


Hyde Park Hayes

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Halcrow Group Limited
Elms House, 43 Brook Green, London W6 7EF
tel +44 20 3479 8000 fax +44 20 3479 8001
halcrow.com

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1 Introduction

1.1 Background

In March 2012 Halcrow Group Ltd were commissioned to specify a ground investigation for two separate areas HPH4 and HPH5 at the Hyde Park, Hayes business park for HPHA Ltd, a subsidiary of Melford Capital Partners LP. The Halcrow ground investigation specification was amended by SKM Enviros to include requirements for HPH6 from 3DReid and the ground investigation was conducted by Endeavour Drilling Ltd under the supervision of SKM Enviros.

The site is located between North Hyde Road and Millington Road, within Hyde Park Business Centre, Hayes, Greater London. It is approximately 1.5 miles north of Junction 3 of the M4 motorway. An approximate grid reference for the site is Easting 509210, Northing 179260. The site is a commercial centre comprising of three, multi-storey office buildings named HPH1, HPH2 and HPH3, and a separate multi-storey car park. It is proposed to construct similar multi storey structures at HPH4, HPH5 and HPH6.

1.2 Aim of the report

This report has been prepared for the following objectives:

- Outline the geological setting of the site
- Describe the recent extent of ground investigations
- Comment on the ground conditions and material properties
- Highlight any geotechnical risks to the development
- Make recommendations for geotechnical design

2 Geology

2.1 Regional geology

The British Geological Survey 1:50,000 scale map of the area, Sheet 269 Windsor, Solid and Drift Edition, indicates Lynch Hill Gravel Member and Langley Silt Formation to outcrop beneath the site, which in turn are underlain by London Clay Formation. The site is situated at the western end of the London Basin and the London Clay Formation is underlain by the Lambeth Group, Thanet Sand Formation and Chalk respectively.

2.2 Site geology

The site is covered with a shallow depth of variable Made Ground between 0.3 to 2.1 metres thick. The Lynch Hill Gravel Member is in part overlain by the Langley Silt Formation to the northwest and southeast but are absent from the central part of the site between HPH4 and HPH5. This also coincides with the greatest thickness of Made Ground. The top of the London Clay shows a shallow depression in the central part of the site.

3 Ground Investigation

3.1 Site investigation

The recent ground investigation was undertaken over the 2nd to 19th July 2012. The investigation comprised:

- Eight cable percussion boreholes (BH11 to BH18) to depths of 6.1 to 40 metres below ground level (mbgl) installed with combined 50mm diameter gas and groundwater monitoring standpipes
- 8 No. machine excavated trial pits (TP1 to TP8) to depths of 1.75 to 3.2mbgl
- 2 No. infiltration tests
- 2 No. Handheld TRL Dynamic Probes (TRL-TP8a and TRL-TP8B)

All exploratory hole locations were CAT scanned and a hand dug inspection pit was undertaken to 1.2m to avoid buried services.

3.2 Ground summary

The table below describes the strata encountered at the site and their relative thicknesses.

Strata	Description	Depth to top (mbgl)	Thickness (m)
Made Ground	Variable. Sandy gravelly CLAY, sandy GRAVEL with brick, clinker, concrete, brick, asphalt and flint	0.0	0.3 to 2.1
Langley Silt Formation	Silty gravelly CLAY	0.3 to 1.5	0.5 to 2.4
Lynch Hill Gravel Member	Very dense sandy GRAVEL	0.9 to 7.0	2.8 to 5.7
London Clay Formation	Medium strength to high strength stiff brown fissured CLAY	4.3 to 7.3	not proven

Table 3-1 Sequence of strata

Appendix A of this report shows the as-built location plan of exploratory locations and (Drawing No: 110475-HPH-3DR-00-DR-C-1000) as well as inferred geological cross-sections for areas HPH4 & HPH5 and HPH6 in drawings 1001 and 1002 respectively. Geological profiles do not differ significantly hence a unique soil model as per Table 3-1 can be adopted in a design.

4 Ground Conditions and Material Properties

4.1 Soil Properties

Upon review of the data from across the site no discernible differences in material properties were noted in the observed geology between HPH4, HPH5 and HPH6 parts of the site. Therefore all material properties from the geology observed at the Hyde Park, Hayes site have been plotted on cumulative graphs presented in Appendix B. This section aims to interpret the soil conditions and summarise index and strength properties based on the findings from the recent ground investigation at Hyde Park, Hayes, as well as suggest design parameters that can be used for assessment of piled foundations, deep basements and retaining walls. Soil characteristics and suggested design values are summarised in three tables at the end of this section. Table 4-1 presents soil classification and strength characteristics measured by either field or laboratory testing. Following the approach given in BRE Special Digest 1, [ref 1], chemical properties of the observed geology for assessment of soil aggressiveness to concrete are summarised in Table 4-2. The table also suggests required ACEC concrete class. Possible design parameters are presented in Table 4-3.

4.1.1 Made Ground

Made Ground observed at the site is of a variable nature typical for this type of soil. Broadly two different material types predominate:

- Upper layer of silty sandy Gravel with usual inclusions of brick, concrete, asphalt and clinker pieces. Occasional fragments of metal, plastic and glass are also present.
- Lower layer of silty sand clay with occasional gravel size fragments of manmade material, wood and flint.

It was noted that these layers are discontinuous and may not be present in all parts of the site.

4.1.1.1 Classification and Index Properties

A series of laboratory tests were performed on a number of samples of Made Ground to identify the characteristics of the material. Classification tests included determination of Particle Size Distribution on eleven disturbed samples; Natural Moisture Content on eight samples as well as Atterberg limits on nine disturbed samples.

The PSD curves for each tested sample are presented in Figure 42, Appendix B. The analyses suggest the composition of Made Ground to be more variable within area HPH6 whilst the material encountered within areas HPH4 and HPH5 appears to be relatively uniform and predominantly granular in nature. Six test results for areas HPH4 and HPH5 showed the material to be sandy gravel ranging from 47% to 61% gravel and 18% to 37% sand size particles. The content of fines for this material was between 10 and 31%. Six number PSD analyses on samples from area HPH6 showed the material to vary from a sandy clay/silt (BH16, 1.0m bgl) to sandy gravel (BH18, 0.5m bgl). The respective test data recorded the content of sand and gravel size particles to range from 11 to 64 per cent and the clay fraction to range from 17% to 40%.

The results from the Atterberg limit determinations and natural moisture content (NMC) tests from cohesive made ground were used to produce a plasticity chart and a plot of plastic limit (PL), liquid limit (LL) and NMC versus depth (Figure 1, Appendix B). The results from the Atterberg limit determinations were also used to calculate the values of a Plasticity Index (PI) and a Liquidity Index (LI). Figures 5 and 9 in Appendix B, presents plasticity index (PI) and liquidity index (LI) values versus elevation.

The plasticity chart presented in Figures 13 (Appendix B) indicates that cohesive Made Ground comprises clay of low to intermediate plasticity. The NMC values are generally close to PL values with both parameters varying within a narrow range from the average value of 17%.

LL and PL both exhibit a similar trend and generally decreasing with depth. Proposed design values of PI and NMC for Made Ground are summarized in Table 4-3

4.1.1.2 Consistency and Shear Strength

Four Standard Penetration Tests (SPT) were carried out in cohesive Made Ground. The uncorrected SPT 'N' values were plotted against depth (Figures 18) and range from N=2 to N=17. An SPT test performed in BH14 at 1.0m bgl did not achieve the full 300mm required penetration. This test has reached effective refusal and is not representative of the material tested.

An assessment of the undrained shear strength (S_u) of Made Ground was made from correlation with the liquidity index after Muir Wood (1983) and SPT 'N' values and plasticity indices after Stroud and Butler (1975). Inferred values of S_u show a large scatter with depth (Figure 23, Appendix B). This range of undrained shear strength corresponds to low to extremely high strength material which is not anticipated for Made Ground. The unexpectedly high strength values are a result of NMC measured below the PL from six tested samples (reference: BH11/30.1m AOD; BH11/31.1m AOD; BH12/30.6m AOD; BH16/32.15m AOD and BH18/30.85m AOD). This could be a consequence of desiccation of the material as it is close to the existing ground surface. For design purposes a moderate average S_u value of 56 kPa should be considered.

An assessment of effective angle of shearing resistance, ϕ' , for cohesive Made Ground, was made by means of correlation with the plasticity index after Kenny (1959). The interpreted ϕ' values with depth are plotted on Figure 31. The data exhibits a reasonably uniform trend with depth increasing from 26° to 30°.

4.1.1.3 Chemical Tests

Water soluble sulphate determinations (SO_4) were performed on four samples of Made Ground. The results mainly lie between 0.04g/l and 0.41g/l with a higher result of 1.47g/l determined on sample BH12/30.6m AOD. Five determinations of pH gave results between 7.9 and 10.6 with an average of 8.9. These results were assessed in accordance with BRE Special Digest 1(2005) assuming a mobile groundwater and brownfield site conditions, which classify the material within Aggressive Chemical Environment for Concrete (ACEC) class AC-2 and indicate a minimum design sulphate class DS-2.

4.1.2 Langley Silt Formation

The Langley Silt deposit was encountered in boreholes BH14, BH15 and B18 and in trial pits TP4 to TP8. This material typically comprises soft to firm brown to orange-brown slightly gravelly sandy silty clay or clayey silt. Gravel is sub-angular to sub-rounded, fine to coarse gravel of flint.

4.1.2.1 Classification and Index Properties

Classification tests performed on Langley Silt included particle size distribution analyses on six disturbed and bulk samples and determination of Natural Moisture Content and Atterberg limits on six disturbed samples respectively.

The results of the PSD analyses showed this material to be a clayey silt and silty clay with between 25 and 54 per cent silt sized particles, ref Figure 43. The clay fraction ranged between 25 and 40 per cent and the sand fraction between 8 to 30 per cent.

Atterberg limit tests were performed on the fines portion (material $<425\mu\text{m}$) of six samples of Langley Silt. The results of the tests are shown on Figure 14 and all plot above the 'A' line indicating the samples to be inorganic clay of intermediate plasticity.

The liquid and plastic limits of the samples vary within narrow ranges of 42 and 47 per cent and 16 and 22 per cent respectively. The plasticity index of the samples ranges from 20 to 27 per cent respectively.

Natural moisture content determinations on the above samples gave values ranging from 14 to 25 per cent. Figure 2 presents a plot of the NMC, plasticity limit and liquid limits against depth. The plot shows all parameters to be consistent with depth, with the NMC plotting close to the plastic limit.

Plasticity and liquidity index values are quite consistent with depth (Figures 6 and 10, respectively) suggesting a relatively homogenous nature of the stratum. Proposed design values for PI and NMC for Langley Silt are summarized in Table 4-3.

4.1.2.2 Consistency and Shear Strength

A single SPT test was performed in Langley Silt deposit and the uncorrected 'N' value is presented in Figure 19.

As no specific laboratory testing was available the undrained shear strength was estimated from the correlation with the Liquidity Index. The results range from 41kPa to 239kPa indicating medium to very high strength fine grained material. This range however is not typical of Langley Silt formation. The unexpectedly high strength values are believed to be caused by natural moisture contents (NMC) measured below or at the PL on three separate samples (reference: BH18/31.85m AOD; TP4/32.05m AOD and TP05/31.35m AOD;). The low NMC values are believed to be caused by desiccation of the deposit being so close to the ground surface. In terms of design parameters for undrained strength a more moderate range of values, between 59 and 90kPa with an average of 75kPa, should be considered.

The inferred values of effective angle of shearing resistance (based on the plasticity index correlation) were plotted against depth (Figure 32). The ϕ' values show a narrow spread between 26° and 28° with an average of 27° . For design purposes the following effective shear strength parameters should be considered:

effective cohesion

$$c' = 0\text{kN/m}^2$$

angle of shearing resistance

$\phi' = 27$ degrees.

4.1.2.3 Chemical Tests

Water soluble sulphate determinations (SO_4) were carried out on two samples of Langley Silt. Contents of 0.03g/l and 0.20g/l on samples obtained from BH15 and TP6 respectively, both located in HPH6 area, were obtained. Values of pH factor from the same locations gave results of 7.7 and 7.5 respectively. Assuming static groundwater and brownfield site conditions Langley Silt can be classified as ACEC class AC-1. Consequently the design concrete sulphate class DS-1 would be required.

4.1.3 Lynch Hill Gravel Member

This layer was encountered throughout the whole of the site area. The deposit mainly comprises medium dense to dense orange brown slightly clayey sandy gravel. Sand is fine to coarse, gravel is sub-angular to sub-rounded fine to coarse of flint with some quartz.

4.1.3.1 Classification and Index Properties

Classification tests on Lynch Hill Gravel included twenty eight particle size distribution analyses which confirm the granular nature of the deposit (Figure 44).

Results show the deposit to be predominantly very sandy gravel, gravel content being between 37% and 93% and less than 10% fines (silt and clay sized particles). Owing to the coarse nature of the material undisturbed samples could not been recovered. However, based on the particle size distribution, and the deposit being dense to very dense a representative value of bulk unit weight $\gamma_b = 21.0 \text{ kN/m}^3$ was adopted for design purposes. This value corresponds to the moist bulk unit weight of a well graded dense sand and gravel mix in accordance with BS8002:1994, Table 1.

4.1.3.2 Relative Density and Shear Strength

Thirty Standard Penetration Tests (SPT) were undertaken in Lynch Hill Gravel. Figure 20 (Appendix B) presents a plot of uncorrected SPT 'N' values with depth. A significant scatter of the results is evident and no trend in relation to depth can be observed, which is not unusual for a coarse granular material. The 'N' values ranged between $N=10$ and $N=67$ that show the deposit to vary from medium dense to very dense. Nevertheless, only three tests returned values greater than $N=50$, which define the boundary between dense and very dense material.

The test results were corrected to the equivalent SPT resistance values $(N_1)_{60}$ for non-cohesive soils in accordance with CIRIA Report 143 (1995). Based on an empirical correlation (Peck *et al*, 1974) with the $(N_1)_{60}$ values of internal friction angle (ϕ') for Lynch Hill Gravel were estimated to be 29 and 40 degrees. Therefore the proposed effective shear strength design values for Lynch Hill Gravel are:

effective cohesion

$c' = 0 \text{ kN/m}^2$

angle of shearing resistance

$\phi' = 34$ degrees.

It is known that this correlation somewhat underestimates ϕ' values, however it is widely used for the routine design applications.

4.1.3.3 Chemical Tests

The summary of chemical test results for soil aggressiveness to concrete are shown in Table 4-2. Water soluble SO_4 tests were performed on nine samples of Lynch Hill Gravel. Test results ranged between 0.01g/l and 0.12g/l with an average of 0.06g/l. The pH factor determinations ranged between 7.0 and 10.6 with an average of 8.6. The results assessed in accordance with BRE Special Digest 1(2005) assuming mobile water and brownfield site conditions. The Lynch Hill Gravel, within Aggressive Chemical Environment for Concrete, can be classified as AC-1 indicating a minimum design sulphate class of DS-1 for concrete mixes.

4.1.4 Weathered London Clay

A distinct sub-layer of weathered London Clay was observed at the river terrace gravel / clay horizon. This is a common feature where an older geological formation is overlain uncoformably by a more recent one. At the HPH site this sub-layer is relatively thin and in some instances undistinguishable from the unweathered London Clay (borehole B12).

4.1.4.1 Classification and Index Properties

The soil can be described as sandy gravelly Clay of high to very high plasticity (Figure 15, Appendix B). Sand is often found in lenses and gravel is sub-rounded to rounded of flint. The natural moisture content reduces with depth and approaches the plastic limit. This is a characteristic of the unweathered material, hence not a lot of softening is expected compared to the unweathered London Clay.

The results of PSD analyses, performed on four samples of weathered London Clay (Figure 45, Appendix B), show that the material predominantly comprises clay and silt with sand and gravel as a secondary constituent, ranging from 10% to 20%.

Atterberg limits determinations were carried out on five samples and gave liquid limits between 64% and 75% and plastic limits within a narrow range of 25% to 27%. Therefore, plasticity index ranges from 39% to 48%.

No specific density tests were performed on weathered London Clay, however based on similarity of other index properties it can be assumed that it is the same as for unweathered base layer.

4.1.4.2 Consistency and Shear Strength

No direct measurement of the shear strength of Weathered London Clay was available so this property had to be inferred from plasticity data and standard penetration tests (SPT). Using an empirical relationship in respect to plasticity index of clay (Stroud & Butler 1975) a factor of 4.5 (f_1) was assumed for correlation of SPT N values and undrained shear strength. SPT test results yielded relatively consistent value of shear strength where the correlation with the liquidity index (LI) produced much more scatter, (Figure 25, Appendix B). The scatter maybe due to the rounding errors and errors in accuracy of LI prediction as it is close to zero in many cases. Therefore predominantly relaying on SPT N values a design parameter of 60kPa is recommended.

Drained shear strength parameter (ϕ') was inferred from the correlation with plasticity characteristics suggested by Kenny (1959) and utilising the BS8002 line. A design value of 21° was derived, which correlates well with historic values from the company's experience.

4.1.4.3 Chemical Tests

No specific tests were available for the Weathered London Clay. However it is considered reasonable to assume the same conditions as for the London Clay proper.

4.1.5 London Clay Formation

London Clay represents the starting stratum of the solid geology and most probably the founding layer underlying the site. Neither of the boreholes reached the base horizon of London Clay therefore the layer is at least 35m thick at the proposed location of the HPH site. The observed nature and structure is typical of upper units of the layer being overwhelmingly clayey in nature with very closely spaced closed undulating fissures and black speckling.

4.1.5.1 Classification and Index Properties

London Clay at this location boasts high fines content between 90% and almost 100% (Figure 46). Consequently the plasticity is in the high to very high region. As expected the average natural moisture content coincides with the plastic limit suggesting a high shear strength and a significant overconsolidation of the material. Index properties show considerable uniformity with depth implying relatively uniform strength characteristics, which are discussed further in the next paragraph. The average plasticity and liquidity index values of 45% and 0% respectively can be assumed. A uniform unit weight of 20.2kN/m³ could be assumed for design purposes as the density of the stratum does not differ considerably with depth.

4.1.5.2 Consistency and Shear Strength

The SPT 'N' values show a relatively high scatter for this material and a bi-linear average value as shown in Figure 22 seems as a reasonable approximation. However a cumulative plot of inferred and directly measured undrained shear strength values (Figure 26) supports a simplified design line with increasing trend with depth. This moderately conservative trend was predominantly based on results of unconsolidated undrained triaxial laboratory testing.

Similar to the other fine grained layers, the effective stress strength (ϕ') was inferred from plasticity index correlation. A design value of 21° and a apparent cohesion of 0kPa is considered appropriate for design of deep basements and retaining structures. The design values are summarised in Table 4-3 below.

4.1.5.3 Chemical Tests

It is considered that London Clay has a considerably low permeability and with no direct evidence of elevated pyrite content it was considered that no specific testing for soil aggressiveness to concrete would be warranted.

Strata	Natural Moisture Content (%)	Plastic Limit (%)	Liquid Limit (%)	Plasticity Index (%)	Liquidity Index (%)	γ_b (kN/m ³)	SPT N	Undrained Shear Strength S_u (kPa)
Made Ground	⁽¹⁾ 12 to 24 (17) [9]	15 to 20 (17) [9]	28 to 45 (38) [9]	12 to 26 (21) [9]	-0.9 to 0.54 (0) [9]	–	2 to 17 (7) [5]	9 to 392 (147) [13]
Langley Silt Formation	⁽¹⁾ 14 to 25 (21) [6]	16 to 22 (20) [6]	42 to 47 (44) [6]	20 to 27 (24) [6]	-7 to 12.5 (2) [6]	–	9 [1]	41 to 239 (143) [7]
Lynch Hill Gravel Member	No Data	No Data	No Data	No Data	No Data	–	14 to 67 (39) [29]	N/A
Weathered London Clay	26 to 32 (28) [5]	25 to 27 (26) [5]	64 to 75 (69) [5]	39 to 48 (43) [5]	0.0 to 0.16 (0.05) [5]	19.0 to 21.2 (20.2) [67]	11 to 13 (12) [3]	50 to 170 (107) [12]
London Clay Formation	8 to 43 (26) [42]	22 to 29 (26) [35]	60 to 78 (71) [35]	37 to 50 (45) [35]	-0.2 to +0.2 (0) [35]		13 to 80* (37) [64]	14 to 360 (173) [99]

Table 4-1 Summary of measured soil characteristics {range, average value (x) and No. tests [x]}

1. Applicable to fine grained sub-layers only

Strata	pH	SO ₄ (g/l)	BRE Design Sulphate Class	BRE ACEC Class
Made Ground	7.9 to 10.6 (8.9) [5]	0.04 to 1.47 (0.52) [4]	DS-2	AC-2
Langley Silt Formation	7.5 to 7.7 (7.6) [2]	0.03 to 0.2 (0.12) [2]	DS-1	AC-1
Lynch Hill Gravel Member	7.0 to 10.6 (8.6) [9]	0.01 to 0.12 (0.06) [9]	DS-1	AC-1
Weathered London Clay	No Data	No Data	-	-
London Clay Formation	No Data	No Data	-	-

Table 4-2: Summary of chemical data, {range, average value (x) and No. tests [x]}

Strata	Strata thickness (m)	NMC (%)	PI (%)	γ_b (kN/m ³)	S_u (kPa)	Φ' (kPa)	c' (kPa)	⁽³⁾ Undrained Youngs Modulus E_u (MPa)	⁽⁴⁾ Drained Poissons Ratio ν'	⁽⁴⁾ Drained Youngs Modulus E' (MPa)
Made Ground	1.2 (0.3-2.1)	17 (12-24)	23 (19-26)	no data	⁽⁵⁾ 40 (10-70)	⁽²⁾ 28 (26-30)	0 (N/A)	5.4 to 204 (71) [13]	0.35	93
Langley Silt Formation	0.9 (0.2-1.4)	20 (16-22)	24 (20-27)	no data	⁽⁵⁾ 75 (59-90)	⁽²⁾ 27 (26-27)	0 (N/A)	24 to 110 (61) [7]	0.35	60
Lynch Hill Gravel Member	3.6 (2.7-5.7)	no data	N/A	21	N/A	⁽²⁾ 34 (30-40)	0 (N/A)	N/A	0.3	101
Weathered London Clay	0.5 (0.0-0.9)	28 (26-32)	45 (40-48)	20.2	60 (49-120)	⁽¹⁾ 21 (N/A)	0 (N/A)	20 to 68 (43) [8]	0.3	33
London Clay Formation	not proven	26	45	20.2 (19.6-20.6)	110+1.8z	⁽¹⁾ 21 (N/A)	0 (N/A)	6 to 144 (69) [99]	0.25	45

Table 4-3: Suggested design values and possible range of design soil parameters in parenthesis

1. Based on Kenny (1959) correlation
2. Based on Stroud and Butler (1975) correlation
3. Undrained Poisson's ratio $\nu_u=0.5$, $E_u=600*S_u$ for Made Ground & Langley Silt Formation. $E_u=400*S_u$ for Weathered London Clay & London Clay Formation, after Duncan & Buchignani (1976)
4. Drained Poisson's ratio and Young's modulus from EPRI, 1990. For cohesive soils $E'=E_u/(1+\mu_u)*(1+\mu')$ for granular soils $E'=2N(1+\mu')$. A single value of E' has been calculated from the average E_u for cohesive soils and SPT N-value for Lynch Hill Gravel.
5. Applicable to fine grained sub-layers only

4.2 Groundwater

Groundwater was not encountered whilst drilling, but overnight seepage was noted. A summary of the two rounds of post fieldwork groundwater monitoring is given below:

Borehole	Groundwater Depth (mbgl)	Groundwater Level (mOD)	Response zone strata
BH11	1.65 to 2.39	29.96 to 29.22	Lynch Hill Gravel
BH12	1.74 to 2.86	29.85 to 28.73	London Clay
BH13	1.44 to 2.02	30.48 to 29.90	Lynch Hill Gravel
BH14	1.74 to 1.76	30.04 to 30.02	London Clay
BH15	3.38 to 3.55	28.95 to 28.78	Lynch Hill Gravel
BH16	3.51 to 3.71	28.95 to 28.75	London Clay
BH17	3.29 to 3.49	28.97 to 28.77	London Clay
BH18	2.89 to 3.09	28.97 to 28.77	Lynch Hill Gravel

Table 4-4 Summary of groundwater monitoring results

The table shows the groundwater pressure is close to hydrostatic within the London Clay Formation. A water table was not encountered during drilling but it would appear that there is a shallow water table at the site coincident with the top of the Lynch Hill Gravel Member.

5 Geotechnical Risk Assessment

This section contains details of the Geotechnical Risk Register, where these issues are assessed. General risks from land contamination are outside the scope of this report and will be covered elsewhere by SKM Enviros. Appendix C of this report concentrates on risks to human health and controlled waters due to construction of piled foundations only in order to satisfy Environment Agency (2001) requirements.

Risk registers are site specific and are therefore developed with site and project specific issues in mind. This is a 'live' document and therefore additions and amendments should be made as the project develops and as the overall understanding of the consequence of ground conditions on particular structures evolves. In particular, the Risk Register should be reviewed and updated by the main contractor and the specialist piling contractor once appointed.

Items which have been identified as potential risk to the project are listed below in Table 5-3.

At this stage, main risks to both design and construction have been identified.

This risk register records the assessed hazard probability and hazard consequence in order to define a risk and its severity. Mitigation measures are then applied in order to manage the risk.

Risk severity is calculated by multiplying a probability of a hazard occurring by the consequence of that hazard to the project:

$$\text{Risk rating (R)} = \text{Probability (P)} \times \text{Consequence (C)}$$

Probability (P)	Scale	Consequence (C)	Scale
Probable	4	Very High	4
Likely	3	High	3
Unlikely	2	Low	2
Negligible	1	Very Low	1

Table 5-1 Scales of hazard probability and consequence

Hazard probability and impact are assigned numeric values (scales) in order to define the risk rating, see Table 5-1 and Table 5-2, respectively.

Risk Rating	Risk Level	Action required
1 to 4	Trivial	None
5 to 8	Significant	Consider attention
9 to 12	Substantial	Attention required
13 to 16	Intolerable	Unacceptable

Table 5-2 Risk ratings and actions required in order to manage risk

It is possible to reduce the risk from hazards by applying mitigation measures. The geotechnical risks associated with the project as anticipated at this stage and possible mitigation measures are shown in Table 5-3. If the risk rating is deemed to be greater than 5 or 'significant', as defined in Table 5-2, appropriate mitigation measures should then be applied to that risk. Mitigation measures can either reduce the probability of a hazard occurring, reduce its severity of consequence, or do both, which in turn reduces the final risk rating.

Hazard	Consequence	Risk Level before Mitigation			Mitigation	Risk Level after Mitigation		
		P	C	R		P	C	R
Buried services and obstructions	Electrocution, fire, flooding, abortive work, delays	3	4	12	Review service plans, locate pile locations away from services. CAT and genny scan locations and hand dig to 1.2m.	1	4	4
Unexploded Ordnance	Explosion, delays	3	4	12	UXO desk study to be undertaken, construction UXO risk management plan to be developed, UXO safety and awareness briefings to be carried out	1	4	4
Compressible Langley Silt Formation	Total and differential settlement	3	3	9	Structures are likely to be piled into London Clay Formation; shallow strip footings may be affected, consider raft foundations.	1	2	2
Hard bands in London Clay Formation	Obstruction to driven piling	2	3	6	Review borehole information and local experience of piling. Consider bored or CFA piling methods or use steel driven piles	2	1	2
Aggressive ground conditions	Chemical attack on buried concrete	4	2	8	Assign correct design concrete class or use of steel piles with sacrificial thickness of sections	1	2	2
Excavation below the water table in Lynch Hill Gravel	Instability of temporary excavations	4	4	16	Temporary or permanent retaining structures would require adequate penetration into London Clay to form effective groundwater cut-off	1	4	4
Over-drilling or washout within granular soil layers	Necking of cast in situ concrete piles	3	3	9	Use of driven piles or effective casing of cast-in situ piles into top of London Clay	1	3	3
Basement structures	Alteration of groundwater flow	3	1	3	The terrain and geological horizons are relatively flat hence no adverse consequence of groundwater flow is expected	3	1	3

Table 5-3 Geotechnical risk register

6 Conclusions and Recommendations

Geological profiles do not differ significantly hence a unique soil model as per Table 3-1 can be adopted for the design of piled foundations and deep basements.

Weathered London Clay is relatively thin at the site hence it will not influence the design of foundations significantly. London Clay proper is considered to be the main founding layer. This stratum is in excess of 35m thick at the location, hence it can be assumed that proposed piled foundation will be terminating in this layer. Due to absence of visible traces of pyrite and its low permeability London Clay should not present particular aggressive environment for reinforced concrete and the highest design class from overlying strata should be assumed for the design.

6.1 Piles

Piles into the London Clay are the preferred foundation for the Hyde Park, Hayes development. The London Clay is a firm to stiff clay and should provide adequate bearing capacity provided the piles are of sufficient length to give enough skin friction. Detailed pile design is outside the scope of this report.

To fully assess risks to the preferred piling foundations the risk assessment presented in Appendix C has been developed to cover relevant findings of the contamination site investigation carried out by SKM Enviro Ltd. The initial environmental and contamination site investigation revealed some volatile organic contaminants in the form of chlorinated hydrocarbons within the fine-grained London Clay formation as reported in the SKM Enviro report (ref 9). Further contamination investigation, also by SKM Enviro, revealed the same contaminant within the granular Lynch Hill Gravel formation overlying London Clay (ref 10). It is believed that the contamination must have originated from overlying Lynch Hill Gravel formation as London Clay is comparatively impervious.

The risk to human health due to contamination of aquifers by construction of piled foundation was assessed and it was concluded that situation will not be worsened as no new receptors will be affected. That is to say that the geological formation where it is perceived that piled foundations will terminate, London Clay, is already contaminated, together with the overlying Lynch Hill Gravel.

Similarly the risk posed by increased release of vinyl chloride (VC) or other vapours is considered negligible as adhesion of the fine grained London Clay to piles would prevent formation of a pathway.

VC vapours from Lynch Hill Gravel are relatively free to migrate as overlying strata are relatively permeable, and therefore do not pose a barrier in the current situation. Therefore piling would not worsen the situation.

6.2 Retaining Walls

Retaining walls will most likely be using imported free draining granular backfill materials. Underground basements construction within the Lynch Hill Gravel Member may require the installation of an appropriate cut off wall and/or dewatering measures.

6.3 Recommendations

The information contained herein should provide adequate information for foundation design at the Hyde Park, Hayes development. Should the design change a review of the data and potentially additional ground investigation data may be required.

7 References

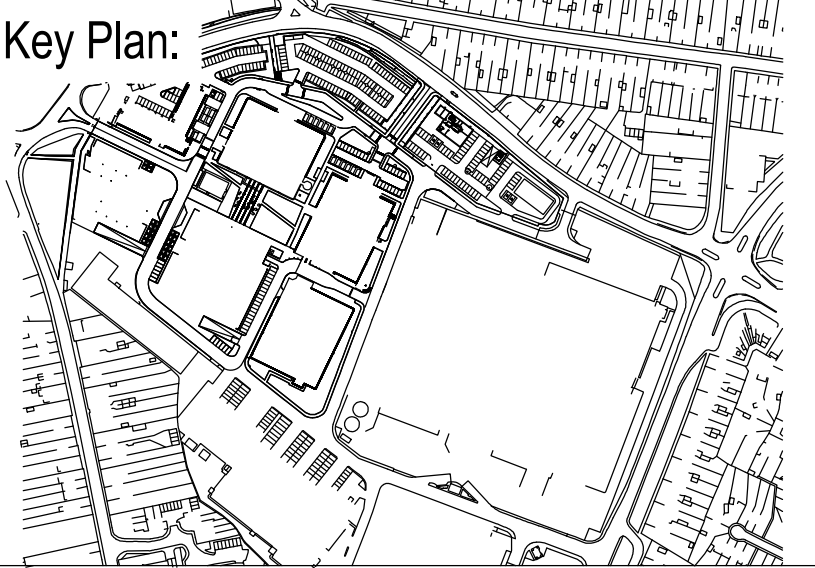
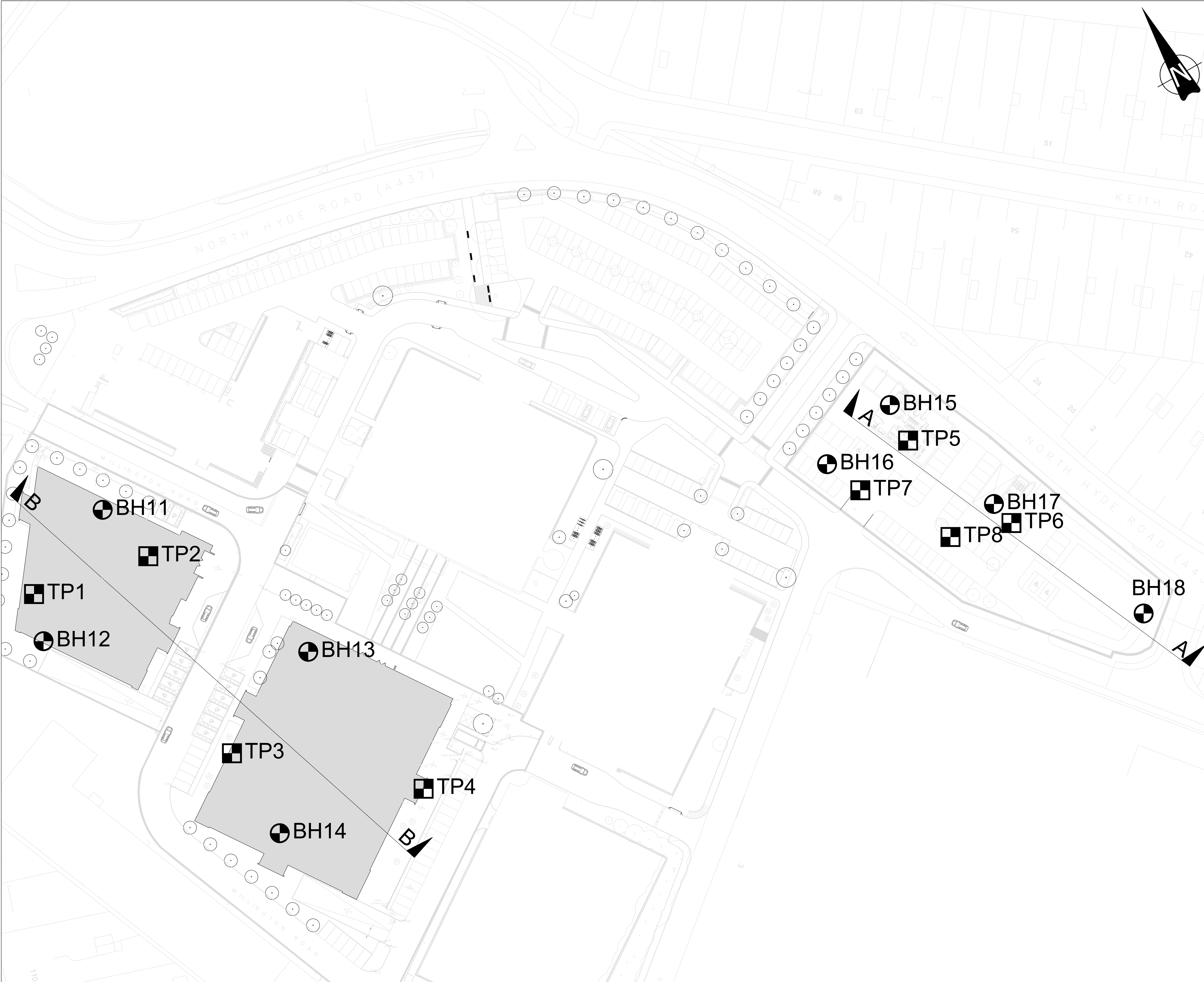
1. British Research Establishment (2005). Special Digest 1 Third Edition. Concrete in aggressive ground.
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8. Padfield CJ and Mair RJ, 1984. Design of Retaining Walls Embedded in Stiff Clays, CIRIA Report 104, Construction Industry Research Information Association
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11. Environment Agency (2001). Piling and penetrative ground improvement methods on land affected by contamination: guidance on pollution prevention.
12. Environment Agency (2006). Piling in layered ground: risks to groundwater and archaeology.

Appendix A	Drawings
Appendix B	Parameter Figures
Appendix C	Piling Risk Assessment



Appendix A

Appendix A Drawings



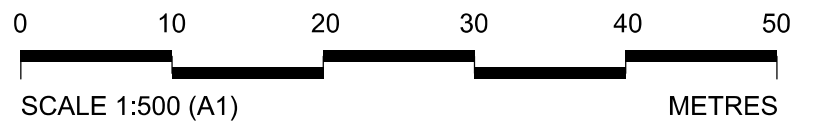
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 2. ALL DIMENSIONS IN METRES UNLESS OTHERWISE NOTED.

Key:

A

A

SECTION LINE
(FOR SECTIONS SEE DRG. NOS.
110475-HPH-3DR 00-DR-C-1001 & 1002)



2	MJY	TS	SMCM	12.03.13	FINAL ISSUE
1	MJY	DB	SMCM	26.02.13	FIRST ISSUE
Rev	By	Chkd	Apprtd	Date	Description

Client

HPHA Ltd.

3DReid

West End House
11 Telford Place
London
W1F 7SE
T: +44 (0)20 7297 5600
F: +44 (0)20 7297 5601
W: www.3DReid.com

Birmingham
Edinburgh
Glasgow
London
Manchester

3D
REID

Halcrow Group Limited

5th Floor 3 Shoreditch Hammersmith London W6 8DA
tel +44 (0)20 8233 3800 fax +44 (0)20 8233 3801
halcrow.com

Halcrow Yolles

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HYDE PARK HAYES

Drawing

EXPLORATORY HOLE
LOCATION PLAN

Drawn by: MJY

Checked by: TS

Approved by: SMCM

Drawing No.
110475-HPH-3DR-00-DR-C-1000

Date: MAR 2013

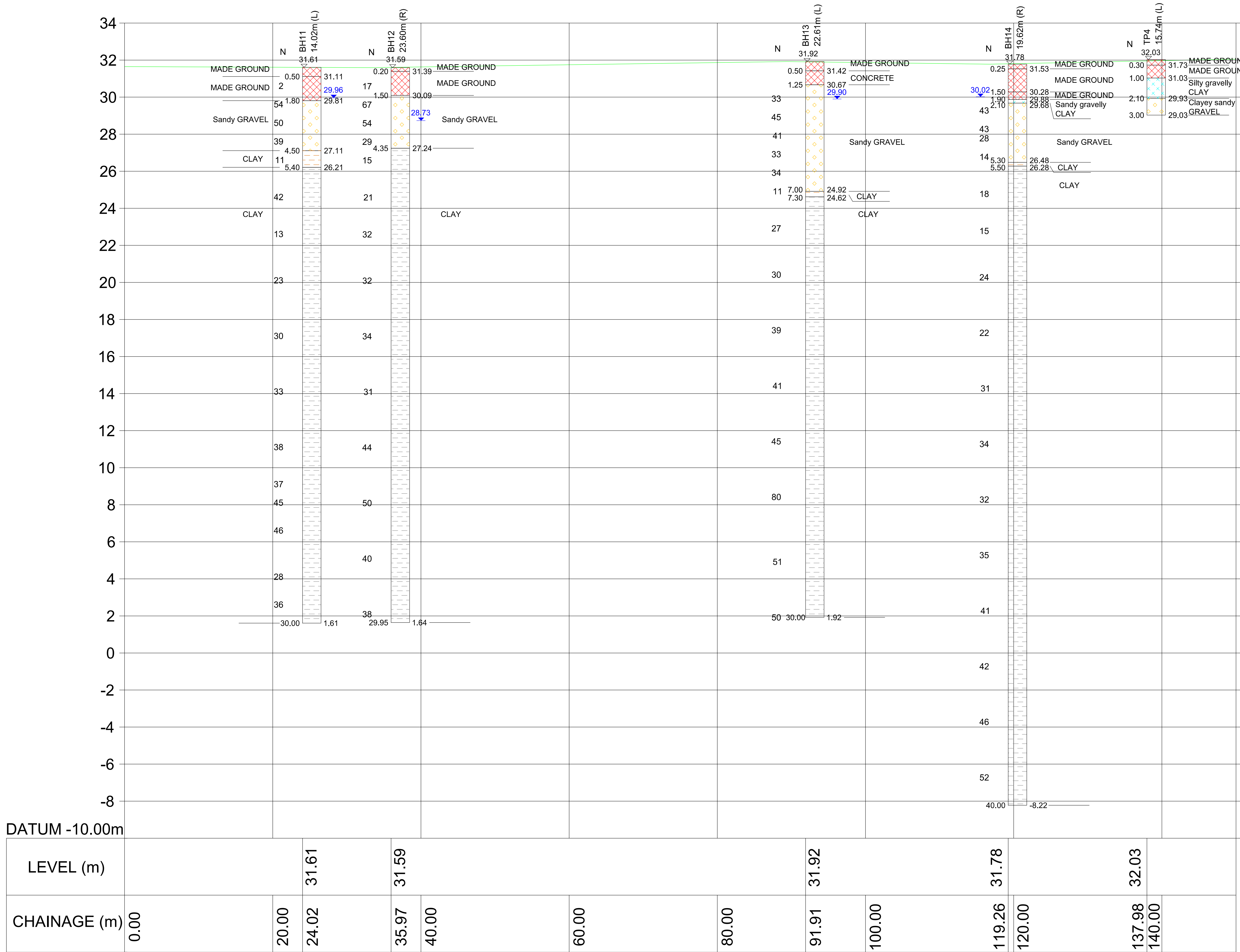
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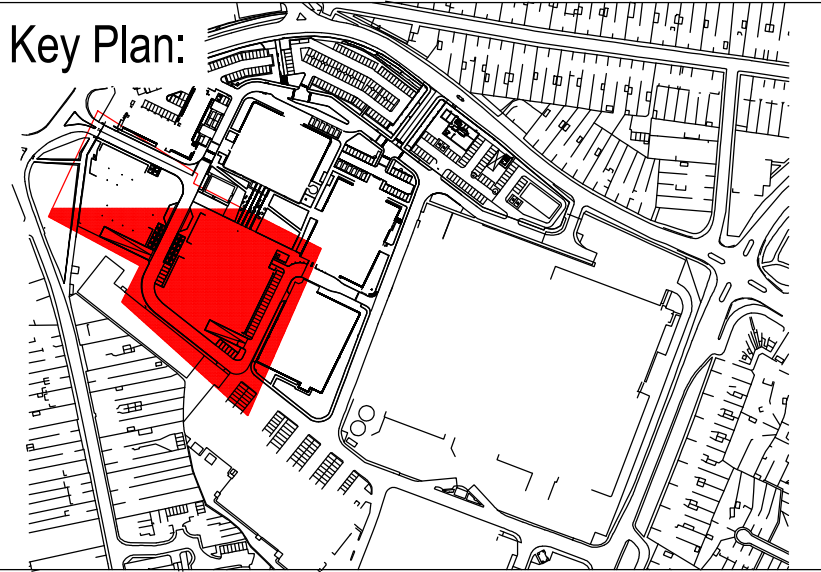
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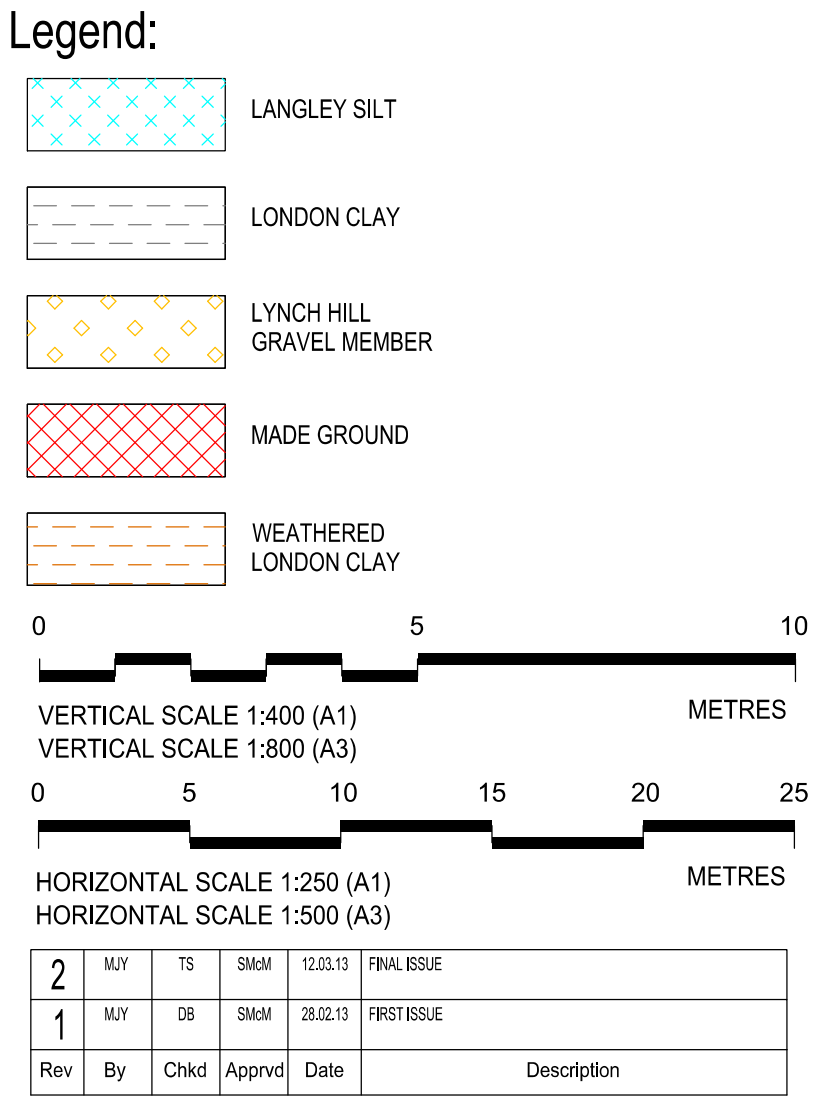
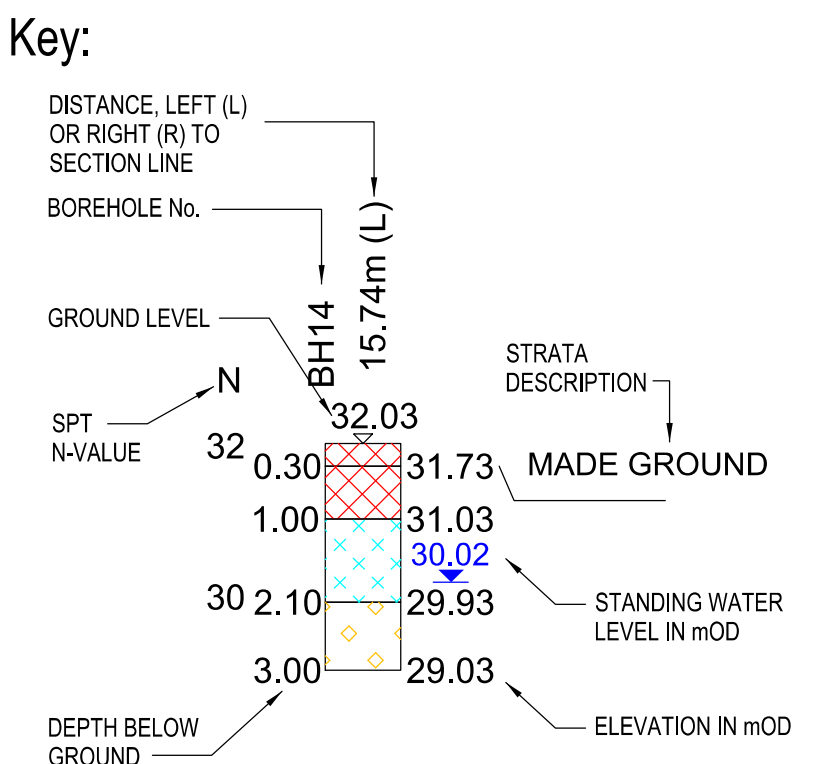
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SECTION A - A



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Client

HPHA Ltd.

3DReid
West End House
11 Little Piece
London
W1F 7SE
T: +44 (0)20 7297 5600
F: +44 (0)20 7297 5601
W: www.3DReid.com

Halcrow Group Limited
5th Floor 3 Shoreditch Hammersmith London W6 8DA
tel +44 (0)20 8233 3800 fax +44 (0)20 8233 3801
halcrow.com

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Drawing

HPH 4 & 5 HPH 6
GEOLOGICAL CROSS-SECTION

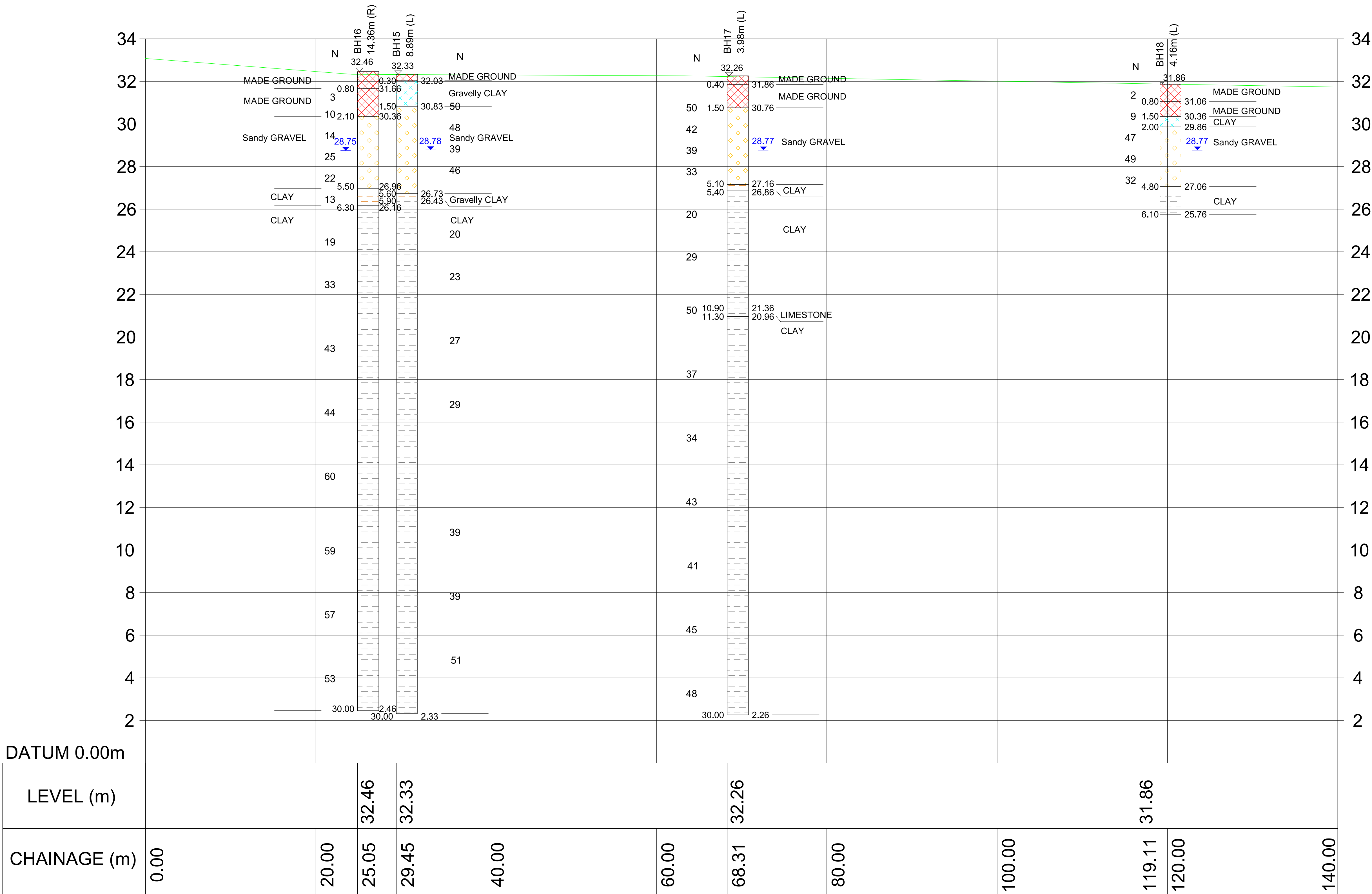
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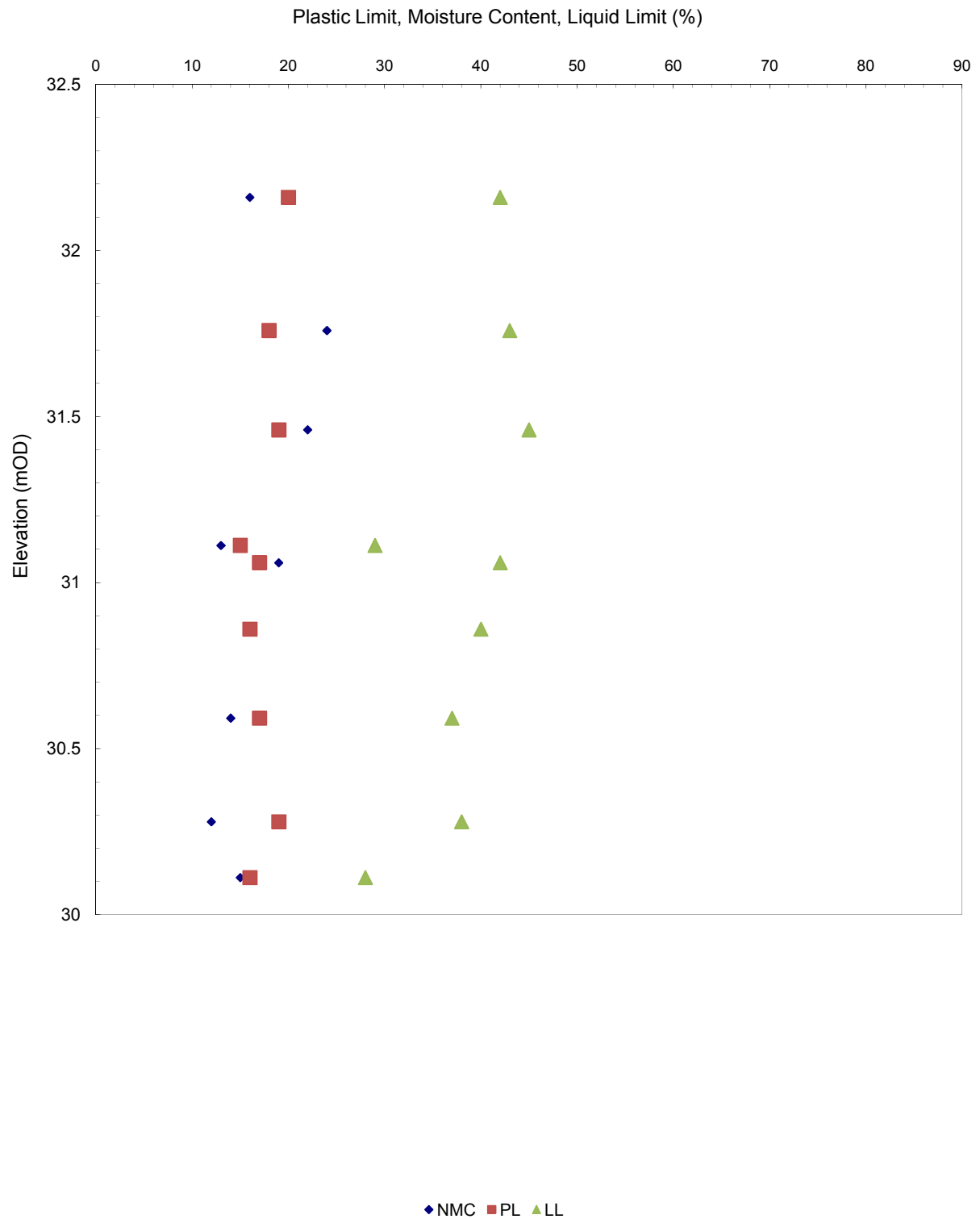
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Appendix B

Appendix B Parameter Figures



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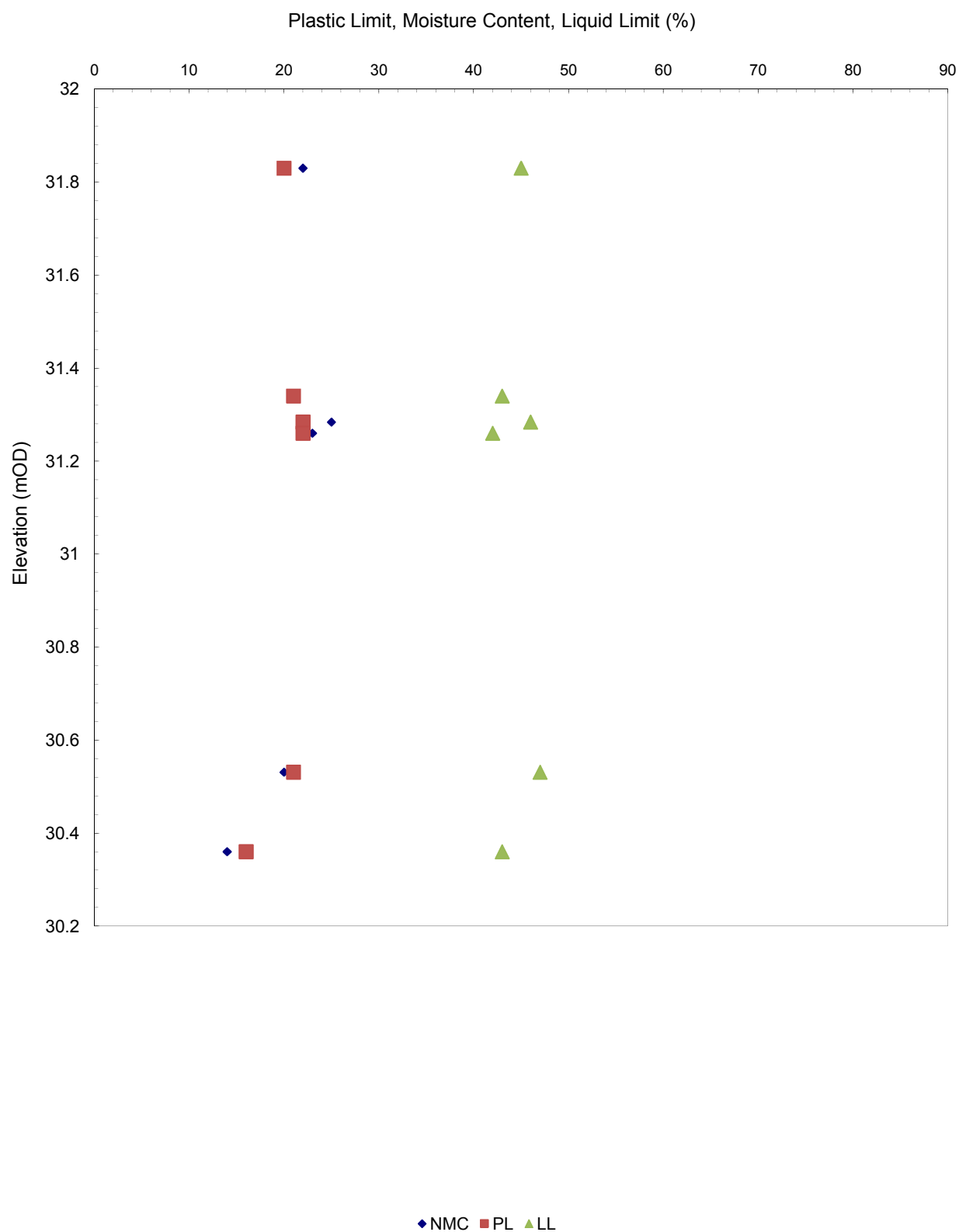
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**PLASTICITY DATA vs. ELEVATION
MADE GROUND**

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Figure No.: 1



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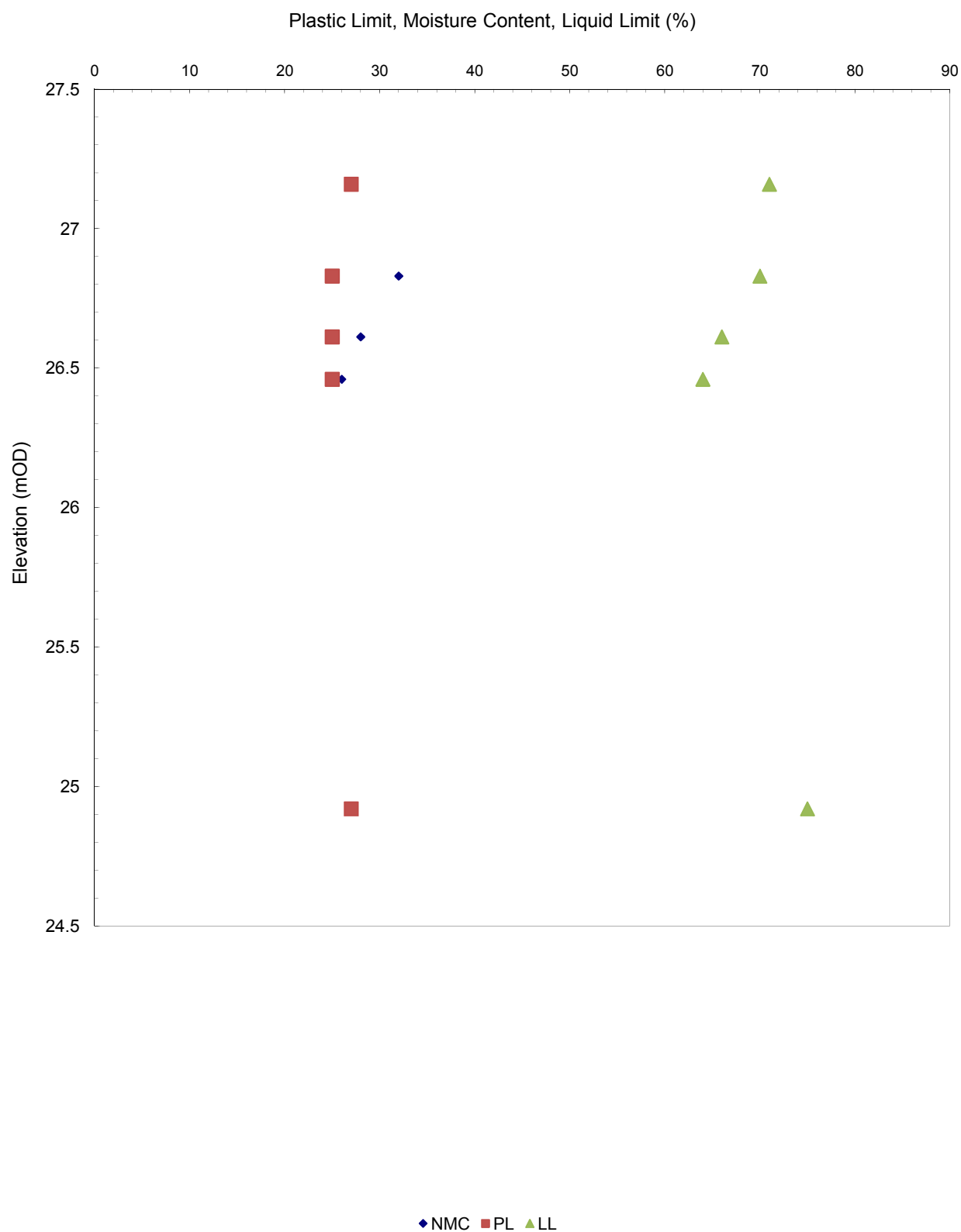
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PLASTICITY DATA vs. ELEVATION
LANGLEY SILT

Report No.: GIB016-GEO-RPT-001

Figure No.: 2



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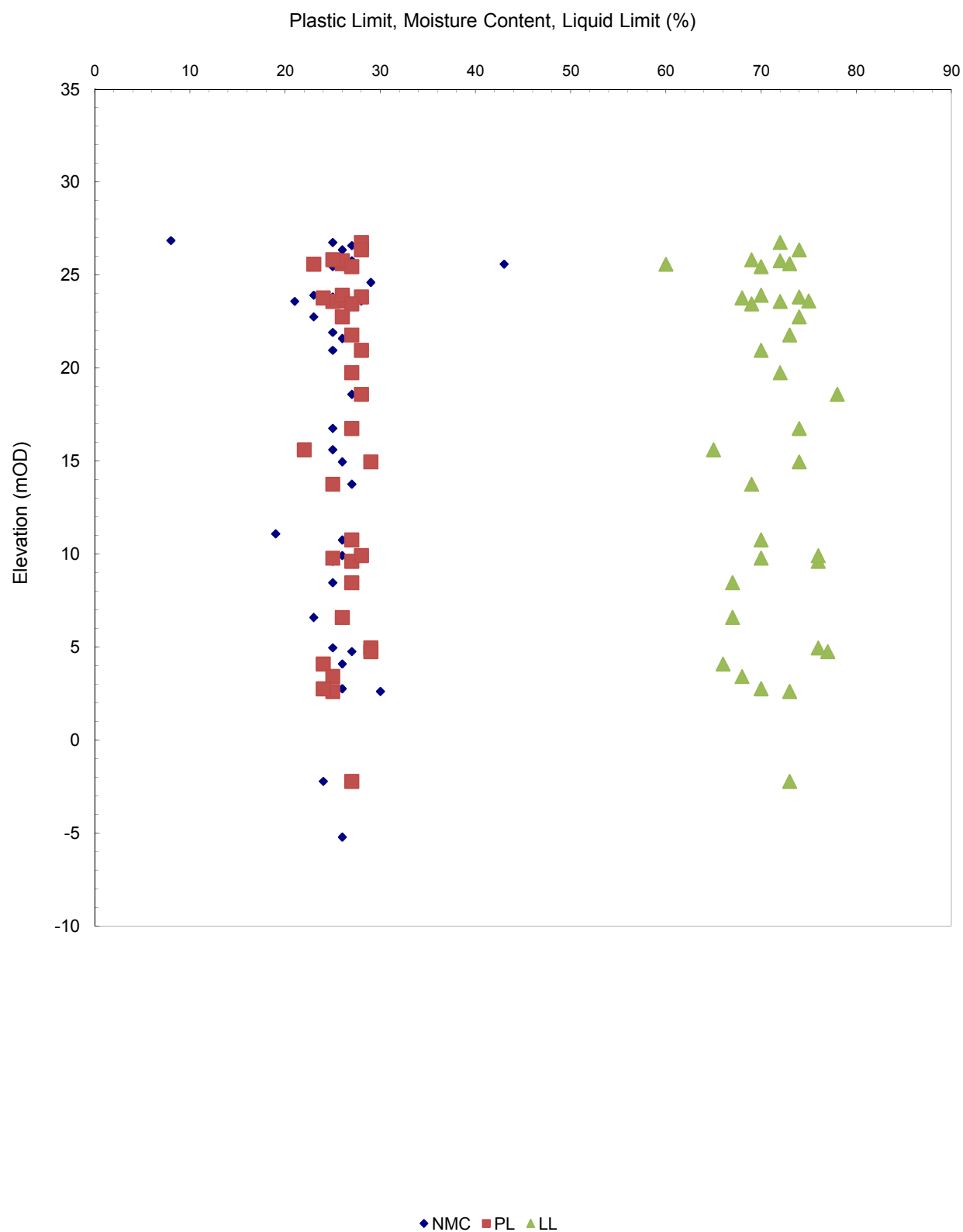
Hyde Park, Hayes

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PLASTICITY DATA vs. ELEVATION
WEATHERED LONDON CLAY

Report No.: GIB016-GEO-RPT-001

Figure No.: 3



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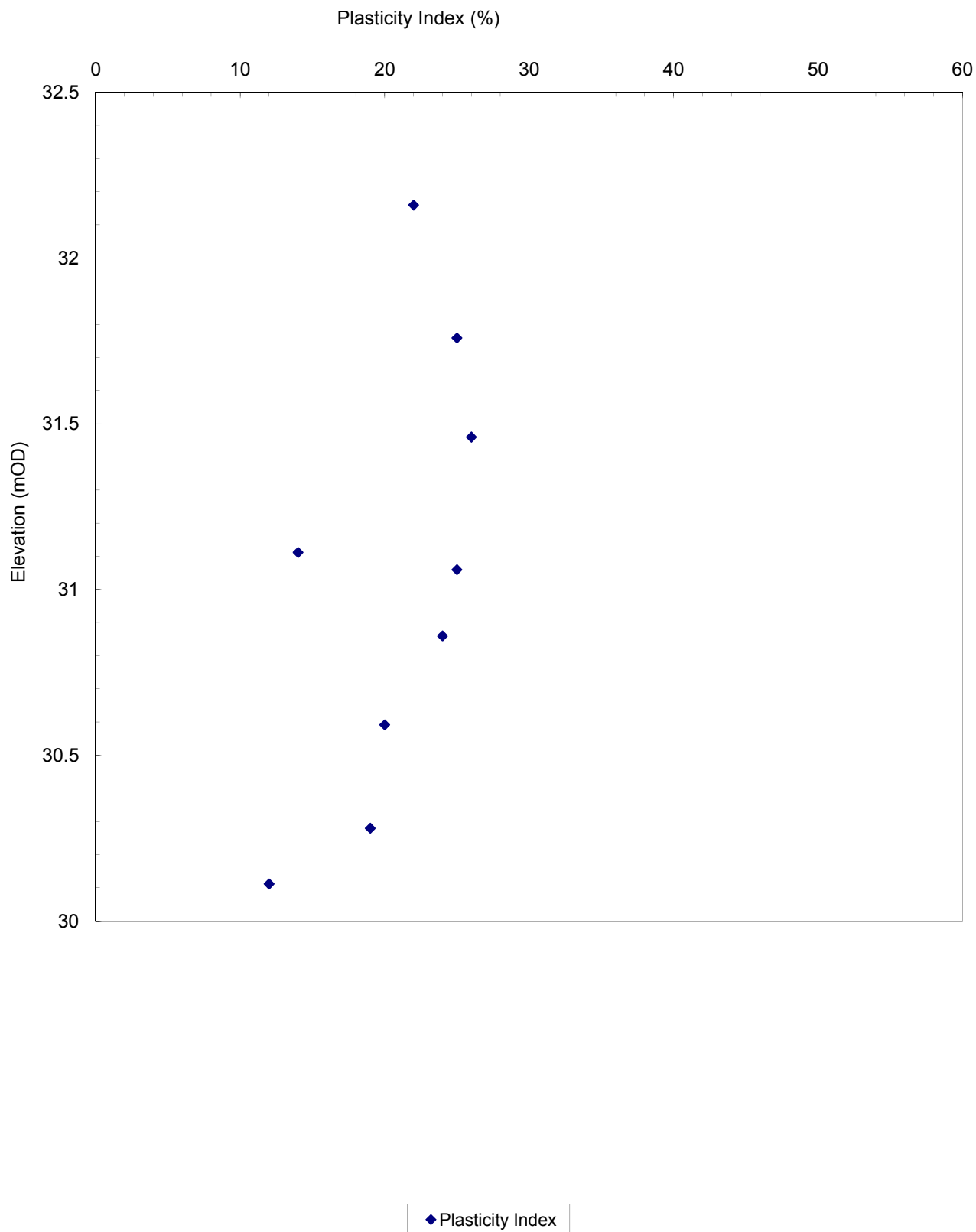
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PLASTICITY DATA vs. ELEVATION
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Report No.: GIB016-GEO-RPT-001

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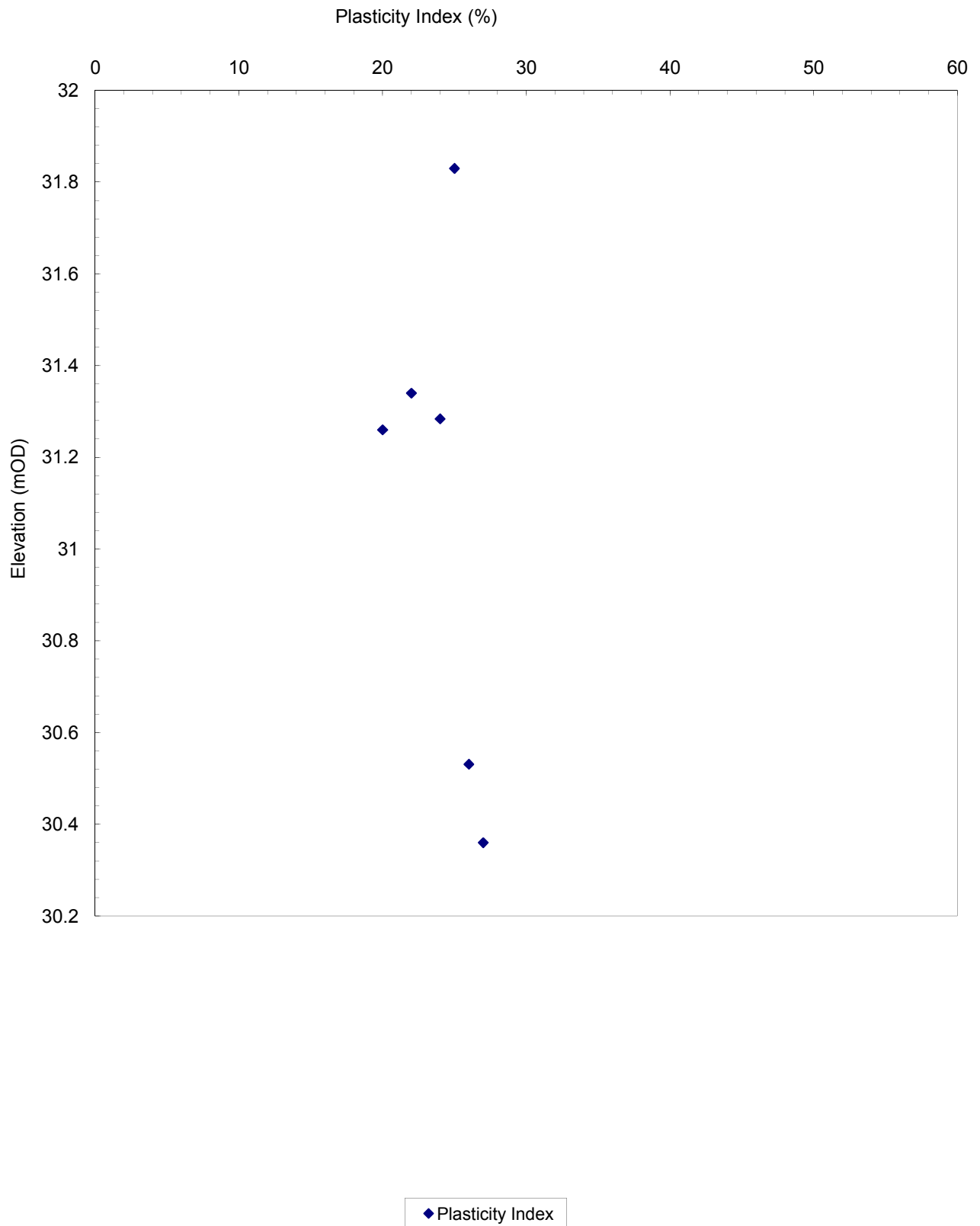
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PLASTICITY INDEX vs. ELEVATION
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Report No.: GIB016-GEO-RPT-001

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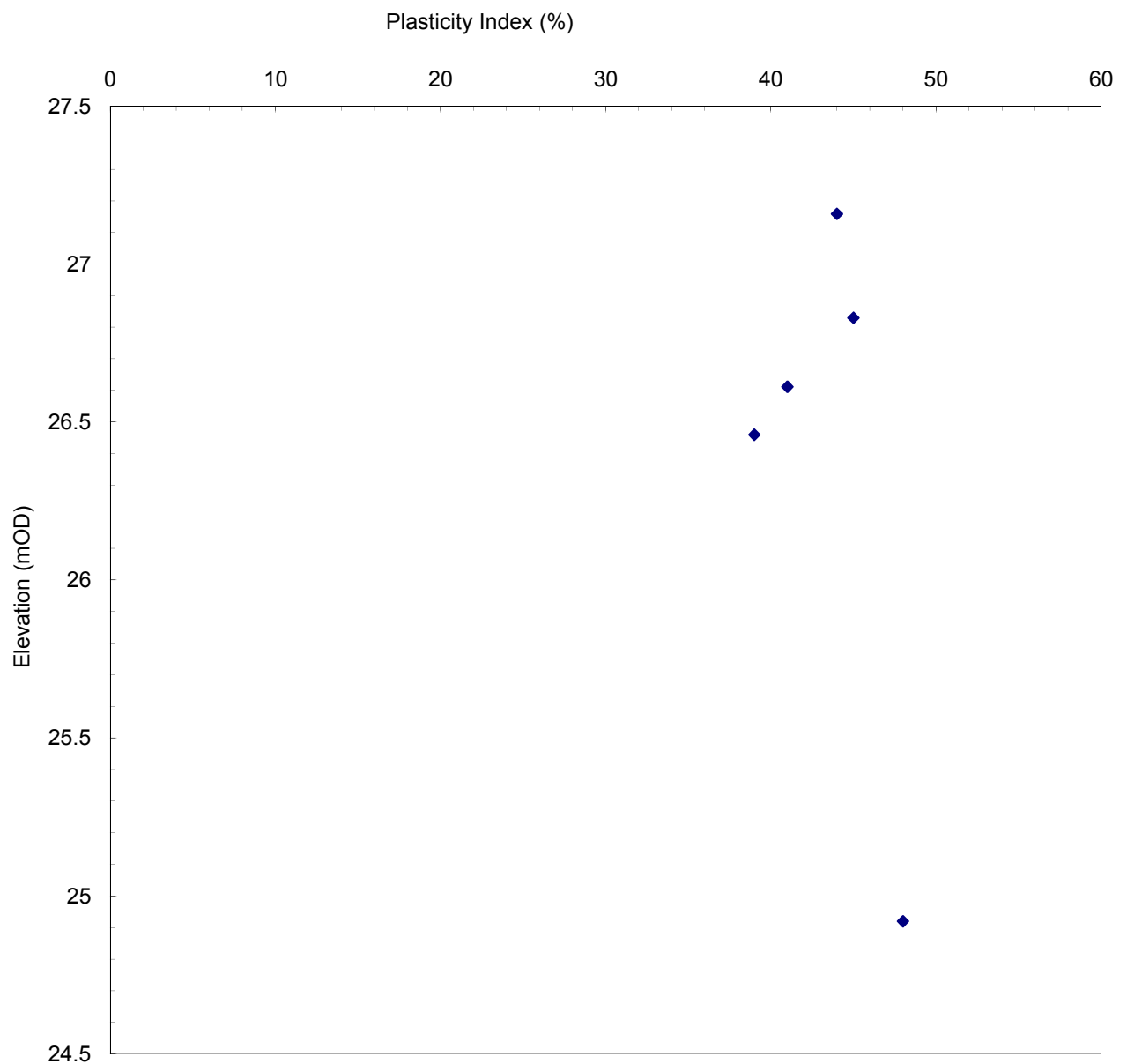
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PLASTICITY INDEX vs. ELEVATION
LANGLEY SILT

Report No.: GIB016-GEO-RPT-001

Figure No.: 6



◆ Plasticity Index

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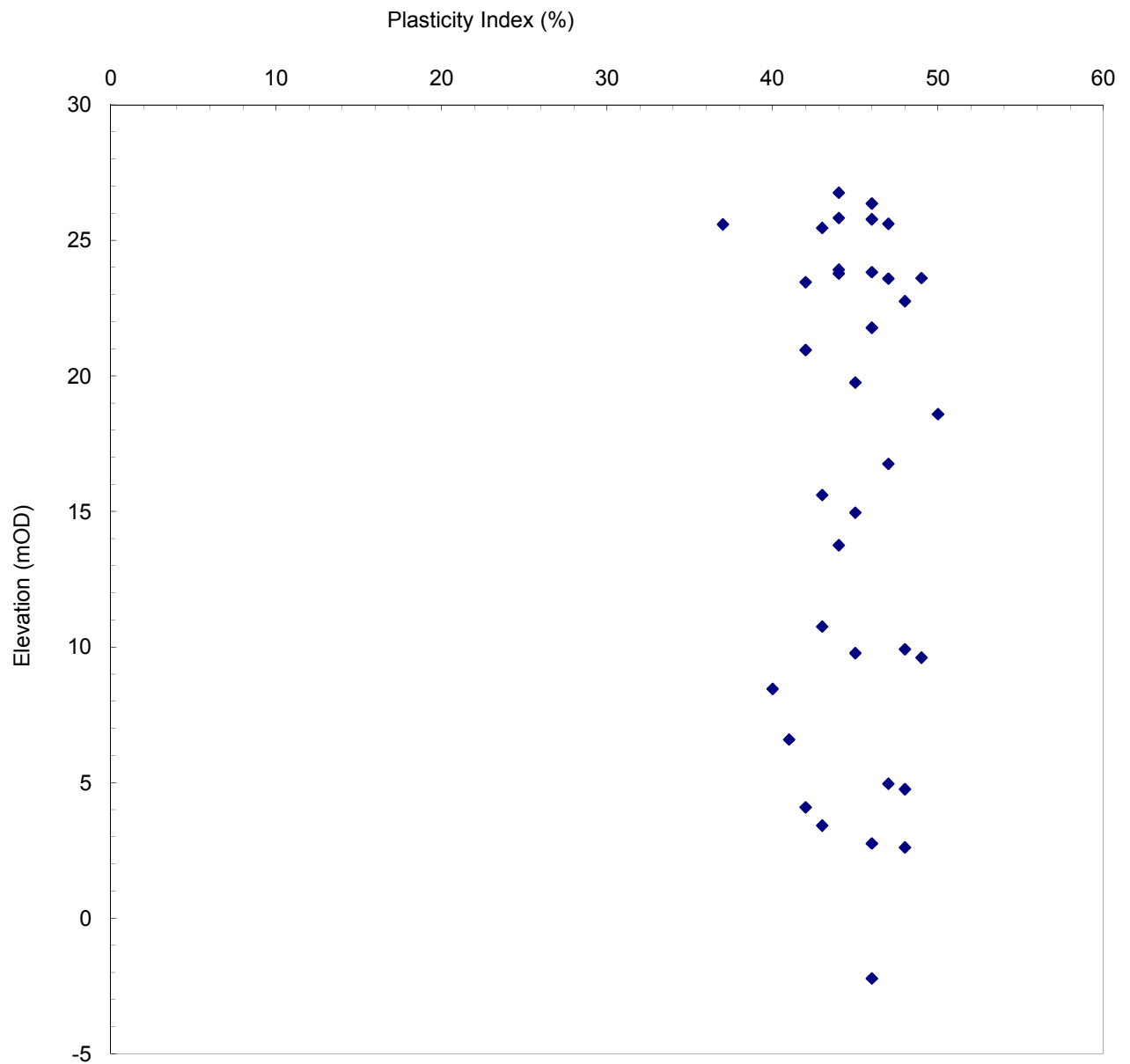
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**PLASTICITY INDEX vs. ELEVATION
WEATHERED LONDON CLAY**

Report No.: GIB016-GEO-RPT-001

Figure No.: 7



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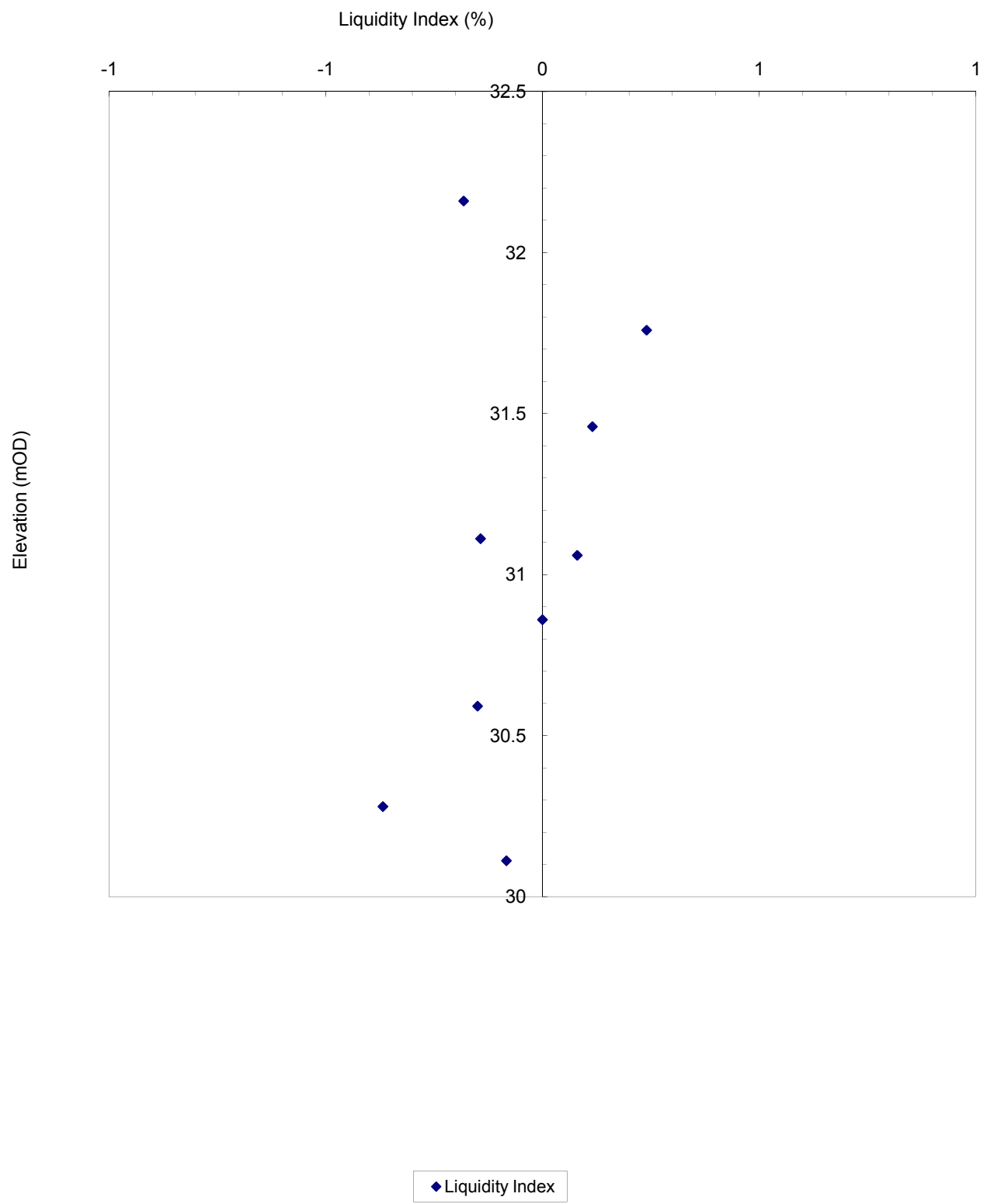
Hyde Park, Hayes

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PLASTICITY INDEX vs. ELEVATION
LONDON CLAY

Report No.: GIB016-GEO-RPT-001

Figure No.: 8



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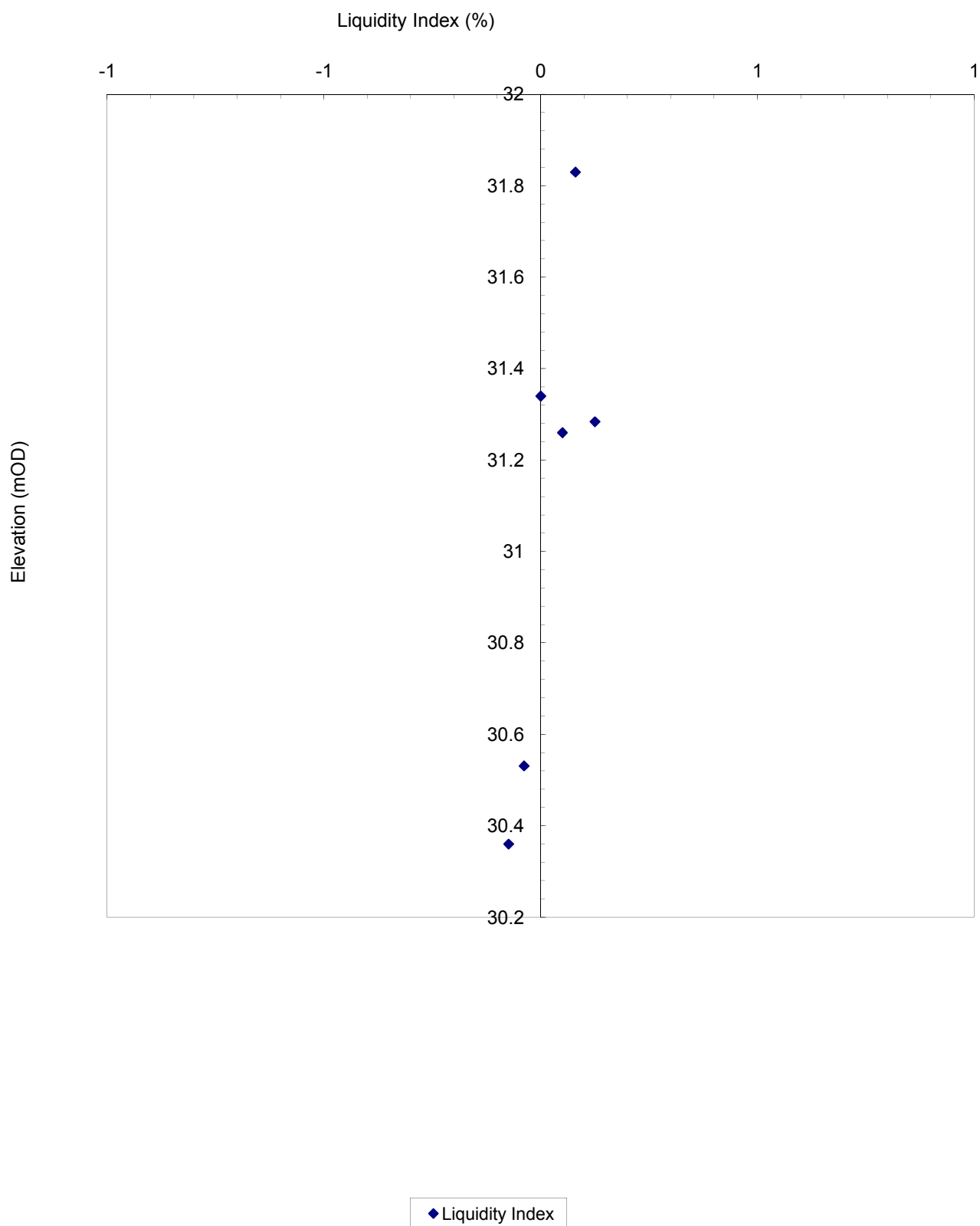
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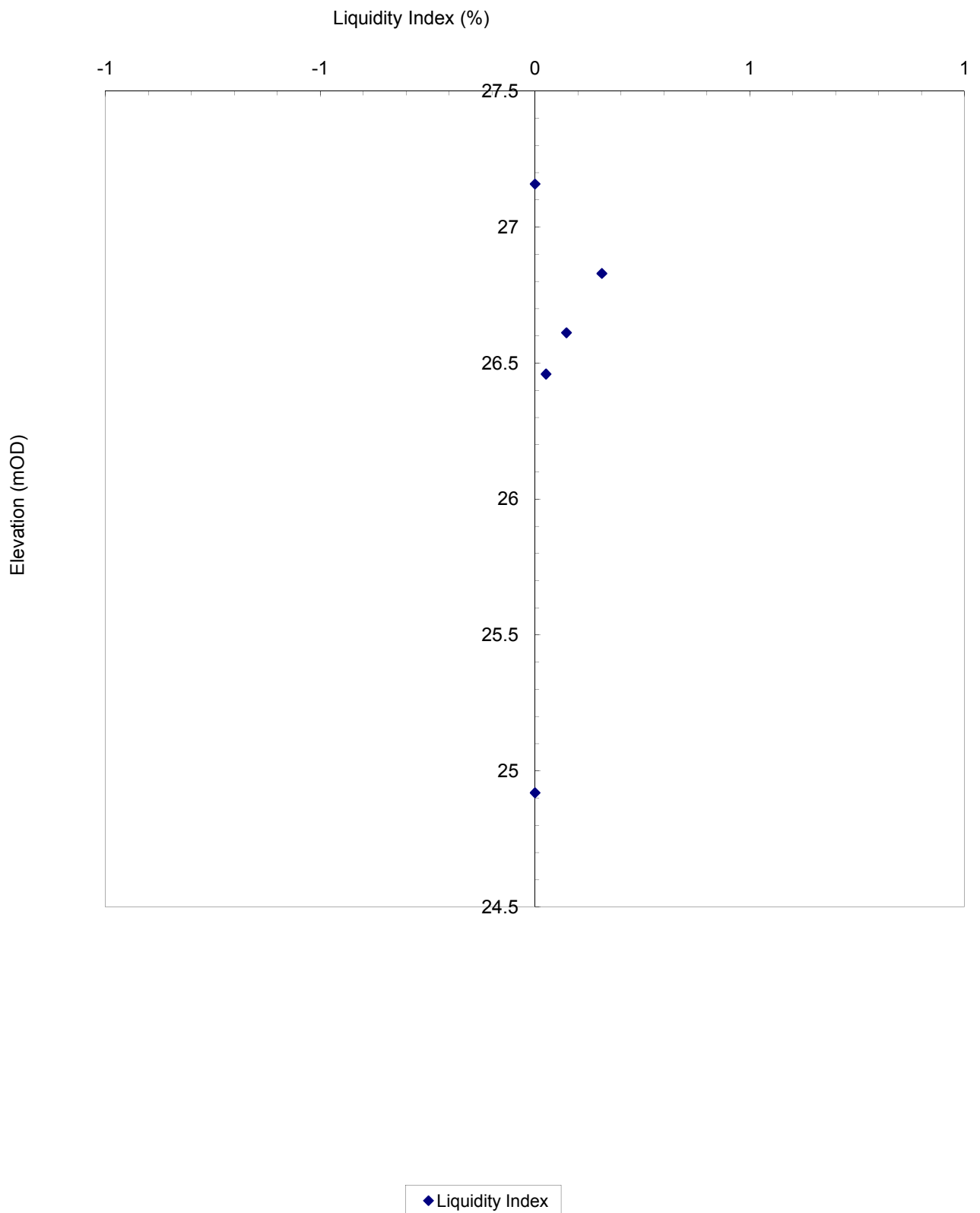
**LIQUIDITY INDEX vs. ELEVATION
MADE GROUND**

Report No.: GIB016-GEO-RPT-001

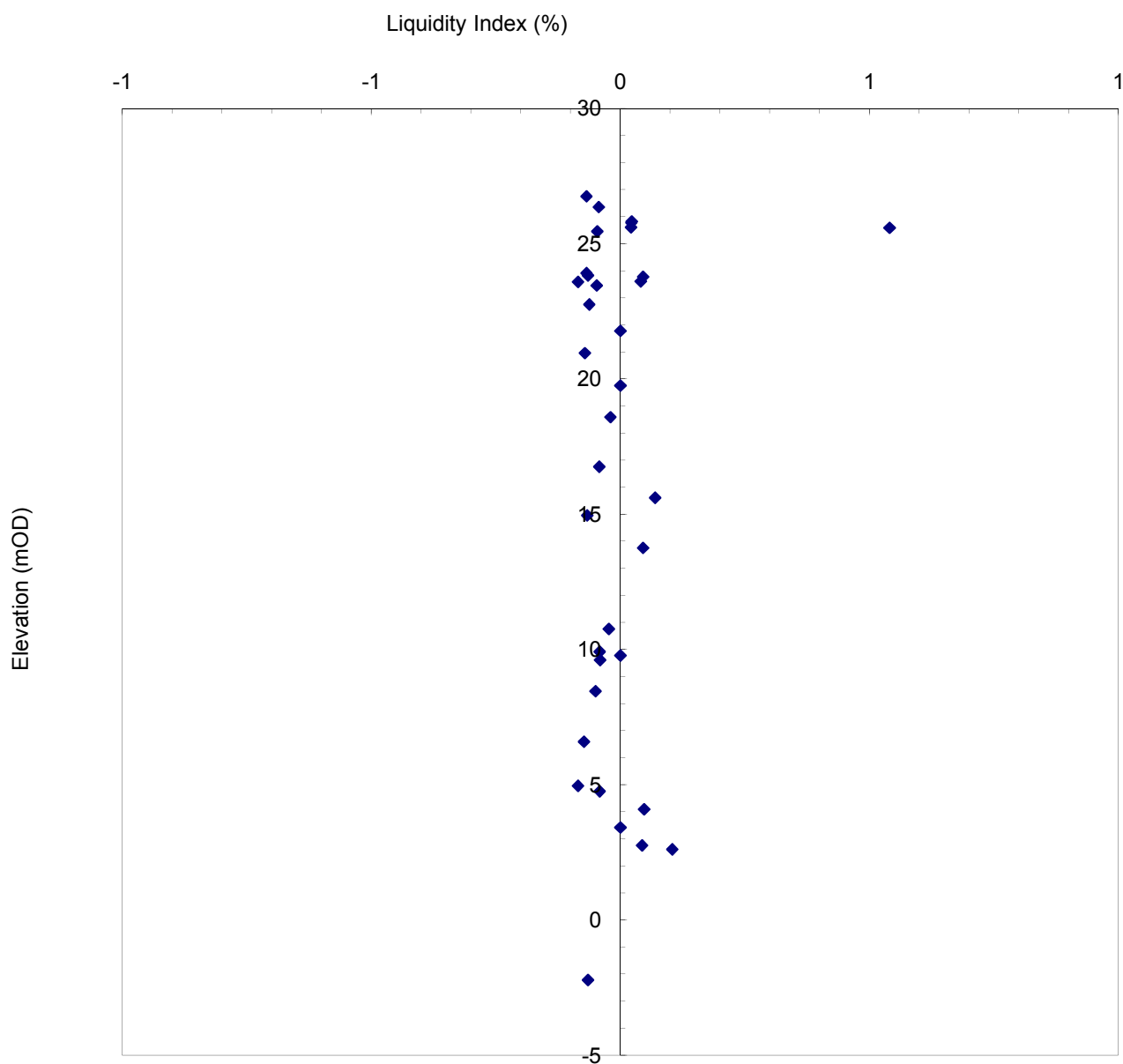
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HPHA	Hyde Park, Hayes	<i>Halcrow</i>
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◆ Liquidity Index

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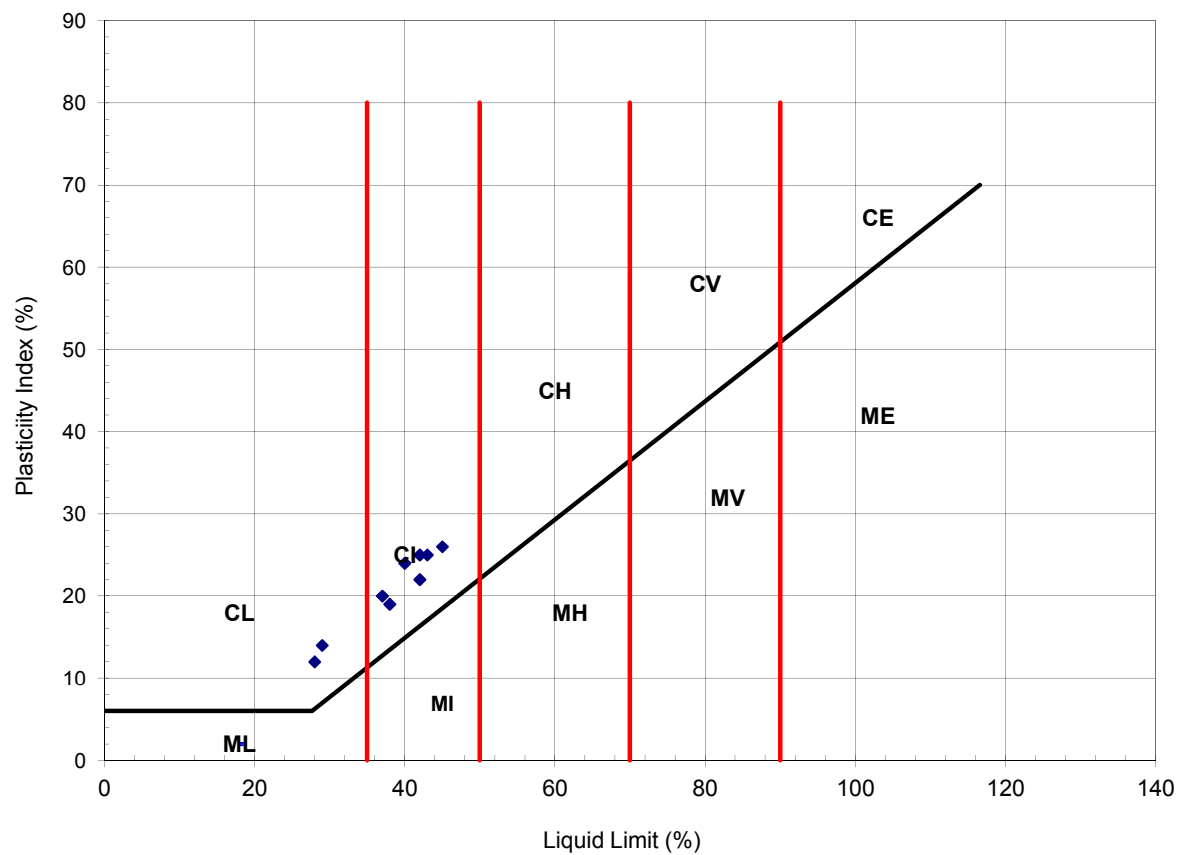
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LIQUIDITY INDEX vs. ELEVATION
LONDON CLAY

Report No.: GIB016-GEO-RPT-001

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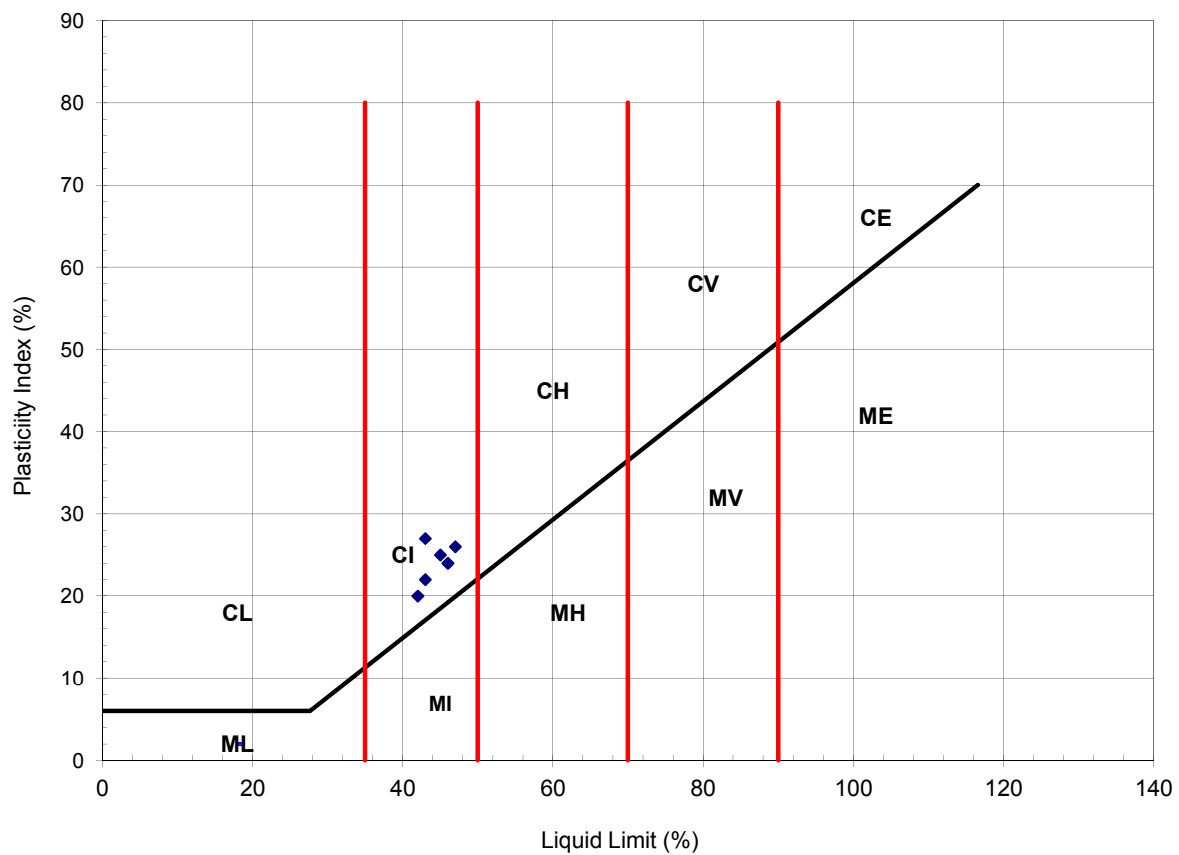
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**PLASTICITY CHART (LIQUID LIMIT versus PLASTICITY INDEX)
MADE GROUND**

Report No.: GIB016-GEO-RPT-001

Figure No.: 13



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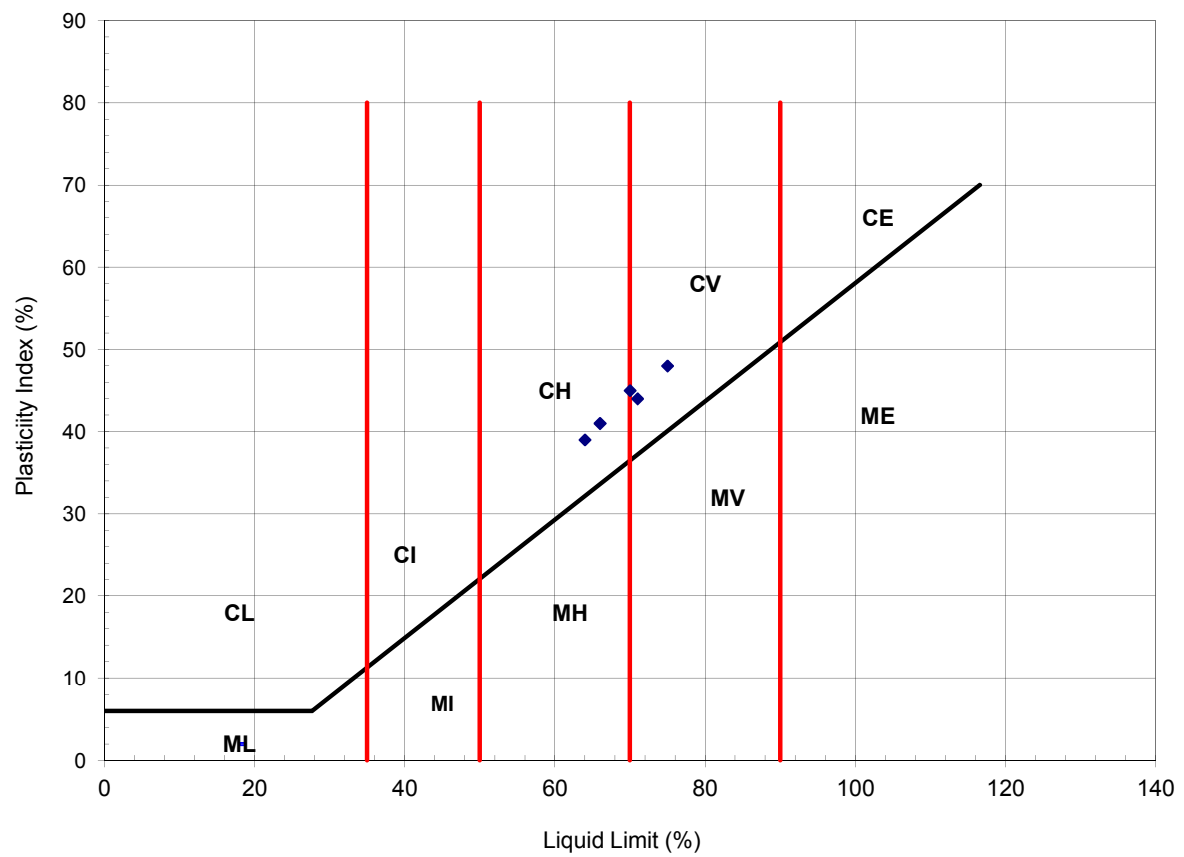
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**PLASTICITY CHART (LIQUID LIMIT versus PLASTICITY INDEX)
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Report No.: GIB016-GEO-RPT-001

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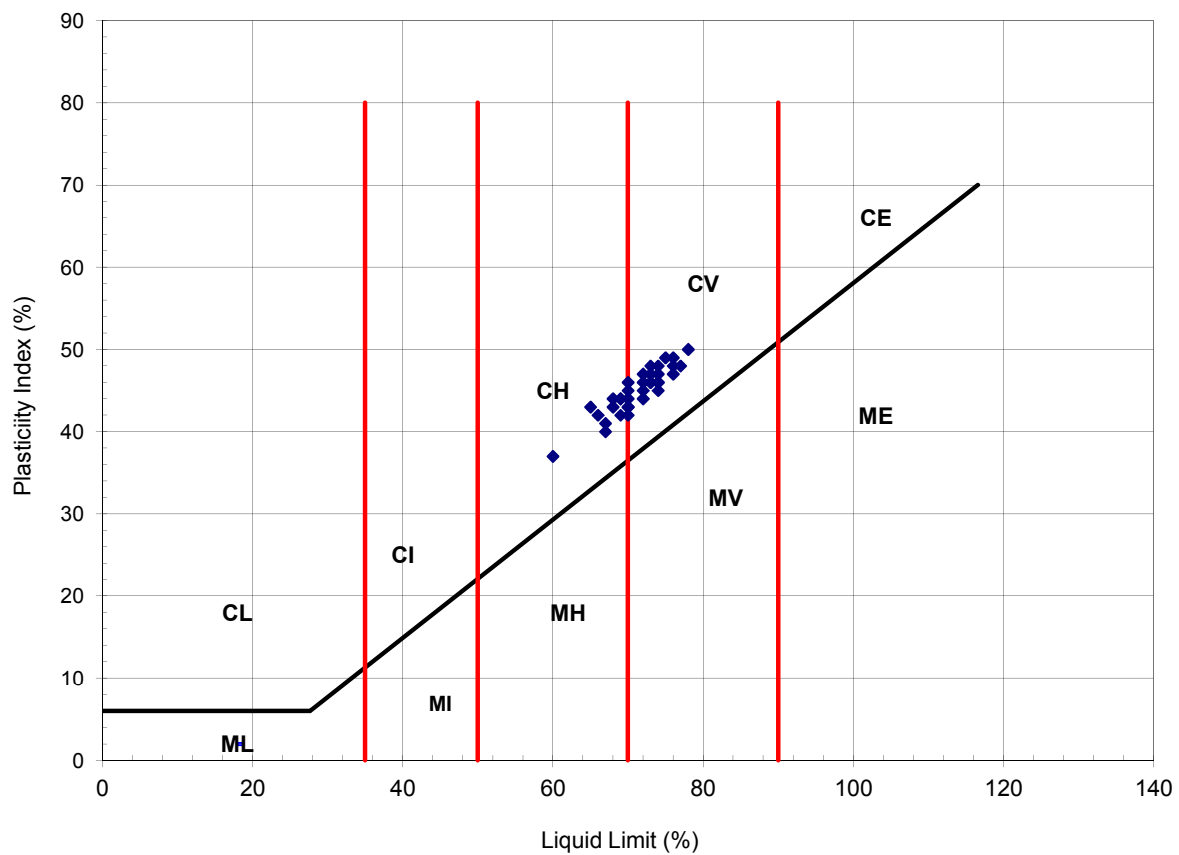
Hyde Park, Hayes

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**PLASTICITY CHART (LIQUID LIMIT versus PLASTICITY INDEX)
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Report No.: GIB016-GEO-RPT-001

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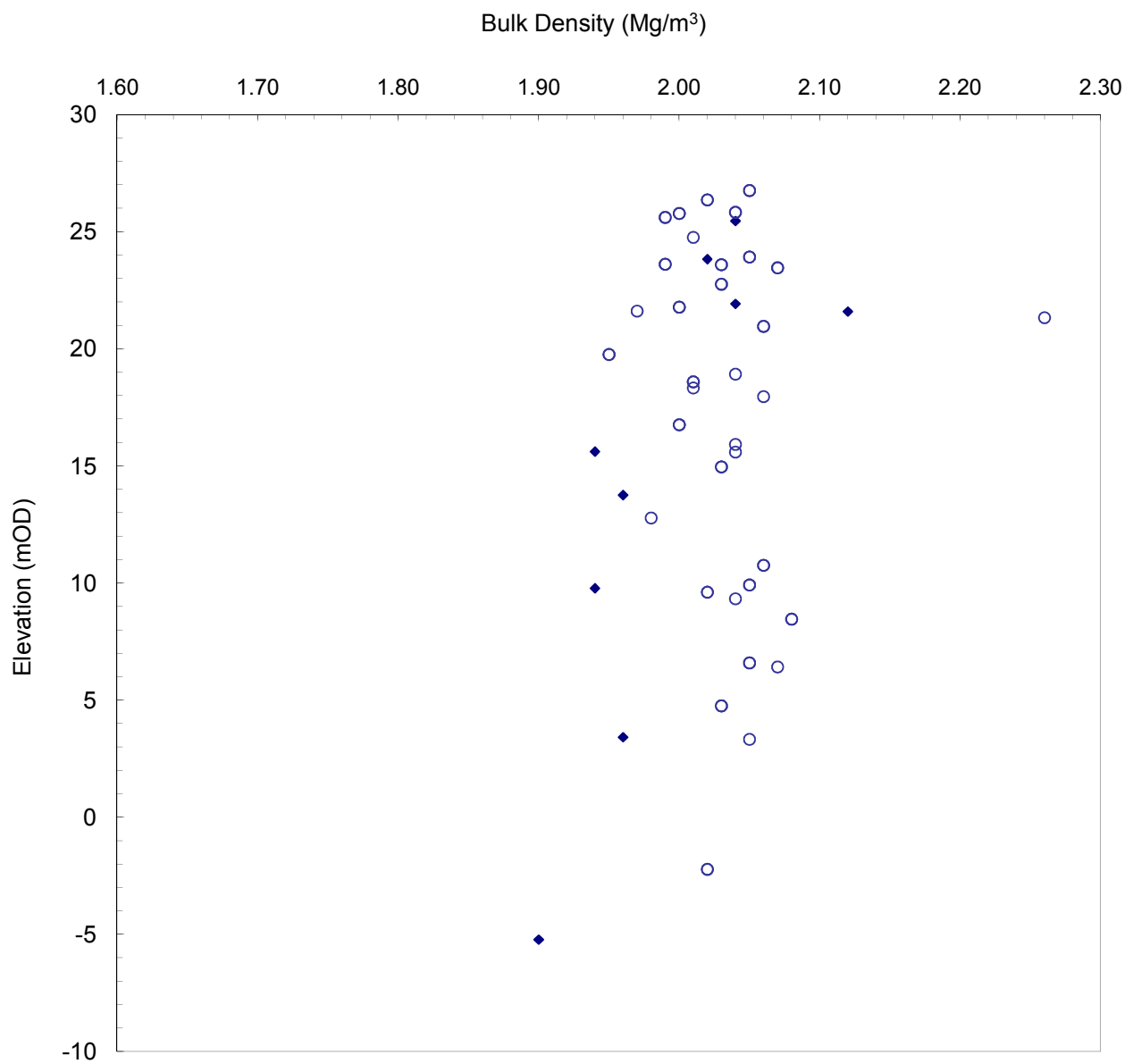
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**PLASTICITY CHART (LIQUID LIMIT versus PLASTICITY INDEX)
LONDON CLAY**

Report No.: GIB016-GEO-RPT-001

Figure No.: 16



◆ Classification Tests ○ Triaxial Tests

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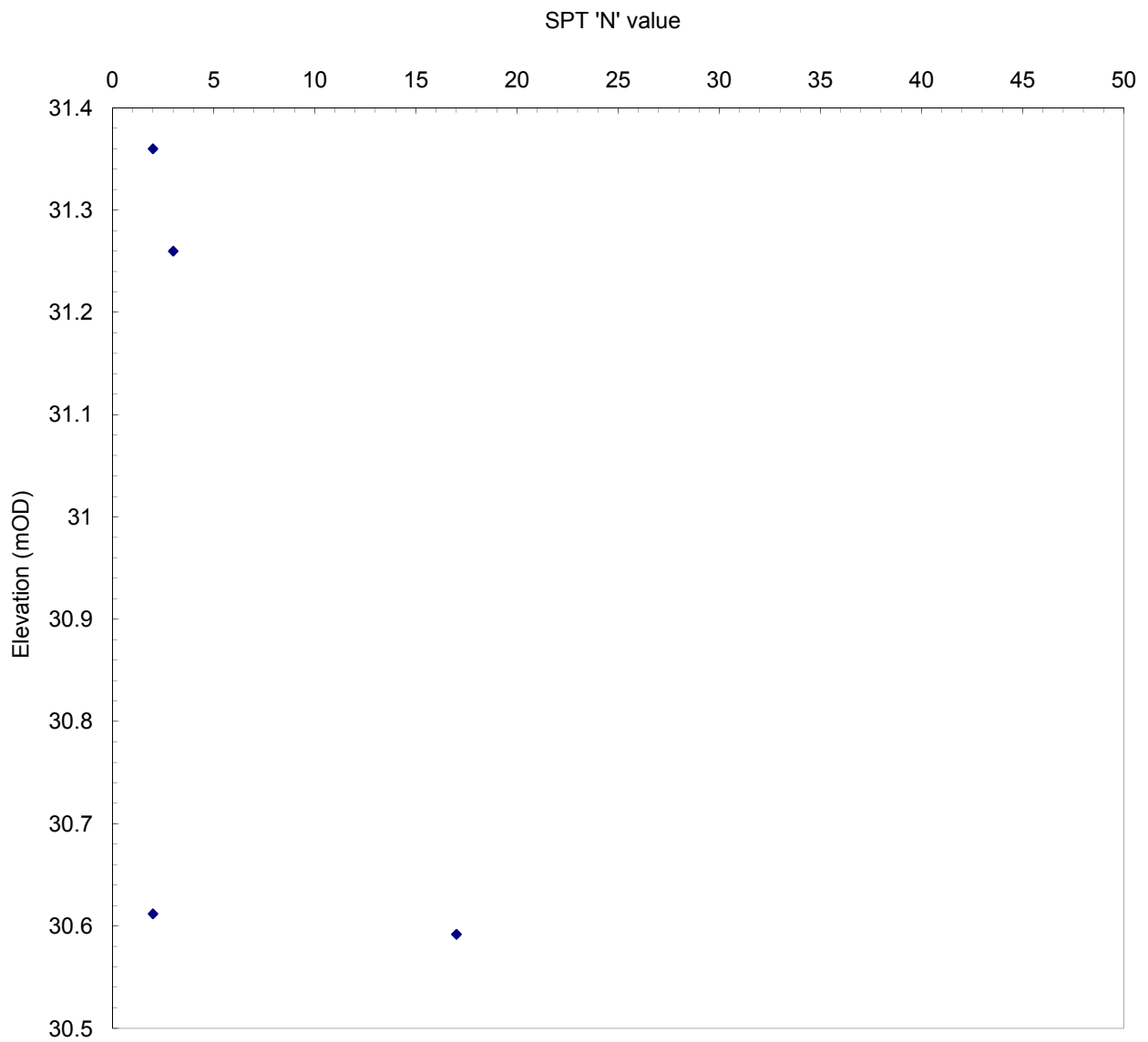
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**BULK DENSITY vs. ELEVATION
LONDON CLAY**

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Figure No.: 17



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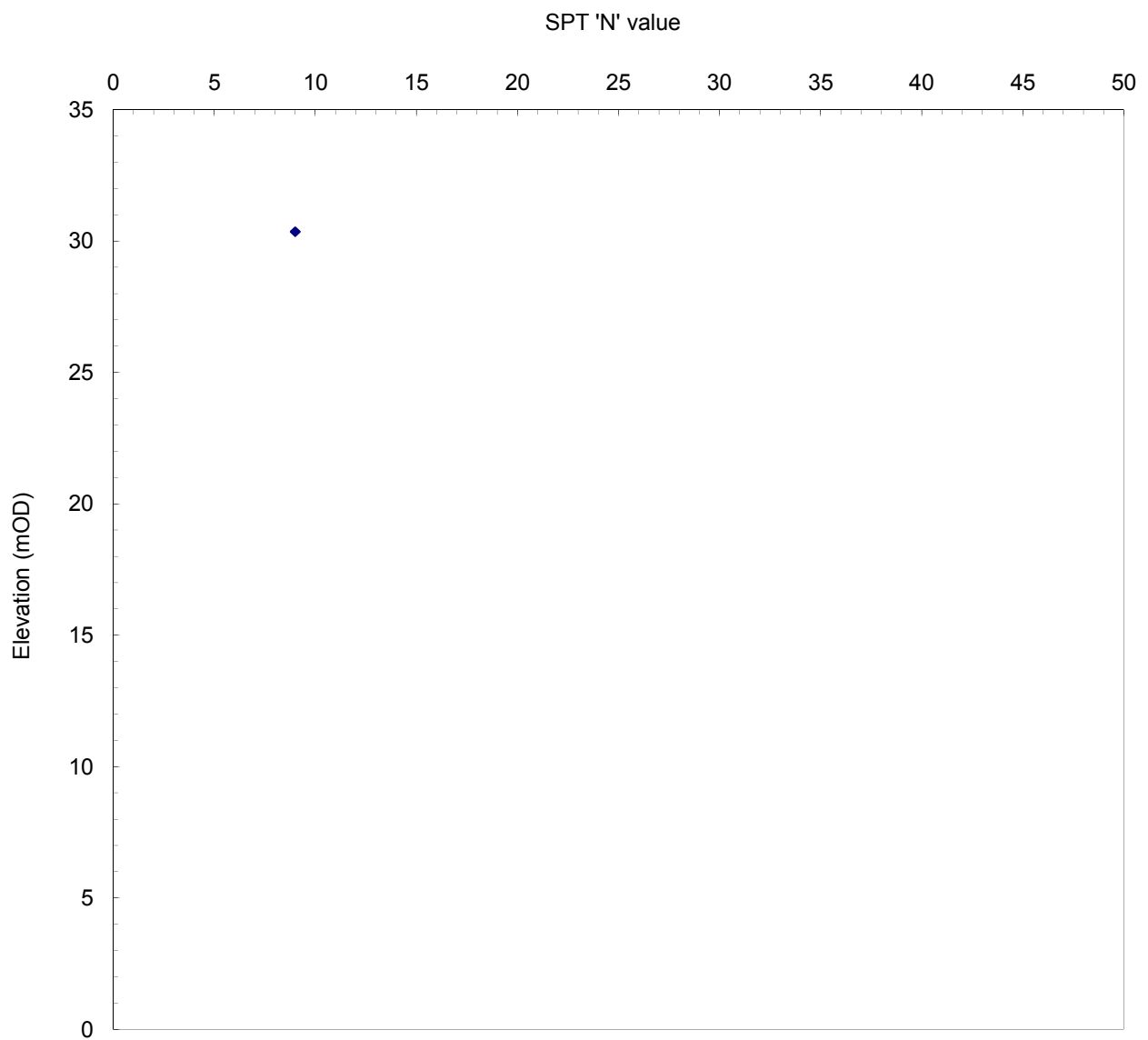
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**SPT 'N' VALUES vs. ELEVATION
MADE GROUND**

Report No.: GIB016-GEO-RPT-001

Figure No.: 18



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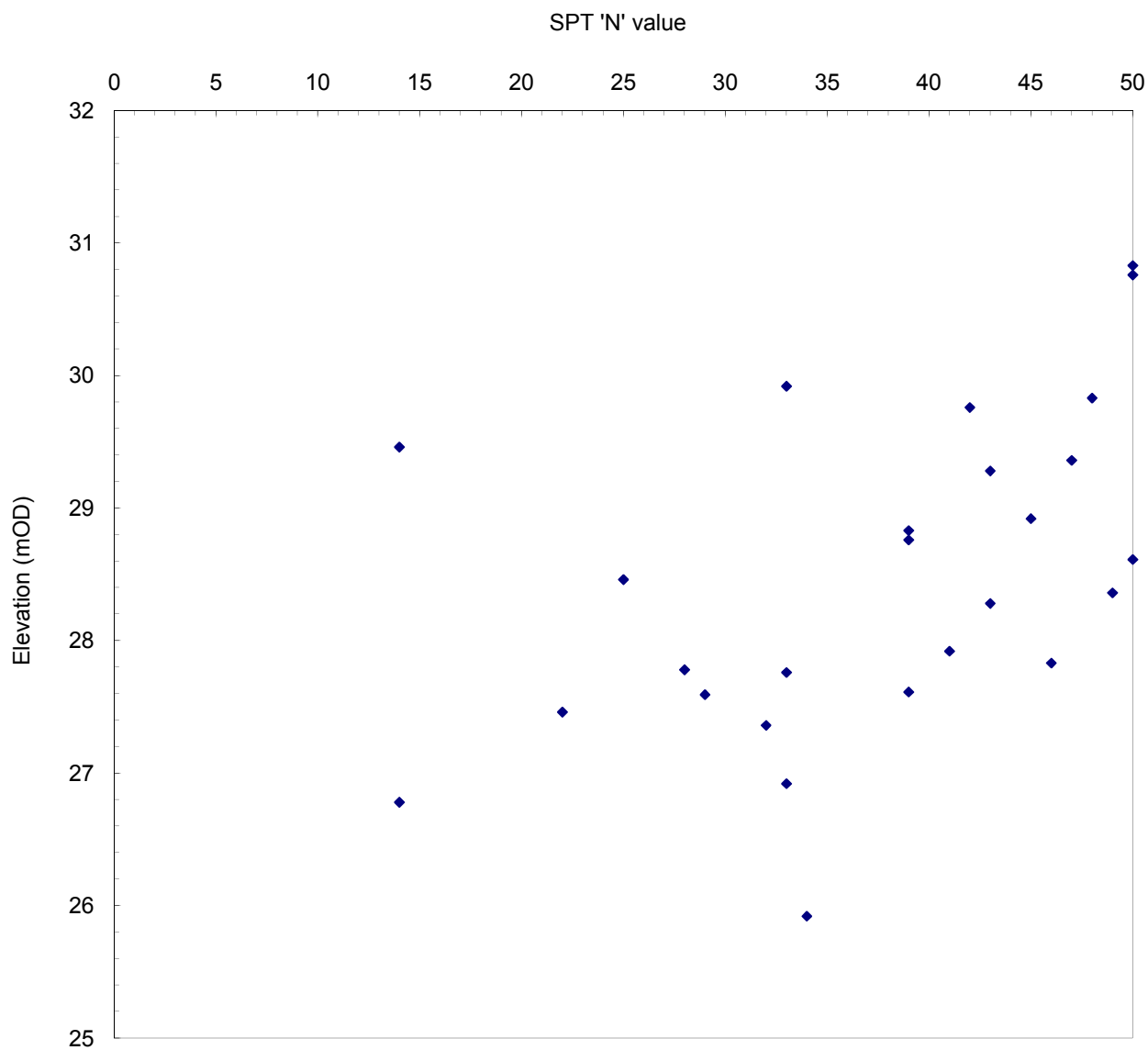
Hyde Park, Hayes

Halcrow

**SPT 'N' VALUES vs. ELEVATION
LANGLEY SILT**

Report No.: GIB016-GEO-RPT-001

Figure No.: 19



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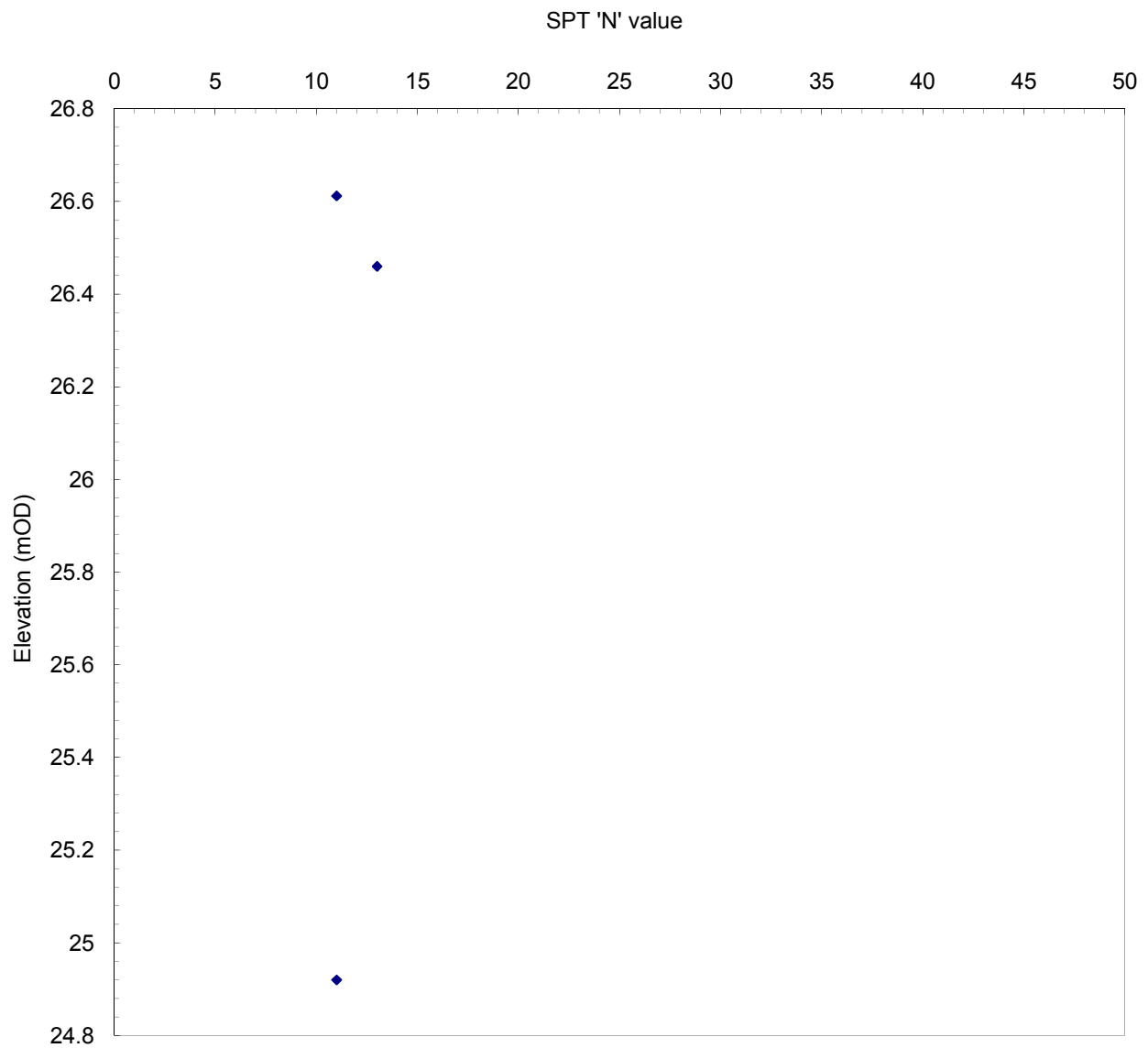
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**SPT 'N' VALUES vs. ELEVATION
LYNCH HILL GRAVEL**

Report No.: GIB016-GEO-RPT-001

Figure No.: 20



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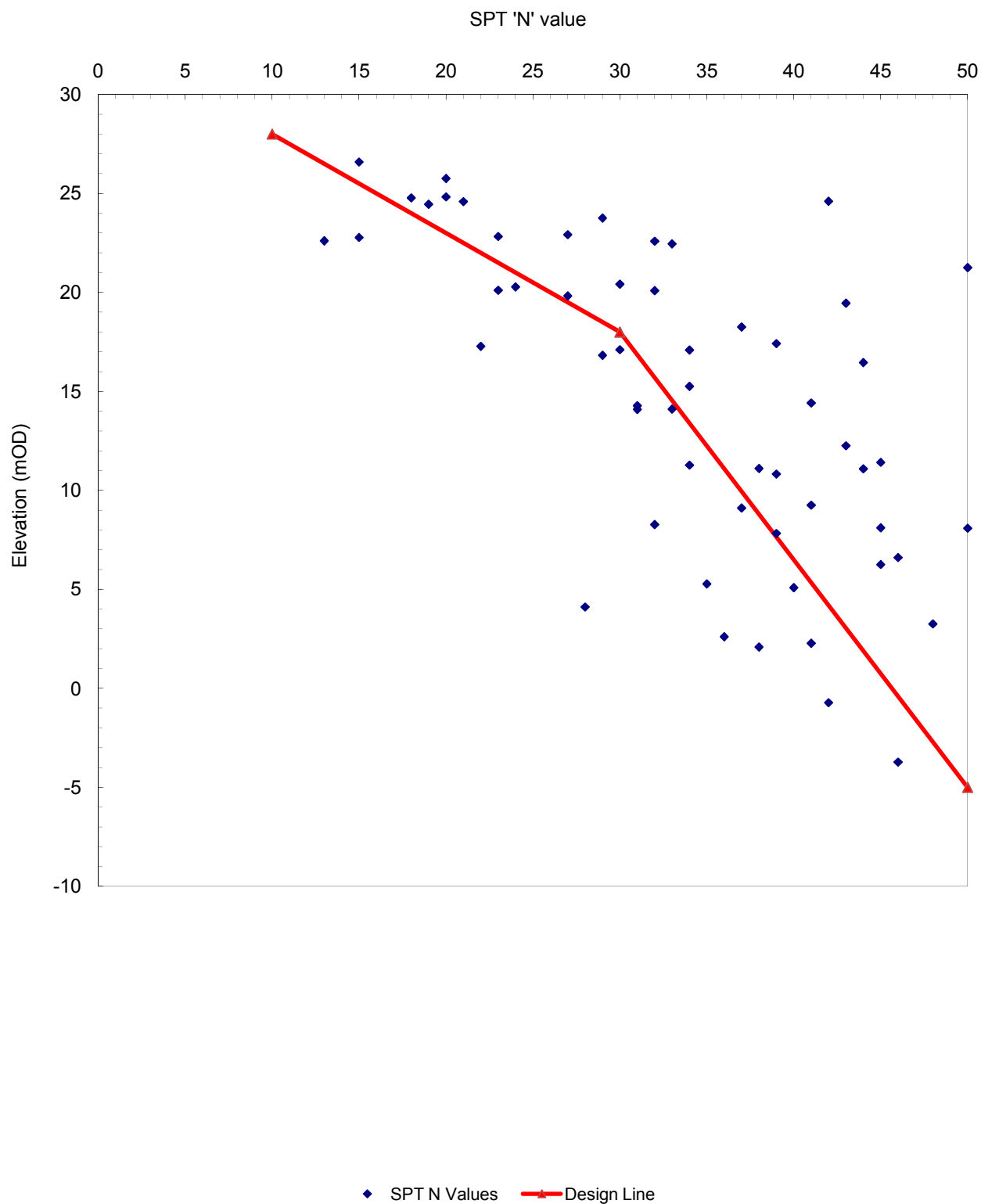
Hyde Park, Hayes

Halcrow

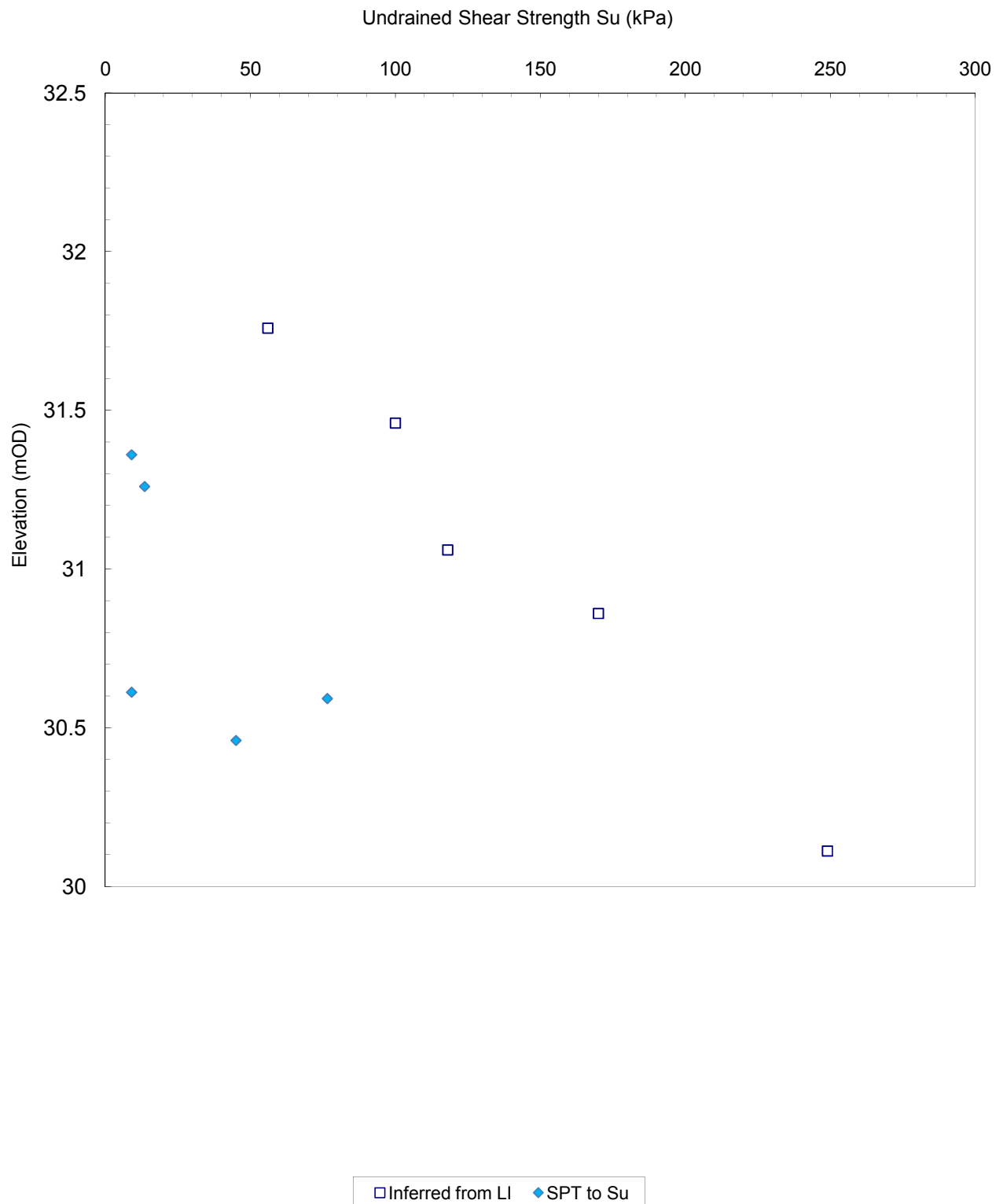
**SPT 'N' VALUES vs. ELEVATION
WEATHERED LONDON CLAY**

Report No.: GIB016-GEO-RPT-001

Figure No.: 21



HPHA	Hyde Park, Hayes	<i>Halcrow</i>
SPT 'N' VALUES vs. ELEVATION LONDON CLAY		Report No.: GIB016-GEO-RPT-001
		Figure No.: 22



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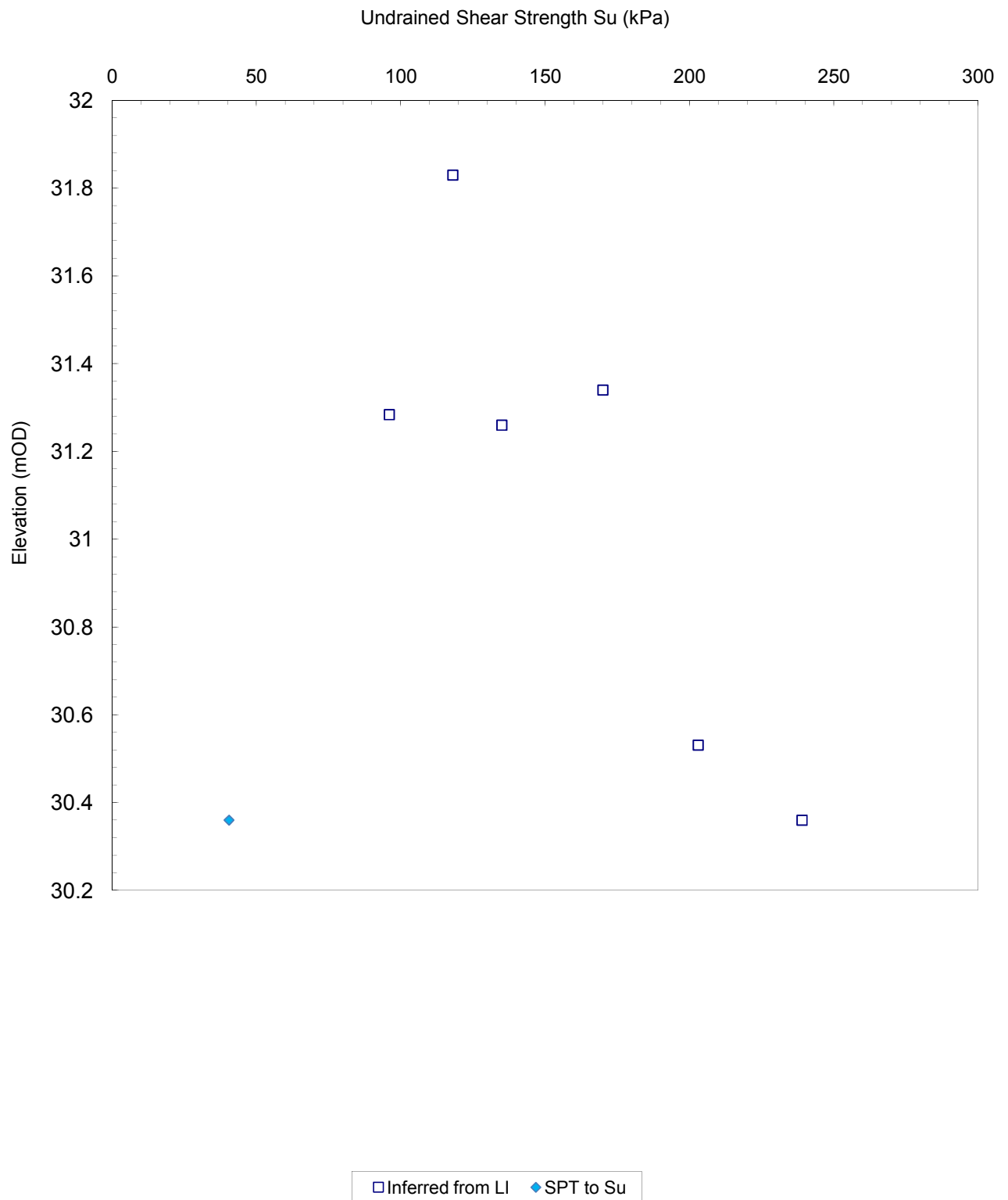
Hyde Park, Hayes

Halcrow

**UNDRAINED SHEAR STRENGTH S_u vs. ELEVATION
MADE GROUND**

Report No.: GIB016-GEO-RPT-001

Figure No.: 23



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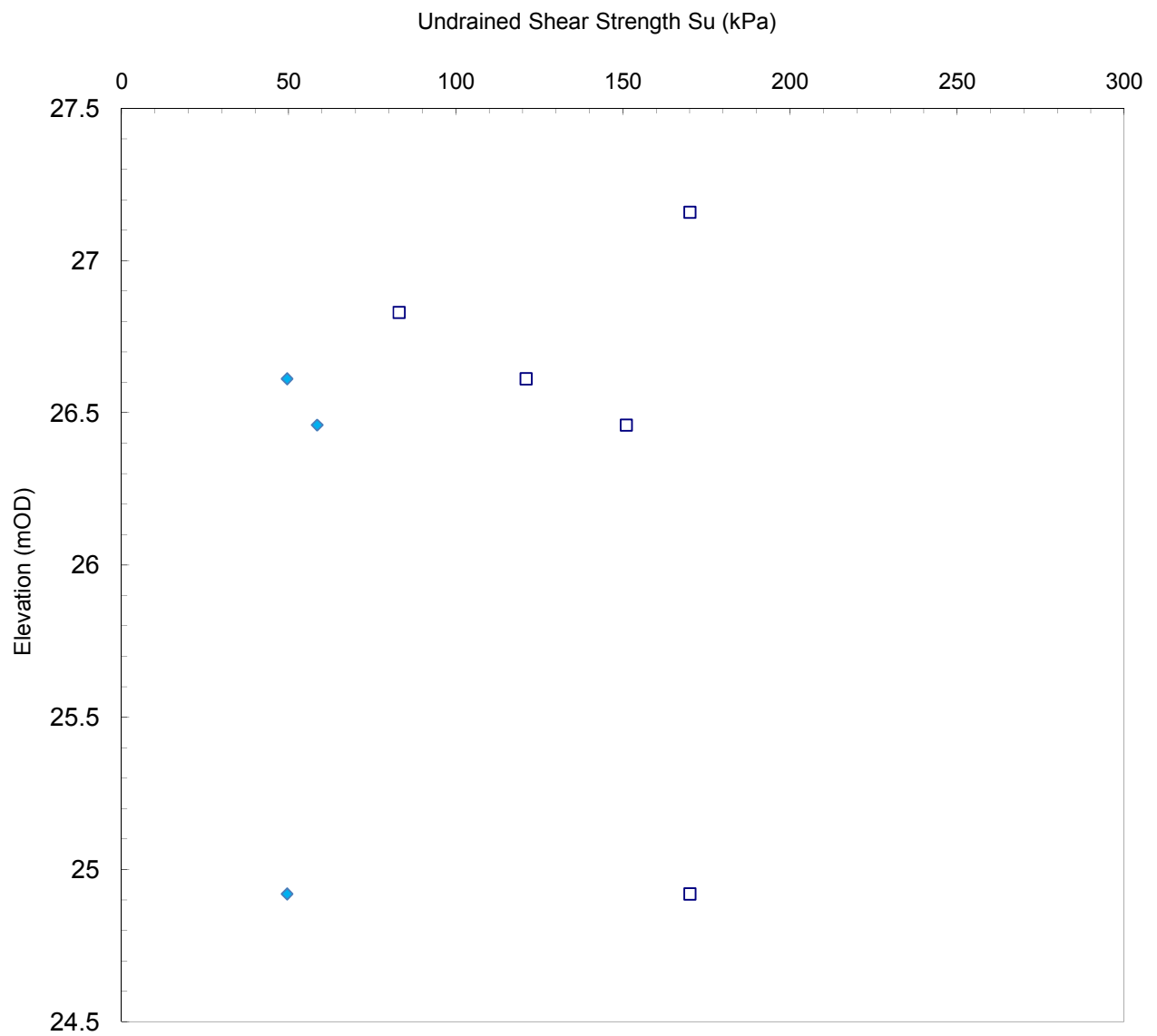
Hyde Park, Hayes

Halcrow

**UNDRAINED SHEAR STRENGTH S_u vs. ELEVATION
LANGLEY SILT**

Report No.: GIB016-GEO-RPT-001

Figure No.: 24



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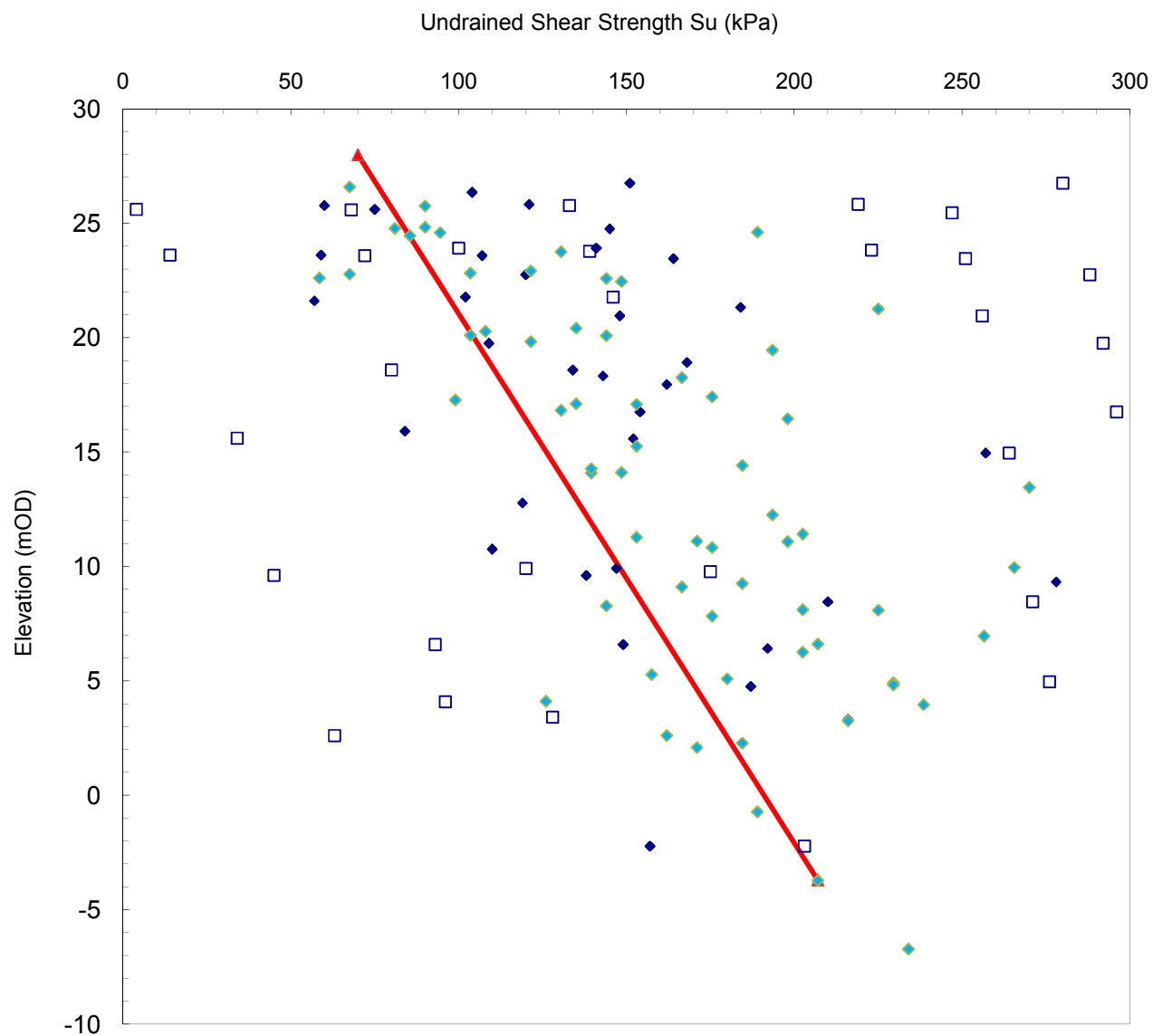
Hyde Park, Hayes

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**UNDRAINED SHEAR STRENGTH S_u vs. ELEVATION
WEATHERED LONDON CLAY**

Report No.: GIB016-GEO-RPT-001

Figure No.: 25



◆ Triaxial □ Inferred from LI —▲— Design Line ◆ SPT to S_u

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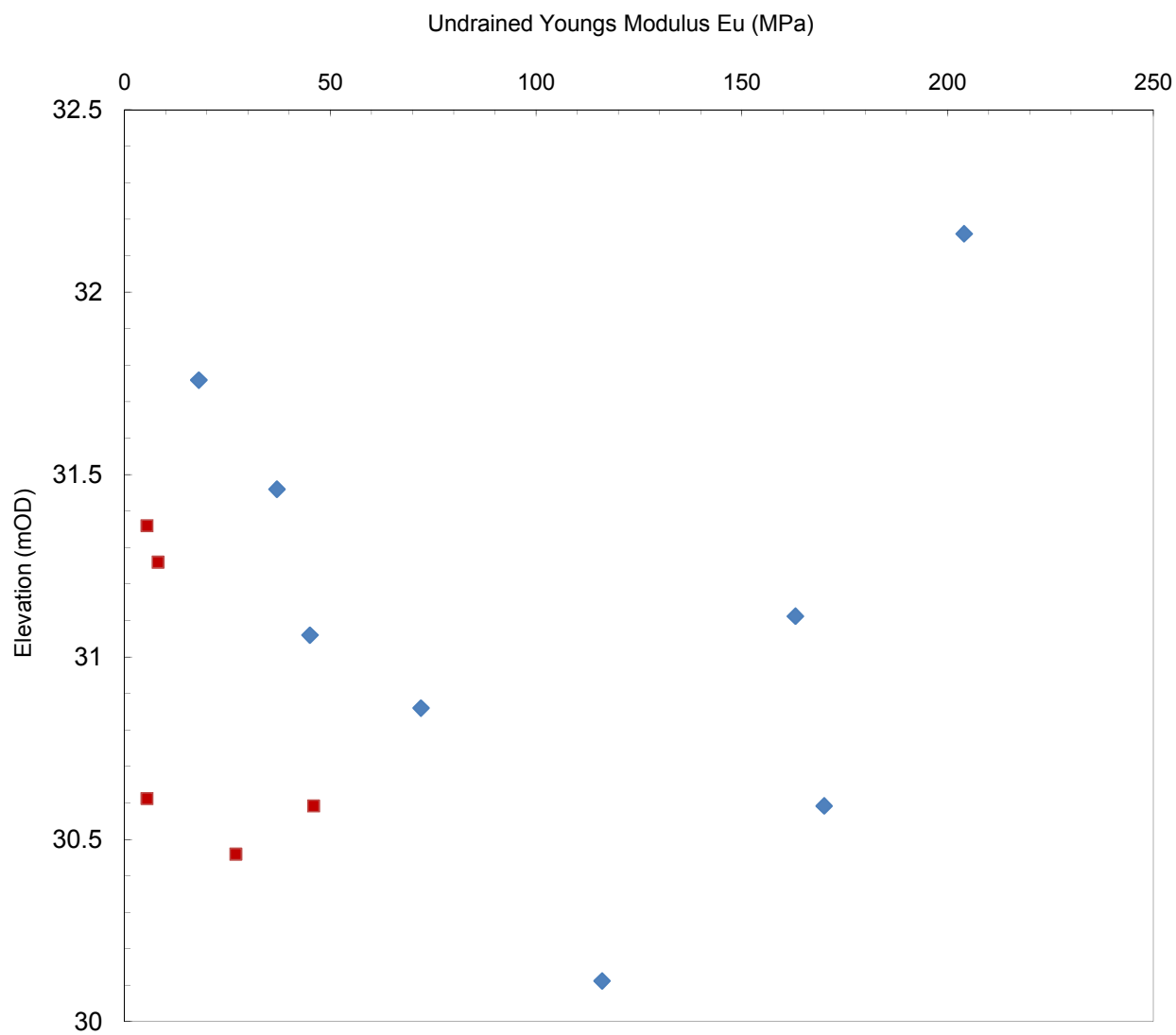
Hyde Park, Hayes

Halcrow

**UNDRAINED SHEAR STRENGTH S_u vs. ELEVATION
LONDON CLAY**

Report No.: GIB016-GEO-RPT-001

Figure No.: 26



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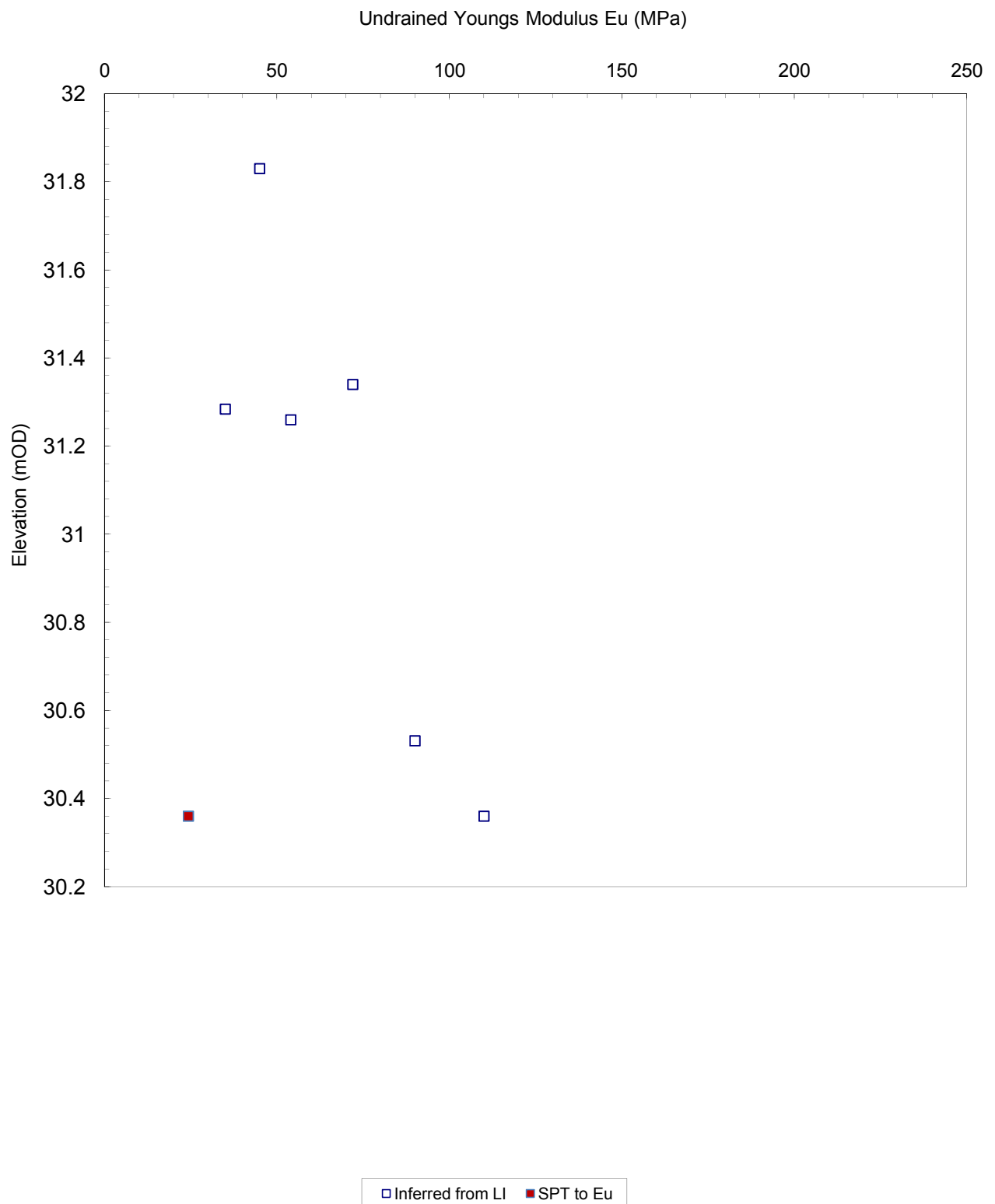
Hyde Park, Hayes

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**UNDRAINED YOUNGS MODULUS E_u vs. ELEVATION
MADE GROUND**

Report No.: GIB016-GEO-RPT-001

Figure No.: 27



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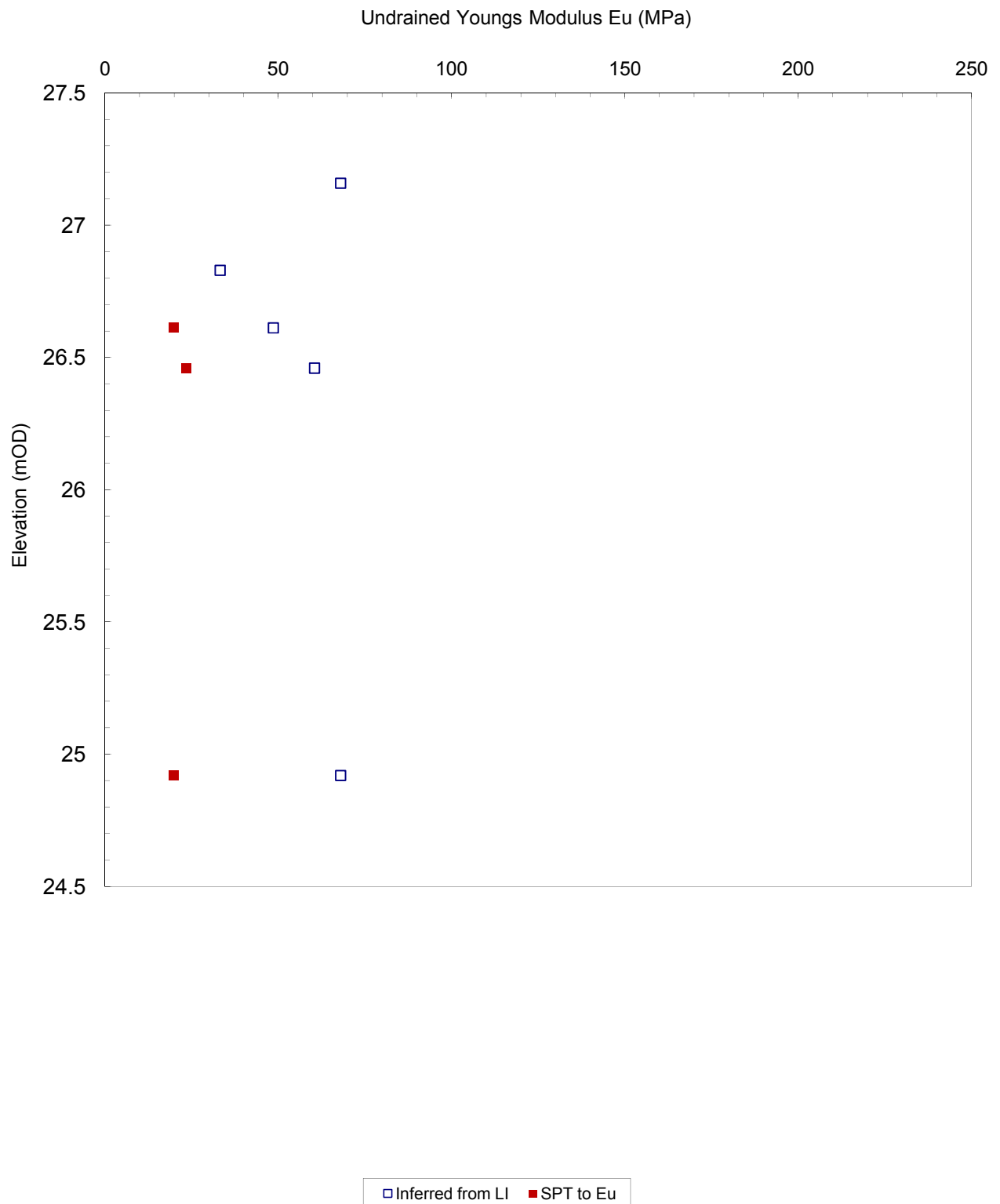
Hyde Park, Hayes

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**UNDRAINED YOUNGS MODULUS E_u vs. ELEVATION
LANGLEY SILT**

Report No.: GIB016-GEO-RPT-001

Figure No.: 28



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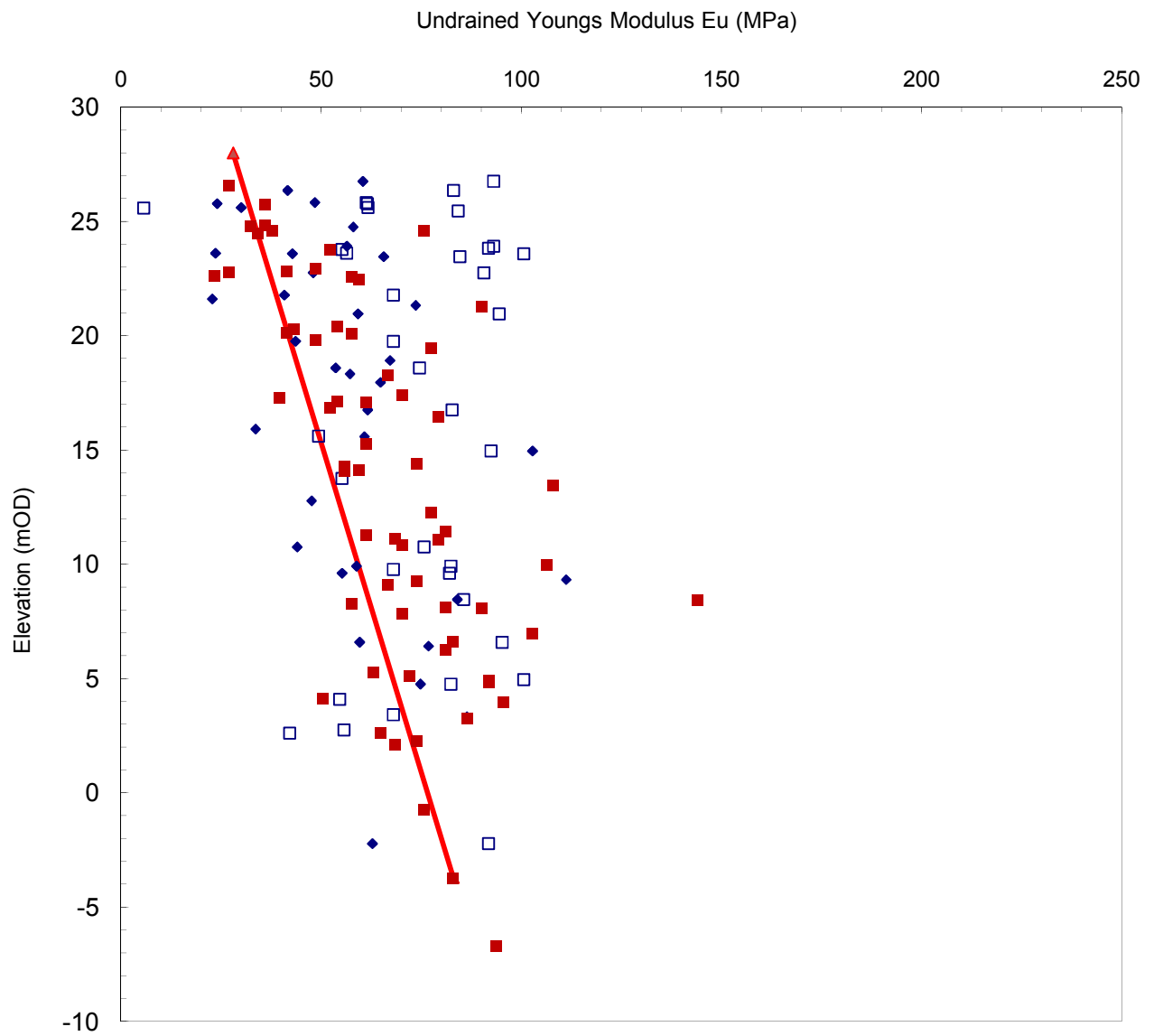
Hyde Park, Hayes

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**UNDRAINED YOUNGS MODULUS E_u vs. ELEVATION
WEATHERED LONDON CLAY**

Report No.: GIB016-GEO-RPT-001

Figure No.: 29



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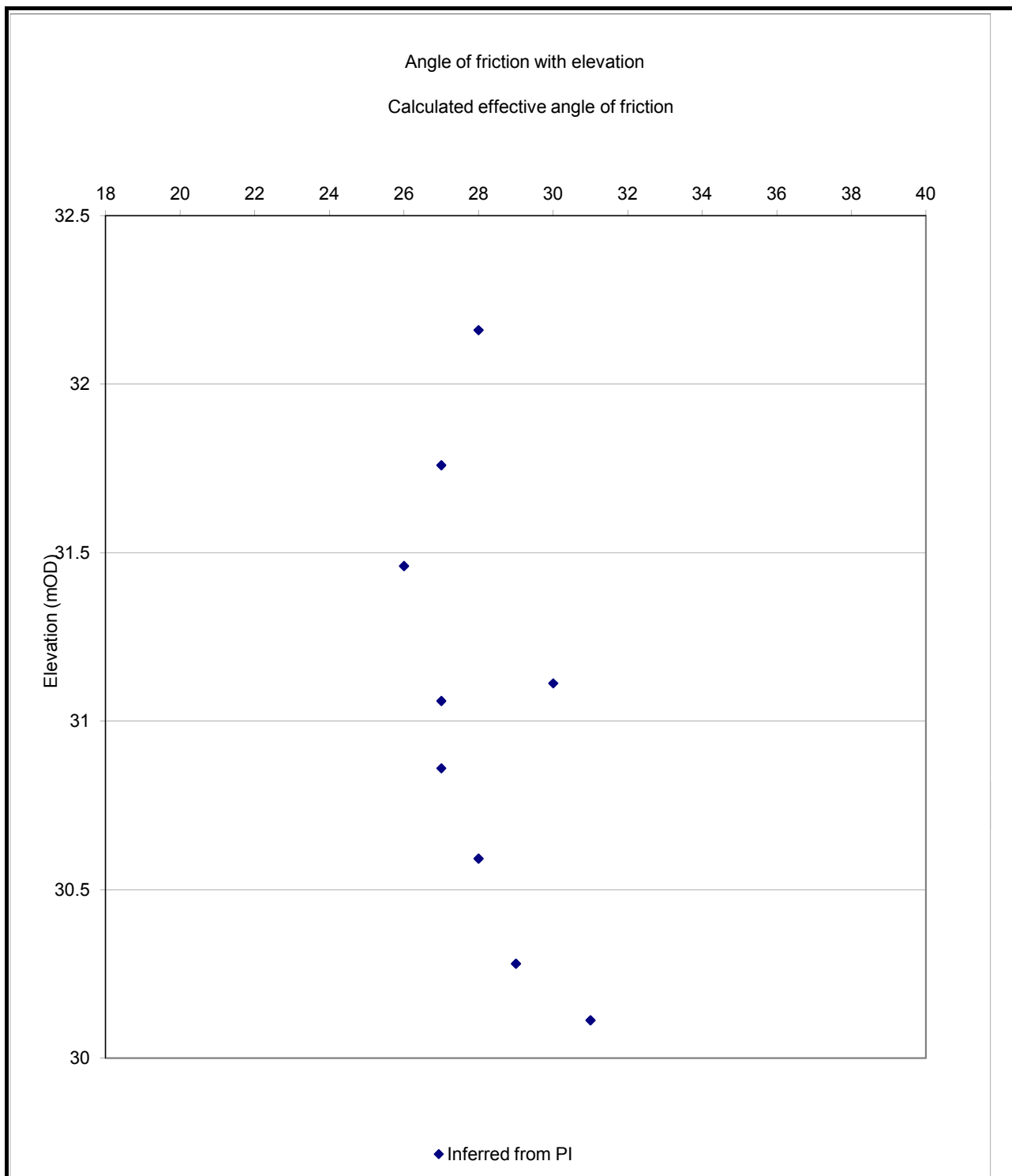
Hyde Park, Hayes

Halcrow

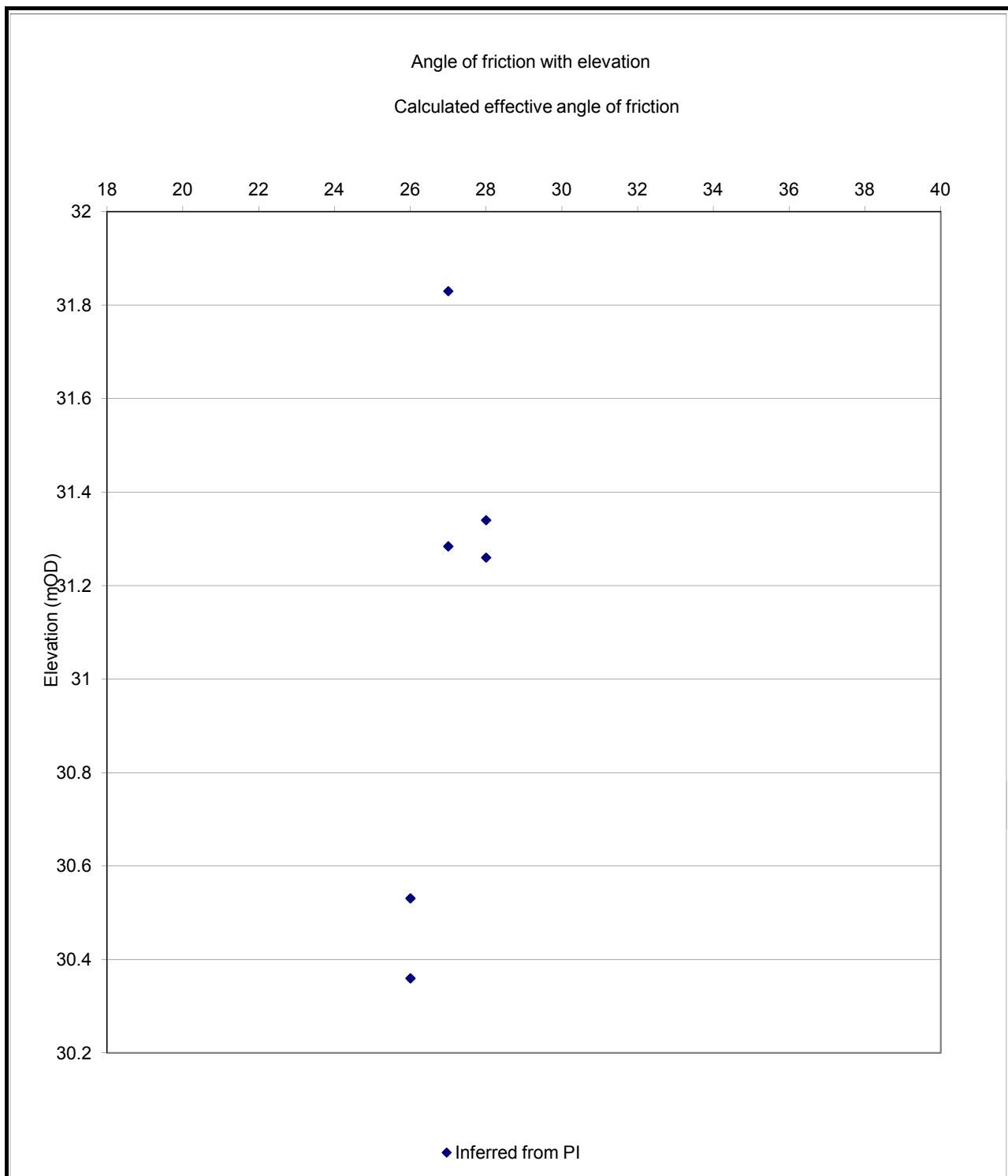
**UNDRAINED YOUNGS MODULUS E_u vs. ELEVATION
LONDON CLAY**

Report No.: GIB016-GEO-RPT-001

Figure No.: 30

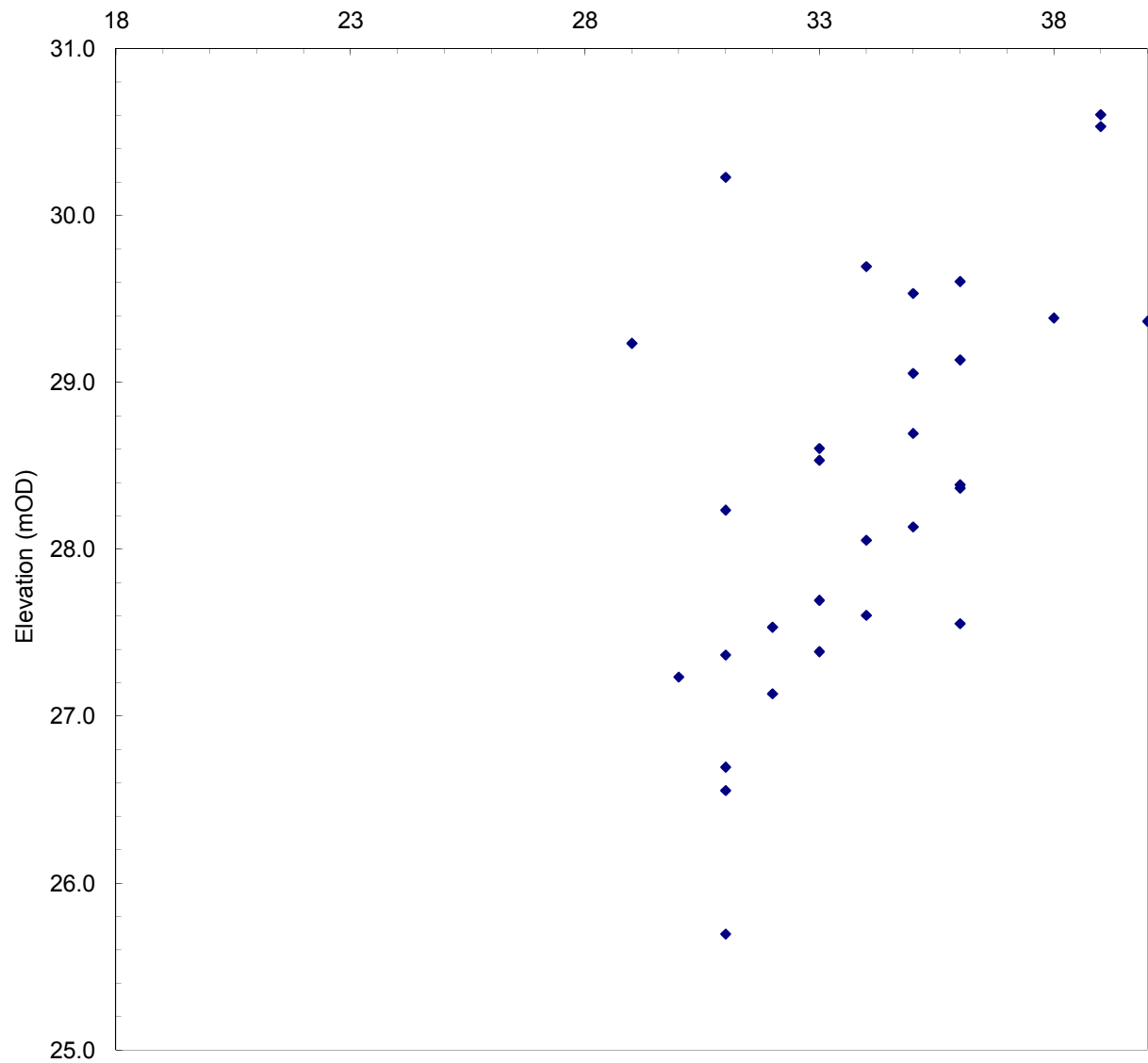


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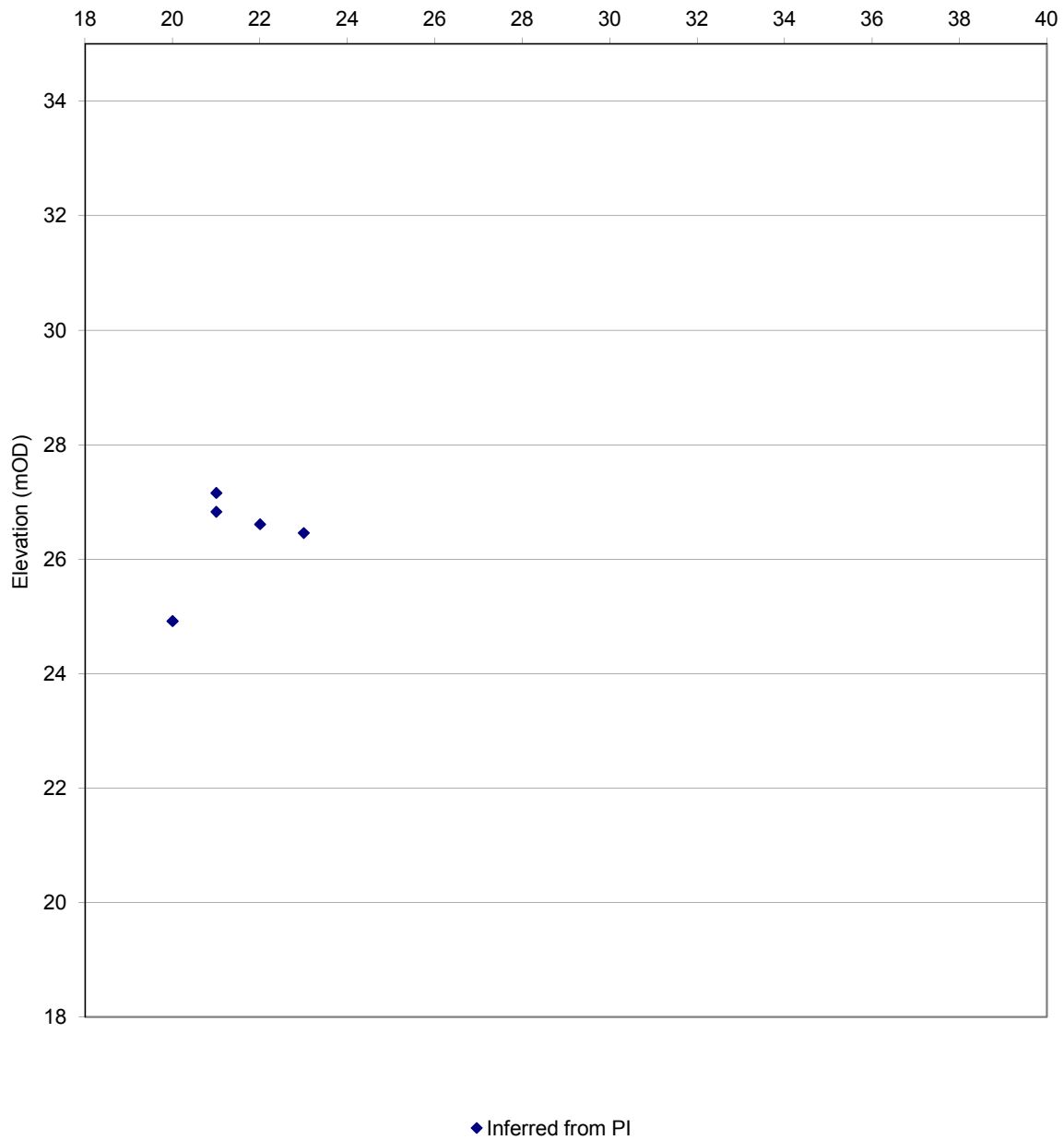


HPHA	Hyde Park, Hayes		
Φ' vs. ELEVATION LANGLEY SILT		Report No.:	GIB016-GEO-RPT-001
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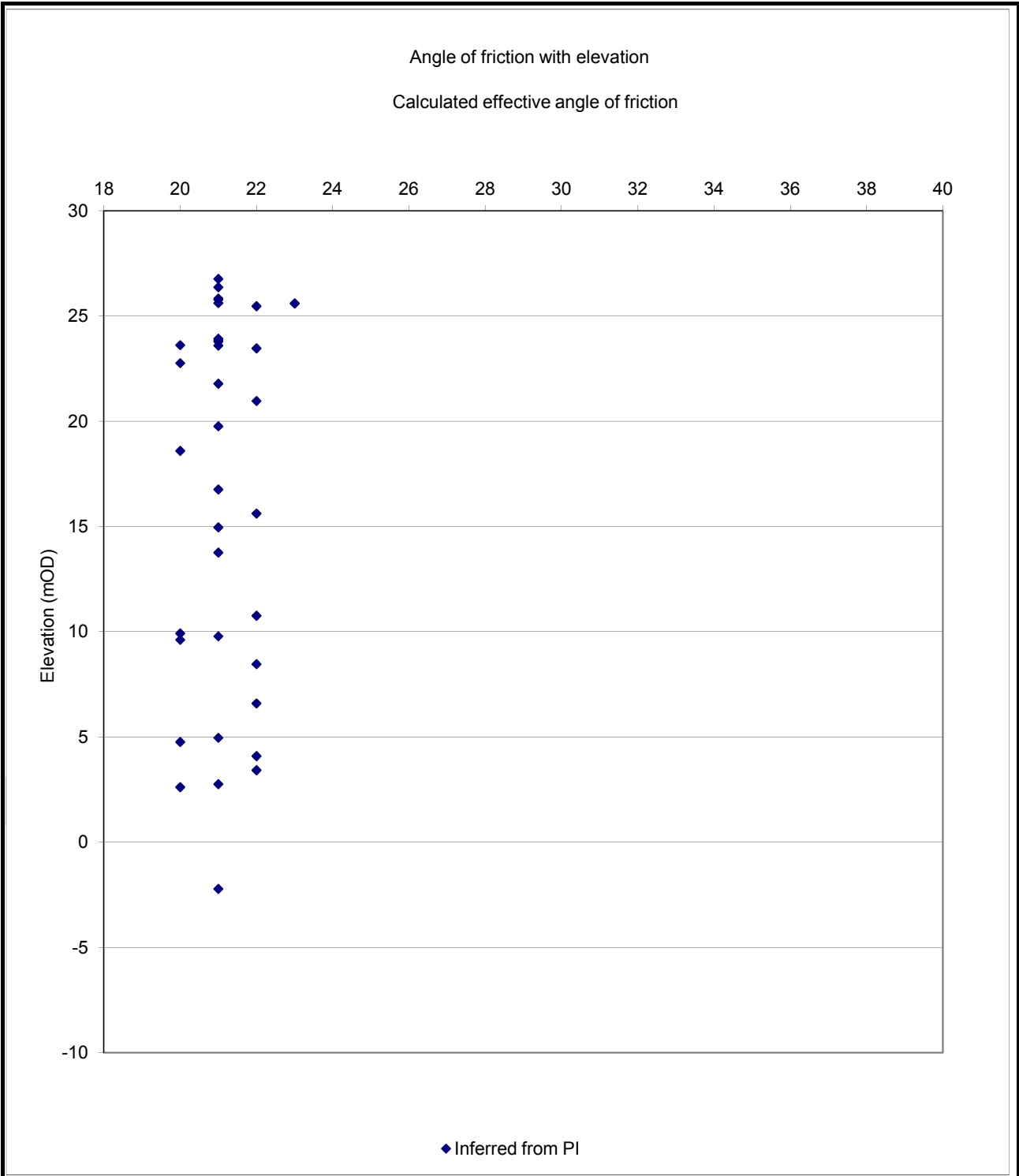
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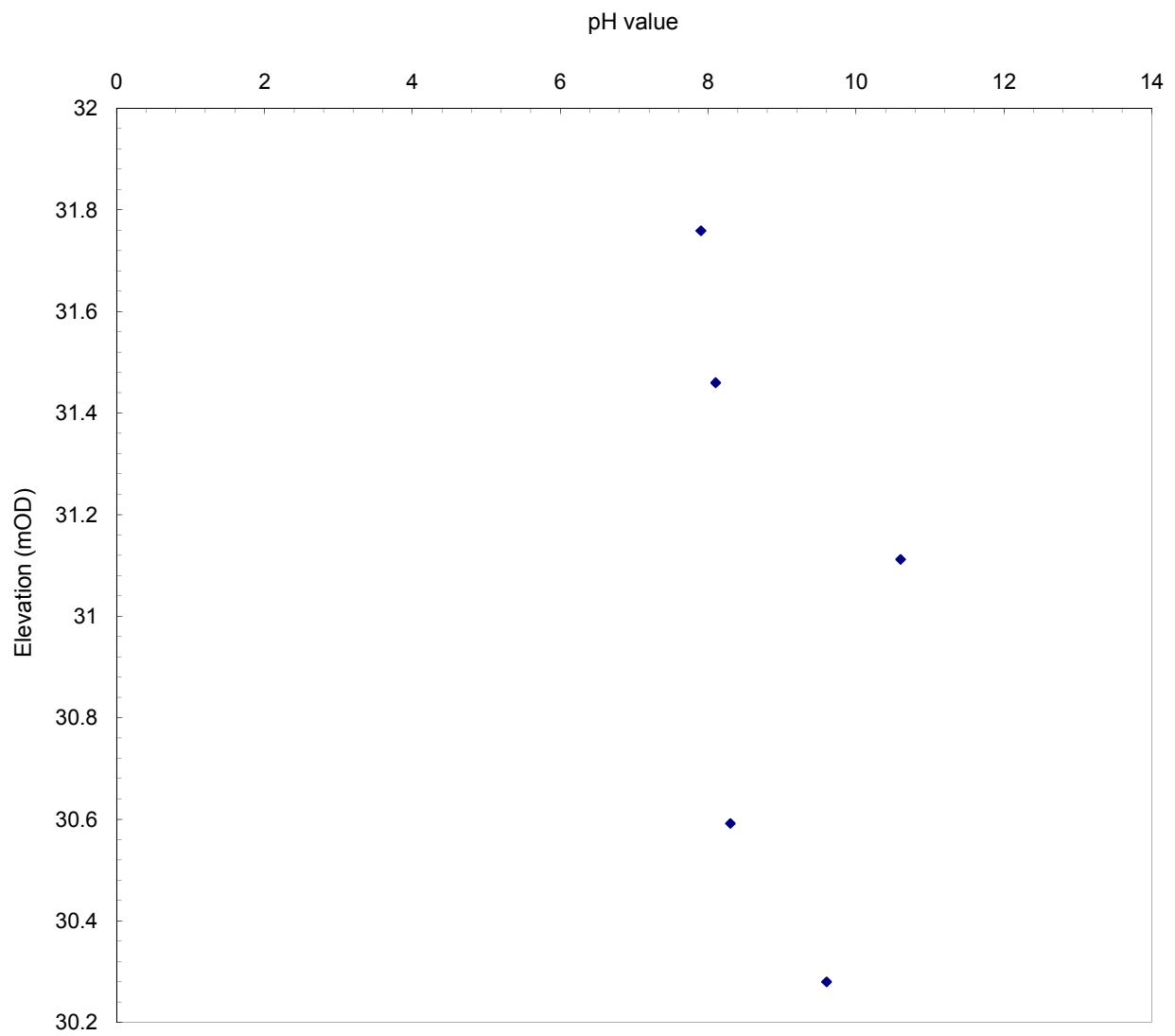
Angle of friction with elevation
 Calculated effective angle of friction



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Φ' vs. ELEVATION WEATHERED LONDON CLAY		Report No.:	GIB016-GEO-RPT-001
		Figure No.:	34



HPHA	Hyde Park, Hayes		
Φ' vs. ELEVATION LONDON CLAY		Report No.:	GIB016-GEO-RPT-001
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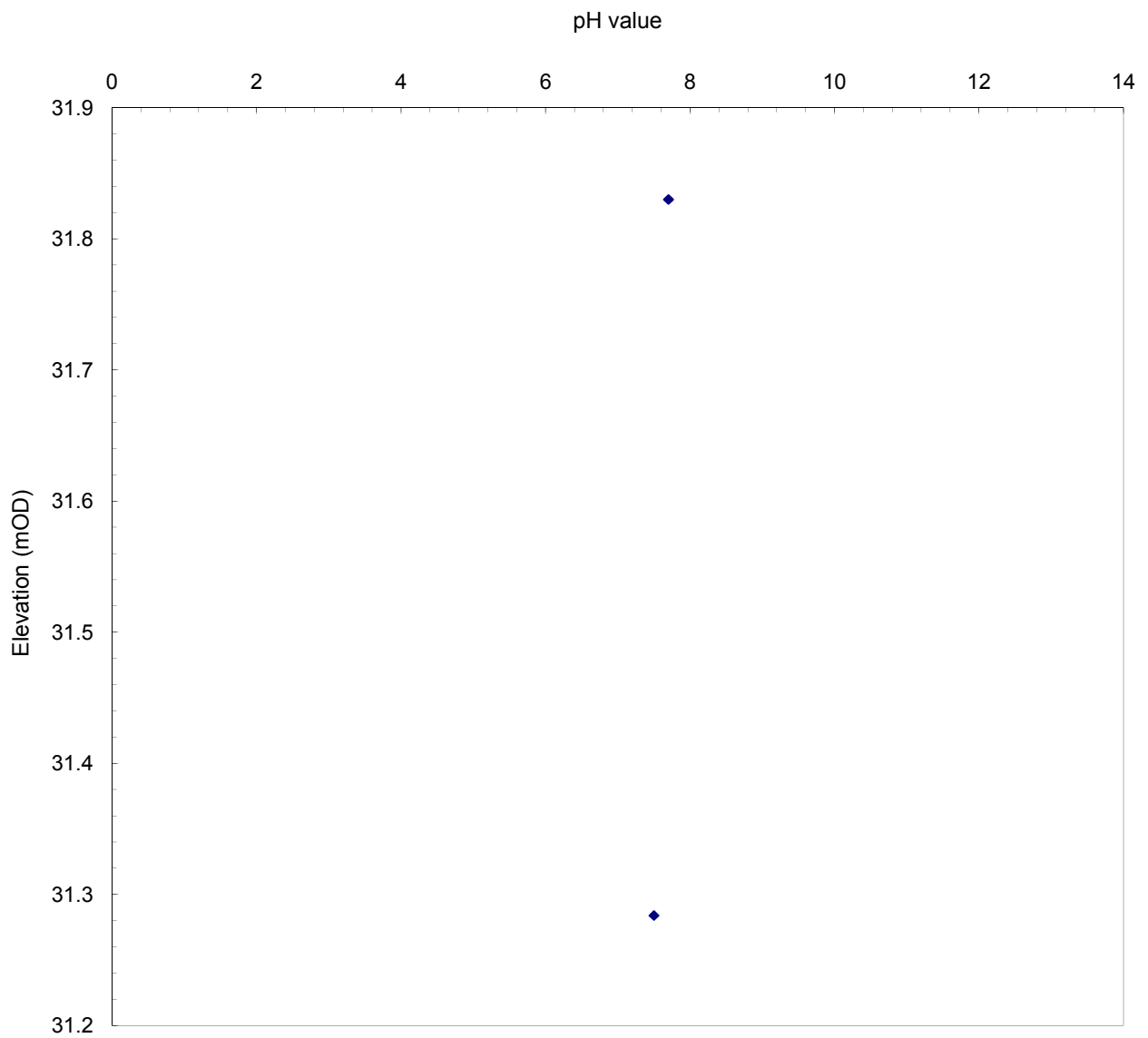
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**pH VALUES vs. ELEVATION
MADE GROUND**

Report No.: GIB016-GEO-RPT-001

Figure No.: 36



HPHA

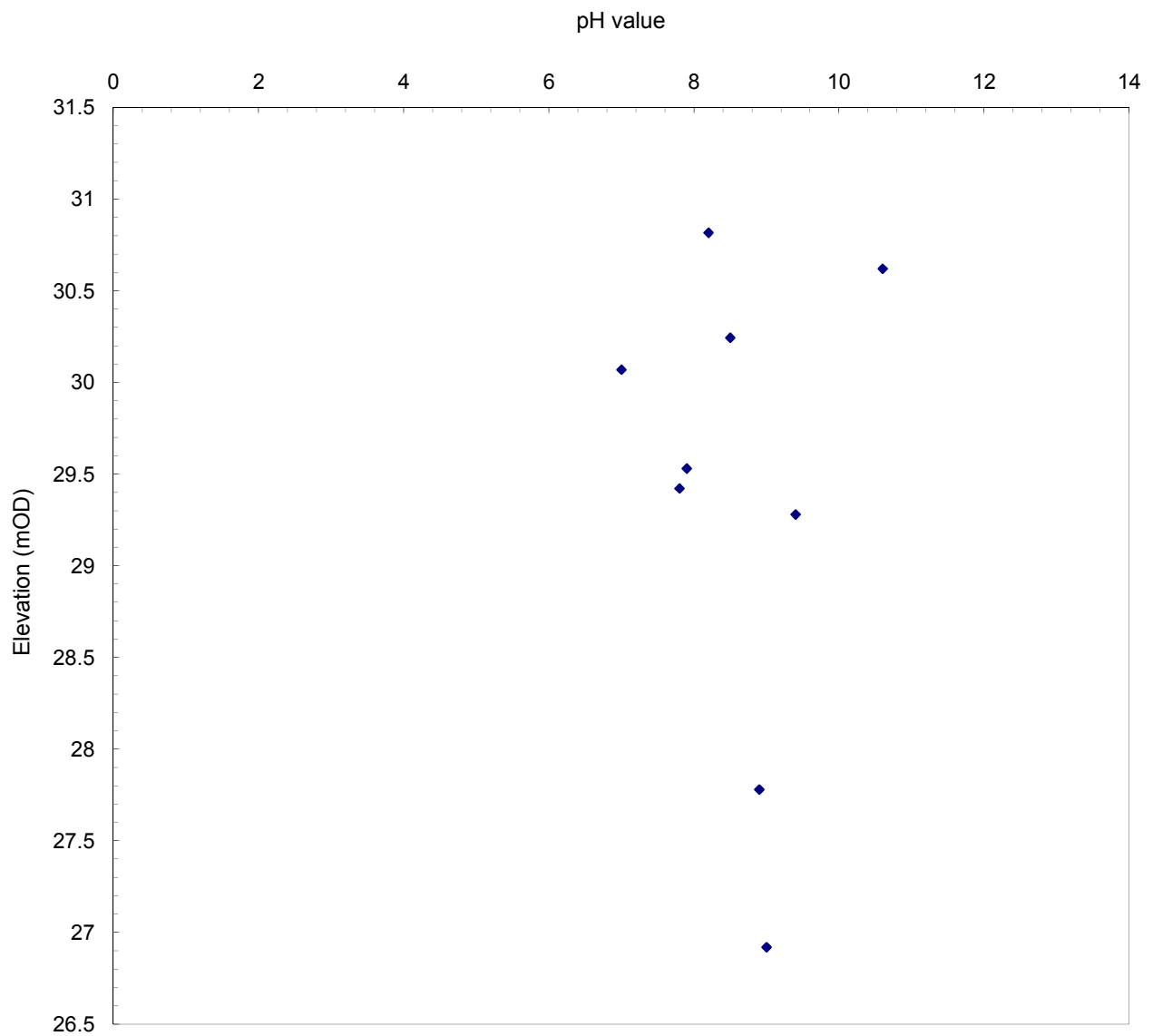
Hyde Park, Hayes

Halcrow

pH VALUES vs. ELEVATION
LANGLEY SILT

Report No.: GIB016-GEO-RPT-001

Figure No.: 37



HPHA

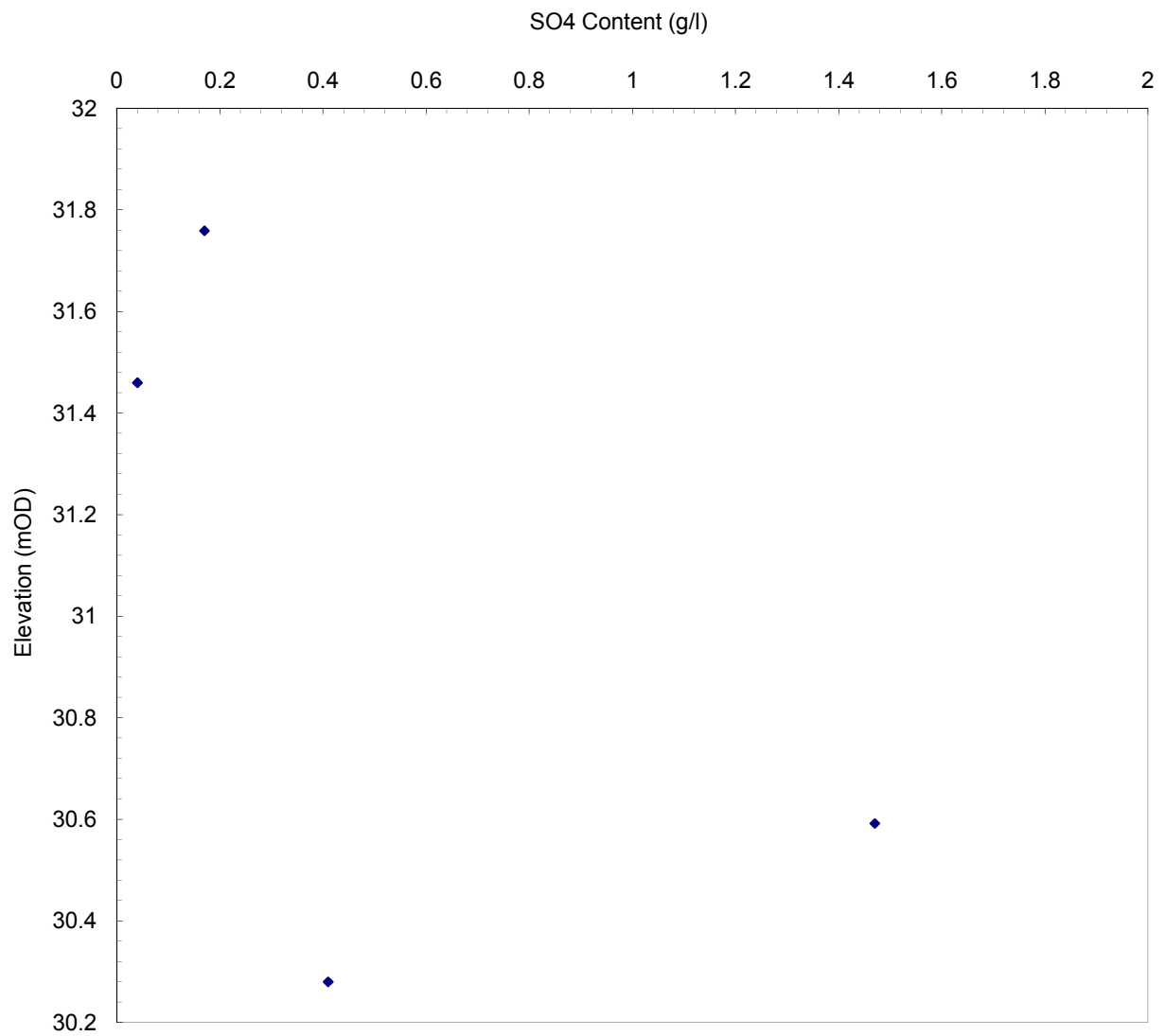
Hyde Park, Hayes

Halcrow

pH VALUES vs. ELEVATION
LYNCH HILL GRAVEL

Report No.: GIB016-GEO-RPT-001

Figure No.: 38



HPHA

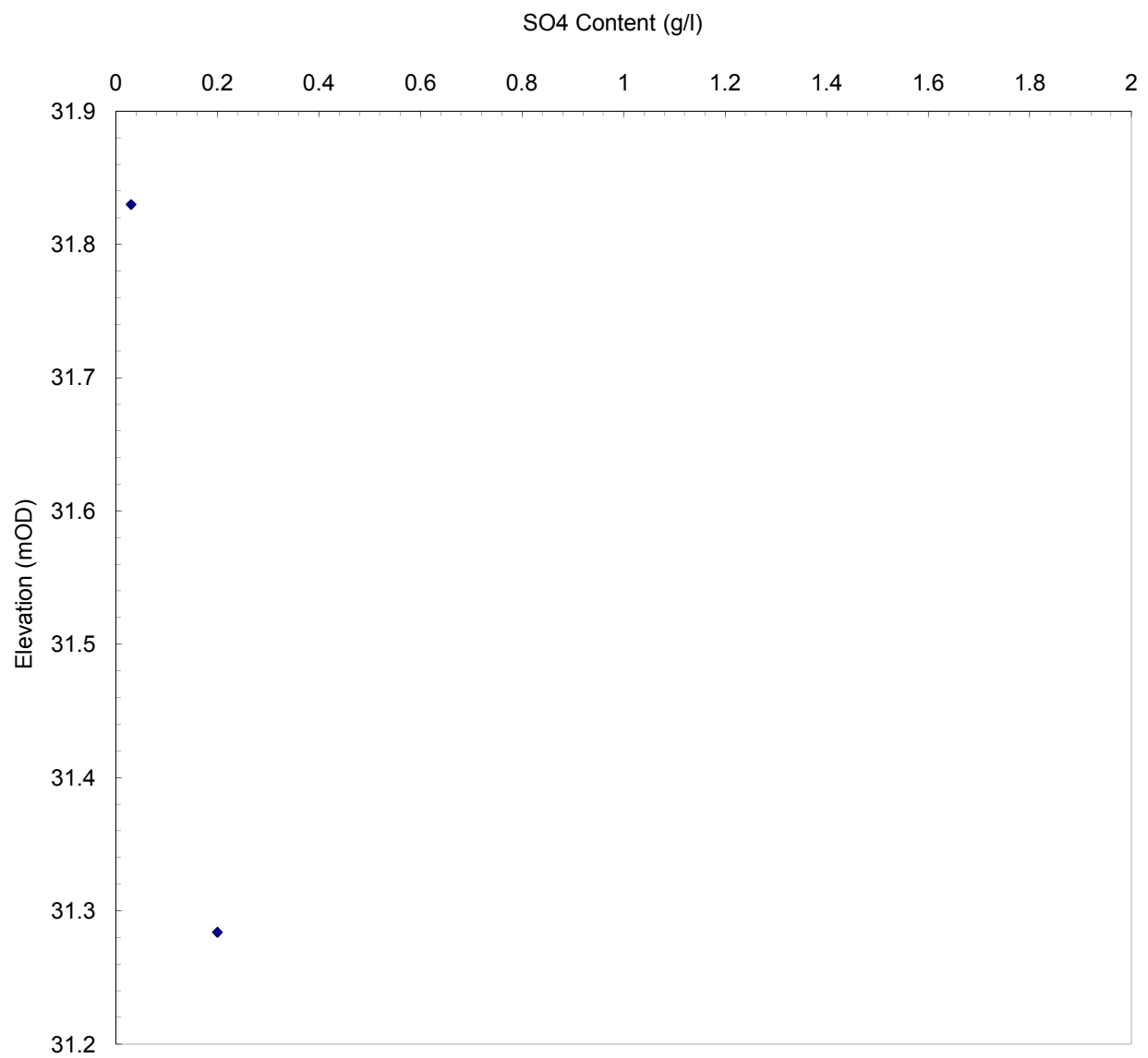
Hyde Park, Hayes

Halcrow

**SO4 CONTENT vs. ELEVATION
MADE GROUND**

Report No.: GIB016-GEO-RPT-001

Figure No.: 39



HPHA

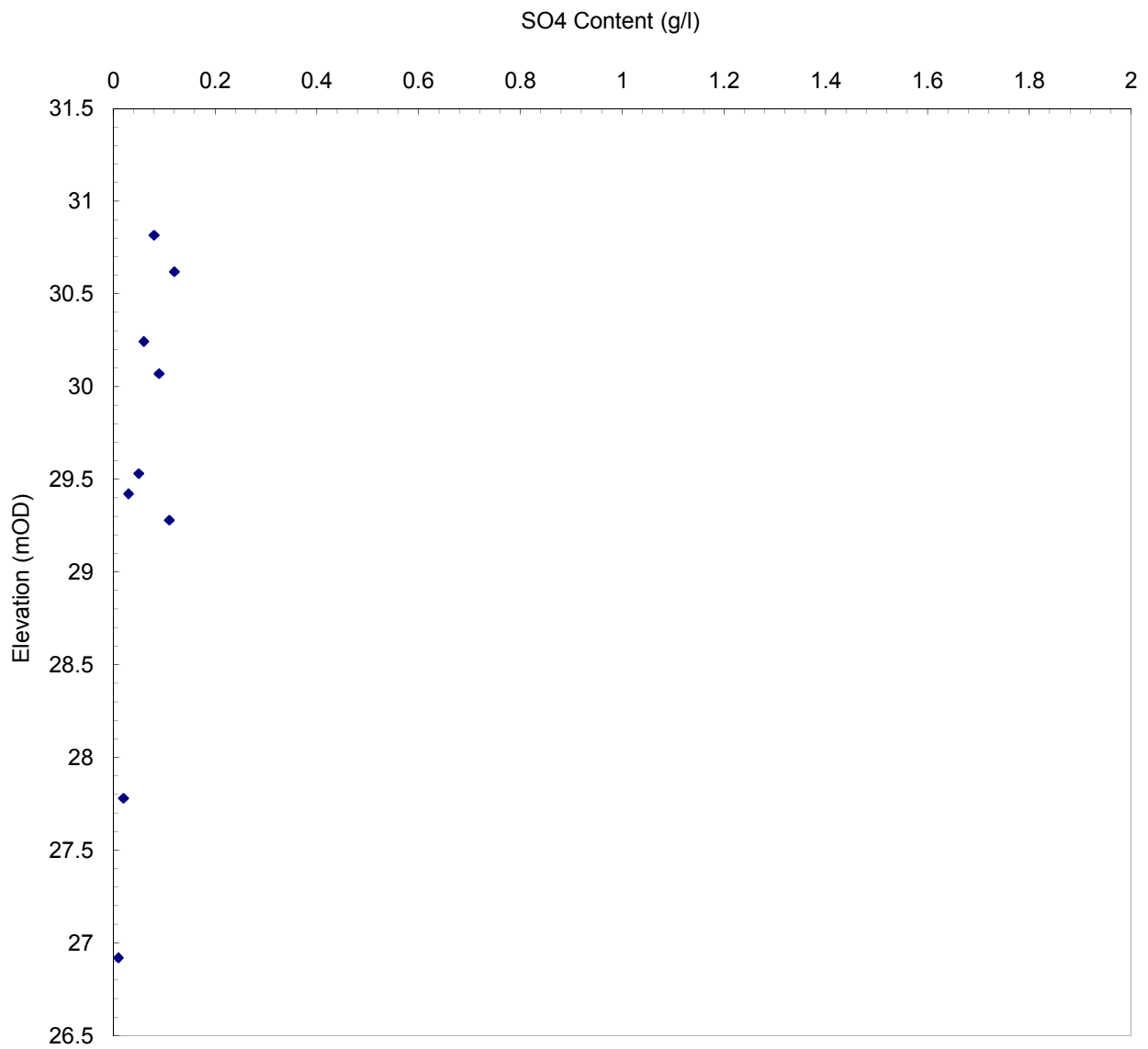
Hyde Park, Hayes

Halcrow

**SO4 CONTENT vs. ELEVATION
LANGLEY SILT**

Report No.: GIB016-GEO-RPT-001

Figure No.: 40



HPHA

Hyde Park, Hayes

Halcrow

**SO4 CONTENT vs. ELEVATION
LYNCH HILL GRAVEL**

Report No.: GIB016-GEO-RPT-001

Figure No.: 41

Report No: GIB016-GEO-RPT-001

Project: Hyde Park, Hayes

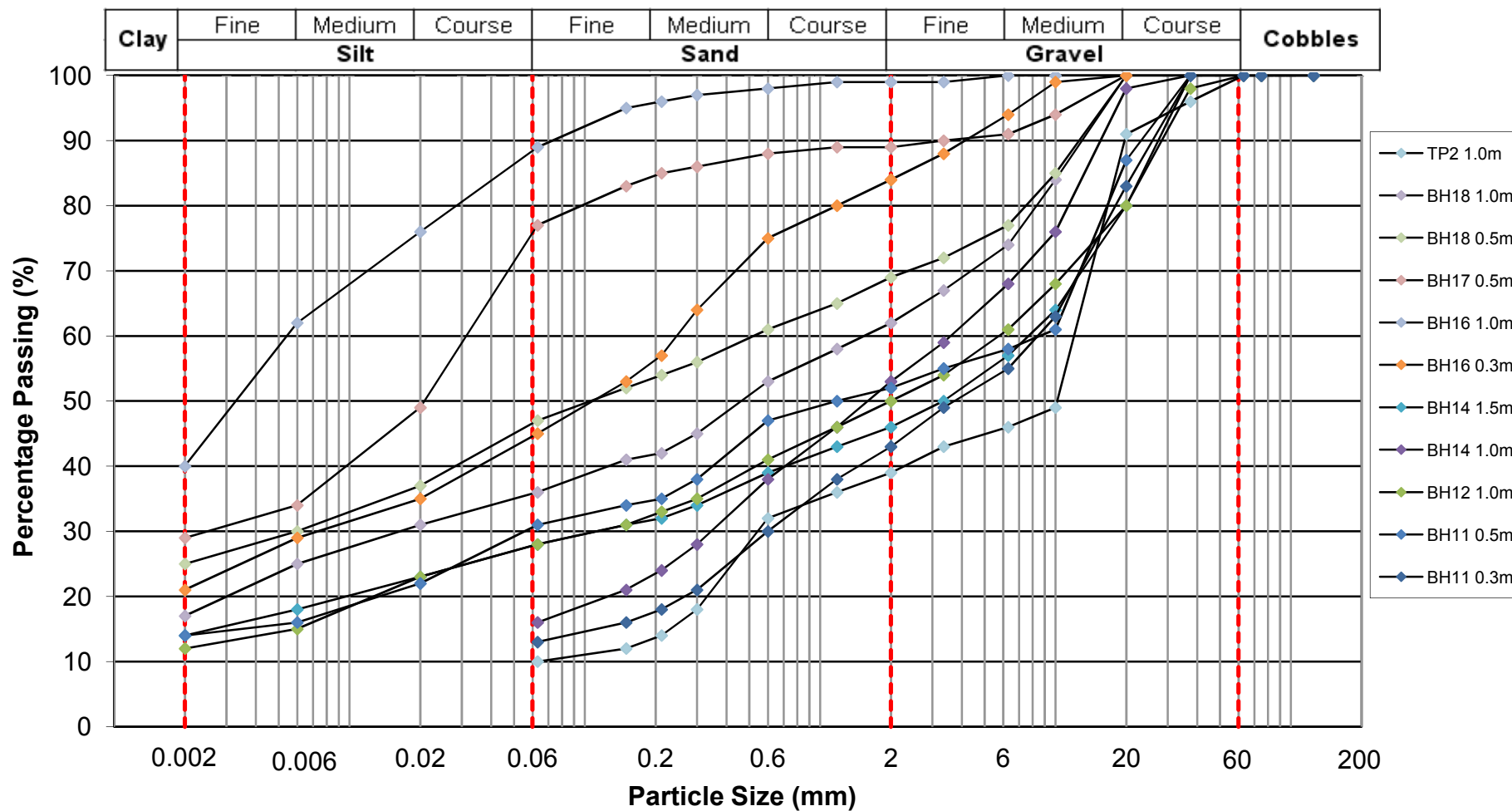


Figure 42: Particle Size Distribution Curves Made Ground

Report No: GIB016-GEO-RPT-001

Project: Hyde Park, Hayes

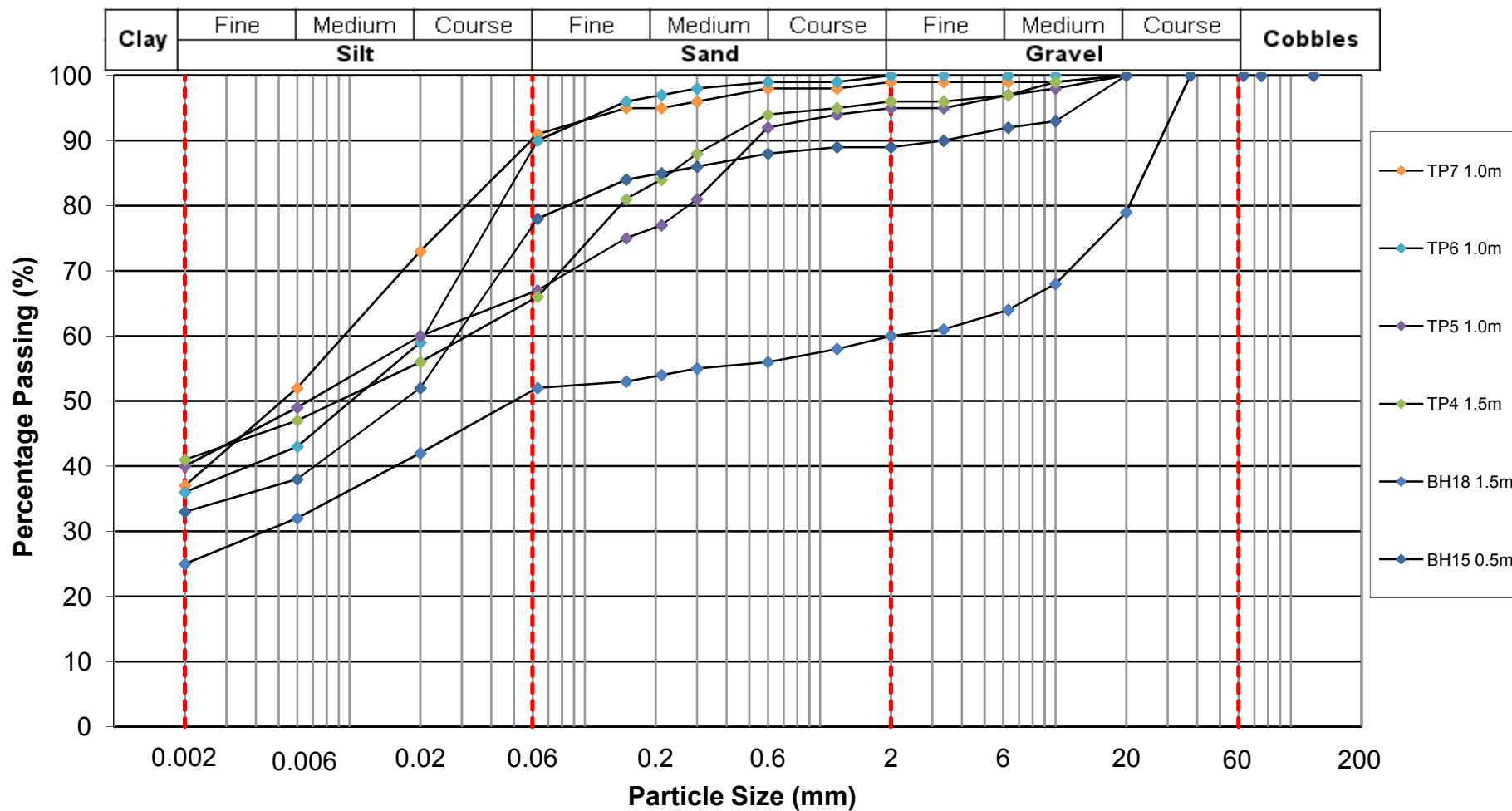


Figure 43: Particle Size Distribution Curves Langley Silt

Report No: GIB016-GEO-RPT-001

Project: Hyde Park, Hayes

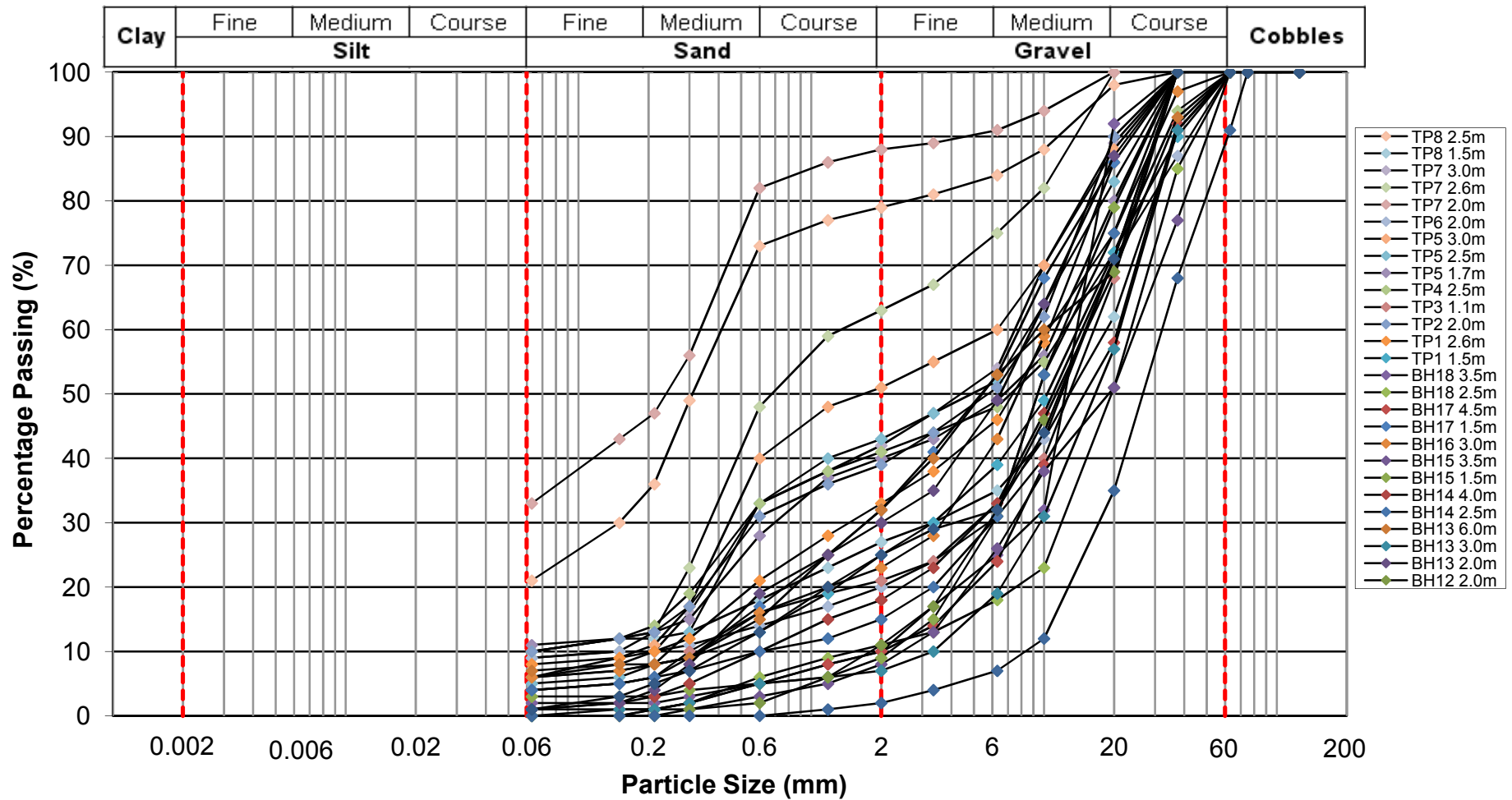


Figure 44: Particle Size Distribution Curves Lynch Hill Gravel

Report No: GIB016-GEO-RPT-001

Project: Hyde Park, Hayes

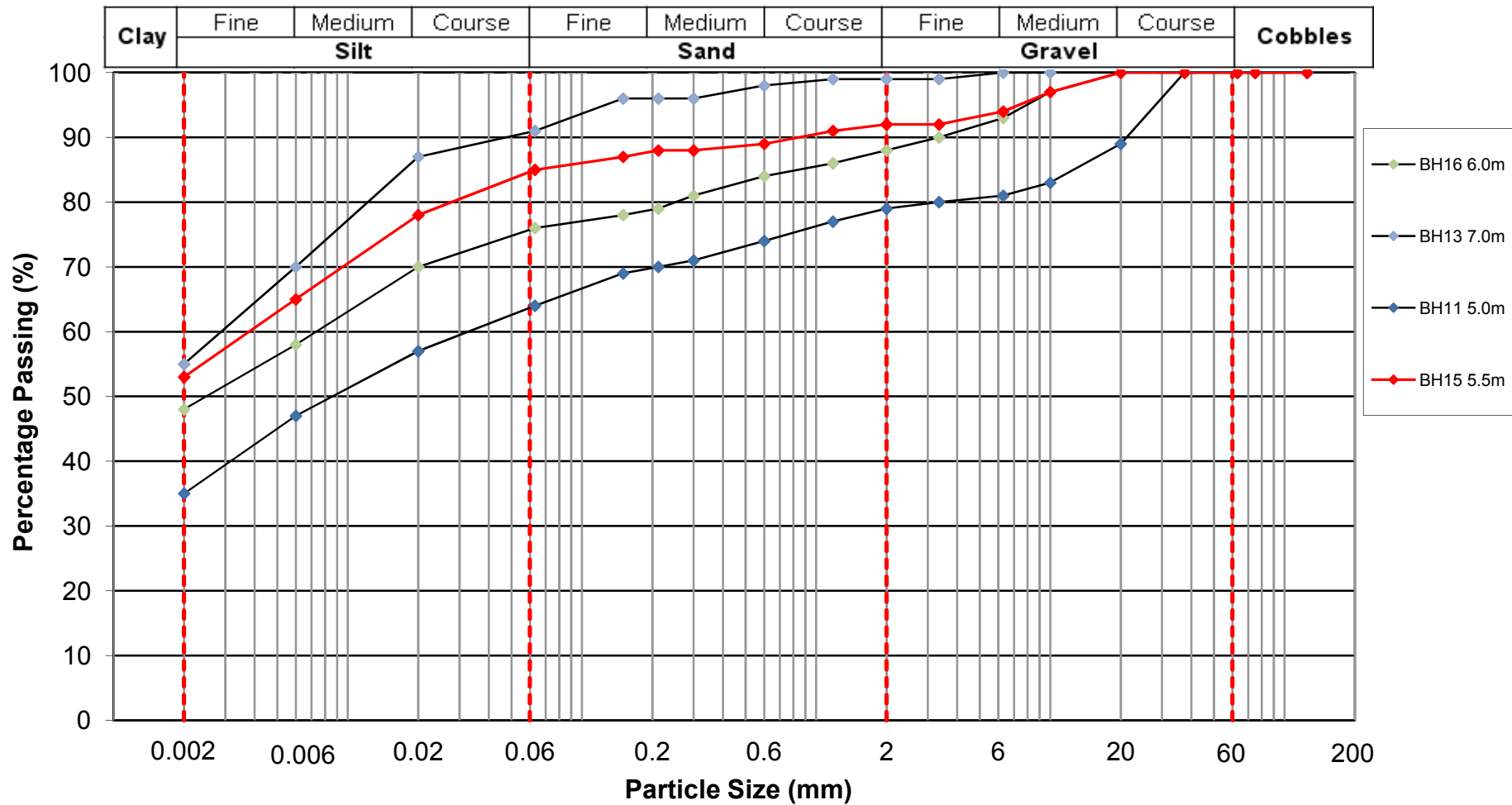


Figure 45: Particle Size Distribution Curves Weathered London Clay

Report No: GIB016-GEO-RPT-001

Project: Hyde Park, Hayes

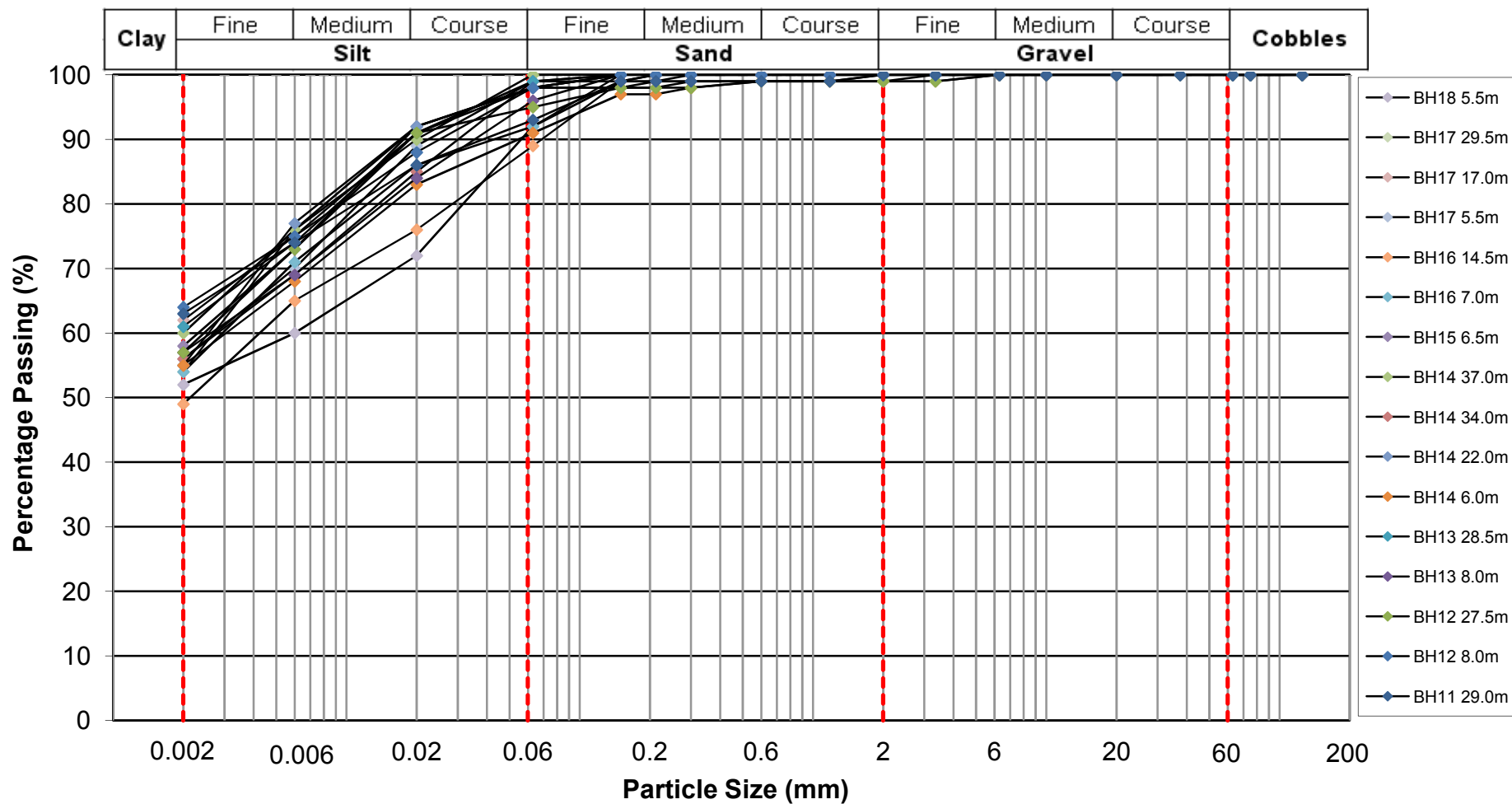


Figure 46: Particle Size Distribution Curves London Clay



Appendix C

Appendix C Piling Risk Assessment

1 Piling Risk Assessment

1.1 Introduction

This Appendix concentrates on risks to human health risks and controlled waters due to construction of piled foundations only. Other geotechnical risks are included in the main report. Risks to human health and controlled waters from the ground conditions at the Hyde Park, Hayes site are covered by SKM Enviros.

The Environment Agency (2001) has identified six scenarios that piling or penetrative ground improvement operations have a potential to cause pollution. The six scenarios considered are as follows:

1. Creation of preferential pathways, through a low permeability layer (an aquitard), to allow potential contamination of an underlying aquifer.
2. Creation of preferential pathways, through a low permeability surface layer, to allow upward migration of landfill gas, soil gas or contaminant vapours to the surface;
3. Direct contact of site workers and others with contaminated soil arisings which have been brought to the surface;
4. Direct contact of the piles or engineered structures with contaminated soil or leachate causing degradation of pile materials (where the secondary effects are to increase the potential for contaminant migration);
5. The driving of solid contaminants down into an aquifer during pile driving; and
6. Contamination of groundwater and, subsequently, surface waters by concrete, cement paste or grout.

1.2 Methodology

Risk severity is calculated by multiplying a probability of a hazard occurring by the consequence of that hazard to the project:

$$\text{Risk rating (R)} = \text{Probability (P)} \times \text{Consequence (C)}$$

Probability (P)	Scale
Probable	4
Likely	3
Unlikely	2
Negligible	1

Consequence (C)	Scale
Very High	4
High	3
Low	2
Very Low	1

Probability (P)	Scale	Consequence (C)	Scale
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Table 1-1 Scales of hazard probability and consequence

Hazard probability and impact are assigned numeric values (scales) in order to define the risk rating, see Table 1-1 and Table 1-2, respectively.

Risk Rating	Risk Level	Action required
1 to 4	Trivial	None
5 to 8	Significant	Consider attention
9 to 12	Substantial	Attention required
13 to 16	Intolerable	Unacceptable

Table 1-2 Risk ratings and actions required in order to manage risk

It is possible to reduce the risk from hazards by applying mitigation measures. The geotechnical risks associated with the project as anticipated at this stage and possible mitigation measures are shown in Table 1-3. If the risk rating is deemed to be greater than 5 or 'significant', as defined in Table 1-2, appropriate mitigation measures should then be applied to that risk. Mitigation measures can either reduce the probability of a hazard occurring, reduce its severity of consequence, or do both, which in turn reduces the final risk rating.

1.3 Conclusion

As can be seen from table 1.3 there are no risks that have been assessed as greater than 5 or 'significant'. Therefore no further mitigation is required for the piling works at the proposed Hyde Park, Hayes development.

1.4 References

Environment Agency (2001). Piling and penetrative ground improvement methods on land affected by contamination: guidance on pollution prevention.

Environment Agency (2006). Piling in layered ground: risks to groundwater and archaeology.

Hazard	Consequence	Risk Level before Mitigation			Mitigation	Risk Level after Mitigation		
		P	C	R		P	C	R
Creation of preferential pathways, through a low permeability layer (an aquitard), to allow potential contamination of an underlying aquifer.	Potential pollution of an aquifer	1	4	4	No action is required as pollutants are already present in Lynch Hill gravel formation which has been classified by the Environment Agency as a Major Aquifer and piles will not penetrate the low permeability London Clay into deeper aquifers.	1	4	4
Creation of preferential pathways, through a low permeability surface layer, to allow upward migration of landfill gas, soil gas or contaminant vapours to the surface;	Human health hazard due to gas or vapours	4	1	4	Given that Lynch Hill Gravel and London Clay formations (piling termination layer) are already contaminated and that the porosity of Lynch Hill Gravel is higher than that of the piling material no creation of a preferential pathways will be caused by construction of piled foundations. In addition, good adhesion between pile shaft and London Clay is anticipated (and required for effective pile design) therefore no new pathway is created by insertion of piles.	4	1	4
Direct contact of site workers and others with contaminated soil arisings which have been brought to the surface;	Intoxication	2	4	8	Contractor to assess potential human contact with vinyl chloride and other potential contaminants, provide adequate PPE and implement safe procedures for excavation, handling and disposal of spoil	1	4	4

Hazard	Consequence	Risk Level before Mitigation			Mitigation	Risk Level after Mitigation		
		P	C	R		P	C	R
Direct contact of the piles or engineered structures with contaminated soil or leachate causing degradation of pile materials (where the secondary effects are to increase the potential for contaminant migration);	Degradation of construction material	4	2	8	Quantity of sacrificial material or protection to be included in the design	4	1	4
The driving of solid contaminants down into an aquifer during pile driving	Pollution spread to an aquifer	1	4	4	No mitigation necessary as piles would be terminated in London Clay which is considered as Unproductive Stratum or an aquiclude	1	4	4
Contamination of groundwater and, subsequently, surface waters by concrete, cement paste or grout.	Contamination of groundwater and, subsequently, surface waters	4	1	4	No specific mitigation is necessary as the nearest surface water receptors is approximately 600m away, therefore even for a maximum average permeability of Lynch Hill Gravel calculated to be 20mm/s no risk of pollution from wet concrete is expected.	4	1	4

Table 1-3 Piling risk register