Wessex Water

BRISTOL WWTW; SECONDARY TREATMENT

Geotechnical Report

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BRISTOL WWTW; SECONDARY TREATMENT
GEOTECHNICAL REPORT

CONTENTS

1 INTRODUCTION

1.1 Terms of Reference

Following the submission of the factual report by Thyssen Geotechnical Ltd in January 1998, it was agreed that Halcrow would carry out a limited interpretation of the ground conditions. This report has therefore been prepared to provide a summary interpretation as agreed.

1.2 Site Description

It is proposed to construct a secondary treatment plant to augment the existing sewage treatment facilities at Wessex Water's Avonmouth Treatment Works. The plant is to be located within the boundary of the existing wastewater treatment works. The approximate National Grid reference of the site of the proposed secondary treatment plant is ST 534 797.

The site of the proposed plant lies immediately north east of the existing works. The site is approximately 6 hectares in extent, and rectangular in plan shape (about 300m x 200m). The ground surface is relatively flat and, on the basis of a survey plan supplied by WW, generally lies between elevations of 6.2 and 7.0m OD, rising slightly in the south western corner to some 7.5m OD.

The site is bounded to the north by a road and drainage ditch. To the south are buildings of the former Katherine Farm and other WW stores, and to the west is part of the existing WWTW. The eastern limit of the site is formed by the boundary fence adjacent to Lawrence Weston Road.

A fuller description of the site, including previous land usage (where known) is contained in the Desk Study Report (Halcrow, 1997).

1.3 Investigations and Reports

Descriptions of previous investigations at and adjacent to the site are contained in the Desk Study Report (Halcrow 1997).

In accordance with the recommendations of that report, a ground investigation was carried out at the site in November/December 1997. Thyssen Geotechnical Ltd was the Contractor. The fieldwork for the investigation comprised 27 cable percussion boreholes, of which 20 were continued into bedrock using rotary coring, and 8 trial pits. Six of the boreholes (BH 22, 23A and 24-27) were sunk outside the main site area, to investigate the routes of planned culverts. In situ tests were performed as appropriate, and piezometers and standpipes were installed in order to monitor groundwater and gas levels.

In addition to the fieldwork, a comprehensive programme of laboratory testing was performed on samples of soil and rock recovered from the boreholes and trial pits.

A factual report on the investigation was prepared by Thyssen Geotechnical Ltd, and this forms the basis for the preparation of this summary interpretative report.

2 GEOLOGY AND HYDROGEOLOGY

2.1 General

As reported in the Desk Study Report, the Geological Survey Sheet ST57NW, indicates that the site is underlain by drift deposits comprising estuarine alluvium, beneath which is Keuper Marl and Sandstone (now termed Triassic Strata of the Mercia Mudstone Group (MMG)). The boreholes from the Thyssen investigation confirmed this sequence, and also revealed evidence of glacial till beneath the alluvium in some areas. The thickness of the Triassic strata was also proved in one borehole.

2.2 Superficial Deposits

The investigation ascertained that the general ground conditions at the site comprise the following, in descending order from ground surface:

- Made ground, where encountered, between 0.1 and 3.2m thick, with a median thickness of 0.3m. This was encountered in 14 of the boreholes, and 10 of the trial pits. This material is generally described as firm/soft brown sandy silty clay with gravels of various lithologies. Some cobbles, bricks and broken concrete are recorded in the boreholes. Hydrocarbon odours were noted in TP1 and sewage remnants were observed in TP2, 2A, 4, 4A, 5 and 8.

- Estuarine alluvium was encountered in all the boreholes and every trial pit except TP8, which terminated in made ground. The alluvium varied in thickness between 13.2m and 16.7m with a median thickness of 15m. This corresponds to a base elevation of around -8.71m OD. The material was generally described as a soft grey/brown silty clay, although some areas of loose to dense silty fine sand were also encountered. Pockets and smaller traces of soft to firm brown peat were recorded within the alluvium throughout the thickness. Methane gas was occasionally found, primarily associated with peaty layers.

- Glacial till was recorded beneath the estuarine alluvium in 11 of the boreholes. The thickness of this material, where encountered, ranged between 0.35 and 1.2m with a median thickness of 0.75m. The base of the stratum lies at a median elevation of -9.56m OD. The till comprises a firm to stiff grey/ brown silty clay with some to much angular to sub-angular fine to medium gravel.

2.3 Solid Geology

Triassic strata of the Mercia Mudstones Group (Keuper Marl) underlie the site. The strata encompass the complete range of weathering zones IVb to I, after Chandler and Davies (1973). In broad terms, weathering decreases with depth, although, as is typical for this material, the decrease is not a uniform and linear one, preferential weathering along discontinuities leading to the formation of highly weathered zones in otherwise less weathered parent material. Typical descriptions for the different weathering zones encountered are:

- Zone IVa-IVb (completely to highly weathered); Firm to stiff red brown/grey green silty very sandy clay with sand to fine gravel sized siltstone lithorelicts.

- Zone III (moderately weathered); Reddish brown and greenish grey, indistinctly bedded sandy siltstone, very weak to weak. Generally recovered as a silty sandy clay with many mudstone lithorelicts.

- Zone II (slightly weathered); Reddish brown and greenish grey, indistinctly bedded, sandy siltstone, moderately weak to moderately strong.

- Zone I (unweathered); Reddish brown, indistinctly bedded, fresh sandy siltstone, moderately strong to strong.

Some small voids or vugs (up to about 50mm diameter), were recorded in the material in a number of the boreholes. These are believed to be due to leaching out of gypsum bands or nodules. This phenomenon was also noted in the Mercia Mudstones during the nearby investigations for the Second Severn Crossing (Halcrow, 1993).

The upper surface of the Mercia Mudstone lies between -7.22 and -10.64m OD. The general rockhead surface is at a median elevation of around -8.71m OD, low points, or hollows, in the rockhead being filled with glacial till and extending to a median elevation of 9.56m OD. The thickness of the completely to highly weathered layer (Zones IVa and IVb) is variable and somewhat difficult to ascertain. It should be noted that borehole records and the results of laboratory tests have not always been cross-matched in the factual report in respect of the weathering zone of the material. However, on the basis of the borehole records, this layer may be between some 1.9m and 5.6m in thickness, with a median of 2.8m (ref also Section 3).

Borehole 17 encountered the base of the Triassic strata at an elevation of -49.90m OD. Coal and mudrocks of Carboniferous age were then proved to the base of the borehole at -51.4m OD.

2.4 Hydrogeology

Information on ground water is available from drilling records, and from records of piezometer/standpipe installations in boreholes, which have been monitored between their installation and 6 January 1998.

During the period of monitoring, water levels in the Made Ground and Alluvium varied between 0.45m and 5.70m below ground level and were usually 2 to 3.5m below ground level

Six piezometers where installed in the upper part of the Mercia Mudstone, between 20m and 28m below ground level. Monitored water levels range between 12.8 m and 15.5m below ground level and were typically some 14m below ground level. Two additional piezometers were installed in the 'deep' boreholes, BH4 and BH17 at depths of 55.0m and 49.0m respectively. The deep piezometer in borehole 4 recorded water levels between 15.01m and 15.34m below ground level and averaged 15.3m. Water levels between 9.4m and 15.1m below ground level (and averaging 13.4m) were recorded in the deep instrument in borehole 17.

During the investigation, a number of groundwater samples were taken for chemical analysis. The results of the groundwater analyses are presented in Appendix B, Table 2. In the absence of other UK guidance it is common to compare groundwater sampling results to the Drinking Water Standards. When compared to the UK Drinking Water Standards many of the concentrations recorded were found to be elevated. However, the groundwater within the alluvial materials is not likely to be abstracted for drinking water, or indeed any other use.

Another point to note is that groundwater samples were only taken during drilling and cannot therefore be taken, necessarily, as representative of true groundwater conditions, beneath the site.

Due to the limited mobility of the groundwaters it is unlikely that the concentrations recorded will cause significant harm to human health or the environment.

3 MATERIAL PROPERTIES

3.1 General

The ground investigation has revealed a variety of soils and bedrock at the site, which have been categorised as follows:

- Made ground. As this is present over only part of the site and is generally less than about 1m in thickness, this had been grouped with the alluvium (see below) in terms of a discussion of the engineering parameters.
- Alluvium. This includes all the alluvial materials, ranging from silty sands to silty clays, including peat.
- Glacial Till.
- Completely and Highly Weathered Mercia Mudstone
- Mercia Mudstone

The results of laboratory and in situ tests performed on these materials to determine their characteristics are included in Thyssen Geotechnical Ltd's factual report, and are presented graphically on Figures 1 to 15.

3.2 Classification of Materials

3.2.1 General

This sub section presents an assessment of laboratory classification tests (BS1377 : Part 2 : 1990) for each strata with the aim of classifying the materials.

3.2.2 Classification of Made Ground and Alluvium

Particle size distribution analyses were performed on 4 samples of made ground and 33 samples of alluvium. The envelopes are presented on Figure 1. The made ground envelope ranges between a sandy gravel with cobbles to a sandy clayey silt. The alluvium range was from a slightly clayey silty sand to a slightly sandy silty clay. The median line indicates the material to be a slightly sandy clayey silt.

The results of 78 Atterberg limit tests performed on the made ground and alluvium are presented on Figure 3. A further 10 samples were non-plastic. The results generally plot above the 'A' line, indicating that the materials would behave as inorganic clays of predominantly intermediate to high plasticity, defined in accordance with BS5930 (1981). Liquid and plastic limits ranged from 32 to 73 % (median 48 %) and 17 to 35 % (median 22 %) respectively. The plasticity index ranged from 10 to 45 % with a median of 26 %.

The natural moisture contents of the made ground and alluvium are plotted against depth on Figure 5. This plot reveals the presence of a desiccated layer down to about 2m depth. In this layer, moisture contents (excluding the made ground as unrepresentative) ranged between 22 and 32 %, with a median of about 27 %. Beneath this depth, moisture contents covered a wide range, which may be indicative of variations in the grading of the material. Excluding 6 unrepresentatively low values, and 13 high values possibly indicative of peat, the general range was between 24 and 60 % with a median of some 42 %. The median moisture content of the material exceeds 1.2 x plastic limit, a value often adopted as the upper acceptability limit for general cohesive fill for intermediate to high plasticity clays. This would indicate that excavated material would not be acceptable as cohesive fill without pre-treatment.

In situ bulk densities reflected the findings of the moisture content determinations, in that noticeably higher values were obtained for the material above 2m depth, compared with the deeper materials (ref Figure 7). Values ranged between 1.8 and 2.05 Mg/m^3 above 2m depth, and between 1.3 and 2.13 Mg/m^3 below that depth. Some slight increase of density with depth may be apparent below 2m. The median value of 1.82 Mg/m^3 may be used in design.

Eight laboratory CBR tests were performed on 4 samples of alluvium. These indicated a range of 0.6 to 2 % with a median of 1.05 %.

3.2.3 Classification of Glacial Till

Two particle size distribution analyses on samples of glacial till (ref Figure 1) indicated the material to comprise a slightly clayey silt, sand and gravel.

One Atterberg limit determination was carried out. This gave a liquid limit of 53 % and a plastic limit of 30 %, with a plasticity index of 23 %. The material would be classified as an inorganic silt of high plasticity in accordance with BS5930 (1981).

Fifteen natural moisture content determinations were carried out. Excluding three non-typical results, these revealed a range of 11 to 44 % with a median of 25 %.

Thirteen bulk density determinations indicated a range of 1.73 to 2.17 Mg/m^3. Where appropriate, a median of 1.97 Mg/m^3 may be used. However, given the non-persistent nature of this stratum, and its limited thickness, the use of the median bulk density for completely and highly weathered Mercia Mudstone (1.88 Mg/m^3) is viewed as an acceptable simplification to represent this material.

3.2.4 Classification of Completely and Highly Weathered Mercia Mudstone

Particle size distribution analyses were carried out on 15 samples of this material, as shown on Figure 2. The envelopes indicated a range between a slightly sandy clayey silt and a slightly silty sand and gravel. The median grading would be a slightly clayey silt and sand.

Two Atterberg limit determinations were performed and are shown on Figure 4. Liquid limits ranged between 28 and 48 %, and plastic limits ranged between 14 and 20 %. Plasticity index ranged between 14 and 28 %. Both samples plotted above the 'A' line, which would classify them as inorganic clays of low to intermediate plasticity according to BS5930 (1981).

Natural moisture contents were determined for 28 samples, and these are plotted against depth ('soil tests') on Figure 6. The range was from 13 to 36 % with a median of 30 %.

Bulk density was determined for 24 samples and is plotted against depth ('soil tests') on Figure 8. The range was from 1.73 to 2.14 Mg/m^3. The median value of 1.88 Mg/m^3 is appropriate for design.

3.2.5 Classification of Mercia Mudstone

Moisture contents were determined for 28 samples of rock core. These ranged between 3.8 and 11 % with a median of 5.9 %. The values are plotted with depth ('rock' tests) on Figure 6.

Bulk and dry densities were determined for 19 samples of rock core. The ranges for these were 2.12 to 2.51 Mg/m^3 (median 2.41) and 1.98 to 2.45 Mg/m^3 (median 2.3 Mg/m^3) respectively. The results are plotted with depth ('rock tests') on Figures 8 and 9.

3.3 Strength of Materials

3.3.1 General

This sub section presents an assessment of the laboratory shear strength tests (BS1377 : Parts 7 & 8 : 1990) and strengths determined from in situ tests, for each category of soil with the aim of determining geotechnical parameters for use in the design of cut slopes, temporary works and foundations.

3.3.2 Strength of Alluvium (and Made Ground)

Undrained strengths were determined by triaxial testing in the laboratory (202 specimens) and also in situ using field vanes. Values of c_u were also derived following the procedures described in CIRIA (1995) from the results of standard penetration testing, adopting the factor f_1 = 5 based on the median plasticity index of the deposits. The test results and derived strengths are plotted on Figure 10. For the design of permanent works, the use of lower bound parameters would be appropriate:

Depth 0-2m c_u = 20 kPa

Depth 2-14m c_u = 10 kPa

Depth 14-18m c_u = 10+(10(d-14)) kPa

where d = depth below ground surface in m

For the design of temporary works, where the use of median parameters may be appropriate, the following parameters would be valid:

Depth 0-2m c_u = 50 kPa

Depth 2-14m c_u = 30 kPa

Depth 14-18m c_u = 30+(10(d-14)) kPa

where d = depth below ground surface in m

Effective stress testing was carried out on 24 samples of alluvium. Figure 13 shows the results of these tests, plotted as normal stress versus shear stress. From the figure, the effective shear strength of the alluvium may be defined by a line as follows:

c' = 0 kPa ϕ' = 30 °

This figure is reasonably consistent with effective strength inferred on the basis of the plasticity test data. For a median plasticity index of 26 %, the angle of drained shear would be 27-28°. This correlation assumes that the effective cohesion intercept is 0 kPa, which is reasonable for a normally consolidated clay (Carter and Bentley (1991)). The design parameters may therefore be taken as derived above from Figure 13.

3.3.3 Strength of Completely and Highly Weathered Mercia Mudstone

Undrained strengths were determined by triaxial testing in the laboratory (15 specimens). Values of c_u were also derived following the procedures described in CIRIA (1995) from the results of standard penetration testing, adopting the factor f_1 = 5.2 based on the median plasticity index of the deposits. The test results and derived strengths are plotted on Figure 11. It may be noted that the test results from the laboratory tests all indicate lower strengths than those indicated by the SPT's. This is considered to be due to the effects of sample disturbance both on sampling, and on preparation of the 38mm diameter test samples. A further point is that the test data indicate a change from completely/highly weathered material to less weathered rock at about 2-2.5m into the Mercia Mudstone. This is consistent with the classification tests (ref Figures 6,8 and 9), and slightly different from the same boundary interpreted from descriptions on the borehole records, which indicates a median depth into rock of 2.8m for the interface (ref Section 2.3). The lower bound line on the plot would indicate strengths of around 50 kPa at rockhead, increasing to 125 kPa at a penetration of 2.5m. This would be consistent with descriptions of the material as 'firm' becoming 'stiff'. For design purposes therefore, the strength may be defined by:

Depth below rockhead <2.5m $\quad c_u = 50+30d$ kPa

where d = depth below rockhead in m

3.3.4 Strength of Mercia Mudstone

Undrained strength (c_u) was determined for the Mercia Mudstone by means of correlation with SPT data using the method described in CIRIA (1995). The value of f_1 was 5.2 based on the plasticity test data for the completely and highly weathered material. The results are shown on Figure 11. The use of lower bound parameters would be appropriate for design, using the envelope shown on Figure 11, which is defined by:

Depth below rockhead >2.5m $\quad c_u = 250+45(d-2.5)$ kPa

where d = depth below rockhead in m

A median line would be defined by:

Depth below rockhead >2.5m $\quad c_u = 500+118(d-2.5))$ kPa

where d = depth below rockhead in m

Uniaxial compressive strength tests were carried out on 14 samples of rock core. Moisture contents averaged 6.25% for the test specimens, compared with 5.9% obtained from a larger number of classification tests (ref Section 3.). This indicates that the specimens were tested at moisture contents comparable with in situ conditions. In addition, 62 axial and 59 diametral point load tests were performed on specimens of selected rock core. Using the correlation of Broch and Franklin (1972), inferred uniaxial compressive strengths were obtained from these tests. Figure 14 shows the test results plotted with depth into Mercia Mudstone, diametral point load test results having been excluded for clarity. The plot shows a considerable degree of scatter, particularly within the zone down to some 15m penetration, which may be of most significance to the design of foundation piles. The plot may show some evidence of a slight reduction in strength with depth, the samples from the depth range 23-40m showing less scatter than the shallower samples, and grouped around 10 MPa. Taking account of these factors, a reasonable design compressive strength may be defined by:

UCS = 10 MPa

A median strength would be 16 MPa. This would classify the material as moderately strong in accordance with BS5930 (1981), and compares with a median strength of 16.6 MPa reported for Trias Mudrocks in the investigations for the Second Severn Crossing (Chambers et al (1995)).

Triaxial tests were carried out on 9 samples of Mercia Mudstone core. These indicated intact shear strengths defined by:

$c' = 0$ kPa $\qquad \phi' = 76°$

These were somewhat higher than the values of intact strength of 0 kPa, 51° obtained for Trias Mudrocks in the Second Severn Crossing investigations (Chambers et al (1995)). This may be explained by the relatively sandy nature of much of the 'mudstone' at this site.

No discontinuity shear strengths were measured as this property is not of significance to the proposed works at this site.

3.4 Consolidation and Deformation Characteristics

3.4.1 General

This sub section presents an assessment of the laboratory consolidation tests (BS1377: Part 5 : 1990) for each category of soil with the aim of determining geotechnical parameters for use in the assessment of the stress-strain response of the ground and evaluation of settlements resulting from imposed loadings. Deformation properties determined for the Mercia Mudstone bedrock in accordance with the ISRM Suggested Methods (1981) are also discussed.

3.4.2 Consolidation Characteristics of Alluvium

Sixteen specimens of alluvium were tested to determine their one-dimensional consolidation properties in an oedometer. In compression, the values of the coefficient of volume compressibility m_v ranged between 0.04 and 1.0 m^2/MN, with a median value of 0.58 m^2/MN. Testing of similar materials from the Second Severn Crossing site yielded a median of 0.57 m^2/MN (1996). An m_v of 0.58 would classify the material as being of high compressibility (Tomlinson (1995)). On unloading, the applicable m_v range was 0.007 to 0.38 m^2/MN, with a median of 0.056 m^2/MN. Coefficients of consolidation were in the range 0 to 39 m^2/yr (median 1.95) for compression and 0.13 to 79 m^2/yr (median 9.3) for expansion. Care should be exercised in the application of laboratory c_v values to the field situation, as laboratory derived coefficients of consolidation may give poor predictions of field consolidation times owing to the effects of soil fabric and sampling techniques (Jones et al (1986)). In practice, consolidation occurs more quickly than is inferred from the laboratory test data.

3.4.3 Deformation Characteristics of Completely to Highly Weathered Mercia Mudstone

Eight specimens of completely to highly weathered Mercia Mudstone were subjected to oedometer testing in order to determine their one-dimensional consolidation properties. In compression, the values of the coefficient of volume compressibility m_v ranged between 0.065 and 0.29 m^2/MN, with a median value of 0.10 m^2/MN. This would classify the material as low to medium compressibility in accordance with Tomlinson (1995). On unloading, the applicable m_v range was 0.008 to 0.019 m^2/MN, with a median of 0.01 m^2/MN. Coefficients of consolidation were in the range 4.3 to 58 m^2/yr (median 10.1), for compression and 3.4 to 130 m^2/yr (median 44) for expansion.

3.4.4 Deformation Characteristics of Mercia Mudstone

Of the 14 uniaxial compressive strength tests carried out on samples of rock core, 5 were instrumented with strain gauges in order to measure stress-strain response. The median value of Young's modulus was 6700 MPa. The values of Young's modulus so obtained are only representative of the intact rock material owing to the small sample size. In order to apply these data to the field situation, a mass factor 'j' needs to be applied. On the basis of the descriptions on the borehole records, the use of 'j' = 0.2 would be appropriate. This would result in a median Young's modulus for the rock mass of 1340 MPa. Five Poisson's Ratio determinations indicated a median of 0.22.

3.5 Chemical and Contamination

3.5.1 General

This sub section presents an assessment of the chemical and contamination tests for each category of soil with the aim of determining relevant parameters for use in the chemical assessment of the ground and the evaluation of any necessary protective/remediation measures. This section is intended to present a brief summary and discussion and is not intended to provide a full assessment of the results. Summary statistics of the soil and groundwater sampling results are shown in Appendix B, Tables 1 and 2 respectively.

3.5.2 Chemical and Contamination Characteristics for Made Ground and Alluvium

Five pH determinations were carried out on samples of made ground. These indicated generally neutral conditions, with a median pH of 7.05. Determination of soluble sulphate content was also carried out on 5 samples of the material. These ranged between 0.06 and 0.17 g/l, with a median of 0.12 g/l. On this basis, and using BRE Digest 363, this would mean that concrete in contact with the made ground may be of Class 1 or possibly 2 as defined therein.

Eighteen pH tests carried out on samples of alluvium also indicated near neutral conditions, with a range of 6.1 to 8.2, and a median of 7.1. Soluble sulphate determinations carried out on 18 samples yielded a range from 0.04 to 0.19 g/l, with a median value of 0.095 g/l. On this basis, and using BRE Digest 363, this would mean that concrete in contact with the made ground may be of Class 1 or possibly 2 as defined therein.

Soil samples have been compared where possible to existing UK guidance values (ICRCL 59/83, open space/landscaped areas threshold values). Where values do not exist they have been compared to natural background values (Berrow and Burridge 1980) and the Dutch guideline intervention values. Although not developed for the UK, and therefore not necessarily representing the UK political perspective, these are used to represent a comparative value; the intervention value is used.

To summarise the data, several statistical methods have been used. These include the standard descriptive statistics of, maximum, minimum, and mean, along with the Upper Confidence Limit (UCL) of the mean (USEPA 1989). This last statistical method calculates the maximum likely mean of the sample based on the sample, number and standard deviation. This method is used to assess the likely upper mean of the sample for comparison to guideline values. To clarify, should the sampling exercise be repeated, the mean of the sample should not exceed the UCL calculated from this sampling exercise.

Table 1 (Appendix B) presents the sample statistics. Several samples were found to have elevated maximum concentrations (boron, zinc, iron), although only one contaminant, zinc, is consistently raised in several samples. Indeed, the UCL of the zinc sample is raised above the ICRCL threshold.

3.5.3 Chemical and Contamination Characteristics for Completely and Highly Weathered Mercia Mudstone

Two pH determinations on samples of this material indicated a median pH of 6.85. Soluble sulphate determination yielded a maximum value of 0.15 g/l and a median value of 0.125 g/l. Using BRE Digest 363, this would mean that concrete in contact with the made ground may be of Class 1 or possibly 2 as defined therein.

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

This report has interpreted the findings of a ground investigation carried out by Thyssen Geotechnical Ltd at the proposed Secondary Treatment site in November/December 1997. The overall level of knowledge in relation to the ground and groundwater conditions at the site may be regarded as adequate for outline and detailed design of permanent and temporary works in connection with the proposed works.

It is understood that this report is to be used in order to assess the design proposals put forward by contractors tendering for the design and construction of the Secondary Treatment works. The conditions at the site have been assessed, and geotechnical design parameters derived to enable designs by others to be reviewed. This report should not be viewed as a comprehensive interpretation.

In respect of the ground and groundwater conditions, the key factors which are likely to affect the design and construction of the proposed Secondary Treatment works may be summarised as follows:

- The site is underlain by superficial deposits comprising made ground, alluvium and glacial till. These deposits are variable in thickness, with the made ground and glacial till being apparently not laterally continuous. Beneath the superficial deposits is Mercia Mudstone of Triassic age, which overlies Carboniferous strata at a depth of some 50m below ground level. The Mercia Mudstone ranges from completely weathered to fresh, using the classification of Chandler and Davies (1973).

- The made ground and, in particular, the alluvium, is weak and highly compressible. These shallow deposits are considered to be unsuitable as founding strata for anything but very lightly loaded single storey structures, tolerant to significant degrees of differential settlement.

- Deep foundations are likely to be needed in order to transmit foundation loads to a suitable stratum to reduce the total and differential settlements of structures to acceptable levels. Consideration could be given to systems incorporating piles, piers and possibly buoyancy rafts. On consideration of the materials at the site, and drawing on experience at the nearby Second Severn Crossing, bored piles socketted into Mercia Mudstone may provide an appropriate design solution. On the basis of the investigation data, the upper 2-3m of the mudstone may be completely to highly weathered, and offer little support for piles. Variations in the thickness of this weathering zone should, however be anticipated as shown by the borehole records. Voids up to some 50mm in size have been encountered within the Mercia Mudstone (below the completely to highly weathered zone), and the design load capacities of piles, particularly in end bearing, should take this into account. This would also apply to driven piles, where end bearing may be a significant proportion of the total pile capacity.

- It is understood that the current proposals for the Secondary Treatment works include large tanks, possibly up to 8m below existing ground level. The construction techniques likely to be required include sheet piling, bored/driven piling, ground anchoring and dewatering. On the basis of the investigation findings, it is unlikely that excavated alluvium would be acceptable as fill material (other than possibly for landscaping purposes) without pre-treatment.

- Groundwater lies within the alluvium, and also a separate water table is present in the bedrock. The design of tanks and other submerged structures should take account of potential uplift effects, both during and post-construction. The dual use of piles, in compression and tension (dependent on loading conditions) may be appropriate.

- Geochemical analyses indicate elevated Boron and Zinc concentrations. However, these are considered to represent very little risk to the development as the ICRCL threshold values are based on phytotoxic (toxicity to plants) risk and therefore, in the concentrations found on this site, do not represent significant risks to human health or the environment. If significant landscaping is planned as part of this development, the advice of a plant specialist regarding the zinc and boron concentrations should be sought.

- The iron concentration found to be raised above natural background concentrations in one sample presents no significant risk to the development.

- If representative of the site as a whole, the raised concentrations of Oils and Grease, and Cadmium may present a risk to human health and/or the environment. However, as they were only recorded in one sample, and the UCL is very much lower than available guidance values, it is thought that they do not present significant risk to the development.

- Should soil need to be disposed of it is likely that the majority of the soil and made ground on site would be classified as non-hazardous industrial waste, although waste regulations will require monitoring of the waste arisings, and some areas of site may be classed as hazardous industrial waste. Consultation with the Environment Agency will be needed to confirm this.

- The main implication to the development identified from the chemical analyses is that groundwaters, if abstracted during the works may not be allowed to be disposed directly to surface water.

- Monitoring of standpipes in some of the boreholes indicates that the alluvium may be the source of methane gas, which was encountered during the investigation, caused by the decay of peat and other plant matter within the stratum. Dependent on the form of the structures proposed for the site, gas protection measures may be needed in order to prevent methane from entering and collecting in confined spaces.

4.2 Recommendations

The recommendations in respect of geotechnical aspects pertaining to the design and construction of the proposed Secondary Treatment works are as follows:

1. Piles or other deep foundations are required to support all substantial structures. These should be founded in the Mercia Mudstone. The design of these piles should take account of weathering and voiding within the mudstone.

2. The design and construction of both permanent and temporary works needs to take account of possible uplift effects owing to the groundwater in the alluvium.

3. Gas protection measures should be incorporated into structures as appropriate.

4. Construction works at the site should take account of possible localised contamination within the made ground and upper levels of the alluvium, namely raised concentrations of oils and grease and cadmium.

5. Appropriate techniques for disposal or treatment of excavated material should be addressed prior to construction commencing. Liaison with the EA would be useful in this regard.

6. Proposals for dewatering during construction should address potential effects on any adjacent services or structures (other than those founded on piles), as well as possible treatment needed for the groundwater prior to disposal. Further sampling and interpretation of the groundwater, along with consultation with the Environment Agency is recommended.

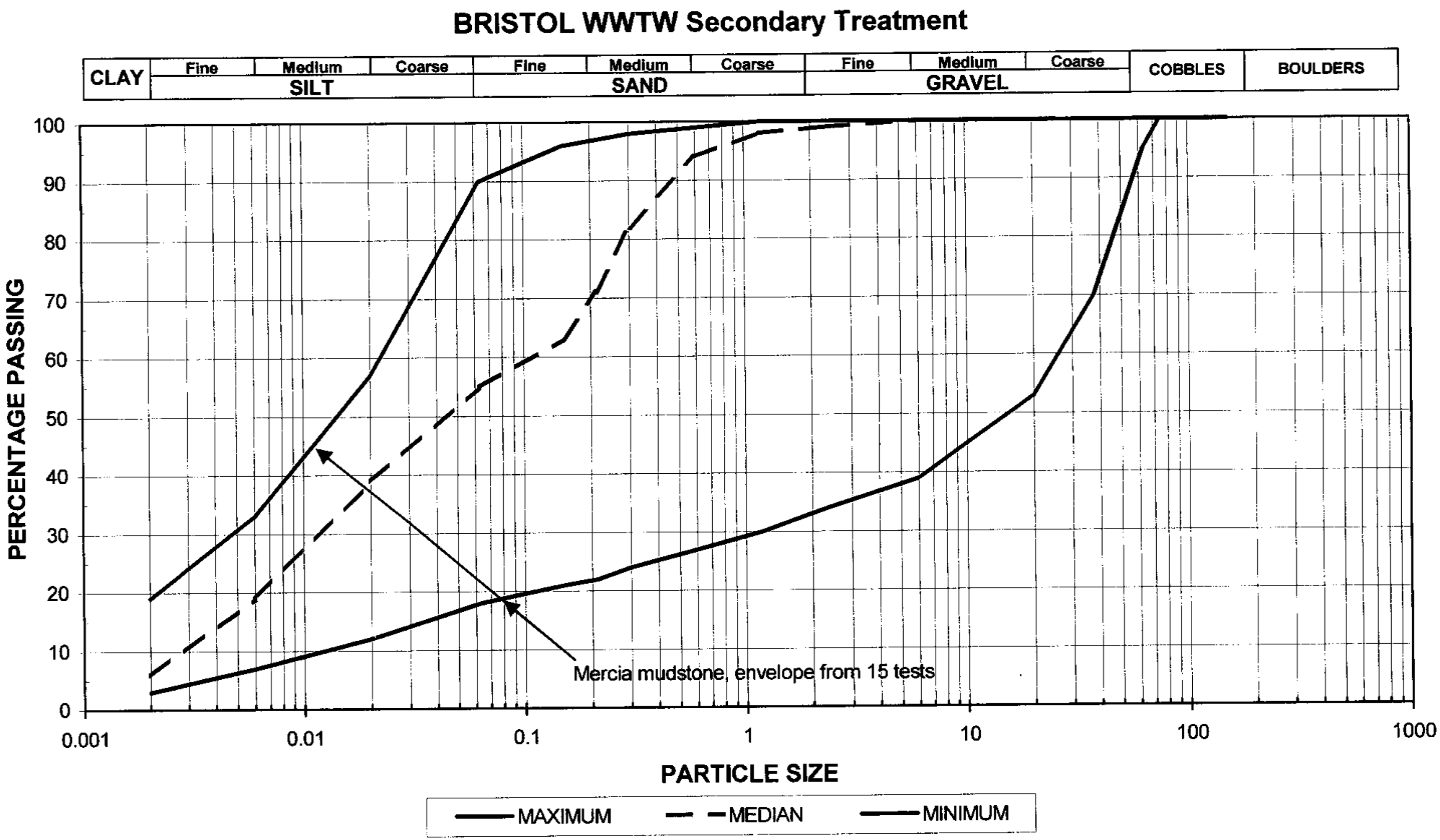

Figure 2 : Particle Size Distribution for Mercia Mudstone

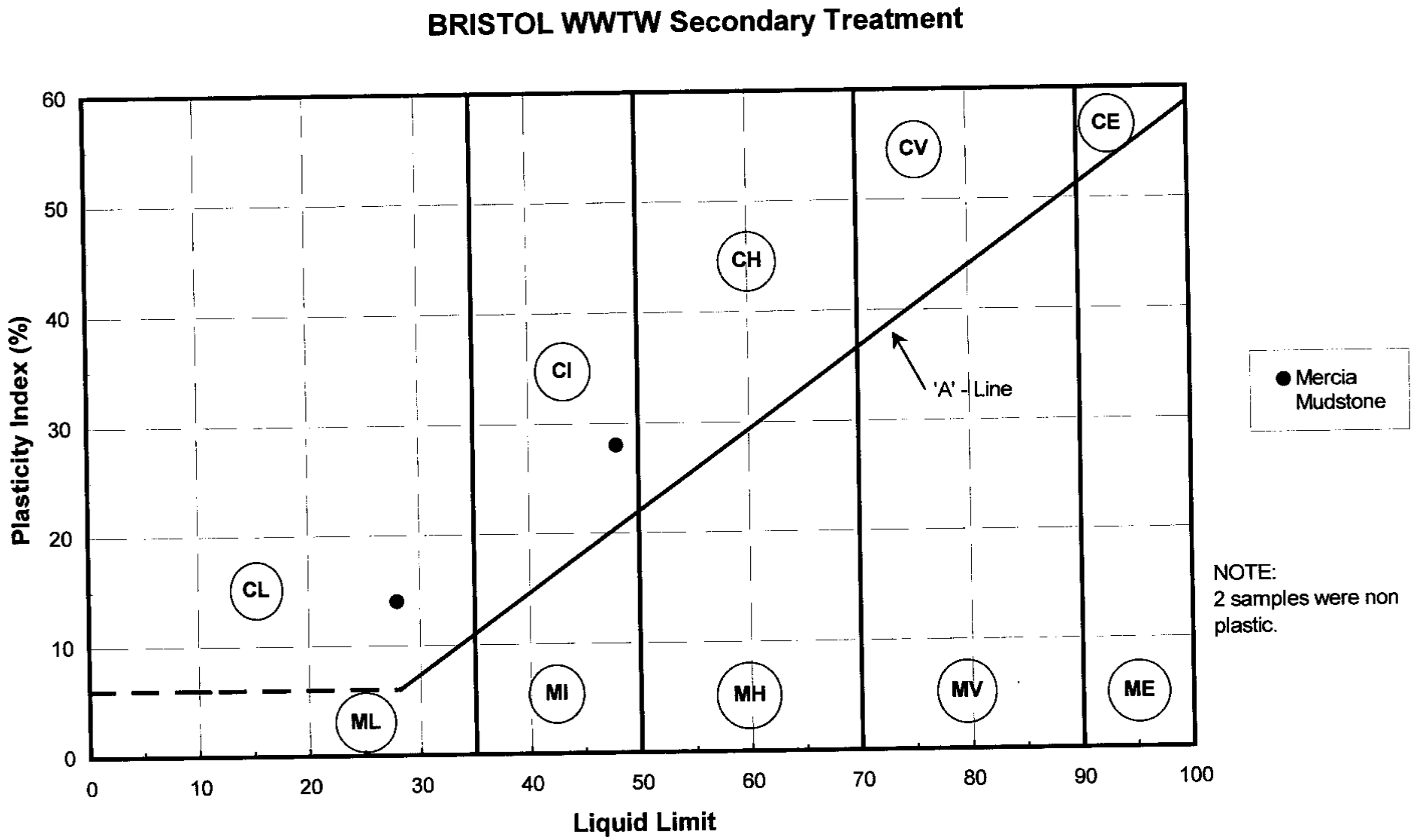

Figure 4 : Plasticity Chart for Mercia Mudstone

Appendix A References

1. Proposed Secondary Treatment Plant, Desk Study Report. Halcrow 1997

2. Bristol Waste Water Treatment Works; Ground Investigation Factual Report, Report No L70001. Thyssen Geotechnical Ltd. January 1998

3. British Geological Survey, Sheet ST57NW, 1:50,000, Solid and Drift

4. 'Further Work on the Engineering Properties of Kueper Marl.' CIRIA Report 47. Chandler R J and Davies A G,1973

5. BS5930; British Standard Code of Practice for Site Investigations. British Standards Institute. 1981

6. BS1377; British Standard Methods of Test for Soils for Civil Engineering Purposes. British Standards Institute. 1990

7. The Standard Penetration Test (SPT): Methods and Use; CIRIA Report 143. Clayton C R I, 1995

8. Correlations of Soil Properties. Carter M and Bentley S P. Pentech Press 1991

9. Chambers S, Maddison J D, Thomas A and Jones D B. 'Investigations in Trias Strata for the Second Severn Crossing.' XI European Conference on Soil Mechanics and Foundation Engineering. Copenhagen, 1995

10. BRE Digest 363; Sulphate and acid resistance of concrete in the ground. January 1996

11. Jones D B, Beasley D H and Pollock D J. 'Ground treatment by surcharging on deposits of soft clay and peat: A case history.' Building on marginal and derelict land. Thomas Telford Ltd 1986

12. Foundation Design and Construction. Tomlinson M J, Longman Scientific and Technical, 6th Ed 1995

13. Maddison J D, Jones D B, Bell A L and Jenner C G. 'Design and performance of an embankment supported using low strength geogrids and vibro concrete columns.' First European Geosynthetics Conference, Maastricht, 1996.

14. Rock Characterisation Testing and Monitoring. ISRM Suggested Methods. E T Brown 1981

15. 'Guidance on the assessment of redevelopment of contaminated land.' Interdepartmental Committee on the Redevelopment of Contaminated Land. ICRCL 59/83. DoE, 1987, 2nd Ed

16. Berrow M L and Burridge J C . 'Inorganic Pollution and Agriculture.' MAFF reference book 326 pp159-183. HMSO, 1980

17. Soil Clean Up Guidelines. Dutch Ministry of Housing, Physical Planning and the Environment, The Hague (SDU). Revised 1987

18. Broch E and Franklin J A. 'The Point Load Strength Test.' Int J Rock Mech. Min. Science, Vol 9 pp669-697. 1972

Table 1 – Soil Analysis

Sample Number	Units	ICRCL*	Maximum	Minimum	Mean	Standard Deviation	95% UCL	99% UCL
Arsenic	mg/kg	40	26	2	11.9	5.2	13.1	13.7
Selenium	mg/kg	6	1	1	1.0	0.0	1.0	1.0
Water soluble Boron	mg/kg	3	**8.6**	0.4	2.1	1.4	2.4	2.6
Total PAH	mg/kg	1000	62	10	13.9	11.4	16.6	17.8
Asbestos		0						
Total Extractable Oil and Grease	mg/kg	5000**	**6820**	27	250.7	1084.2	552.8	696.4
Cyanide	mg/kg	250/100***	0.9	0.5	0.7	0.1	0.7	0.7
Cadmium	mg/kg	15	**36**	1	3.6	6.2	5.1	5.8
Chromium	mg/kg	1000	69	1	30.0	12.0	32.8	34.2
Copper	mg/kg	130	109	1	11.1	18.4	15.5	17.5
Mercury	mg/kg	20	1.3	0.1	0.2	0.2	0.2	0.2
Nickel	mg/kg	70	49	5	27.9	10.8	30.5	31.7
Lead	mg/kg	2000	1650	15	95.6	230.1	150.0	175.9
Zinc	mg/kg	300	**2490**	56	**339.6**	477.7	**452.7**	**506.5**
Iron	mg/kg	40000****	**47900**	2900	28697.6	9532.1	30954.6	32027.4
Dried solids	%		96.2	53.3	76.3	6.2	77.8	78.5
Coal Tar- Semi Quantitative			650	60	163.5	152.8	232.2	264.8
TPH by IR			83.9	25	41.1	15.6	48.1	51.5

* Open space threshold value
** Dutch Mineral Oil Threshold
*** Complex/Free
**** Natural Background (Berrows and Burridge, 1980)

Table 2 – Groundwater Analysis

Sample Number	Units	UK Drinking Water Standards	Maximum	Minimum	Mean	Standard Deviation	95% UCL	99%UCL
Mercury	ug/l	1	4.46	0.02	0.6	1.4	1.5	1.9
Cyanide	mg/l	0.05	0.01	0.01	0.0	0.0	0.0	0.0
Copper	mg/l	3	1.7	0.01	0.4	0.5	0.7	0.8
Zinc	mg/l	5	24	0.03	4.4	7.7	8.6	10.7
Cadmium	mg/l	0.005	0.2	0.005	0.0	0.1	0.1	0.1
Boron	mg/l	2	2.66	0.2	1.3	1.0	1.9	2.1
Lead	mg/l	0.05	19	0.05	3.2	6.1	6.5	8.1
Arsenic	mg/l	0.05	0.135	0.005	0.0	0.0	0.1	0.1
Chromium	mg/l	0.05	0.26	0.03	0.1	0.1	0.1	0.2
Selenium	mg/l	0.01	0.007	0.002	0.0	0.0	0.0	0.0
Iron	mg/l	0.2	242	0.11	80.7	105.4	138.6	166.2
Nickel	mg/l	0.05	0.41	0.003	0.1	0.2	0.2	0.3
Total Extractable Oil and Grease	mg/l	0.01	69.3	27.6	48.5	29.5	84.7	102.0
Persistent Mineral Oil	mg/l	0.01	3.26	3.17	3.2	0.1	3.3	3.3
Total PAH	mg/l	0.0002	1	1	1.0	0.0	1.0	1.0