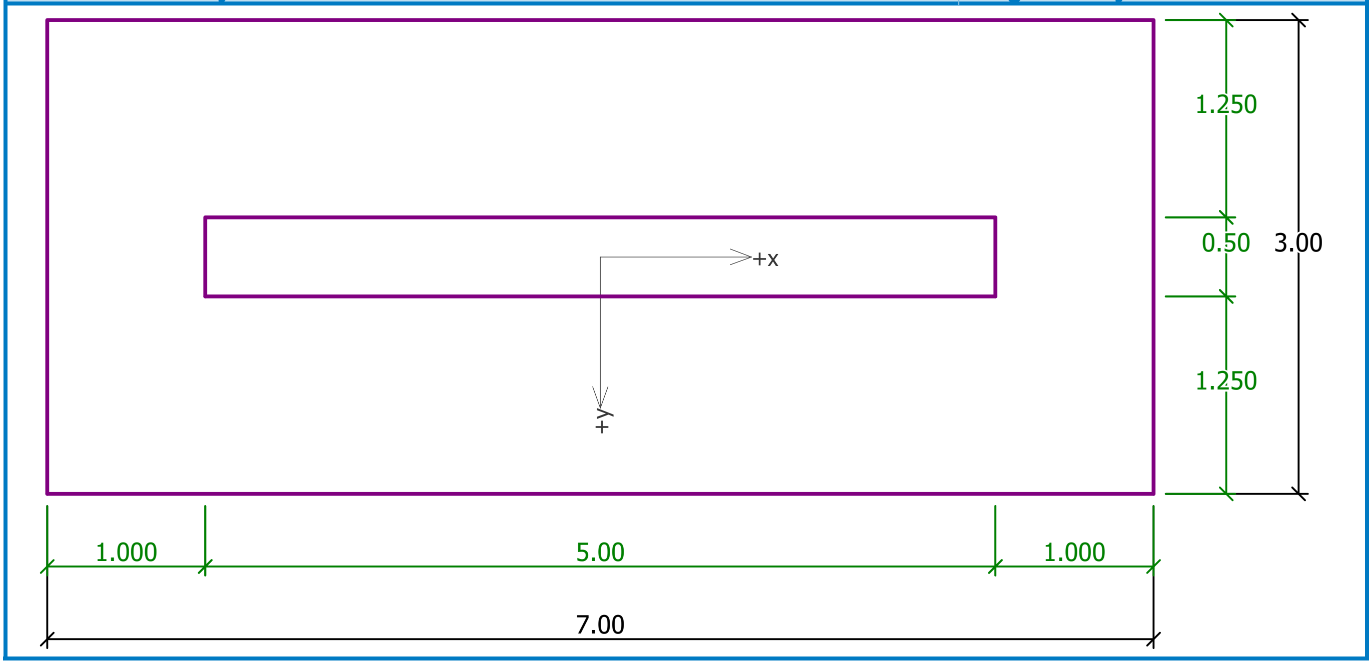
Unit weight of soil above foundation = 20.00 kN/m^3

Geometry of structure

Foundation type: centric spread footing

Spread footing length	x	=	7.00	m
Spread footing width	y	=	3.00	m
Column width in the direction of x	c_x	=	5.00	m
Column width in the direction of y	c_y	=	0.50	m
Spread footing volume		=	21.00	m^3

Name : Geometry **Stage - analysis : 1 - 0**



Material of structure

Unit weight γ = 25.00 kN/m^3
Analysis of concrete structures carried out according to the standard EN 1992-1-1 (EC2).

Concrete : C 20/25

Cylinder compressive strength	f_{ck}	=	20.00	MPa
Tensile strength	f_{ctm}	=	2.20	MPa
Elasticity modulus	E_{cm}	=	30000.00	MPa

Longitudinal steel : B500
Yield strength f_{yk} = 500.00 MPa

Transverse steel: B500
Yield strength f_{yk} = 500.00 MPa

Geological profile and assigned soils

No.	Layer [m]	Assigned soil	Pattern
1	0.60	Made Ground	
2	1.90	River Terrace Deposits	
3	11.00	Nar Valley (Clay)	
4	1.50	Nar Valley (Lignite)	
5	9.80	Nar Valley (Sand and Gravel)	
6	17.20	Varved Clay	
7	8.00	Varved Clay	
8	-	Varved Clay	

Load

No.	Load		Name	Type	N	M_x	M_y	H_x	H_y
	new	change			[kN]	[kNm]	[kNm]	[kN]	[kN]
1	Yes		Load No. 1	Design	2400.00	0.00	0.00	0.00	100.00
2	Yes		Load No. 2	Service	2400.00	0.00	0.00	0.00	100.00

Ground water table

The ground water table is at a depth of 0.00 m from the original terrain.

Global settings

Type of analysis : analysis for drained conditions

Settings of the stage of construction

Design situation : permanent

Verification No. 1

Load case verification

Name	Self w. in favor	e_x [m]	e_y [m]	σ [kPa]	R_d [kPa]	Utilization [%]	Is satisfied
Load No. 1	Yes	0.00	-0.04	132.54	203.58	65.11	Yes
Load No. 1	No	0.00	-0.04	137.79	204.37	67.42	Yes
Load No. 2	Yes	0.00	-0.04	132.54	106.38	124.59	No
Load No. 2	No	0.00	-0.04	132.54	106.38	124.59	No

Analysis carried out with automatic selection of the most unfavourable load cases.

Computed weight of spread footing $G = 315.00$ kN
Computed weight of overburden $Z = 0.00$ kN

Vertical bearing capacity check

Shape of contact stress : rectangle

Most unfavorable load case No. 2. (Load No. 2)

Parameters of slip surface below foundation:
Depth of slip surface z_{sp} = 4.22 m
Length of slip surface l_{sp} = 12.03 m

Design bearing capacity of found.soil R_d = 106.38 kPa
Extreme contact stress σ = 132.54 kPa

Bearing capacity in the vertical direction is NOT SATISFACTORY

Verification of load eccentricity

Max. eccentricity in direction of base length e_x = 0.000<0.333
Max. eccentricity in direction of base width e_y = 0.012<0.333
Max. overall eccentricity e_t = 0.012<0.333

Eccentricity of load is SATISFACTORY

Horizontal bearing capacity check

Most unfavorable load case No. 2. (Load No. 2)

Earth resistance: at rest
Design magnitude of earth resistance S_{pd} = 5.01 kN

Horizontal bearing capacity R_{dh} = 1362.23 kN
Extreme horizontal force H = 100.00 kN

Bearing capacity in the horizontal direction is SATISFACTORY

Bearing capacity of foundation is NOT SATISFACTORY

Verification No. 1

Settlement and rotation of foundation - input data

Analysis carried out with automatic selection of the most unfavourable load cases.
Analysis carried out with accounting for coefficient κ_1 (influence of foundation depth).
Stress at the footing bottom considered from the finished grade.

Computed weight of spread footing G = 315.00 kN
Computed weight of overburden Z = 0.00 kN

Settlement and rotation of foundation - partial results

Layer No.	Origin [m]	End [m]	Thickness [m]	E_{def} [MPa]	σ_{or} [kPa]	$\Delta\sigma_z$ [kPa]	Settlement [mm]
1	1.00	1.05	0.05	1.75	7.00	122.38	0.20
2	1.05	1.10	0.05	1.75	7.40	121.68	0.20
3	1.10	1.15	0.05	1.75	7.80	119.84	0.20
4	1.15	1.20	0.05	1.75	8.20	116.84	0.19
5	1.20	1.25	0.05	1.75	8.60	113.09	0.19
6	1.25	1.30	0.05	1.75	9.00	108.99	0.18
7	1.30	1.40	0.10	1.75	9.60	102.88	0.34
8	1.40	1.50	0.10	1.75	10.40	95.28	0.32
9	1.50	1.60	0.10	1.75	11.20	88.62	0.30
10	1.60	1.70	0.10	1.75	12.00	82.87	0.28
11	1.70	1.80	0.10	1.75	12.80	77.91	0.26

Layer No.	Origin [m]	End [m]	Thickness [m]	E_{def} [MPa]	σ_{or} [kPa]	$\Delta\sigma_z$ [kPa]	Settlement [mm]
12	1.80	1.90	0.10	1.75	13.60	73.59	0.25
13	1.90	2.15	0.25	1.75	15.00	67.49	0.56
14	2.15	2.40	0.25	1.75	17.00	60.25	0.50
15	2.40	2.50	0.10	1.75	18.40	56.08	0.19
16	2.50	2.65	0.15	0.47	19.48	53.53	1.00
17	2.65	2.90	0.25	0.47	21.30	49.86	1.56
18	2.90	3.15	0.25	0.47	23.58	45.90	1.43
19	3.15	3.40	0.25	0.47	25.85	42.47	1.33
20	3.40	3.90	0.50	0.47	29.27	38.18	2.39
21	3.90	4.40	0.50	0.47	33.82	33.32	2.08
22	4.40	4.90	0.50	0.47	38.37	29.34	1.83
23	4.90	5.40	0.50	0.47	42.92	26.02	1.63
24	5.40	5.90	0.50	0.47	47.47	23.22	1.45
25	5.90	6.40	0.50	0.47	52.02	20.82	1.30
26	6.40	7.40	1.00	0.47	58.84	17.92	2.24
27	7.40	8.40	1.00	0.47	67.94	14.75	1.84
28	8.40	9.40	1.00	0.47	77.04	12.31	1.54
29	9.40	10.40	1.00	0.47	86.14	10.40	1.30
30	10.40	10.61	0.21	0.47	91.67	9.41	0.05

Settlement of mid point of edge x - 1 = 30.0 mm
Settlement of mid point of edge x - 2 = 29.0 mm
Settlement of mid point of edge y - 1 = 22.4 mm
Settlement of mid point of edge y - 2 = 22.4 mm
Settlement of foundation center point = 38.8 mm
Settlement of characteristic point = 27.1 mm

(1-max.compressed edge; 2-min.compressed edge)

Settlement and rotation of foundation - results

Foundation stiffness:
Computed weighted average modulus of deformation E_{def} = 0.95 MPa
Foundation in the longitudinal direction is rigid (k=91.98)
Foundation in the direction of width is rigid (k=1168.46)

Verification of load eccentricity

Max. eccentricity in direction of base length e_x = 0.000<0.333
Max. eccentricity in direction of base width e_y = 0.012<0.333
Max. overall eccentricity e_t = 0.012<0.333

Eccentricity of load is SATISFACTORY

Overall settlement and rotation of foundation:
Foundation settlement = 27.1 mm
Depth of influence zone = 9.61 m

Rotation in direction of x = 0.000 (tan*1000); (5.8E-17 °)
Rotation in direction of y = 0.326 (tan*1000); (1.9E-02 °)

Spread footing verification

Input data

Project

Task : NARC Batch 2 2018 Foundation Design
Part : Locations 1-6 & 8
Description : Outline Pad Foundation Design
Customer : [redacted]
Author : [redacted]
Date : 07/08/2018
Project ID : Kings Lynn Compressor Station
Project number : GN21822

Settings

Standard - EN 1997 - DA1

Materials and standards

Concrete structures : EN 1992-1-1 (EC2)
Coefficients EN 1992-1-1 : standard

Settlement

Analysis method : Analysis using oedometric modulus
Restriction of influence zone : by percentage of Sigma,Or
Coeff. of restriction of influence zone : 10.0 [%]

Spread Footing

Analysis for drained conditions : EC 7-1 (EN 1997-1:2003)
Analysis of uplift : Standard
Allowable eccentricity : 0.333
Verification methodology : according to EN 1997
Design approach : 1 - reduction of actions and soil parameters

Partial factors on actions (A)					
Permanent design situation					
		Combination 1		Combination 2	
		Unfavourable	Favourable	Unfavourable	Favourable
Permanent actions :	γ_G =	1.35 [–]	1.00 [–]	1.00 [–]	1.00 [–]

Partial factors for soil parameters (M)			
Permanent design situation			
		Combination 1	Combination 2
Partial factor on internal friction :	γ_ϕ =	1.00 [–]	1.25 [–]
Partial factor on effective cohesion :	γ_c =	1.00 [–]	1.25 [–]
Partial factor on undrained shear strength :	γ_{cu} =	1.00 [–]	1.40 [–]
Partial factor on unconfined strength :	γ_v =	1.00 [–]	1.40 [–]

Basic soil parameters

No.	Name	Pattern	φ_{ef} [°]	c_{ef} [kPa]	γ [kN/m^3]	γ_{su} [kN/m^3]	δ [°]
1	Made Ground		21.00	0.00	16.00	6.00	
2	River Terrace Deposits		32.00	0.00	18.00	8.00	
3	Nar Valley (Clay)		24.00	0.00	19.10	9.10	

No.	Name	Pattern	φ_{ef} [°]	c_{ef} [kPa]	γ [kN/m^3]	γ_{su} [kN/m^3]	δ [°]
4	Nar Valley (Lignite)		12.00	500.00	11.80	1.80	
5	Nar Valley (Sand and Gravel)		38.00	0.00	20.00	10.00	
6	Varved Clay		24.00	5.00	20.00	10.00	

All soils are considered as cohesionless for at rest pressure analysis.

Soil parameters

Made Ground

Unit weight : γ = 16.00 kN/m^3
Angle of internal friction : φ_{ef} = 21.00 °
Cohesion of soil : c_{ef} = 0.00 kPa
Oedometric modulus : E_{oed} = 4.00 MPa
Saturated unit weight : γ_{sat} = 16.00 kN/m^3

River Terrace Deposits

Unit weight : γ = 18.00 kN/m^3
Angle of internal friction : φ_{ef} = 32.00 °
Cohesion of soil : c_{ef} = 0.00 kPa
Oedometric modulus : E_{oed} = 30.00 MPa
Saturated unit weight : γ_{sat} = 18.00 kN/m^3

Nar Valley (Clay)

Unit weight : γ = 19.10 kN/m^3
Angle of internal friction : φ_{ef} = 24.00 °
Cohesion of soil : c_{ef} = 0.00 kPa
Oedometric modulus : E_{oed} = 8.00 MPa
Saturated unit weight : γ_{sat} = 19.10 kN/m^3

Nar Valley (Lignite)

Unit weight : γ = 11.80 kN/m^3
Angle of internal friction : φ_{ef} = 12.00 °
Cohesion of soil : c_{ef} = 500.00 kPa
Oedometric modulus : E_{oed} = 10.00 MPa
Saturated unit weight : γ_{sat} = 11.80 kN/m^3

Nar Valley (Sand and Gravel)

Unit weight : γ = 20.00 kN/m^3
Angle of internal friction : φ_{ef} = 38.00 °
Cohesion of soil : c_{ef} = 0.00 kPa
Oedometric modulus : E_{oed} = 200.00 MPa
Saturated unit weight : γ_{sat} = 20.00 kN/m^3

Varved Clay

Unit weight : γ = 20.00 kN/m^3
Angle of internal friction : φ_{ef} = 24.00 °
Cohesion of soil : c_{ef} = 5.00 kPa
Oedometric modulus : E_{oed} = 14.00 MPa

Saturated unit weight : γ_{sat} = 20.00 kN/m^3

Foundation

Foundation type: centric spread footing

Depth from original ground surface	h_z	=	1.00	m
Depth of footing bottom	d	=	1.00	m
Foundation thickness	t	=	1.00	m
Incl. of finished grade	s_1	=	0.00	°
Incl. of footing bottom	s_2	=	0.00	°

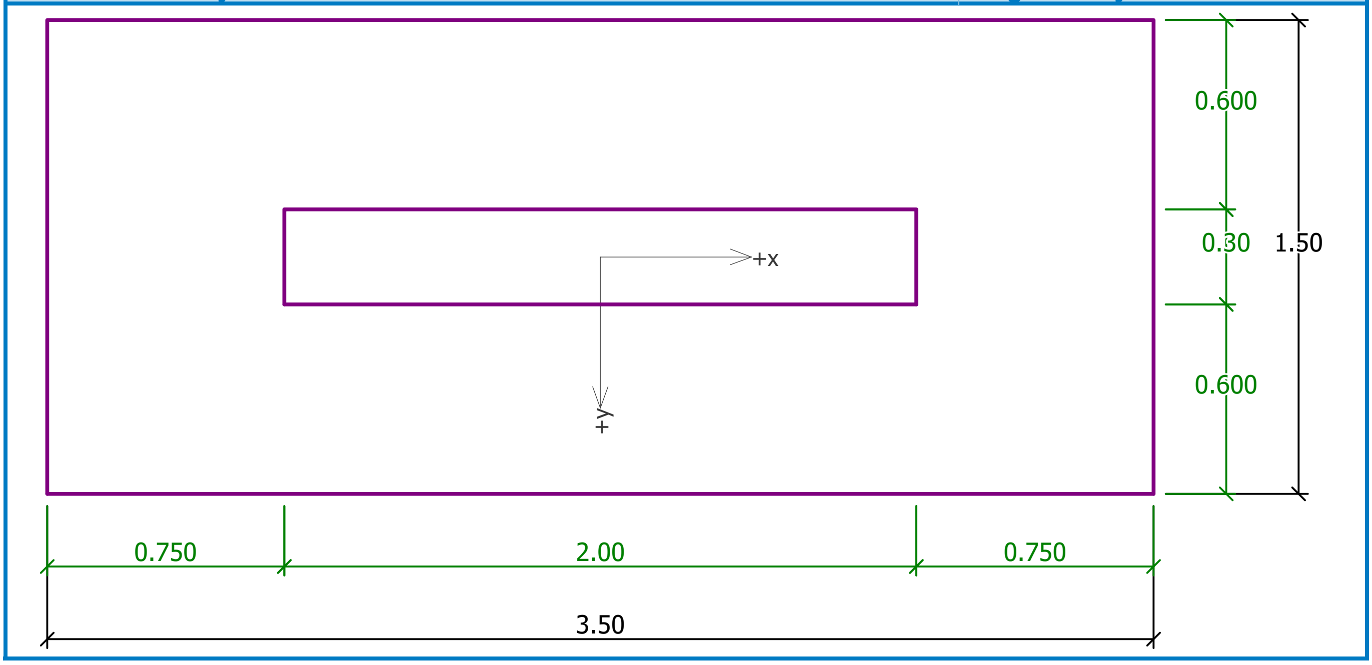
Unit weight of soil above foundation = 20.00 kN/m^3

Geometry of structure

Foundation type: centric spread footing

Spread footing length	x	=	3.50	m
Spread footing width	y	=	1.50	m
Column width in the direction of x	c_x	=	2.00	m
Column width in the direction of y	c_y	=	0.30	m
Spread footing volume		=	5.25	m^3

Name : Geometry **Stage - analysis : 1 - 0**



Material of structure

Unit weight γ = 25.00 kN/m^3
Analysis of concrete structures carried out according to the standard EN 1992-1-1 (EC2).

Concrete : C 20/25

Cylinder compressive strength	f_{ck}	=	20.00	MPa
Tensile strength	f_{ctm}	=	2.20	MPa
Elasticity modulus	E_{cm}	=	30000.00	MPa

Longitudinal steel : B500
Yield strength f_{yk} = 500.00 MPa

Transverse steel: B500
Yield strength f_{yk} = 500.00 MPa

Geological profile and assigned soils

No.	Layer [m]	Assigned soil	Pattern
1	0.60	Made Ground	
2	1.90	River Terrace Deposits	
3	11.00	Nar Valley (Clay)	
4	1.50	Nar Valley (Lignite)	
5	9.80	Nar Valley (Sand and Gravel)	
6	17.20	Varved Clay	
7	8.00	Varved Clay	
8	-	Varved Clay	

Load

No.	Load new	Load change	Name	Type	N [kN]	M_x [kNm]	M_y [kNm]	H_x [kN]	H_y [kN]
1	Yes		Load No. 1	Design	500.00	0.00	0.00	0.00	100.00
2	Yes		Load No. 2	Service	500.00	0.00	0.00	0.00	100.00

Ground water table

The ground water table is at a depth of 0.00 m from the original terrain.

Global settings

Type of analysis : analysis for drained conditions

Settings of the stage of construction

Design situation : permanent

Verification No. 1

Load case verification

Name	Self w. in favor	e_x [m]	e_y [m]	σ [kPa]	R_d [kPa]	Utilization [%]	Is satisfied
Load No. 1	Yes	0.00	-0.17	143.24	128.88	111.14	No
Load No. 1	No	0.00	-0.16	148.04	132.15	112.03	No
Load No. 2	Yes	0.00	-0.17	143.24	68.48	209.15	No
Load No. 2	No	0.00	-0.17	143.24	68.48	209.15	No

Analysis carried out with automatic selection of the most unfavourable load cases.

Computed weight of spread footing $G = 78.75$ kN
Computed weight of overburden $Z = 0.00$ kN

Vertical bearing capacity check

Shape of contact stress : rectangle

Most unfavorable load case No. 2. (Load No. 2)

Parameters of slip surface below foundation:
Depth of slip surface z_{sp} = 2.26 m
Length of slip surface l_{sp} = 6.68 m

Design bearing capacity of found.soil R_d = 68.48 kPa
Extreme contact stress σ = 143.24 kPa

Bearing capacity in the vertical direction is NOT SATISFACTORY

Verification of load eccentricity

Max. eccentricity in direction of base length e_x = 0.000<0.333
Max. eccentricity in direction of base width e_y = 0.115<0.333
Max. overall eccentricity e_t = 0.115<0.333

Eccentricity of load is SATISFACTORY

Horizontal bearing capacity check

Most unfavorable load case No. 2. (Load No. 2)

Earth resistance: at rest
Design magnitude of earth resistance S_{pd} = 2.51 kN

Horizontal bearing capacity R_{dh} = 291.82 kN
Extreme horizontal force H = 100.00 kN

Bearing capacity in the horizontal direction is SATISFACTORY

Bearing capacity of foundation is NOT SATISFACTORY

Verification No. 1

Settlement and rotation of foundation - input data

Analysis carried out with automatic selection of the most unfavourable load cases.
Analysis carried out with accounting for coefficient κ_1 (influence of foundation depth).
Stress at the footing bottom considered from the finished grade.

Computed weight of spread footing G = 78.75 kN
Computed weight of overburden Z = 0.00 kN

Settlement and rotation of foundation - partial results

Layer No.	Origin [m]	End [m]	Thickness [m]	E_{def} [MPa]	σ_{or} [kPa]	$\Delta\sigma_z$ [kPa]	Settlement [mm]
1	1.00	1.05	0.05	18.69	7.00	102.83	0.17
2	1.05	1.10	0.05	18.69	7.40	99.62	0.17
3	1.10	1.15	0.05	18.69	7.80	93.39	0.16
4	1.15	1.20	0.05	18.69	8.20	86.23	0.14
5	1.20	1.25	0.05	18.69	8.60	79.51	0.13
6	1.25	1.30	0.05	18.69	9.00	73.61	0.12
7	1.30	1.40	0.10	18.69	9.60	66.46	0.22
8	1.40	1.50	0.10	18.69	10.40	58.71	0.20
9	1.50	1.60	0.10	18.69	11.20	52.71	0.18
10	1.60	1.70	0.10	18.69	12.00	47.91	0.16
11	1.70	1.80	0.10	18.69	12.80	43.95	0.15

Layer No.	Origin [m]	End [m]	Thickness [m]	E_{def} [MPa]	σ_{or} [kPa]	$\Delta\sigma_z$ [kPa]	Settlement [mm]
12	1.80	1.90	0.10	18.69	13.60	40.60	0.14
13	1.90	2.15	0.25	18.69	15.00	35.99	0.30
14	2.15	2.40	0.25	18.69	17.00	30.61	0.26
15	2.40	2.50	0.10	18.69	18.40	27.57	0.09
16	2.50	2.65	0.15	0.47	19.48	25.76	0.48
17	2.65	2.90	0.25	0.47	21.30	23.19	0.72
18	2.90	3.15	0.25	0.47	23.58	20.50	0.64
19	3.15	3.40	0.25	0.47	25.85	18.25	0.57
20	3.40	3.90	0.50	0.47	29.27	15.60	0.98
21	3.90	4.40	0.50	0.47	33.82	12.76	0.80
22	4.40	4.90	0.50	0.47	38.37	10.60	0.66
23	4.90	5.40	0.50	0.47	42.92	8.93	0.56
24	5.40	5.90	0.50	0.47	47.47	7.60	0.48
25	5.90	6.40	0.50	0.47	52.02	6.54	0.41
26	6.40	6.67	0.27	0.47	55.54	5.87	0.05

Settlement of mid point of edge x - 1 = 10.8 mm
Settlement of mid point of edge x - 2 = 8.4 mm
Settlement of mid point of edge y - 1 = 7.5 mm
Settlement of mid point of edge y - 2 = 7.5 mm
Settlement of foundation center point = 12.0 mm
Settlement of characteristic point = 8.9 mm

(1-max.compressed edge; 2-min.compressed edge)

Settlement and rotation of foundation - results

Foundation stiffness:
Computed weighted average modulus of deformation E_{def} = 11.43 MPa
Foundation in the longitudinal direction is rigid (k=61.23)
Foundation in the direction of width is rigid (k=777.90)

Verification of load eccentricity

Max. eccentricity in direction of base length e_x = 0.000<0.333
Max. eccentricity in direction of base width e_y = 0.115<0.333
Max. overall eccentricity e_t = 0.115<0.333

Eccentricity of load is SATISFACTORY

Overall settlement and rotation of foundation:
Foundation settlement = 8.9 mm
Depth of influence zone = 5.67 m

Rotation in direction of x = 0.000 (tan*1000); (0.0E+00 °)
Rotation in direction of y = 1.630 (tan*1000); (9.3E-02 °)

Pile verification

Input data

Project

Task	:	NARC Batch 2 2018 Foundation Design
Description	:	Outline Pile Foundation Design
Customer	:	[redacted]
Author	:	[redacted]
Date	:	07/08/2018
Project ID	:	Kings Lynn Compressor Station
Project number	:	GN21822

Settings

Standard - EN 1997 - DA1

Materials and standards

Concrete structures :	EN 1992-1-1 (EC2)
Coefficients EN 1992-1-1 :	standard
Steel structures :	EN 1993-1-1 (EC3)
Partial factor on bearing capacity of steel cross section :	γ_{M0} = 1.00
Timber structures :	EN 1995-1-1 (EC5)
Partial factor for timber property :	γ_M = 1.30
Modif. factor of load duration and moisture content :	k_{mod} = 0.50
Coeff. of effective width for shear stress :	k_{cr} = 0.67

Pile

Analysis for drained conditions :	NAVFAC DM 7.2
Load settlement curve :	linear (Poulos)
Horizontal bearing capacity :	Elastic subsoil (p-y method)
Verification methodology :	according to EN 1997
Design approach :	1 - reduction of actions and soil parameters

Partial factors on actions (A)									
Permanent design situation									
		Combination 1				Combination 2			
		Unfavourable		Favourable		Unfavourable		Favourable	
Permanent actions :	γ_G =	1.35	[–]	1.00	[–]	1.00	[–]	1.00	[–]

Partial factors for soil parameters (M)					
Permanent design situation					
		Combination 1		Combination 2	
Partial factor on internal friction :	γ_ϕ =	1.00	[–]	1.25	[–]
Partial factor on effective cohesion :	γ_c =	1.00	[–]	1.25	[–]
Partial factor on undrained shear strength :	γ_{cu} =	1.00	[–]	1.40	[–]

Partial factors for resistances (R)					
Permanent design situation					
		Combination 1		Combination 2	
Partial factor on shaft resistance :	γ_s =	1.00	[–]	1.30	[–]
Partial factor on base resistance :	γ_b =	1.00	[–]	1.45	[–]
Partial factor on resistance in tension :	γ_{st} =	1.25	[–]	1.60	[–]

Basic soil parameters

No.	Name	Pattern	γ [kN/m^3]	ν [–]
1	Made Ground		16.00	0.30
2	River Terrace Deposits		18.00	0.40
3	Nar Valley (Clay)		19.10	0.30
4	Nar Valley (Lignite)		11.80	0.49
5	Nar Valley (Sand and Gravel)		20.00	0.49
6	Varved Clay		20.00	0.49

All soils are considered as cohesionless for at rest pressure analysis.

No.	Name	Pattern	E_{oed} [MPa]	E_{def} [MPa]	γ_{sat} [kN/m^3]	γ_s [kN/m^3]	n [–]
1	Made Ground		1.00	-	16.00	-	-
2	River Terrace Deposits		10.00	-	18.00	-	-
3	Nar Valley (Clay)		8.00	-	19.10	-	-
4	Nar Valley (Lignite)		10.00	-	11.80	-	-
5	Nar Valley (Sand and Gravel)		200.00	-	20.00	-	-
6	Varved Clay		14.00	-	20.00	-	-

No.	Name	Pattern	φ_{ef} [°]	δ [°]	K [–]	c_u [kPa]	α [–]
1	Made Ground		-	-	-	20.00	1.00
2	River Terrace Deposits		32.00	-	-	-	-
3	Nar Valley (Clay)		-	-	-	91.00	0.70
4	Nar Valley (Lignite)		-	-	-	500.00	0.33
5	Nar Valley (Sand and Gravel)		38.00	-	-	-	-
6	Varved Clay		-	-	-	123.00	0.45

Soil parameters

Made Ground

Unit weight :	γ	=	16.00 kN/m^3
Poisson's ratio :	ν	=	0.30
Oedometric modulus :	E_{oed}	=	1.00 MPa
Saturated unit weight :	γ_{sat}	=	16.00 kN/m^3
Cohesion of soil :	c_u	=	20.00 kPa
Adhesion factor :	α	=	1.00
Angle of internal friction :	φ_{ef}	=	21.00 °

River Terrace Deposits

Unit weight :	γ	=	18.00 kN/m^3
Poisson's ratio :	ν	=	0.40
Oedometric modulus :	E_{oed}	=	10.00 MPa
Saturated unit weight :	γ_{sat}	=	18.00 kN/m^3
Angle of internal friction :	φ_{ef}	=	32.00 °

Nar Valley (Clay)

Unit weight :	γ	=	19.10 kN/m^3
Poisson's ratio :	ν	=	0.30
Oedometric modulus :	E_{oed}	=	8.00 MPa
Saturated unit weight :	γ_{sat}	=	19.10 kN/m^3
Cohesion of soil :	c_u	=	91.00 kPa
Adhesion factor :	α	=	0.70
Angle of internal friction :	φ_{ef}	=	24.00 °

Nar Valley (Lignite)

Unit weight :	γ	=	11.80 kN/m^3
Poisson's ratio :	ν	=	0.49
Oedometric modulus :	E_{oed}	=	10.00 MPa
Saturated unit weight :	γ_{sat}	=	11.80 kN/m^3
Cohesion of soil :	c_u	=	500.00 kPa
Adhesion factor :	α	=	0.33
Angle of internal friction :	φ_{ef}	=	12.00 °

Nar Valley (Sand and Gravel)

Unit weight :	γ	=	20.00 kN/m^3
Poisson's ratio :	ν	=	0.49
Oedometric modulus :	E_{oed}	=	200.00 MPa
Saturated unit weight :	γ_{sat}	=	20.00 kN/m^3
Angle of internal friction :	φ_{ef}	=	38.00 °

Varved Clay

Unit weight :	γ	=	20.00 kN/m^3
Poisson's ratio :	ν	=	0.49
Oedometric modulus :	E_{oed}	=	14.00 MPa
Saturated unit weight :	γ_{sat}	=	20.00 kN/m^3
Cohesion of soil :	c_u	=	123.00 kPa
Adhesion factor :	α	=	0.45
Angle of internal friction :	φ_{ef}	=	24.00 °

Geometry

Pile profile: circular

Dimensions
Diameter d = 0.30 m
Length l = 16.00 m

Calculated cross-sectional characteristics
Area A = 7.07E-02 m^2
Moment of inertia I = 3.98E-04 m^4

Location
Off ground height h = 0.00 m
Depth of finished grade h_z = 0.00 m

Technology: CFA piles

Material of structure

Unit weight γ = 23.00 kN/m^3
Analysis of concrete structures carried out according to the standard EN 1992-1-1 (EC2).

Concrete : C 20/25

Cylinder compressive strength	f_{ck}	=	20.00 MPa
Tensile strength	f_{ctm}	=	2.20 MPa
Elasticity modulus	E_{cm}	=	30000.00 MPa
Shear modulus	G	=	12500.00 MPa

Longitudinal steel : B500
Yield strength f_{yk} = 500.00 MPa

Transverse steel: B500
Yield strength f_{yk} = 500.00 MPa

Geological profile and assigned soils

No.	Layer [m]	Assigned soil	Pattern
1	0.60	Made Ground	
2	1.90	River Terrace Deposits	
3	11.00	Nar Valley (Clay)	
4	1.50	Nar Valley (Lignite)	
5	9.80	Nar Valley (Sand and Gravel)	
6	17.20	Varved Clay	
7	8.00	Varved Clay	
8	-	Varved Clay	

Load

No.	Load new	Load change	Name	Type	N [kN]	M_x [kNm]	M_y [kNm]	H_x [kN]	H_y [kN]
1	Yes		Load No. 1	Design	700.00	0.00	0.00	0.00	100.00

No.	Load		Name	Type	N	M_x	M_y	H_x	H_y
	new	change			[kN]	[kNm]	[kNm]	[kN]	[kN]
2	Yes		Load No. 1 - service	Service	700.00	0.00	0.00	0.00	100.00

Ground water table

The ground water table is at a depth of 0.00 m from the original terrain.

Global settings

Analysis of vertical bearing capacity : analytical solution
Analysis type : analysis for drained conditions

Settings of the stage of construction

Design situation : permanent
Verification methodology : without reduction of soil parameters

Verification No. 1

Verification of pile bearing capacity according to NAVFAC DM 7.2 - partial results

Computation of pile base bearing capacity:
The soil under the base is cohesionless
Coefficient of bearing capacity N_q = 43.00
Area of pile transverse cross-section A_p = 7.07E-02 m^2

Pile ultimate skin resistance capacity:

Depth [m]	Thickness [m]	c_{ud} [kPa]	α [–]	k_{dc} [–]	δ [°]	σ_{or} [kPa]	R_{si} [kN]
0.00	-	-	-	-	-	0.00	-
0.30	0.30	20.00	1.00	-	-	0.90	5.65
0.30	-	-	-	-	-	0.90	-
0.60	0.30	20.00	1.00	-	-	1.80	5.65
0.60	-	-	-	-	-	1.80	-
2.50	1.90	-	-	1.34	24.00	1.80	1.93
2.50	-	-	-	-	-	1.80	-
13.50	11.00	91.00	0.70	-	-	1.80	660.39
13.50	-	-	-	-	-	1.80	-
15.00	1.50	500.00	0.33	-	-	1.80	233.26
15.00	-	-	-	-	-	1.80	-
16.00	1.00	-	-	1.61	28.50	1.80	1.48

Verification of pile bearing capacity according to NAVFAC DM 7.2 - partial results

Computation of pile base bearing capacity:
The soil under the base is cohesionless
Coefficient of bearing capacity N_q = 43.00
Area of pile transverse cross-section A_p = 7.07E-02 m^2

Pile ultimate skin resistance capacity:

Depth [m]	Thickness [m]	c_{ud} [kPa]	α [–]	k_{dc} [–]	δ [°]	σ_{or} [kPa]	R_{si} [kN]
0.00	-	-	-	-	-	0.00	-
0.30	0.30	14.29	1.00	-	-	0.90	3.11
0.30	-	-	-	-	-	0.90	-
0.60	0.30	14.29	1.00	-	-	1.80	3.11

Depth [m]	Thickness [m]	c_{ud} [kPa]	α [–]	k_{dc} [–]	δ [°]	σ_{or} [kPa]	R_{si} [kN]
0.60	-	-	-	-	-	1.80	-
2.50	1.90	-	-	1.18	19.92	1.80	1.06
2.50	-	-	-	-	-	1.80	-
13.50	11.00	65.00	0.70	-	-	1.80	362.85
13.50	-	-	-	-	-	1.80	-
15.00	1.50	357.14	0.33	-	-	1.80	128.17
15.00	-	-	-	-	-	1.80	-
16.00	1.00	-	-	1.34	24.00	1.80	0.78

Verification of bearing capacity : NAVFAC DM 7.2

Analysis carried out with automatic selection of the most unfavourable load cases.
Factor determining critical depth k_{dc} = 1.00

Verification of compressive pile:
Most unfavorable load case No. 2. (Load No. 1 - service)

Pile skin bearing capacity R_s = 499.08 kN
Pile base bearing capacity R_b = 275.86 kN

Pile bearing capacity R_c = 774.94 kN
Ultimate vertical force V_d = 714.70 kN

R_c = 774.94 kN > 714.70 kN = V_d

Pile bearing capacity is SATISFACTORY

Verification No. 1

Analysis of load settlement curve - input data

Layer No.	E_s [MPa]
1	150.00
2	100.00
3	50.00
4	20.00
5	150.00

Maximum pile settlement s_{lim} = 25.0 mm

Analysis of load settlement curve - partial results

Correction factor for pile compressibility C_k = 0.61
Correction factor for Poisson's ratio of soil C_v = 0.82
Correction factor for stiffness of bearing stratum C_b = 2.27
Base-load proportion for incompressible pile β_0 = 0.04
Proportion of applied load transferred to pile base β = 0.04

Influence coefficients of settlement :
Basic - dependent on ratio l/d I_0 = 0.04
Correction factor for pile compressibility R_k = 1.73
Correction factor for finite depth of layer on a rigid base R_h = 1.00
Correction factor for Poisson's ratio of soil R_v = 0.93

Analysis of load settlement curve - results

Load at the onset of mobilization of skin friction	R_{yu}	=	946.88	kN
The settlement for the force R_{yu}	s_y	=	3.2	mm
Total resistance	R_c	=	1164.41	kN
Maximum settlement	s_{lim}	=	25.0	mm

The settlement for maximum service load V = 700.00kN is 2.4mm.

Pile verification

Input data

Project

Task	:	NARC Batch 2 2018 Foundation Design
Description	:	Outline Pile Foundation Design
Customer	:	[redacted]
Author	:	[redacted]
Date	:	07/08/2018
Project ID	:	Kings Lynn Compressor Station
Project number	:	GN21822

Settings

Standard - EN 1997 - DA1

Materials and standards

Concrete structures :	EN 1992-1-1 (EC2)
Coefficients EN 1992-1-1 :	standard
Steel structures :	EN 1993-1-1 (EC3)
Partial factor on bearing capacity of steel cross section :	γ_{M0} = 1.00
Timber structures :	EN 1995-1-1 (EC5)
Partial factor for timber property :	γ_M = 1.30
Modif. factor of load duration and moisture content :	k_{mod} = 0.50
Coeff. of effective width for shear stress :	k_{cr} = 0.67

Pile

Analysis for drained conditions :	NAVFAC DM 7.2
Load settlement curve :	linear (Poulos)
Horizontal bearing capacity :	Elastic subsoil (p-y method)
Verification methodology :	according to EN 1997
Design approach :	1 - reduction of actions and soil parameters

Partial factors on actions (A)									
Permanent design situation									
		Combination 1				Combination 2			
		Unfavourable		Favourable		Unfavourable		Favourable	
Permanent actions :	γ_G =	1.35	[–]	1.00	[–]	1.00	[–]	1.00	[–]

Partial factors for soil parameters (M)					
Permanent design situation					
		Combination 1		Combination 2	
Partial factor on internal friction :	γ_ϕ =	1.00	[–]	1.25	[–]
Partial factor on effective cohesion :	γ_c =	1.00	[–]	1.25	[–]
Partial factor on undrained shear strength :	γ_{cu} =	1.00	[–]	1.40	[–]

Partial factors for resistances (R)					
Permanent design situation					
		Combination 1		Combination 2	
Partial factor on shaft resistance :	γ_s =	1.00	[–]	1.30	[–]
Partial factor on base resistance :	γ_b =	1.00	[–]	1.45	[–]
Partial factor on resistance in tension :	γ_{st} =	1.25	[–]	1.60	[–]

Basic soil parameters

No.	Name	Pattern	γ [kN/m^3]	ν [–]
1	Made Ground		16.00	0.30
2	River Terrace Deposits		18.00	0.40
3	Nar Valley (Clay)		19.10	0.30
4	Nar Valley (Lignite)		11.80	0.49
5	Nar Valley (Sand and Gravel)		20.00	0.49
6	Varved Clay		20.00	0.49

All soils are considered as cohesionless for at rest pressure analysis.

No.	Name	Pattern	E_{oed} [MPa]	E_{def} [MPa]	γ_{sat} [kN/m^3]	γ_s [kN/m^3]	n [–]
1	Made Ground		1.00	-	16.00	-	-
2	River Terrace Deposits		10.00	-	18.00	-	-
3	Nar Valley (Clay)		8.00	-	19.10	-	-
4	Nar Valley (Lignite)		10.00	-	11.80	-	-
5	Nar Valley (Sand and Gravel)		200.00	-	20.00	-	-
6	Varved Clay		14.00	-	20.00	-	-

No.	Name	Pattern	φ_{ef} [°]	δ [°]	K [–]	c_u [kPa]	α [–]
1	Made Ground		-	-	-	20.00	1.00
2	River Terrace Deposits		32.00	-	-	-	-
3	Nar Valley (Clay)		-	-	-	91.00	0.70
4	Nar Valley (Lignite)		-	-	-	500.00	0.33
5	Nar Valley (Sand and Gravel)		38.00	-	-	-	-
6	Varved Clay		-	-	-	123.00	0.45

Soil parameters

Made Ground

Unit weight :	γ	=	16.00 kN/m^3
Poisson's ratio :	ν	=	0.30
Oedometric modulus :	E_{oed}	=	1.00 MPa
Saturated unit weight :	γ_{sat}	=	16.00 kN/m^3
Cohesion of soil :	c_u	=	20.00 kPa
Adhesion factor :	α	=	1.00
Angle of internal friction :	φ_{ef}	=	21.00 °

River Terrace Deposits

Unit weight :	γ	=	18.00 kN/m^3
Poisson's ratio :	ν	=	0.40
Oedometric modulus :	E_{oed}	=	10.00 MPa
Saturated unit weight :	γ_{sat}	=	18.00 kN/m^3
Angle of internal friction :	φ_{ef}	=	32.00 °

Nar Valley (Clay)

Unit weight :	γ	=	19.10 kN/m^3
Poisson's ratio :	ν	=	0.30
Oedometric modulus :	E_{oed}	=	8.00 MPa
Saturated unit weight :	γ_{sat}	=	19.10 kN/m^3
Cohesion of soil :	c_u	=	91.00 kPa
Adhesion factor :	α	=	0.70
Angle of internal friction :	φ_{ef}	=	24.00 °

Nar Valley (Lignite)

Unit weight :	γ	=	11.80 kN/m^3
Poisson's ratio :	ν	=	0.49
Oedometric modulus :	E_{oed}	=	10.00 MPa
Saturated unit weight :	γ_{sat}	=	11.80 kN/m^3
Cohesion of soil :	c_u	=	500.00 kPa
Adhesion factor :	α	=	0.33
Angle of internal friction :	φ_{ef}	=	12.00 °

Nar Valley (Sand and Gravel)

Unit weight :	γ	=	20.00 kN/m^3
Poisson's ratio :	ν	=	0.49
Oedometric modulus :	E_{oed}	=	200.00 MPa
Saturated unit weight :	γ_{sat}	=	20.00 kN/m^3
Angle of internal friction :	φ_{ef}	=	38.00 °

Varved Clay

Unit weight :	γ	=	20.00 kN/m^3
Poisson's ratio :	ν	=	0.49
Oedometric modulus :	E_{oed}	=	14.00 MPa
Saturated unit weight :	γ_{sat}	=	20.00 kN/m^3
Cohesion of soil :	c_u	=	123.00 kPa
Adhesion factor :	α	=	0.45
Angle of internal friction :	φ_{ef}	=	24.00 °

Geometry

Pile profile: circular

Dimensions
Diameter d = 0.30 m
Length l = 16.00 m

Calculated cross-sectional characteristics
Area A = 7.07E-02 m^2
Moment of inertia I = 3.98E-04 m^4

Location
Off ground height h = 0.00 m
Depth of finished grade h_z = 0.00 m

Technology: CFA piles

Material of structure

Unit weight γ = 23.00 kN/m^3
Analysis of concrete structures carried out according to the standard EN 1992-1-1 (EC2).

Concrete : C 20/25

Cylinder compressive strength	f_{ck}	=	20.00	MPa
Tensile strength	f_{ctm}	=	2.20	MPa
Elasticity modulus	E_{cm}	=	30000.00	MPa
Shear modulus	G	=	12500.00	MPa

Longitudinal steel : B500
Yield strength f_{yk} = 500.00 MPa

Transverse steel: B500
Yield strength f_{yk} = 500.00 MPa

Geological profile and assigned soils

No.	Layer [m]	Assigned soil	Pattern
1	0.60	Made Ground	
2	1.90	River Terrace Deposits	
3	11.00	Nar Valley (Clay)	
4	1.50	Nar Valley (Lignite)	
5	9.80	Nar Valley (Sand and Gravel)	
6	17.20	Varved Clay	
7	8.00	Varved Clay	
8	-	Varved Clay	

Load

No.	Load		Name	Type	N [kN]	M_x [kNm]	M_y [kNm]	H_x [kN]	H_y [kN]
	new	change							
1	Yes		Load No. 1	Design	400.00	0.00	0.00	0.00	100.00

No.	Load		Name	Type	N	M_x	M_y	H_x	H_y
	new	change			[kN]	[kNm]	[kNm]	[kN]	[kN]
2	Yes		Load No. 1 - service	Service	400.00	0.00	0.00	0.00	100.00

Ground water table

The ground water table is at a depth of 0.00 m from the original terrain.

Global settings

Analysis of vertical bearing capacity : analytical solution
Analysis type : analysis for drained conditions

Settings of the stage of construction

Design situation : permanent
Verification methodology : without reduction of soil parameters

Verification No. 1

Verification of pile bearing capacity according to NAVFAC DM 7.2 - partial results

Computation of pile base bearing capacity:
The soil under the base is cohesionless
Coefficient of bearing capacity N_q = 43.00
Area of pile transverse cross-section A_p = 7.07E-02 m^2

Pile ultimate skin resistance capacity:

Depth [m]	Thickness [m]	c_{ud} [kPa]	α [–]	k_{dc} [–]	δ [°]	σ_{or} [kPa]	R_{si} [kN]
0.00	-	-	-	-	-	0.00	-
0.30	0.30	20.00	1.00	-	-	0.90	5.65
0.30	-	-	-	-	-	0.90	-
0.60	0.30	20.00	1.00	-	-	1.80	5.65
0.60	-	-	-	-	-	1.80	-
2.50	1.90	-	-	1.34	24.00	1.80	1.93
2.50	-	-	-	-	-	1.80	-
13.50	11.00	91.00	0.70	-	-	1.80	660.39
13.50	-	-	-	-	-	1.80	-
15.00	1.50	500.00	0.33	-	-	1.80	233.26
15.00	-	-	-	-	-	1.80	-
16.00	1.00	-	-	1.61	28.50	1.80	1.48

Verification of pile bearing capacity according to NAVFAC DM 7.2 - partial results

Computation of pile base bearing capacity:
The soil under the base is cohesionless
Coefficient of bearing capacity N_q = 43.00
Area of pile transverse cross-section A_p = 7.07E-02 m^2

Pile ultimate skin resistance capacity:

Depth [m]	Thickness [m]	c_{ud} [kPa]	α [–]	k_{dc} [–]	δ [°]	σ_{or} [kPa]	R_{si} [kN]
0.00	-	-	-	-	-	0.00	-
0.30	0.30	14.29	1.00	-	-	0.90	3.11
0.30	-	-	-	-	-	0.90	-
0.60	0.30	14.29	1.00	-	-	1.80	3.11

Depth [m]	Thickness [m]	c_{ud} [kPa]	α [–]	k_{dc} [–]	δ [°]	σ_{or} [kPa]	R_{si} [kN]
0.60	-	-	-	-	-	1.80	-
2.50	1.90	-	-	1.18	19.92	1.80	1.06
2.50	-	-	-	-	-	1.80	-
13.50	11.00	65.00	0.70	-	-	1.80	362.85
13.50	-	-	-	-	-	1.80	-
15.00	1.50	357.14	0.33	-	-	1.80	128.17
15.00	-	-	-	-	-	1.80	-
16.00	1.00	-	-	1.34	24.00	1.80	0.78

Verification of bearing capacity : NAVFAC DM 7.2

Analysis carried out with automatic selection of the most unfavourable load cases.
Factor determining critical depth k_{dc} = 1.00

Verification of compressive pile:
Most unfavorable load case No. 2. (Load No. 1 - service)

Pile skin bearing capacity R_s = 499.08 kN
Pile base bearing capacity R_b = 275.86 kN

Pile bearing capacity R_c = 774.94 kN
Ultimate vertical force V_d = 414.70 kN

$R_c = 774.94\ \text{kN} > 414.70\ \text{kN} = V_d$

Pile bearing capacity is SATISFACTORY

Verification No. 1

Analysis of load settlement curve - input data

Layer No.	E_s [MPa]
1	5.00
2	100.00
3	50.00
4	20.00
5	150.00

Maximum pile settlement s_{lim} = 25.0 mm

Analysis of load settlement curve - partial results

Correction factor for pile compressibility C_k = 0.63
Correction factor for Poisson's ratio of soil C_v = 0.82
Correction factor for stiffness of bearing stratum C_b = 2.33
Base-load proportion for incompressible pile β_0 = 0.04
Proportion of applied load transferred to pile base β = 0.04

Influence coefficients of settlement :
Basic - dependent on ratio l/d I_0 = 0.04
Correction factor for pile compressibility R_k = 1.68
Correction factor for finite depth of layer on a rigid base R_h = 1.00
Correction factor for Poisson's ratio of soil R_v = 0.93

Analysis of load settlement curve - results

Load at the onset of mobilization of skin friction	R_{yu}	=	949.55	kN
The settlement for the force R_{yu}	s_y	=	3.4	mm
Total resistance	R_c	=	1164.72	kN
Maximum settlement	s_{lim}	=	25.0	mm

The settlement for maximum service load V = 400.00kN is 1.4mm.

Pile verification

Input data

Project

Task	:	NARC Batch 2 2018 Foundation Design
Description	:	Outline Pile Foundation Design
Customer	:	[redacted]
Author	:	[redacted]
Date	:	07/08/2018
Project ID	:	Kings Lynn Compressor Station
Project number	:	GN21822

Settings

Standard - EN 1997 - DA1

Materials and standards

Concrete structures :	EN 1992-1-1 (EC2)
Coefficients EN 1992-1-1 :	standard
Steel structures :	EN 1993-1-1 (EC3)
Partial factor on bearing capacity of steel cross section :	γ_{M0} = 1.00
Timber structures :	EN 1995-1-1 (EC5)
Partial factor for timber property :	γ_M = 1.30
Modif. factor of load duration and moisture content :	k_{mod} = 0.50
Coeff. of effective width for shear stress :	k_{cr} = 0.67

Pile

Analysis for drained conditions :	NAVFAC DM 7.2
Load settlement curve :	linear (Poulos)
Horizontal bearing capacity :	Elastic subsoil (p-y method)
Verification methodology :	according to EN 1997
Design approach :	1 - reduction of actions and soil parameters

Partial factors on actions (A)									
Permanent design situation									
		Combination 1				Combination 2			
		Unfavourable		Favourable		Unfavourable		Favourable	
Permanent actions :	γ_G =	1.35	[–]	1.00	[–]	1.00	[–]	1.00	[–]

Partial factors for soil parameters (M)					
Permanent design situation					
		Combination 1		Combination 2	
Partial factor on internal friction :	γ_ϕ =	1.00	[–]	1.25	[–]
Partial factor on effective cohesion :	γ_c =	1.00	[–]	1.25	[–]
Partial factor on undrained shear strength :	γ_{cu} =	1.00	[–]	1.40	[–]

Partial factors for resistances (R)					
Permanent design situation					
		Combination 1		Combination 2	
Partial factor on shaft resistance :	γ_s =	1.00	[–]	1.30	[–]
Partial factor on base resistance :	γ_b =	1.00	[–]	1.45	[–]
Partial factor on resistance in tension :	γ_{st} =	1.25	[–]	1.60	[–]

Basic soil parameters

No.	Name	Pattern	γ [kN/m^3]	ν [–]
1	Made Ground		16.00	0.30
2	River Terrace Deposits		18.00	0.40
3	Nar Valley (Clay)		19.10	0.30
4	Nar Valley (Lignite)		11.80	0.49
5	Nar Valley (Sand and Gravel)		20.00	0.49
6	Varved Clay		20.00	0.49

All soils are considered as cohesionless for at rest pressure analysis.

No.	Name	Pattern	E_{oed} [MPa]	E_{def} [MPa]	γ_{sat} [kN/m^3]	γ_s [kN/m^3]	n [–]
1	Made Ground		1.00	-	16.00	-	-
2	River Terrace Deposits		10.00	-	18.00	-	-
3	Nar Valley (Clay)		8.00	-	19.10	-	-
4	Nar Valley (Lignite)		10.00	-	11.80	-	-
5	Nar Valley (Sand and Gravel)		200.00	-	20.00	-	-
6	Varved Clay		14.00	-	20.00	-	-

No.	Name	Pattern	φ_{ef} [°]	δ [°]	K [–]	c_u [kPa]	α [–]
1	Made Ground		-	-	-	20.00	1.00
2	River Terrace Deposits		32.00	-	-	-	-
3	Nar Valley (Clay)		-	-	-	91.00	0.70
4	Nar Valley (Lignite)		-	-	-	500.00	0.33
5	Nar Valley (Sand and Gravel)		38.00	-	-	-	-
6	Varved Clay		-	-	-	123.00	0.45

Soil parameters

Made Ground

Unit weight :	γ	=	16.00 kN/m3
Poisson's ratio :	ν	=	0.30
Oedometric modulus :	E_{oed}	=	1.00 MPa
Saturated unit weight :	γ_{sat}	=	16.00 kN/m3
Cohesion of soil :	c_u	=	20.00 kPa
Adhesion factor :	α	=	1.00
Angle of internal friction :	φ_{ef}	=	21.00 °

River Terrace Deposits

Unit weight :	γ	=	18.00 kN/m3
Poisson's ratio :	ν	=	0.40
Oedometric modulus :	E_{oed}	=	10.00 MPa
Saturated unit weight :	γ_{sat}	=	18.00 kN/m3
Angle of internal friction :	φ_{ef}	=	32.00 °

Nar Valley (Clay)

Unit weight :	γ	=	19.10 kN/m3
Poisson's ratio :	ν	=	0.30
Oedometric modulus :	E_{oed}	=	8.00 MPa
Saturated unit weight :	γ_{sat}	=	19.10 kN/m3
Cohesion of soil :	c_u	=	91.00 kPa
Adhesion factor :	α	=	0.70
Angle of internal friction :	φ_{ef}	=	24.00 °

Nar Valley (Lignite)

Unit weight :	γ	=	11.80 kN/m3
Poisson's ratio :	ν	=	0.49
Oedometric modulus :	E_{oed}	=	10.00 MPa
Saturated unit weight :	γ_{sat}	=	11.80 kN/m3
Cohesion of soil :	c_u	=	500.00 kPa
Adhesion factor :	α	=	0.33
Angle of internal friction :	φ_{ef}	=	12.00 °

Nar Valley (Sand and Gravel)

Unit weight :	γ	=	20.00 kN/m3
Poisson's ratio :	ν	=	0.49
Oedometric modulus :	E_{oed}	=	200.00 MPa
Saturated unit weight :	γ_{sat}	=	20.00 kN/m3
Angle of internal friction :	φ_{ef}	=	38.00 °

Varved Clay

Unit weight :	γ	=	20.00 kN/m3
Poisson's ratio :	ν	=	0.49
Oedometric modulus :	E_{oed}	=	14.00 MPa
Saturated unit weight :	γ_{sat}	=	20.00 kN/m3
Cohesion of soil :	c_u	=	123.00 kPa
Adhesion factor :	α	=	0.45
Angle of internal friction :	φ_{ef}	=	24.00 °

Geometry

Pile profile: circular

Dimensions
Diameter d = 0.30 m
Length l = 16.00 m

Calculated cross-sectional characteristics
Area A = 7.07E-02 m^2
Moment of inertia I = 3.98E-04 m^4

Location
Off ground height h = 0.00 m
Depth of finished grade h_z = 0.00 m

Technology: CFA piles

Material of structure

Unit weight γ = 23.00 kN/m^3
Analysis of concrete structures carried out according to the standard EN 1992-1-1 (EC2).

Concrete : C 20/25
Cylinder compressive strength f_{ck} = 20.00 MPa
Tensile strength f_{ctm} = 2.20 MPa
Elasticity modulus E_{cm} = 30000.00 MPa
Shear modulus G = 12500.00 MPa

Longitudinal steel : B500
Yield strength f_{yk} = 500.00 MPa

Transverse steel: B500
Yield strength f_{yk} = 500.00 MPa

Geological profile and assigned soils

No.	Layer [m]	Assigned soil	Pattern
1	0.60	Made Ground	
2	1.90	River Terrace Deposits	
3	11.00	Nar Valley (Clay)	
4	1.50	Nar Valley (Lignite)	
5	9.80	Nar Valley (Sand and Gravel)	
6	17.20	Varved Clay	
7	8.00	Varved Clay	
8	-	Varved Clay	

Load

No.	Load		Name	Type	N	M_x	M_y	H_x	H_y
	new	change			[kN]	[kNm]	[kNm]	[kN]	[kN]
1	Yes		Load No. 1	Design	250.00	0.00	0.00	0.00	100.00

No.	Load		Name	Type	N	M_x	M_y	H_x	H_y
	new	change			[kN]	[kNm]	[kNm]	[kN]	[kN]
2	Yes		Load No. 1 - service	Service	250.00	0.00	0.00	0.00	100.00

Ground water table

The ground water table is at a depth of 0.00 m from the original terrain.

Global settings

Analysis of vertical bearing capacity : analytical solution
Analysis type : analysis for drained conditions

Settings of the stage of construction

Design situation : permanent
Verification methodology : without reduction of soil parameters

Verification No. 1

Verification of pile bearing capacity according to NAVFAC DM 7.2 - partial results

Computation of pile base bearing capacity:
The soil under the base is cohesionless
Coefficient of bearing capacity N_q = 43.00
Area of pile transverse cross-section A_p = 7.07E-02 m^2

Pile ultimate skin resistance capacity:

Depth [m]	Thickness [m]	c_{ud} [kPa]	α [–]	k_{dc} [–]	δ [°]	σ_{or} [kPa]	R_{si} [kN]
0.00	-	-	-	-	-	0.00	-
0.30	0.30	20.00	1.00	-	-	0.90	5.65
0.30	-	-	-	-	-	0.90	-
0.60	0.30	20.00	1.00	-	-	1.80	5.65
0.60	-	-	-	-	-	1.80	-
2.50	1.90	-	-	1.34	24.00	1.80	1.93
2.50	-	-	-	-	-	1.80	-
13.50	11.00	91.00	0.70	-	-	1.80	660.39
13.50	-	-	-	-	-	1.80	-
15.00	1.50	500.00	0.33	-	-	1.80	233.26
15.00	-	-	-	-	-	1.80	-
16.00	1.00	-	-	1.61	28.50	1.80	1.48

Verification of pile bearing capacity according to NAVFAC DM 7.2 - partial results

Computation of pile base bearing capacity:
The soil under the base is cohesionless
Coefficient of bearing capacity N_q = 43.00
Area of pile transverse cross-section A_p = 7.07E-02 m^2

Pile ultimate skin resistance capacity:

Depth [m]	Thickness [m]	c_{ud} [kPa]	α [–]	k_{dc} [–]	δ [°]	σ_{or} [kPa]	R_{si} [kN]
0.00	-	-	-	-	-	0.00	-
0.30	0.30	14.29	1.00	-	-	0.90	3.11
0.30	-	-	-	-	-	0.90	-
0.60	0.30	14.29	1.00	-	-	1.80	3.11

Depth [m]	Thickness [m]	c_{ud} [kPa]	α [–]	k_{dc} [–]	δ [°]	σ_{or} [kPa]	R_{si} [kN]
0.60	-	-	-	-	-	1.80	-
2.50	1.90	-	-	1.18	19.92	1.80	1.06
2.50	-	-	-	-	-	1.80	-
13.50	11.00	65.00	0.70	-	-	1.80	362.85
13.50	-	-	-	-	-	1.80	-
15.00	1.50	357.14	0.33	-	-	1.80	128.17
15.00	-	-	-	-	-	1.80	-
16.00	1.00	-	-	1.34	24.00	1.80	0.78

Verification of bearing capacity : NAVFAC DM 7.2

Analysis carried out with automatic selection of the most unfavourable load cases.
Factor determining critical depth k_{dc} = 1.00

Verification of compressive pile:
Most unfavorable load case No. 2. (Load No. 1 - service)

Pile skin bearing capacity R_s = 499.08 kN
Pile base bearing capacity R_b = 275.86 kN

Pile bearing capacity R_c = 774.94 kN
Ultimate vertical force V_d = 264.70 kN

R_c = 774.94 kN > 264.70 kN = V_d

Pile bearing capacity is SATISFACTORY

Verification No. 1

Analysis of load settlement curve - input data

Layer No.	E_s [MPa]
1	150.00
2	100.00
3	50.00
4	20.00
5	150.00

Maximum pile settlement s_{lim} = 25.0 mm

Analysis of load settlement curve - partial results

Correction factor for pile compressibility C_k = 0.61
Correction factor for Poisson's ratio of soil C_v = 0.82
Correction factor for stiffness of bearing stratum C_b = 2.27
Base-load proportion for incompressible pile β_0 = 0.04
Proportion of applied load transferred to pile base β = 0.04

Influence coefficients of settlement :
Basic - dependent on ratio l/d I_0 = 0.04
Correction factor for pile compressibility R_k = 1.73
Correction factor for finite depth of layer on a rigid base R_h = 1.00
Correction factor for Poisson's ratio of soil R_v = 0.93

Analysis of load settlement curve - results

Load at the onset of mobilization of skin friction	R_{yu}	=	946.88	kN
The settlement for the force R_{yu}	s_y	=	3.2	mm
Total resistance	R_c	=	1164.41	kN
Maximum settlement	s_{lim}	=	25.0	mm

The settlement for maximum service load V = 250.00kN is 0.9mm.