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Ground Movement Assessment Report

Middlesex Hospital Annexe

Middlesex Annexe LLP

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	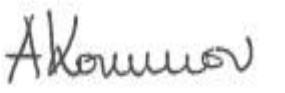		
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Revision History

Revision	Revision date	Details	Authorized	Position
01	21/04/2017	First Issue	Gary Kellett	Associate Director
02	24/04/2020	Second Issue	Alexander Conrad	Associate Director
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1 Introduction

1.1 Aim of the Report

AECOM has been commissioned by the Middlesex Annexe LLP to provide civil and structural engineering advice in relation to the proposed redevelopment of the Middlesex Hospital Annexe in London. As part of this appointment, historical site investigation data and site-specific data obtained in 2018 and 2020 Ground Investigations performed by Concept, have been reviewed to obtain information on the ground and groundwater conditions. In support of the Basement Impact Assessment, this Ground Movement Assessment report has been prepared and updated. It sets out the assessment methodology to determine the impact of the proposed basement construction on adjacent buildings, considering the effects of installation of the perimeter retaining wall, excavation down to basement level B1 and to part level 2 basement (B2) and subsequent structural loading, and to present in detail the analysis results. It should be noted that the effect of temporary works, other than temporary wall props, has not been assessed in the analysis, as this is the responsibility of the Contractor.

1.2 Report Objectives

The main objectives of the report are listed below:

- Describe the setting of the site
- Summarise the underlying geology and hydrogeology
- Reference the conceptual site model of the ground and groundwater conditions at the site
- Report the geotechnical parameters for the analysis of the proposed basement development
- Describe details of the basement development, including the methods of excavation and construction advised by the Contractor
- Summarise details of the geotechnical analyses carried out to estimate ground movement associated with the installation of the perimeter retaining wall, the excavation to basement levels B1 and B2 and the subsequent structural loading from the superstructure
- Identify neighbouring structures to be affected by the proposed works
- Consider the impact of the proposed basement development on the surrounding buildings

1.3 Sources of Information

The following source of information has been referred to in the preparation of this report:

- AECOM (2016) *Phase 1 Geotechnical and Geo-environmental Desk Study Report*. Middlesex Hospital Annexe, Issue 2 8th December 2016, 60516144/DS/002.
- AECOM (2017) *Geotechnical and Geo-environmental Interpretative Report.* Middlesex Hospital Annexe, 8th April 2017, 60516144/GIR/001.
- AECOM (2017) *Site Investigation Data Report.* Middlesex Hospital Annexe, 8th April 2017, 60516144/SIR/01.
- AECOM (2020) *Geotechnical and Geo-environmental Interpretative Report*. Middlesex Hospital Annexe, Issue 1 26th March 2020, 60516144/GIR/001.
- Concept Consultants Limited (2020) Site Investigation Report, Middlesex Hospital Annexe, 19/3355-FR-01 Issue 00 March 2020.
- Concept Consultants Limited (2018) Site Investigation Report, Middlesex Hospital Annexe, 18/3104-FR-01 Issue 01 July 2018.
- AECOM (2018) *Basement Impact Assessment Report*. Middlesex Hospital Annexe, Issue 4 27th March 2018, 60516144/BIA/0014.
- AECOM (2017) *Preliminary Ground Movement Assessment Report.* Middlesex Hospital Annexe, 8th April 2017, 60516144/GMA/001.
- AECOM (2020) *Specification for Piling and Embedded Retaining Walls.* Middlesex Hospital Annexe, 20th April 2020, MHA-ACM-XX-SP-SE-0009.

- AECOM (2018) *Movements and Tolerances Specification.* Middlesex Hospital Annexe, 16th April 2020, MHA-ACM-XX-SP-SE-0007.
- ARUP (2012) *Piling Plan.* UCL Howland Street, 10th August 2012, ARP-S42-X-2-01.
- ARUP (2012) *Piling Schedule.* UCL Howland Street, 10th August 2012, ARP-S42-X-7-04.
- Michael Barclay Partnership (2016). *Piling Layout*. Astor College New Rear Extension, 3rd November 2016, MBP-6775-150-C1.

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The methodology adopted and the sources of information used by AECOM in providing its services are outlined in this Report. The work described in this Report was undertaken between **October** and **November 2020** and is based on the conditions encountered and the information available during the said period of time. The scope of this Report and the services are accordingly factually limited by these circumstances. AECOM disclaim any undertaking or obligation to advise any person of any change in any matter affecting the Report, which may come or be brought to AECOM's attention after the date of the Report.

The exploratory holes carried out during the 2018 and 2020 Ground Investigation works, which investigate only a small volume of the ground in relation to the size of the site, can only provide a general indication of site conditions. The comments made and recommendations given in this Report are based on the ground conditions apparent at the site of the exploratory holes. There may be exceptional ground conditions elsewhere on the site which have not been disclosed by this investigation and which have therefore not been taken into account in this Report. The comments made on groundwater conditions are based on observations made during site work and the monitoring programme. It should be noted that groundwater levels might vary owing to seasonal or other effects. Groundwater monitoring should continue throughout the construction of the basement box.

This report assesses adjacent buildings to the Middlesex Hospital Annexe. Party wall agreements and condition surveys are to be undertaken for buildings surrounding the site that may potentially be affected by the proposals. Party wall surveyors will be appointed in this respect and able to review the information relating to ground movements and stability of neighbouring structures. A programme of monitoring of the surrounding buildings during the construction works shall be agreed between parties and implemented by the contractor. Outline of the proposed monitoring is presented in this report which will need to be reviewed following completion of the condition surveys. For further details regarding the monitoring, reference shall be made to the Monitoring Specification carried out by AECOM (Reference: MHA-ACM-XX-SP-SE-0007).

The designs and assessments presented herein have been prepared using the information available at the time of the preparation of the report and on the basis of the stated assumptions. The responsibility for the detailed design of the basement retaining wall will remain the responsibility of the specialist contractors. The ground movement predictions are based on the Contractor's construction methods advised for this report. No consideration of temporary works, beyond simple propping arrangements, are made in the present report, which should be assessed by the Contractor. No external development has been considered in this assessment. Any demolition, excavation or construction in the vicinity of the site at the time of the construction will need to be considered as to whether this impacts the assessment. The predictions made are also highly dependent on the quality of workmanship employed. Therefore, actual movements could be different to the predicted movements.

The information, views and conclusions drawn concerning the site are based, in part, on information supplied to AECOM by other parties. AECOM has proceeded in good faith on the assumption that this information is accurate. AECOM accepts no liability for any inaccurate conclusions, assumptions or actions taken resulting from any inaccurate information supplied to AECOM from others.

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2 Site Description and Ground Conditions

2.1 Location

The site is located within the London Borough of Camden. It is approximately centered on National Grid Reference (NGR) 529262, 181811. A site location plan is presented in Figure 1**Error! Reference source not found.**.

2.2 Site Setting

The site is located on Cleveland Street, approximately 250m west of the Goodge Street London Underground Station.

The site boundary encloses an area of approximately 0.32ha. The site consists of North House located in the northwest corner of the site; South House located in the southwest corner of the site; and the Grade II listed Middlesex Hospital Annexe (the former Union Workhouse) located in the centre of the site with two wing buildings at the rear (already demolished at the time of writing this report).

The site is bounded by buildings with basements that vary in depth from single to double storey. Further details of buildings beyond the building footprint are provided for information in Figure 2. A below ground tunnel associated with the Union Work House building appears to connect with tunnels along Cleveland Street. Beyond the site the tunnel is assumed to be disused as the tunnel stops before the site boundary.

Relevant features immediately surrounding the site are summarised in Table 2-1.

Table 2-1: Features Surrounding the Site

Direction	Summary
North	The Sainsbury Wellcome Centre (UCL Howland Street) with Howland Street and the BT Tower beyond.
South	Middlesex House and the former Day Hospital on Tottenham Mews.
East	Astor College (Astor College Gym and Astor College Extension) with Charlotte Street beyond.
West	Cleveland Street with commercial units beyond.

2.3 Site Walkover Survey

A general inspection of the site was completed by an AECOM Engineer on 4th August 2016. The aim of the visit was to identify the range of activities carried out on the site and any obvious potential sources of ground contamination.

A full account of the visit is included in the Phase 1 report (AECOM, 2016). However, the most significant observations can be summarised as follows:

- Part of the site was managed by Camelot Property Management Ltd, namely part of the Union Work House building and its associated wings (already demolished at the time of writing the present report) and South House. These buildings were occupied by 'guardians' and could be accessed using a secure entrance on Cleveland Street.
- North House was used as a site office by Graham Construction for their site located opposite Middlesex House. A separate secure entrance for this part of the site was located on Cleveland Street.
- The Union Workhouse building consisted of four storeys and a single level basement. Its associated wing buildings (already demolished) consisted of three storeys. North House consisted of two to three storeys and a single level basement. South House consisted of three storeys.
- An enclosed courtyard was located between the wings of the Union Workhouse building. Overgrowth was evident around the courtyard.
- Skips containing household waste were present on site. An area containing general waste was observed to the south of the Union Workhouse building.
- A small tank was observed above a storage building in the southwest corner of the site. No bunding was present around the tank.

- The basement of the Union Workhouse building was unoccupied. Parts of the basement were damp with evidence of water on the floor. The basement mainly contained waste associated with former uses of the building, with a boiler room and pump room at the locations suggested by historical plans.

2.4 Geology

2.4.1 Geological Information from Published Information and Maps

The published 1:50,000 scale geological map of the area produced by the British Geological Survey (BGS Sheet 256, "North London", 2006) indicates the site is underlain by the following geological succession:

Table 2-2: Geological Succession from Published Mapping

Age	Geological Stratum
Quaternary	Lynch Hill Gravel
Eocene	London Clay Formation
Palaeocene	Lambeth Group
	Thanet Formation

The existing topography and history of development of the site suggests that, in addition to these natural strata, Made Ground may be present on the site.

2.4.2 Geological Information from BGS Records

All the available data from relevant BGS records in the vicinity of the site have been considered and are discussed in the relevant Phase 1 report (AECOM, 2016) and in the Ground Investigation Interpretive Reports (AECOM, 2018 and 2020).

2.4.3 Concept 2018 & 2020 Ground Investigations

The findings of the site-specific ground investigations undertaken by Concept in 2018 and in 2020 have been incorporated in this report. The stratigraphy of the site based on these findings is presented in Table 2-3. Figure 3 shows the locations of these ground investigations. For further information regarding the site-specific Concept GI data, reference should be made to the Concept Factual Reports (2018 & 2020) and the latest AECOM Ground Investigation Interpretive report undertaken in April 2020.

Table 2-3: Stratigraphy from Site Specific Ground Investigations

Stratum	Top Level of Straturm	
	Concept GI 2018 (mOD)	Concept GI 2020 (mOD)
Made Ground	+26.59 to +27.50	+24.53 to +26.75
Lynch Hill Gravel	+22.54 to +26.11	+21.20 to +22.90
London Clay Formation	+18.14 to +18.75	+18.75 to +20.30
Lambeth Group	+0.16 to +1.44	+1.70 to +1.75

2.5 Hydrogeology

2.5.1 Aquifer Classification

The EA's Groundwater Protection Policy adopts aquifer designations that are consistent with the Water Framework Directive. According to this system:

- The Lynch Hill Gravel is classified as a Secondary A Aquifer. These are permeable layers capable of supporting water supplies at a local rather than strategic scale, and in some cases forming an important source of base flow to rivers.

- The London Clay Formation is classified as a Unproductive Stratum. These are rock layers or drift deposits with low permeability that has negligible significance for water supply or river base flow.
- The site is underlain by the water-bearing Chalk-Basal Sands aquifer of the London Basin. There is hydraulic continuity between the Chalk and Thanet Formation and some continuity with the basal Lambeth Group units depending on the clay and sand content.

2.5.2 Vulnerability of Groundwater Resources

The EA's Groundwater Vulnerability Map of the area shows that the soils overlying the Secondary A Aquifer have a High Leaching Potential (U). The mapping indicates the site does not lie within a Source Protection Zone.

2.5.3 Site Characteristics

The anticipated depth to the water table in the Lynch Hill Gravel (Secondary A Aquifer), i.e. the thickness of the unsaturated zone, is anticipated to be in the order of a few metres. The regional direction of groundwater flow is expected to be to the south and southeast.

However, it is possible that localised perched water may also be present in the Made Ground.

2.5.4 Risk from Rising Groundwater Levels in the Deep Aquifer

The site lies within the critical areas in the London basin defined in CIRIA Special Publication SP 69 (Simpson and others, 1989) in which exceptional structures are potentially at risk from the rising groundwater levels in the deep aquifer.

With reference to the latest Environment Agency data, the estimated level of the potentiometric surface of the Basal Sands and Chalk aquifer in January 2018 was between -33.0 and -34.0mOD, and the latest reported rate of rise (between January 2017 and January 2018) is less than 1m per year.

2.5.5 Groundwater abstractions

According to the Envirocheck Report (2016), there are fifteen recorded groundwater abstractions and twenty for potable water supply within a 1km and 2km radius of the site respectively. The nearest licence is registered to Ridgeford Properties Ltd approximately 400m west of the site and used for industrial/commercial/public services.

2.5.6 Discharge Consents

The Envirocheck Report (2016) indicates that eight discharge consents are registered within a 1km radius of the site. The closest two entries are located 418m west of the site and relate to trade discharges of cooling water by Ridgeford Properties Ltd. The consents were issued in 2009 and 2013.

2.5.7 Groundwater Conditions

As part of the GI works undertaken by Concept Consultants Limited in 2020, a total of four standpipes have been installed within the River Terrace Deposits (RTD), Made Ground and London Clay Formation and were monitored. BH04 was screened within the Made Ground and River Terrace Deposits with response zones at depths between 1.00m and 3.00mbgl and 4.50m and 8.00mbgl respectively, whilst BH05 was screened with a response zone between 4.50m and 5.90mbgl within the River Terrace Deposits and between 18.00m and 20.00mbgl within London Clay Formation. As part of the GI works undertaken by Concept Consultants Limited in 2018, a total of six standpipes were installed within the River Terrace Deposits, London Clay Formation and Lambeth Group. BH01 was screened with a response zone between 2.80m and 8.90mbgl within the RTD and between 28.00m and 35.00mbgl within the Lambeth Group, in BH02 standpipes had a response zone between 4.10m and 9.10mbgl within the RTD and between 29.00m and 32.00mbgl within the Lambeth Group and in BH03 standpipes had a response zone between 4.30m and 8.70mbgl within the RTD and between 31.00m and 35.00mbgl within the Lambeth Group. Due to accessibility constraints, only BH01 installations were monitored during the recent GI.

Groundwater levels were measured over twenty-five monitoring rounds, thirteen between June 2020 and November 2020 in boreholes BH01, BH04 and BH05, six between February 2020 and March 2020 in boreholes BH01, BH04 and BH05 and six in June 2018 in boreholes BH01, BH02 and BH03. Groundwater was recorded between 4.81m and 6.69mbgl (i.e. between +22.84mOD and +20.06mOD) within the River Terrace Deposits, with a maximum level at +22.84mOD. Allowing for seasonal variation, and based on the 2018 monitoring, a groundwater level of +24.00mOD has been assumed in the geotechnical analyses for the Ultimate Limit States and +22.84mOD for the Serviceability Limit States with hydrostatic pressures below these levels[1]. This corresponds to approximately 4.81m below existing ground level. It is noted that groundwater levels can vary seasonally and in response to extreme weather conditions, and also in response to leakage from water and drainage pipework.

2.6 Hydrology

2.6.1 Surface Water Courses and Drainage

The nearest surface watercourse/feature to the site appears to be a fountain within Hanover Square located 780m southwest of the site.

The Lost Rivers of London (1992) suggests that the River Tyburn (now covered/culverted) is located approximately 1.1km west of the site.

The River Thames is located approximately 2km southeast of the site flowing in a north-easterly direction.

2.6.2 Flooding

The indicative floodplain map for the area, published by the EA, shows that the site does not lie within an area susceptible to risk of flooding from rivers and sea.

Environmental Simulations International (ESI) groundwater flood data indicate that the site is located within an area with a negligible risk of groundwater flooding. Any groundwater flooding incidence has a chance of less than 1 in 100 (<1%) probability of occurrence.

BGS flood data suggest that the site is located within an area with a potential for groundwater flooding of property situated below ground level.

2.6.3 Planning Policy for Flood Risk

The National Planning Policy Framework (NPPF) for England requires local planning authorities to take account of flood risk and the implications of climate change. It requires that inappropriate development in areas at risk of flooding should be avoided by directing development away from areas at highest risk, but where development is necessary, making it safe without increasing flood risk elsewhere.

Technical guidance on flood risk accompanies the NPPF and sets out how this policy should be implemented. It stipulates that development proposals in flood risk Zone 2 (medium probability), Zone 3a (high probability) and Zone 3b (the functional floodplain) should be accompanied by a flood risk assessment.

[1] The monitoring records in the deep installations indicate subartesian pressures within the Lambeth Group and towards the base of the London Clay Formation, thus showing that the assumption of hydrostatic pressures below shallow groundwater table is likely to be conservative.

3 Conceptual Site Ground Model and Design Parameters

3.1 Introduction

This section defines the site geology and geotechnical properties of the soil strata based on findings from the ground investigations undertaken by Concept in 2018 and 2020. The exploratory hole records are provided in the Site Investigation Data Reports (18/3104-FR-01 and 19/3355-FR-01).

The investigation fieldworks were carried out in three phases, during the period May to June 2018 and January to March 2020 respectively, comprising 5 cable percussive boreholes, 4 window sample boreholes and 27 trial pits excavated from ground level.

The ground investigations encountered a variable thickness of Made Ground overlying the Lynch Hill Gravel over London Clay on top of the Lambeth Group.

3.2 Ground Model

Based on the review of published geological and hydrogeological information and of available borehole records and findings from the 2018 and 2020 ground investigations, a conceptual site ground model for the purposes of the ground movement assessment is presented in Table 3-1. Natural strata are relatively consistent across the site, with the top of the London Clay Formation and the Lambeth Group ranging only few metres between adjacent boreholes. The thickness of the Made Ground is more variable as it is associated with the historical development of the site (e.g. presence of single level basement beneath Work House, presence of burial site at the back of the site). The proposed strata levels given in the table below were determined with particular emphasis on the latest (2020) boreholes undertaken at the back of the site. Depths presented in the table below are given as metres below existing ground level at the back of the site, where the basement excavation will take place.

Table 3-1: Ground Model for Ground Movement Assessment

Geology		
Stratum	**Typical Description**	**Top of Stratum mbgl (mOD)**
Made Ground	Highly variable in nature. Reference should be made to the fieldwork records for detailed descriptions of the materials encountered.	G.L. (+26.75)
Lynch Hill Gravel	The Lynch Hill Gravel typically comprises sand and gravel, locally with lenses of silt, clay or peat.	4.15 (+22.70)
London Clay	The London Clay Formation is typically a firm to stiff to very stiff to hard, fissured grey to blue-grey over-consolidated clay, which, at outcrop, becomes firm, brown weathered clay typically within the upper 5m of the stratum. The Formation often becomes sandy to very sandy towards its base with associated high content of glauconite mineral and occasionally bands of laterally extensive imbricated cobbles and boulders of claystone (argillaceous limestone concretions).	6.95 (+18.90)
Lambeth Group	The Lambeth Group comprises strata from the Woolwich and Reading, and Upnor Formations. The group comprises laguno-marine sediments that have been deposited in an embayment of a deep marine water basin with brackish water lagoons, barrier beaches and alluvial plains. It is described as mottled clay with sand and pebble beds.	24.75 (+1.14)
Groundwater		
Designation	**Description**	**Groundwater Level mbgl (m OD)**
Secondary A Aquifer	Lynch Hill Gravel	4.81 (+22.84)
Unproductive Stratum	Weathered London Clay / London Clay	*

*Hydrostatic groundwater pressures have been assumed below +22.84mOD (SLS groundwater level) and below +24.00mOD (ULS groundwater level) within the underlying London Clay Formation.

3.3 Preliminary Design Parameters

3.3.1 Introduction

Preliminary design parameters for each stratum have been derived from in-situ testing and laboratory testing results as part of the ground investigation undertaken by Concept in 2018 and 2020.

The design philosophy adopted in the ground movement assessment is in accordance with CIRIA 760 – Guidance on embedded retaining wall design. The document sets out two design approaches in terms of ultimate limit state (ULS) and serviceability limit state (SLS) analyses. The preliminary pile length of the secant bored pile wall has been determined considering both vertical and lateral capacity of the piles for both SLS and ULS. The final pile length of the retaining wall shall be determined by the Piling Contractor who is responsible for the detailed design. This report presents the findings of SLS analyses to be considered in the ground movement and basement impact assessments. Since the secant pile wall will be constructed around the perimeter of the new basement, five sections of the wall have been considered; Section A-A along the southern site boundary (northwest – southeast direction), Section B-B along the south-eastern boundary (southwest – northeast direction), Section C-C along the northern site boundary (northwest – southeast direction), Section D-D along the north-western site boundary (southwest – northeast direction) and Section E – E along the western site boundary (southwest – northeast direction) as shown in Figure 4.

3.3.2 Summary of Design Parameters

Ground movements associated with the proposed works can be assessed based on empirical relationships and/ or from numerical methods. In the present report, ground movements resulting from the retaining wall installation and basement excavation have been assessed based on Geosolve Wallap, Oasys PDisp and XDisp analyses.

Wallap has been used to predict the horizontal deflections, bending moments and shear forces of the proposed secant bored pile wall due to excavation of the basement, whilst Oasys Pdisp has been employed to estimate the global vertical ground movements associated with the excavation unloading down to basement level B1 and down to the part level 2 basement (B2). The characteristic soil parameters used in the analyses are presented in Table 3-2.

Table 3-2: Summary of SLS Design Ground Parameters

Parameters		Strata		
		Made Ground	Lynch Hill Gravel	London Clay
Angle of shearing resistance	ϕ'	25	30	21
Drained cohesion	c' (kN/m²)	-	0	0
Undrained shear strength	c_u (kN/m²)	20	–	$100 + 6.8z^1$
Bulk unit weight	γ_b (kN/m³)	18	20	20
Young's modulus – undrained	E_u (kN/m²)	-	–	$100{,}000+6{,}800z^2$ $40{,}000+2{,}720z^3$
Poisson's ratio – undrained	v_u	0.50	–	0.50
Young's modulus – drained	E' (kN/m²)	5,000	25,000	$70{,}000+4{,}800z^2$ $26{,}000+1{,}770z^3$
Poisson's ratio – drained	v'	0.20	0.25	0.20

Notes 1:

(1) The active and passive earth pressure coefficients are calculated by WALLAP.

Notes 2:

(1) z = 0 at +18.9mOD;

(2) Higher stiffness values were assumed in the Wallap analyses, corresponding to horizontal stiffness of the London Clay Formation and the (relatively small) strain levels associated with the retaining wall problem (Eu=1000Cu and E'=700Cu)

(3) Lower stiffness values were assumed in the Pdisp analyses, corresponding to vertical stiffness of the London Clay Formation and the (large) strain levels associated with unloading problems (Eu=400Cu and E'=260Cu).

4 Development Details and Analyses

4.1.1 Development Proposal

The proposed development comprises the refurbishment of some of the buildings on site, the demolition of the wing buildings at the rear (already undertaken at the time of writing this report) and the construction of multi-storey mixed-use buildings with a single-level basement across the central and southern part of the site and a double basement at the north of the site.

The proposed basement level B1 is at +22.215mOD, some 2 to 3m lower than the existing basement to the Work House building, which is generally around +25.00mOD in the central section. Levels for specific sections are indicated in Appendix A. The proposed basement level B2 is +18.900mOD.

A 600mm diameter secant pile wall at 1000mm spacing (between secondary piles) will be bored around the perimeter of the new building to facilitate excavation of the basement. The proposed basement floor slabs (Level B1 and Level B2) and ground floor slab (Level 00) will prop the retaining wall in the permanent case.

In the temporary construction case, the basement excavation will be supported by temporary propping along the perimeter secant piled wall. A stiffness of 40000kN/m/m has been assumed for the temporary support system being designed by the Contractor. The proposed construction sequence for the secant pile wall considered in this assessment is provided in the next section.

For the secant pile wall analyses, five cross-sections have been considered as representative of the perimeter conditions in order to assess the potential impact on adjacent buildings:

- Section A-A along the southern site boundary (northwest – southeast direction);
- Section B-B along the south-eastern site boundary (southwest – northeast direction);
- Section C-C along the northern site boundary (northwest – southeast direction);
- Section D-D along the north-western site boundary (southwest – northeast direction);
- Section E-E along the western site boundary (southwest – northeast direction).

4.1.2 Neighbouring Structures

Eight neighbouring buildings have been identified as being impacted by the proposed works of installation of the retaining wall, excavation to proposed formation levels (B1 and B2) and subsequent structural loading from the superstructure, and have been assessed as part of the present BIA; namely the Middlesex House along the southern boundary, the 13 Tottenham Mews around the south-eastern corner, the Astor College Gym and the Astor College extension along the eastern boundary, the Wellcome building along the northern boundary, the North House around the north-western corner, the Work House along the western boundary and the South House around the south-western corner. The proposed basement works are unlikely to adversely impact the perimeter buildings along the northern and north-eastern parts of the site, namely Wellcome Centre (UCL, Howland Street) and Astor College Extension due to the presence of double and single level basements respectively beneath each of these buildings, and the fact that both buildings are founded on piled foundations.

The majority of the buildings surrounding the site have at least a single level of basement; the Sainsbury Wellcome Centre (UCL, Howland Street) has a two-level basement, Astor College Gym and Extension, Middlesex House, North House, Workhouse and South House have single level basements. Figure 2 presents the aforementioned neighbouring buildings.

4.1.3 Proposed Construction Sequence

This report has been prepared using the contractors construction sequence at the time of this report . A ‘bottom up’ construction sequence has been assessed (i.e. install wall, excavate, then construct permanent works from the bottom of the excavation upwards) in the present analysis for the basement construction.

A summary of the proposed construction sequence for the retaining secant pile wall is presented as follows:

- Install perimeter secant piles and construct capping beam
- Construct working platform (or piling mat)

- Install secant and bearing piles to the B2 basement
- Excavate to B2 level and construct pile caps and basement slab
- Construct piling mat and install remainder B1 secant and bearing piles
- Prop and excavate to B1 basement level
- Install structural slab at B1 level
- Install structural slab at ground floor.

No consideration has been given the temporary works that will facilitate the basement excavation across the rest of the site, excepting temporary propping as part of the basement construction sequence, as this lies outside the scope of the present report. The impact of temporary works shall be assessed by the Contractor who is to undertake these works.

With regards to groundwater during the basement excavation, based on the latest monitoring data carried out by Concept in 2020, maximum groundwater levels of +22.84mOD have been recorded across the site, corresponding to approximately 0.6m above the new proposed B1 formation level of +22.215mOD and approximately 4m above the new proposed B2 formation level of +18.900mOD. The proposed secant wall design extends at least 1m into the London Clay Formation to provide cut-off to the groundwater inflow into the basement during excavation works. With the presence of the secant wall most groundwater ingress should be controlled. Should ingress into the excavation occur, control measures such as localised grouting, may be implemented to prevent ingress. Perched water within the Made Ground should be controlled via the secant piles and, if required, selective grouting in the areas of underpinning. Monitoring is still ongoing on site and the present analyses should be reviewed if the ongoing monitoring data suggests different groundwater levels. It is noted that the maximum groundwater level assessed does not allow for accidental leakage from water and drainage pipework or extreme weather conditions, aspects such as these will be managed during construction by the contractor. The retaining wall and the ground slab have been designed for a ULS groundwater level of +24.00mOD, allowing for seasonal variations.

4.2 Ground Movement Analysis

4.2.1 Sources of Ground Movement

The ground beneath and adjacent to the proposed development will undergo a series of stress changes resulting from installation of the perimeter wall, excavation to the new formation levels and reloading with the proposed new building loads. These stress changes will result in short term (undrained soil behaviour) ‘elastic’ movement of the ground and in long term (drained soil behaviour) ‘consolidation’ and/or ‘swelling’ movement associated with changes in pore water pressure and effective stress in the ground.

4.2.2 Movements due to Wall Installation

Ground movements will take place as a result of the installation of the secant bored pile wall. CIRIA Report C760 Guidance on Embedded Retaining Wall Design provides empirical data for the profiles of the ground movements (horizontal and vertical) behind the retaining wall due to installation. These movements are a function of wall depth and wall stiffness and are commonly used in practice. Ground surface vertical and horizontal movements at the back of the secant retaining wall, arising from installation and excavation in front of the wall, have been estimated in accordance with CIRIA C760 recommendations, using Oasys XDisp 20.1.

The ground surface movement curves used in the analysis are as follows:

- Installation of secant pile wall in stiff clay (CIRIA C760 Fig 6.8(a) and (b) for horizontal and vertical movements respectively) (Figure 5).

4.2.3 Movements due to Embedded Wall Deflection

Ground movements behind the retaining wall will occur as a result of the excavation at the front of the wall. In order to assess these movements, soil-structure-interaction (SSI) analysis was undertaken using Wallap by Geosolve. The computed horizontal deflections of the wall were used to estimate ground movements at the back of the wall (vertical and horizontal) due to excavation, in accordance with guidance in C760. The CIRIA guidance suggests that the vertical movement trough at the back of the wall for excavations within the London Clay is equal to half the rotated horizontal deflection profile of the wall (Figure 6). For the horizontal movements, C760 suggests using the empirical graph shown in Figure 7. The range over which the horizontal movements become negligible were taken from the graph, whilst the maximum horizontal deflection was capped based on Wallap deflections at the foundation level of the neighbouring structures.

It should be noted that the C760 empirical data and guidelines refer to short-term conditions in absence of reliable published long-term monitoring data. This suggests that the horizontal and vertical movements, which were observed on a number of sites and reported in CIRIA C760, include short-term heave movements due to undrained deformation, opening of fissures and de-saturation resulting from the excavation unloading.

For the purposes of the WALLAP analysis the proposed construction sequence has been divided into stages, as presented below:

Stage 0 Initial condition: Ground level at its initial stage at the back of the wall; surcharge from adjacent structures modelled as finite width surcharges based on information presented in Figure 2Figure 3 and Figure 4. (Different loading conditions have been assumed for the five sections). Groundwater profile with undrained ground conditions.

Stage 1 Reset wall displacements to zero.

Stage 2 Excavate to install top temporary prop.

Stage 3 Excavate to install second temporary prop (where present)

Stage 4 Excavate to basement level on passive side.

Stage 5 Apply surcharge of basement slab B2 on passive side (wet concrete weight) for double level basement.

Stage 6 Install basement slab B2.

Stage 7 Install basement slab B1 as prop for the double level basement.

Stage 8 Apply surcharge of basement slab B1 on passive side (wet concrete weight) for single level basement.

Stage 9 Install basement slab B1 for single level basement.

Stage 10 Install ground slab where retaining wall extends to ground level.

Stage 11 Apply long term drained ground conditions: Drained soil properties, allow groundwater level to rise/ equalise and allow for 30% wall relaxation

The wall parameters used in the analysis were determined using the guidance in CIRIA C760 and assuming a hard-firm secant pile wall of 600mm diameter with an overlapped spacing of 1000mm between secondary piles.

4.2.4 Movements due to Vertical Unloading

Vertical ground movements resulting from unloading following demolition of the existing building and excavation to the new formation levels (B1 and B2 levels) have been assessed using Pdisp by Oasys (version 20.0). The Boussinesq method of movement calculations has been adopted, with which Pdisp calculates the displacements within a linear elastic or non-linear soil mass as a result of uniform normal or tangential pressure being applied to polygonal and circular loaded planes. When calculating stress changes within the soil, the program assumes the soil is an elastic half-space.

The following three ground movement analyses have been undertaken:

- Undrained analysis accounting for the demolition and excavation unloading
- Drained analysis accounting for the demolition and excavation unloading and subsequent loading from the superstructure.

It should be noted that the recorded movements within the basement excavation will be different to the predicted from the Pdisp analyses as the short-term heave will be removed before casting the slab.

5 Structural Assessment of Ground Movement

5.1 Introduction

This section provides an engineering interpretation of the impact of the development on the buildings surrounding the site. The buildings considered in the present analysis as being impacted by the proposed works (installation of secant wall and excavation in front of the wall) are:

1. Middlesex House (Section A – A);
2. 13 Tottenham Mews (Section A – A);
3. Astor College Gym (Section B – B);
4. Astor College Extension (Section B – B);
5. Wellcome Centre (Section C – C);
6. North House existing building (Section D – D);
7. Grade II listed Work House (Section E – E);
8. South House existing building (Section E – E).

5.2 Building Damage Assessment

5.2.1 Classification of Damage

An assessment of the potential damage to neighbouring structures immediately around the proposed basement has been undertaken. The adopted assessment methodology for buildings looks at the likely risk of damage to a structure. The degree of damage is generally categorised into three progressive levels:

- Visual appearance or aesthetics
- Serviceability or function
- Stability

As ground movements beneath the foundations to adjacent structures increases, the damage to a building will move through these three categories. Burland et al. (1977) defined the classification of visible damage. In addition, further work by Boscardin and Cording (1989) introduced the concept of limiting tensile strain. Following this the categories of damage identified by Burland et al. (1977) have been related to ranges of limiting tensile strain. Table 5-1 summarises the categories of damage identified by Burland et al. (1977) and the relevant limiting tensile strains. In the table categories 0, 1 and 2 relate to aesthetic damage, categories 3 and 4 relate to serviceability damage and category 5 relates to stability damage.

Table 5-1: Classification of Visible Damage to Walls

Damage Category[(1)]	Normal Degree of Severity	Description of Typical Damage (Ease of Repair in Bold Type)	Limiting Tensile Strain ε_{lim} (%)
0	Negligible	Hairline cracks less than about 0.1mm wide	0 - 0.05
1	Very slight	**Fine cracks that are easily treated during normal decoration.** Damage generally restricted to internal wall finishes. Close inspection may reveal some cracks in external brickwork or masonry. Typical crack widths up to 1mm.	0.05 - 0.075
2	Slight	**Cracks easily filled. Redecoration probably required. Recurrent cracks can be masked by suitable linings.** Cracks may be visible externally and **some repointing may be**	0.075 - 0.15

		required to ensure weather tightness. Doors and windows may stick slightly. Typical crack widths up to 5mm.	
3	Moderate	**The cracks require some opening up and can be patched by a mason. Repainting of external brickwork and possibly a small amount of brickwork to be replaced.** Doors and windows sticking. Service pipes may fracture. Weather tightness often impaired. Typical crack widths are 5-15mm or several >3mm.	0.15 - 0.3
4	Severe	**Extensive repair work involving breaking out and replacing sections of walls, especially over doors and windows.** Windows and door frames distorted, floor sloping noticeably. Walls leaning of bulging noticeably, some loss of bearing in beams. Service pipes disrupted. Typical crack widths are 15 - 25mm, but also depends on the number of cracks.	> 0.3
5	Very severe	**This requires a major repair job involving partial or complete rebuilding.** Beams lose bearing, walls lean badly and require shoring. Windows broken with distortion. Danger of instability. Typical crack widths are greater than 25mm but depends on the number of cracks.	–

Notes:
(1) In assessing the degree of damage, account must be taken of its location in the building structure.

The categories of damage given above and the limiting tensile strains suggested by the published literature are based solely on masonry structures. Where a different structural type is present the limiting tensile strains and categories of damage are not directly applicable and may be generally considered conservative. However, in the absence of suitable alternative screening criteria, the assessment methodology based on masonry structures may be permissible for non-masonry buildings in conjunction with engineering judgement.

5.2.2 Basis of Building Damage Assessment

The Building Damage Assessment uses the work described in Burland et al (2001) and Gaba et al (2003). In this approach the façade of the building is represented by a simple beam whose foundations are assumed to follow the displacement of the ground in accordance with 'greenfield' site assumptions. The maximum tensile strains are then calculated using pairs of equations that consider combinations of horizontal strain, bending strain and diagonal strain. If necessary, the building is sub-divided into separate structural elements.

Although this stage of assessment is relatively detailed it is usually still conservative. **Consequently, the categories of damage derived in this level of assessment are only possible degrees of damage. The actual damage should be less than the predicted level of damage in the majority of cases.** The reason for this is that the stiffness of the building will be such that the foundations will interact with the supporting ground and tend to reduce both the deflection ratio and the horizontal strains.

5.2.3 Calculations

Three buildings surrounding the site have been considered in this assessment. Assumptions made in the calculation relating to the structures are listed below in Table 5-2. The cross-sections used in the calculations are shown in Figure 2.

Table 5-2: Summary of Building Damage Assessment Sections

Drawing Section	Building	Wall ID	Structure Width/Length (m)	Estimated Structure Height[1] (m)
A – A	Middlesex House	MH-1	38.00	5.85
A – A	13 Tottenham Mews	TM-1	32.50	18.15
		TM-2	9.00	18.15

Drawing Section	Building	Wall ID	Structure Width/Length (m)	Estimated Structure Height[1] (m)
B - B	Astor College	AC-1	9.80	8.40
		AC-2	18.60	8.40
		AC-3	9.80	8.40
B – B	Astor College Extension	ACE-1	7.31	46.3
	Astor College Extension	ACE-2	14.0	46.3
	Astor College Extension	ACE-3	7.72	46.3
C - C	Wellcome Building (UCL)	WE-1	11.0	58.5
	Wellcome Building (UCL)	WE-2	35.0	58.5
	Wellcome Building (UCL)	WE-3	9.00	58.5
D - D	North House	NH-1	4.90	19.5
	North House	NH-2	5.20	19.5
	North House	NH-3	6.30	19.5
E - E	Workhouse	WH-1	5.30	20.1
	Workhouse	WH-2	25.1	20.1
	Workhouse	WH-3	3.00	20.1
	Workhouse	WH-4	7.42	20.1
	Workhouse	WH-5	1.00	20.1
E - E	South House	SH-1	3.03	18.7
	South House	SH-2	3.52	18.7

[1] Height of neighbouring structures determined based on the greenhatch survey elevation profiles and record drawings showing approximate foundation levels.

The calculations undertaken are based on the procedure presented by Burland et al (2001). For each of the walls considered in this assessment the resultant tensile strain has been calculated. The calculations use the following four equations:

$$\frac{\Delta}{L} = \left(1 + \frac{HL^2}{18I}\frac{G}{E}\right)\epsilon_d$$

$$\frac{\Delta}{L} = \left(\frac{L}{12t} + \frac{3I}{2tLH}\frac{E}{G}\right)\epsilon_b$$

$$\epsilon_{bt} = \epsilon_h + \epsilon_b$$

$$\epsilon_{dt} = 0.35\ \epsilon_h + \sqrt{(0.65\ \epsilon_h)^2 + \epsilon_d{}^2}$$

Where:

Δ = deflection from straight line settlement

H = height of the building

L = length of the building (but limited by any point of inflexion)

E = Young's modulus of building

G = shear modulus of building

I = second moment of area (= $H^3/12$ in the sagging zone and $H^3/3$ in the hogging zone)

t = the furthest distance from the neutral axis to edge of 'beam' (= H/2 in the sagging zone and H in the hogging zone)

ε_b = maximum bending strain

ε_d = maximum diagonal strain

ε_h = maximum horizontal strain

ε_{bt} = total bending strain

ε_{dt} = total diagonal strain

5.2.4 "Greenfield" Results

The results for a ***low support stiffness retaining wall*** (as defined in CIRIA C760) for the short- and long-term cases are summarised in Table 5-3 below. The results assume that the buildings act as a 'whole'. If there are discrete elements of the structures, then these will act separately, and the results presented below would be no longer valid. Reference should be made to Section 5.2.5, which is important as it examines and refines these 'greenfield' results and results in revised damaged categories.

Table 5-3: Results of Building Damage Assessment for short- and long-term cases

Wall	Short-Term Conditions		
	Max Settlement (mm)	Max Tensile Strain ε_{lim} (%)	Damage Category
MH-1	7.13	0.0416	0 – Negligible
TM-1	5.05	0.0538	1 – Very Slight
TM-2	5.05	0.0636	1 – Very Slight
AC-1	6.70	0.0953	2 – Slight
AC-2	9.40	0.0107	0 – Negligible
AC-3	9.40	0.120	2 – Slight
ACE-1	Less than limit sensitivity.	Less than limit sensitivity.	0 – Negligible
ACE-2	Less than limit sensitivity.	Less than limit sensitivity.	0 – Negligible
ACE-3	Less than limit sensitivity.	Less than limit sensitivity.	0 – Negligible
WE-1	Less than limit sensitivity.	Less than limit sensitivity.	0 – Negligible

Wall	Short-Term Conditions		
	Max Settlement (mm)	Max Tensile Strain ε_{lim} (%)	Damage Category
WE-2	Less than limit sensitivity.	Less than limit sensitivity.	0 – Negligible.
WE-3	Less than limit sensitivity.	Less than limit sensitivity.	0 – Negligible
NH-1	6.13	0.0107	0 – Negligible
NH-2	9.37	0.0177	0 – Negligible
NH-3	9.37	0.0832	2 – Slight
WH-1	7.37	0.0649	1 – Very Slight
WH-2	7.37	0.0482	0 – Negligible
WH-3	5.23	0.0710	1 – Very Slight
WH-4	5.12	0.0261	0 – Negligible
WH-5	4.95	0.0681	1 – Very Slight
SH-1	5.61	0.0315	0 – Negligible
SH-2	4.32	0.0491	0 – Negligible
	Long-Term Conditions		
MH-1	17.99	0.0464	0 – Negligible
TM-1	5.29	0.0504	1 – Very Slight
TM-2	5.29	0.124	2 – Slight
AC-1	5.82	0.0961	2 – Slight
AC-2	8.27	0.0112	0 – Negligible
AC-3	8.27	0.183	3 – Moderate
ACE-1	6.13	0.0386	0 – Negligible
ACE-2	8.18	0.0122	0 – Negligible
ACE-3	7.82	0.0347	0 – Negligible
WE-1	1.97	35.8E-9	0 – Negligible
WE-2	Less than limit sensitivity.	Less than limit sensitivity.	0 – Negligible
WE-3	0.801	35.8E-9	0 – Negligible
NH-1	3.34	0.0259	0 – Negligible
NH-2	10.99	0.0261	0 – Negligible
NH-3	11.00	0.120	2 – Slight
WH-1	13.74	0.0740	1 – Very Slight
WH-2	24.56	0.0676	1 – Very Slight
WH-3	11.68	0.100	2 – Slight

Wall	Short-Term Conditions		
	Max Settlement (mm)	Max Tensile Strain ε_{lim} (%)	Damage Category
WH-4	8.87	0.0430	0 – Negligible
WH-5	4.89	0.00767	0 – Negligible
SH-1	9.78	0.0374	0 – Negligible
SH-2	5.33	0.0678	1 – Very Slight

5.2.5 Refinement of Results

To refine the damage assessment and to predict more realistic strains within the walls that fall into damage category 2 or above (i.e. unacceptable damage based on Camden Council guidance) as indicated in Table 5-3, a refined approach is followed, based on the same assumption of an isotropic linear elastic equivalent beam of length L and height H, but considering friction at the beam-soil interface. In limit conditions (i.e. large ground movements), the maximum shear stress (resistance) at the interface will be mobilised at the base of the beam. If the building load is uniformly distributed, interface resistance will be the same along the beam. If the beam is assumed not to be constrained in movement, and ground movements follow a linear profile with distance along the wall base, for equilibrium the sum of all shear stresses will have to be zero, thus the sign will reverse at the middle point.

The shear resistance, for a frictional foundation soil, is given by the expression below (see Figure 8).

$$\tau_{max} = \sigma_v \tan\delta' = H \cdot \gamma_{wall} \cdot \tan\delta' \ \ (kPa)$$

Under the assumptions of this simple model, the integral of shear stresses over half the beam length from one end to the middle will be equal to the maximum axial force on the beam. This axial force will be equal to:

$$T_{tot} = N_{max} = H \cdot \gamma_{wall} \cdot \tan\delta' \cdot \frac{L}{2} \ (kN/m\ width)$$

The maximum axial strain (i.e. horizontal strain assumed in the damage assessment) in the beam ($\varepsilon_{a,max}$) will be at the section where N = N_{max}, and it will be equal to:

$$\varepsilon_{a,max} = \frac{N_{max}}{EA} = \frac{H \cdot \gamma_{wall} \cdot \tan\delta' \cdot \frac{L}{2}}{EA}$$

Assuming Young's Modulus equal to 5GPa (lower bound value) for the masonry walls and 33GPa for the concrete walls and unit weight of 22kN/m^3 for masonry walls and 24kN/m^3 for the concrete walls, maximum axial (horizontal) strains were estimated from the equation above and these are presented in Table 5-4 for the walls falling into damage category 2 or above.

Table 5-4: Maximum Horizontal Strains

Wall ID	Maximum Horizontal Strain (%)
TM-2	0.0004
AC-1	0.0001
AC-3	0.0002
NH-3	0.0008
WH-3	0.0004

Based on these new maximum horizontal strain values, the results from Table 5-3 have been updated as shown in Table 5-5 below.

Table 5-5: Refined results of Building Damage Assessment for short- and long-term cases

Wall	Short-Term Conditions		
	Max Settlement (mm)	Max Tensile Strain ε_{lim} (%)	Damage Category
AC-1	6.70	0.0001	0 - Negligible
AC-3	9.40	0.0002	0 - Negligible
NH-3	9.37	0.0008	0 - Negligible
	Long-Term Conditions		
TM-2	5.29	0.0004	2 – Slight*
AC-1	5.82	0.0001	0 - Negligible
AC-3	8.27	0.0002	1 – Very Slight
NH-3	11.00	0.0008	1 – Very Slight
WH-3	11.68	0.0004	2 – Slight*

*Note: For TM-2 see assessment of building stiffness effects, which indicates a revised Damage Category 1. This approach is similarly valid for WH-3

It appears that for the Tottenham Mews wall running perpendicular to the southern site boundary and the Work House wall running perpendicular to the eastern site boundary, the damage category remains "2-Slight Damage" due to the high deflection ratios.

As previously discussed, all ground movements presented so far are considered as 'greenfield' displacements, i.e. ignoring the presence of any surrounding buildings or developments. However, it is known that the presence of the building and its interface with the ground also influences the profile of the settlement and the way the displacements are transferred to the building.

CIRIA C760 report notes that Potts and Addenbrooke (1997) investigated the effect of building stiffness on tunnelling-induced displacements by undertaking a parametric study using finite element methods adopting a non-linear elastic-plastic soil model, and suggests that this approach could be used in excavation-induced movements. The building was represented as an equivalent beam having bending and axial stiffness EI and EA (where E is the Young's modulus of elasticity, A the cross-sectional area and I the moment of inertia of the beam). They defined bending stiffness ρ* and axial stiffness α* as:

$$\rho^* = E \cdot I \,/ E_s \cdot H^4 \; (m^{-1})$$

$$\alpha^* = E \cdot A \,/ E_s \cdot H \; (-)$$

where

H is the half-width of the beam, E_s is representative soil stiffness.

Design curves were established for the likely modification to the greenfield settlement profile caused by a surface structure (Figure 9, Figure 10 of present report) by Potts and Addenbrooke (1997).

Considering the modification factors for the deflection ratio and the horizontal strains, Tottenham Mews (TM-2) falls in the Damage Category 1.

The refined assessment process, considering 'greenfield' results and applying more realistic 'in-situ' conditions, indicates that all adjacent buildings to the basement excavation fall into Damage Category 1 or lower. Detailed calculations are presented in Appendix B.

6 Conclusions

A Ground Movement Assessment has been undertaken for the proposed redevelopment of the Middlesex Hospital Annex. This has included calculations of predicted ground movements and an assessment of the structural impact on the surrounding buildings.

A range of calculations have been undertaken to assess the potential impact on the surrounding structures. Ground movements in this report are based on the installation effects associated with a secant wall in stiff over-consolidated Clay as reported by CIRIA C760 guidance, the deflection profiles of the retaining wall as predicted by Wallap and the global movements associated with the excavation unloading and subsequent loading from the superstructure as predicted by Oasys Pdisp. The calculations have been carried out assuming a 'bottom-up' construction sequence will be adopted for excavation down to basement levels B1 and B2 formation level.

The predicted 'greenfield' ground movements have been used to calculate potential resultant tensile strains in the structures and thereafter the potential damage category in line with the categories proposed by Burland et al (2001).

Eight structures have been assessed using this method with the resultant potential damage categories calculatedfor 'greenfield' movements and tensile strains. The results indicate that following detailed design process, Middlesex House, Astor College Extension and Wellcome Building were classified as Category 0 "Negligible" for both short- and long-term conditions, whilst South House was classified as Category 0 "Negligible" in the short-term and as Category 1 " Very Slight" in the long-term. 13 Tottenham Mews and Workhouse were categorised as Category 1 "Very Slight" in the short-term and as Category 2 "Slight" in the long-term, whilst the assessment indicates Category 2 "Slight" for North House for both short- and long-term conditions. Finally, Astor College Gym was categorised as Category 2 "Slight" in the short-term and Category 3 "Moderate" in the long-term.

It is noted that these assessments are based on the assumption that movements at ground level are equal to the movements at depth where the adjacent structures are founded. This is a conservative assumption as movements will typically reduce with depth and therefore deflection ratios and horizontal strains will also reduce. The predicted 'greenfield' ground movements have been used to calculate potential resultant tensile strains of the walls, and damage categories proposed by Burland et al (2001), thus ignoring the stiffness of the structure. However, when the ground displaces laterally, relative slip will occur at the foundation level, and the horizontal displacement in the building will be less than that in the ground (Geddes 1977, 1991).

As a result of the Boscardin and Cording assessment methodology ignoring the building stiffness the method is therefore conservative and considered excessively here where results give unrealistic damage categories for relatively small ground movements. It is well understood that the lateral stiffness of buildings is generally large enough to effectively eliminate lateral movements at foundation level (Finno and Bryson, 2002). Consequently, the categories of damage derived with this basic assessment are only possible degrees of damage. The actual damage is likely to be less than the predicted level of damage in the majority of cases. The reason for this is that the stiffness of the building will be such that the foundations will interact with the supporting ground and will tend to reduce both the deflection ratio and the horizontal strains.

To refine the damage assessment, consideration of the relative soil-structure interface has been undertaken on the assumption of a linear elastic beam in order to predict more realistic strains that are likely to develop within the walls. This approach indicated that all walls but two fall into damage category 1 or below. One wall at 13 Tottenham Mews and another wall at the Work House running perpendicular to the basement excavation remain into damage category 2.

Further refinement using the Potts and Addenbrooke approach reported in the CIRIA C760 report has been adopted to account empirically for the stiffness of the walls under consideration using modification factors for both deflection ratio and horizontal strains. Following this approach indicates that **all walls fall into damage category 1 or lower**.

7 Recommendations for Further Work

The present report and the associated Basement Impact Assessment Report (AECOM, November 2020) should be updated if the continuing groundwater monitoring (monthly during basement construction) records a higher groundwater table. Furthermore, the construction sequence for the basement excavation should be confirmed with the Contractor and the presented analysis should be updated if there are any significant changes from the present assumptions. The impact of temporary works lies outside the scope of the present report and shall be assessed by the Contractor separately.

7.1 Structural Survey of Surrounding Buildings and Infrastructure

Party wall agreements and condition surveys are to be undertaken for buildings surrounding the site that may potentially be affected by the proposals. Party wall surveyors will be appointed in this respect and able to review the information relating to ground movements and stability of neighbouring structures.

Once condition surveys are completed the Movement and Tolerances Specification (MHA-ACM-XX-SP-SE-0007 by AECOM) shall be reviewed where there is additional information to consider from the condition surveys.

7.2 Ground and Structure Movement Monitoring

7.2.1 Scope of the Monitoring Regime

Monitoring of the predicted ground movements is proposed to be implemented to ensure compliance between the actual movements associated with the proposed development works and those predicted. At this stage the monitoring scheme is anticipated to comprise as a minimum the following:

1. Pre-construction inspections to establish the condition of the adjacent perimeter buildings. Pre-construction inspections have been carried out to the following buildings by the Client's party wall surveyor in 2019 and up to mid-2020. A further series of pre-construction inspections are planned in early 2021, given that the basement scheme has changed considerably since the earlier inspections.

    i. Astor College Gym

    ii. 13 Tottenham Mews

    iii. Middlesex House

    iv. Astor College Extension

    v. Wellcome Building (UCL)

    vi. North House (On-site Client's building)

    vii. Work House (On-site Client's building)

    viii. South House (On-site Client's building)

2. Present condition surveys for buildings in damage category 1 or any buildings where the results reduce from above Category 1 to below Category 1 following the refinement

3. Monitoring of existing cracks to adjacent buildings with a damage classification of 1 or any buildings where the results reduce from above Category 1 to below Category 1 following the refinement

4. Monitoring of the settlement and movement of the secant pile wall during construction to provide data on wall movements

5. Post construction inspection of the adjacent buildings

6. Review of the monitoring results against predicted displacement levels

Monitoring is to be undertaken to the Workhouse, North House, South House and neighbouring buildings, including the Astor College Gym, 13 Tottenham Mews and Middlesex House. The location where movement targets should be placed on the existing walls are shown on AECOM drawings MHA-ACM-MON-00-DR-S-00001&00002 which can be found in the Movement and Tolerances Specification.

Once implemented, the monitoring data will be assessed at agreed intervals against trigger and action levels set in the monitoring specification.

The instrumentation work is to be carried out in accordance with the ICE (2017) Specification for Piling and Embedded Retaining Walls (SPERW), 3rd edition.

7.2.2 Monitoring of adjacent buildings

The assessment indicates Category 0 “Negligible” for Middlesex House, Astor College Extension and Wellcome Building for both short- and long-term conditions, whilst South House was classified as Category 0 “Negligible” in the short-term and as Category 1 “ Very Slight” in the long-term. 13 Tottenham Mews and Workhouse were categorised as Category 1 “Very Slight” in the short-term and as Category 2 “Slight” in the long-term, whilst the assessment indicates Category 2 “Slight” for North House for both short- and long-term conditions. Finally, Astor College Gym was categorised as Category 2 “Slight” in the short-term and Category 3 “Moderate” in the long-term. Considering the soil-structure interface for the adjacent buildings (refinement of results), all but two walls fall into damage category 1 or below. It is noted that the assessment work has not considered the influence of the basements of these buildings as it assumes movements at ground level to be the same at foundation depth of the adjacent structures, which is likely to be conservative as movements will reduce with depth. The depth of the basements and foundations should reduce the movements and may change damage categories. Where buildings were assessed to be damage category 1 or above prior to the refinement of the results, or the inspections and Present Condition Surveys indicate existing cracks, monitoring will be recommended.

Monitoring will be carried out of existing significant cracks identified from the survey before, during and post construction or of cracks or distortion where analyses indicate potential risk areas during construction works. The rear wall to the retained building will be supported and monitored for distortion during the basement construction works.

7.2.3 Monitoring of the secant pile wall deflection

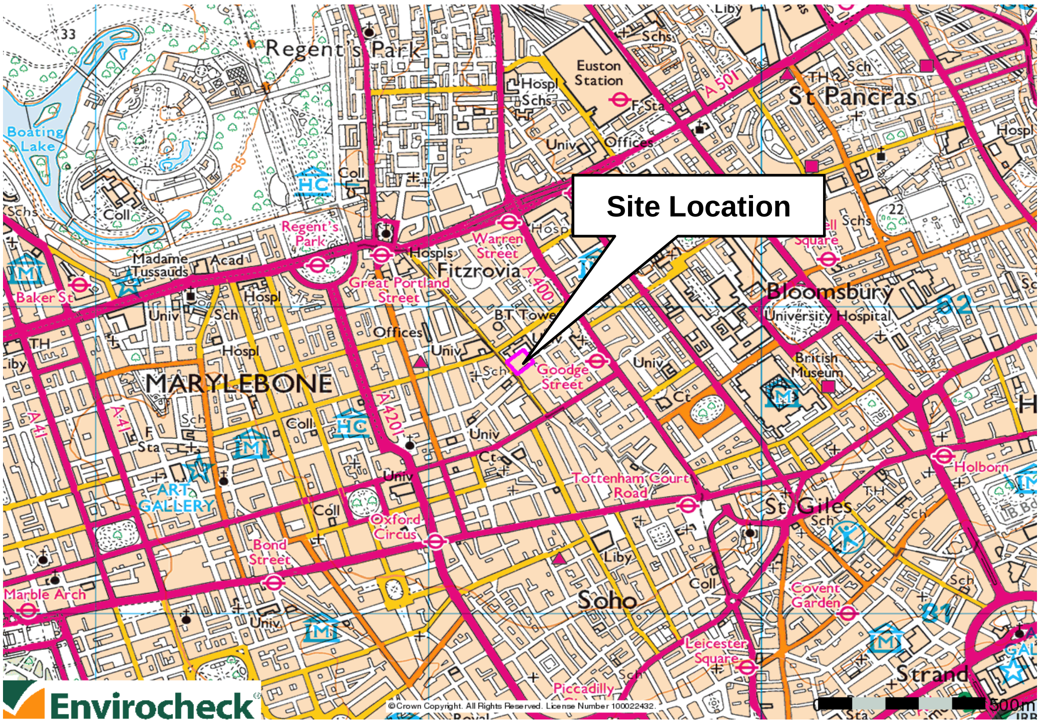
Inclinometer tubes shall be installed to full pile depth of individual piles along centre line of the secant wall, at locations to be defined. Monitoring to be carried out by specialist contractor and in accordance with the AECOM Movement and Tolerances Specification (MHA-ACM-XX-SP-SE-0007) and the AECOM Specification for Piling and Embedded Retaining Walls (MHA-ACM-XX-SP-SE-0009). The monitoring range should be displacement orientated and should be capable of measuring to the nearest 0.1mm. In addition, the capping beam of the retaining wall will be surveyed (3D) in selected positions at regular frequent intervals using precise levelling.

7.2.4 Monitoring details

A Movement and Tolerances Specification (MHA-ACM-XX-SP-SE-0007) has been prepared that specifies the required monitoring details. Each monitoring location will be monitored at predetermined intervals with the designated method and accuracy level as prescribed in the specification. Green, Amber and Red limits shall additionally be determined to classify the level of required action at any occurrence. The system for dealing with amber and red alerts will be specified and appropriate mitigation measures recorded (for example: cessation of excavation; backfilling; additional propping).

Figures

N



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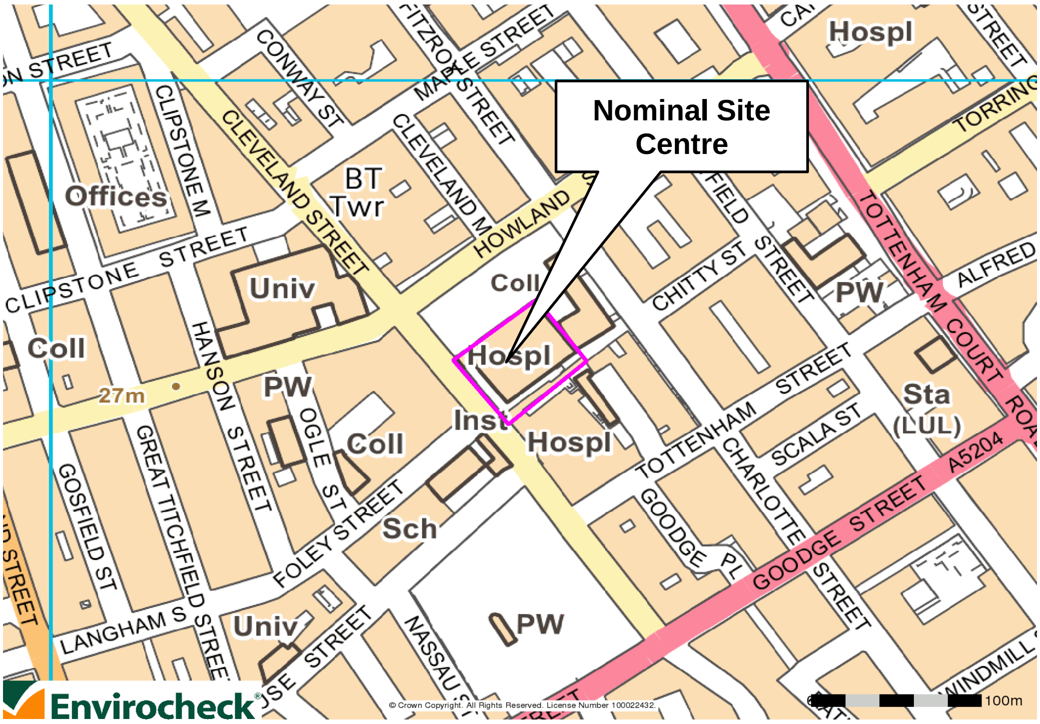
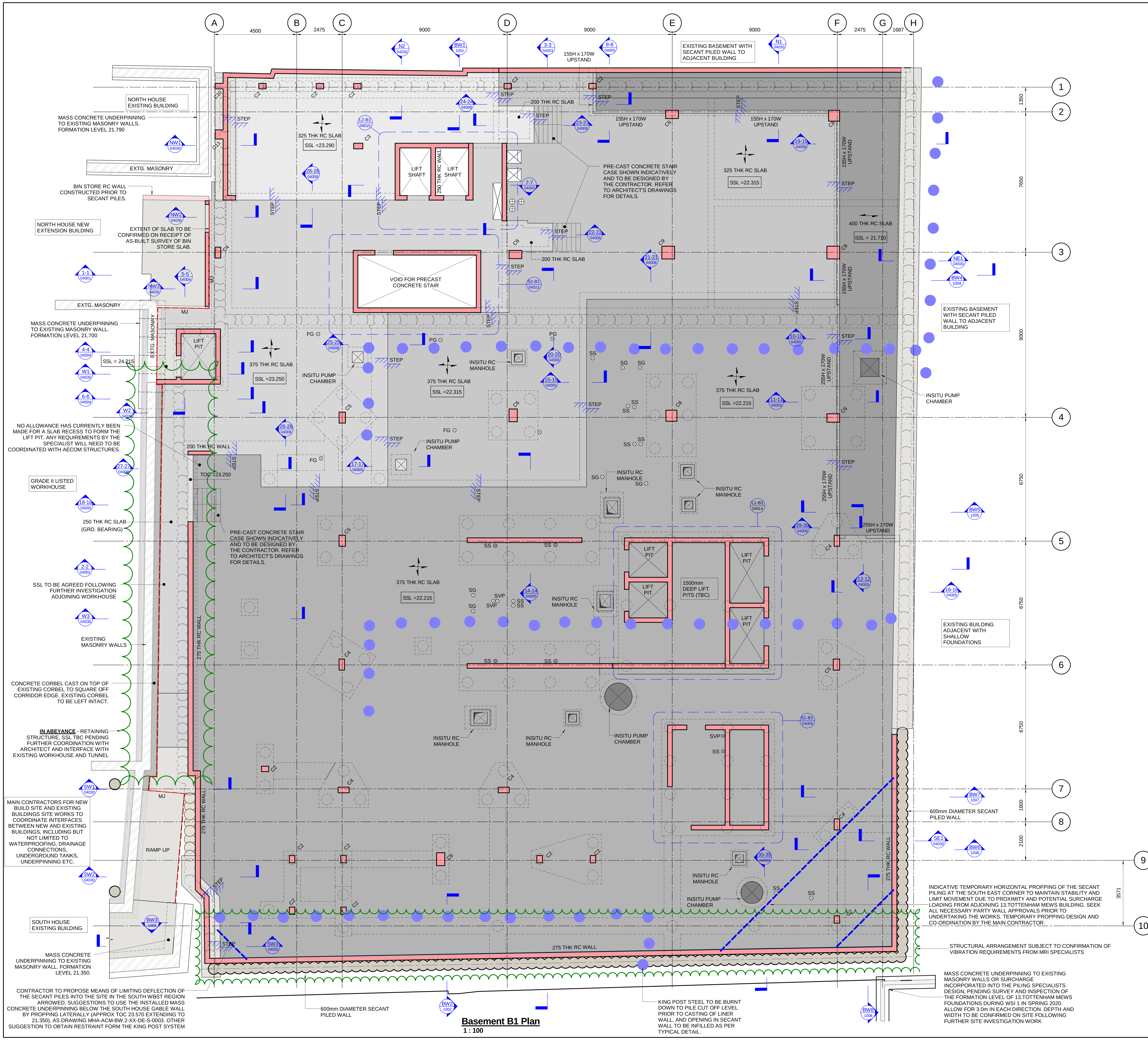


Scale: NTS	Site Centre:	529262, 181811	
Made By: JC	Aug-16	Site Location Plan	
Chk:	PAS		
App:	PAS		
		Project Reference	Figure No.
		60516144	1

ISO A1 594mm x 841mm

Drawn By: MN | Approved: DW | Checked: DW | Project Management Initials: Designer: JB



Basement B1 Plan
1 : 100

Concrete (RC) - Column Schedule

Column Ref	Dimensions	
	Depth	Width
C1	300	300
C2	300	400
C3	300	500
C4	300	600
C5	350	600
C6	450	700
C8	600	600
C9	700	700
C10	300	425
C11	500	425

SERVICE HOLES IN SLABS, INCLUDING RISERS, SVP AND RWP TO BE DEVELOPED AND ARE NOT CURRENTLY FULLY SHOWN ON THESE DRAWINGS AWAITING FINAL COORDINATION FROM THE ARCHITECT AND MEP ENGINEERS. ALLOWANCE TO BE MADE FOR FURTHER OPENINGS IN SLABS AND WALLS.

REFER TO MEP DRAWINGS FOR LOCATIONS OF OPENINGS LESS THAN 200MM DIAMETER

SLAB LEVELS AND BASEMENT PERIMETER WALL ARRANGEMENT ARE TO BE CONFIRMED PENDING CONFIRMATION OF PARTY WALL AGREEMENTS.

EVIDENT DEFECTS TO GABLE WALL TO No 13 TOTTENHAM MEWS TO BE ADRESSED WITH ADJOINING OWNER DURING PARTY WALL AGREEMENTS.

REFER TO DRAINAGE DRAWINGS FOR DETAILS OF ALL BELOW GROUND DRAINAGE RUNS, INVERT LEVELS AND SIZES OF MANHOLES AND PUMPING STATIONS.

PILE LOADS WERE DERIVED BASED ON THE ASSUMPTION OF SUBSTRUCTURE AND GROUND FLOOR SLABS BEING CAST WITHIN 6 MONTHS OF EXCAVATION COMPLETE.

PILE LOADS AS INDICATED IN DRAWING 01012 & 01014 SHALL BE DESIGNED BY PILE SPECIALIST.

ALL HORIZONTAL PILE LOADS UNDER EARTH AND WATER PRESSURES SHALL BE CALCULATED AND DESIGNED BY PILE SPECIALIST.

CONTAMINATION NOTE:
THE GROUNDWORK CONTRACTOR SHOULD FAMILIARISE THEMSELVES WITH THE RESULTS OF ALL AVAILABLE SOIL, GROUND WATER AND WAC TESTS AND ADVISE OF ANY ADDITIONAL INFORMATION OR TESTING NEEDED. ALL CONTAMINATED MATERIAL (WHERE AFFECTED BY SITE ACTIVITY) IS TO BE MANAGED BY THE CONTRACTOR AND DISPOSED OF OFF-SITE TO A SUITABLY LICENSED WASTE MANAGEMENT FACILITY IN A SAFE AND APPROVED MANNER. TO COMPLY WITH THE DUTY OF CARE ALL WASTES TAKEN OFF SITE, IN SOLID OR LIQUID FORM, MUST BE HANDLED BY A REGISTERED WASTE CARRIER AND BE ACCOMPANIED BY A CONSIGNMENT NOTE THAT DESCRIBES THE WASTE.

REFER TO TYPICAL SLAB, PILE CAP AND GROUND BEAM DETAILS FOR WATERPROOFING AS INDICATED ON DRAWING MHA-ACM-00-XX-DR-SE-05001.

ALLOWANCE TO BE MADE FOR PLINTHS WITHIN THE PLANT ROOM AREAS. SETTING OUT AND DIMENSIONS TO BE CONFIRMED BY THE MEP CONTRACTOR. REFER TO DRAWING 05004 FOR TYPICAL POST FIXED PLINTH DETAIL.

ALL TEMPORARY WORKS WILL BE TO THE CONTRACTORS DESIGN AND DETAILS. ALL TEMPORARY WORKS WILL BE COORDINATED WITH THE PERMANENT WORKS BY THE MAIN CONTRACTOR.

PILING CONTRACTOR TO REVIEW PROXIMITY OF PROPOSED BEARING PILES TO EXISTING KING POSTS PILES OR TO UNDERTAKE THE NECESSARY GROUP SETTLEMENT ANALYSIS.

REFER TO ARUP MEP DRAWINGS FOR DETAILS OF LIGHTNING PROTECTION AND EARTHING REQUIREMENTS WITHIN FOUNDATIONS.

BELOW GROUND DRAINAGE SHOWN INDICATIVELY, AWAITING FINAL COORDINATION FROM THE ARCHITECT AND MEP ENGINEERS

LIFT PITS, OPENINGS AND DOOR LOCATIONS HAVE BEEN COORDINATED WITH THE ARCHITECTURAL AND MEP INFORMATION PROVIDED BEFORE 29/09/2020. FINAL INFORMATION WILL NEED TO BE COORDINATED ON RECEIPT OF LIFT MANUFACTURER DETAILS.

EXACT POSITIONS OF SECANT PILES ARE SHOWN INDICATIVELY AND ARE TO BE SET BY THE CONTRACTOR.

THE MAIN CONTRACTOR MUST ENSURE THAT THE INSTALLATION OF ANY TEMPORARY WORKS DOES NOT ADVERSELY IMPACT ON THE INSTALLATION OF PERMANENT STRUCTURE, INCLUDING SECANT AND BEARING PILES.

BASED ON ARCHITECTS SETTING OUT DRAWING BPD-LDW-NB-B1-DR-A-200002 RECEIVED 06/10/2020

SERVICE HOLES IN SLABS, INCLUDING RISERS, SVP AND RWP TO BE DEVELOPED AND ARE NOT CURRENTLY FULLY SHOWN ON THESE DRAWINGS AWAITING FINAL COORDINATION FROM THE ARCHITECT AND MEP ENGINEERS. ALLOWANCE TO BE MADE FOR FURTHER OPENINGS IN SLABS AND WALLS.

STRUCTURE DESIGNED TO CARRY TRADITIONAL BRICK CLADDING, COMPRISING SINGLE BRICK OUTER LEAF AND COLD ROLLED STEEL INFILL INNER LEAF, SINGLE BRICK OUTER LEAF TO BE SUPPORTED ON EITHER EVERY LEVEL OR ALTERNATE LEVELS, DEPENDING ON THE LOCATION. REFER TO SUPERSTRUCTURE DRAWINGS FOR DETAILS. SHOULD THE PROPOSED CLADDING SYSTEM BE CHANGED SUCH AS SUPPORT LEVELS AND CLADDING MATERIALS, STRUCTURE SHALL BE REVIEWED AND SUBJECT TO RE-DESIGN

TOWER CRANE POSITION TO BE COORDINATED WITH AECOM'S STRUCTURE, MAIN CONTRACTOR TO UNDERTAKE DESIGN FOR CRANE AND LIAISE DIRECTLY WITH PILING CONTRACTOR REGARDING PILING LOADING. ALLOWANCE TO BE MADE FOR COUPLERS WITHIN THE B1 AND GROUND FLOOR SLABS TO ACCOMMODATE TEMPORARY OPENINGS

AECOM

Project

BEDFORD PASSAGE DEVELOPMENT

UK & IRELAND

Client

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Notes

- Do not scale from this drawing. Work to figured dimensions only.
- This drawing is to be read in conjunction with:
  - AECOM Structural Specifications
  - Design reports
  - Survey and Interpretative Reports
  - Project Specifications and Performance Specifications
  - Health and Safety Hazard Register
  - Relevant drawings and documentation issued by the architect, engineers and specialists.
  - Basement Sequencing Drawings
  - Movements and Tolerances Report
- All dimensions are in mm except levels which are in metres and relate to [ordance datum].
- Any discrepancies shall be referred to the Designer before work commences.

Legend:

Top of Structural Slabs Shown Thus: SSL = 12.000

Columns:

Columns Under:

Direction of Span in Slab:

Step in Slab: STEP

Beam Sizes shown on plan thus 900x600 indicated as the following: 900 / 600

- Beams to be centred on columns unless noted otherwise as thus 50
- As-Built site coordinates of contractor's steel king post piles (installed in 2020) used for temporary works. All king post steels to be cut down to below formation level unless noted otherwise

Issue/Revision

Rev.	Date	Description	Drn/Chk/Apr
T7	23.10.20	ISSUED FOR TENDER	RH/KSF/DW
		STAGE 4 REDESIGN	
T6	03.07.20	STAGE 4 (PCSA STAGE 1 DESIGN REVIEW)	RH/CL/DW
T5	19.06.20	STAGE 4 (PCSA STAGE 1 DESIGN REVIEW)	RH/CL/DW
T4	26.10.18	TENDER - STAGE 1	MN/DW/DW
T3	19.06.18	STAGE 4 TENDER (2)	MN/DW/DW
T2	01.05.18	STAGE 4 TENDER	MN/DW/DW
T1	29.03.18	STAGE 4 TENDER (DRAFT)	MN/DW/DW
A	21.12.17	STAGE 3 ISSUE. WIP	MN/DW/DW

Purpose Of Issue

STAGE 4 TENDER

Project Number

60516144

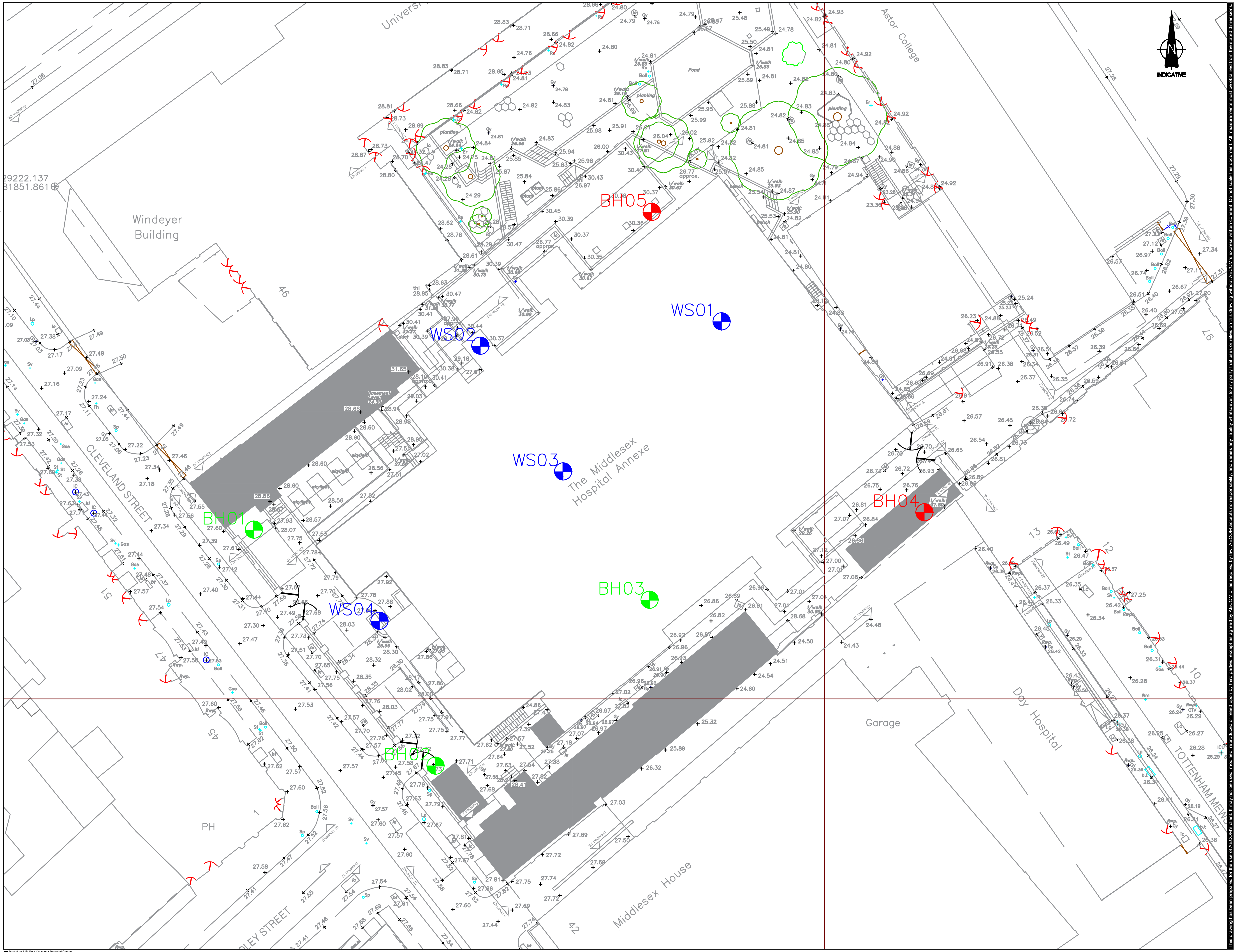
Sheet Title

New Build
General Arrangement
Basement B1

Sheet Number

MHA-ACM-00-B1-DR-SE-01001

Scale: 1 : 100@A1 **Rev:** T7



AECOM

CONSULTANT

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www.aecom.com

PROJECT

Middlesex Hospital Annexe

CLIENT

University College London Hospitals Charity

KEY

- 2020 Concept GI Cable Percussion Borehole
- 2020 Concept GI Window Sampling Hole
- 2018 Concept GI Borehole

ISSUE/REVISION

I/R	DATE	DESCRIPTION
01	21/08/2019	FIRST ISSUE

SHEET TITLE

Proposed Supplementary Exploratory Hole Location Plan

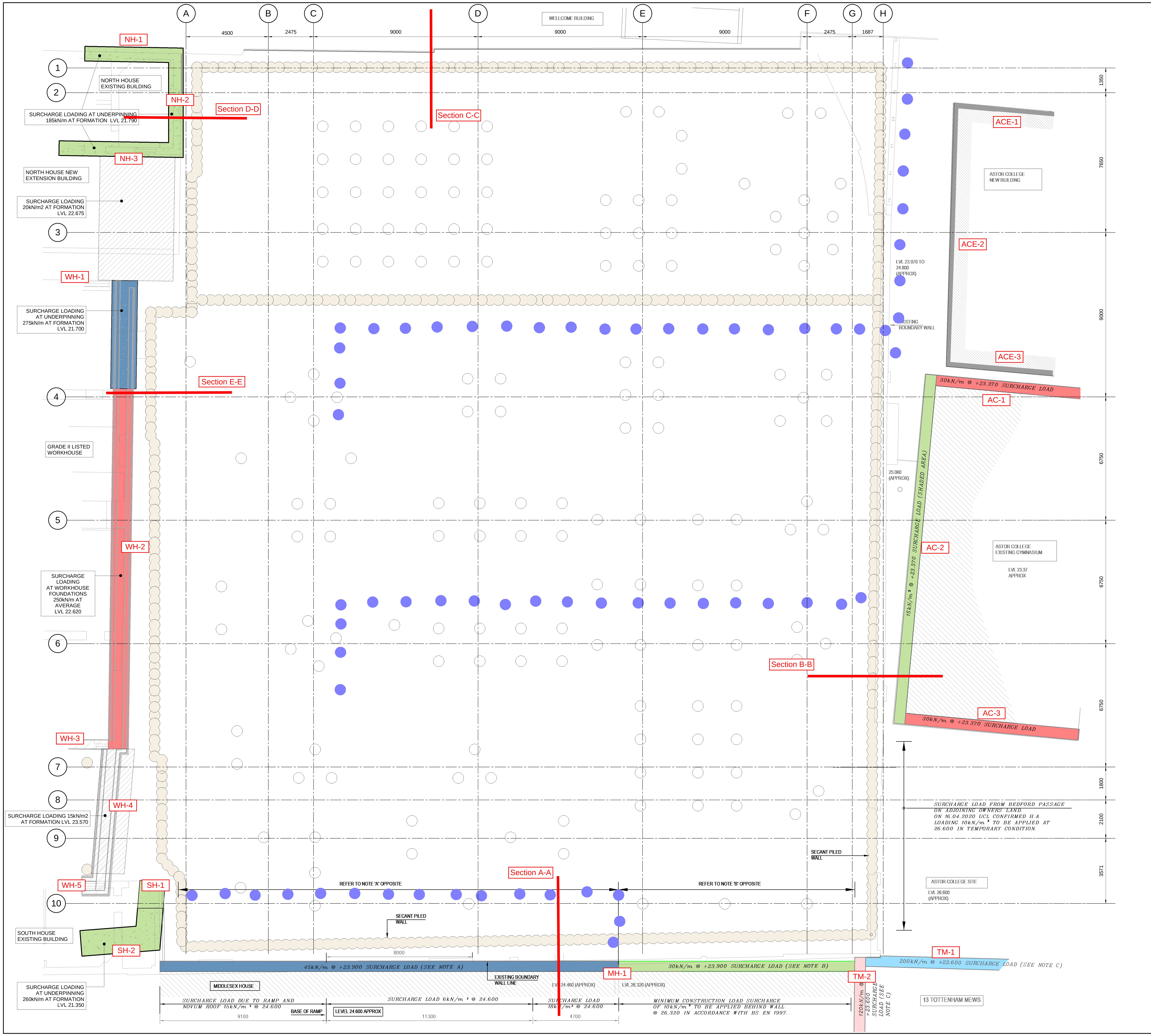
SHEET NUMBER

60516144/GISPEC/FIG2

SCALE

1:200 @ A1

Project Management Initials: Designer: KSF Checked: KSF Approved: DW Drawn By: RH ISO A1 594mm x 841mm



SHORT TERM AND LONG TERM SOIL HEAVE MUST BE CONSIDERED BY THE PILING CONTRACTOR WITHIN THEIR PILING DESIGN AS THIS IS A FUNCION OF THE PILE LENGTH. TENSION DUE TO HYDROSTATIC FORCES HAVE BEEN PROVIDED IN THE PILE SCHEDULE AND THE SECANT LOADING.

REFER TO DRAINAGE DRAWINGS FOR DETAILS OF ALL BELOW GROUND DRAINAGE RUNS, INVERT LEVELS AND SIZES OF MANHOLES AND PUMPING STATIONS.

REFER TO TYPICAL SLAB, PILE CAP AND GROUND BEAM DETAILS FOR WATERPROOFING AS INDICATED ON DRAWING MHA-ACM-00-XX-DR-SE-05001.

CONTAMINATION NOTE:
THE GROUNDWORK CONTRACTOR SHOULD FAMILIARISE THEMSELVES WITH THE RESULTS OF ALL AVAILABLE SOIL, GROUND WATER AND WAC TESTS AND ADVISE OF ANY ADDITIONAL INFORMATION OR TESTING NEEDED. ALL CONTAMINATED MATERIAL (WHERE AFFECTED BY SITE ACTIVITY) IS TO BE MANAGED BY THE CONTRACTOR AND DISPOSED OF OFF-SITE TO A SUITABLY LICENSED WASTE MANAGEMENT FACILITY IN A SAFE AND APPROVED MANNER. TO COMPLY WITH THE DUTY OF CARE ALL WASTES TAKEN OFF SITE, IN SOLID OR LIQUID FORM, MUST BE HANDLED BY A REGISTERED WASTE CARRIER AND BE ACCOMPANIED BY A CONSIGNMENT NOTE THAT DESCRIBES THE WASTE.

PILE LOADING NOTES
1. FOR VERTICAL SECANT PILE LOADING REFER TO DRAWING MHA-ACM-00-XX-DR-SE-00050.

2. SECANT PILED WALLS SURCHARGE LOADS. LOADS MARKED ON THE EXISTING ADJOINING BUILDINGS ARE VERTICAL SURCHARGE LOADS (PERMANENT + VARIABLE UNFACTORED LOADING).

3. FOR INTERNAL PILE LOADS REFER TO PILE SCHEDULE DRAWING MHA-ACM-00-XX-DR-SE-01014.

NOTE A
45kN/m SURCHARGE LOAD (DUE TO DEAD WEIGHT OF SOUTH, BRICK BOUNDARY WALL) IN THE BLUE PORTION. IN THE ZONE ARROWED THE BASE OF THE WALL IS SUPPORTED ON CONCRETE UNDERPINNING, BUT EXTENT OF UNDERPINNING 8m EAST OF BASE OF RAMP IS NOT KNOWN. TOP OF CONCRETE APPROX' 23.900 (TBC ON SITE). BOTTOM OF UNDERPINNING NOT YET KNOWN. THEREFORE LEVEL AND LOAD VALUE FOR SURCHARGE ONTO THE SECANT PILES IS TO BE CONFIRMED IN WSI 1 FOLLOWING EXPOSURE ON SITE.

NOTE B
30kN/m SURCHARGE LOAD (DUE TO DEAD WEIGHT OF SOUTH, BRICK BOUNDARY WALL) IN THE GREEN PORTION. CONCRETE UNDERPINNING IS NOT ENVISAGED IN THIS ARROWED ZONE. ASSUMED BASE OF BRICK WALL IS 23.900 (TBC ON SITE). THEREFORE LEVEL AND LOAD VALUE FOR SURCHARGE ONTO THE SECANT PILES IS TO BE CONFIRMED IN WSI 1 FOLLOWING EXPOSURE ON SITE.

NOTE C
SURCHARGE LOADS (DUE TO DEAD WEIGHT OF 13 TOTTENHAM MEWS BUILDING) IN THE COLOURED PORTIONS IS TAKEN AT ASSUMED LEVELS BASED ON LIMITED TRIAL PITTING IN THE AREA. CONCRETE UNDERPINNING IS NOT ENVISAGED IN THIS AREA. ASSUMED FOUNDATION LEVEL IS 23.600 (TBC ON SITE). THEREFORE LEVEL AND LOAD VALUE FOR SURCHARGE ONTO THE SECANT PILES IS TO BE CONFIRMED IN WSI 1 FOLLOWING EXPOSURE ON SITE.

AECOM

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Notes

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  - Relevant drawings and documentation issued by the architect, engineers and specialists.
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- All dimensions are in mm except levels which are in metres and relate to [ordance datum].
- Any discrepancies shall be referred to the Designer before work commences.

Issue/Revision

T1	28.10.20	ISSUED FOR TENDER	RH/TM/KSF
		STAGE 4 REDESIGN	
C3	30.04.20	UPDATED TO REFLECT NEW LAYOUT	MN/DW/DW
C2	21.04.20	NOTES REVISED	MN/DW/DW
C1	03.04.20	CONSTRUCTION ISSUE	MN/DW/DW
Rev.	Date	Description	Drn/Chk/Apr

Purpose Of Issue

STAGE 4 TENDER

Project Number

60516144

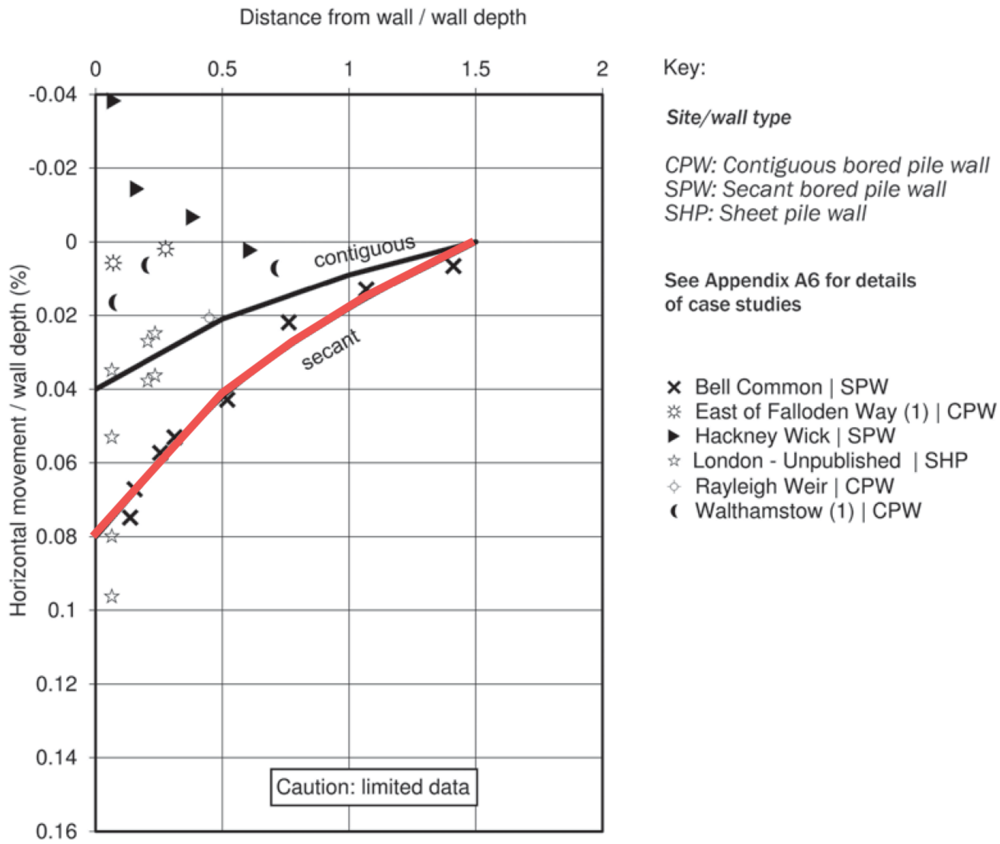
Sheet Title

New Build
Secant Piled Wall Surcharge Loading
Plan

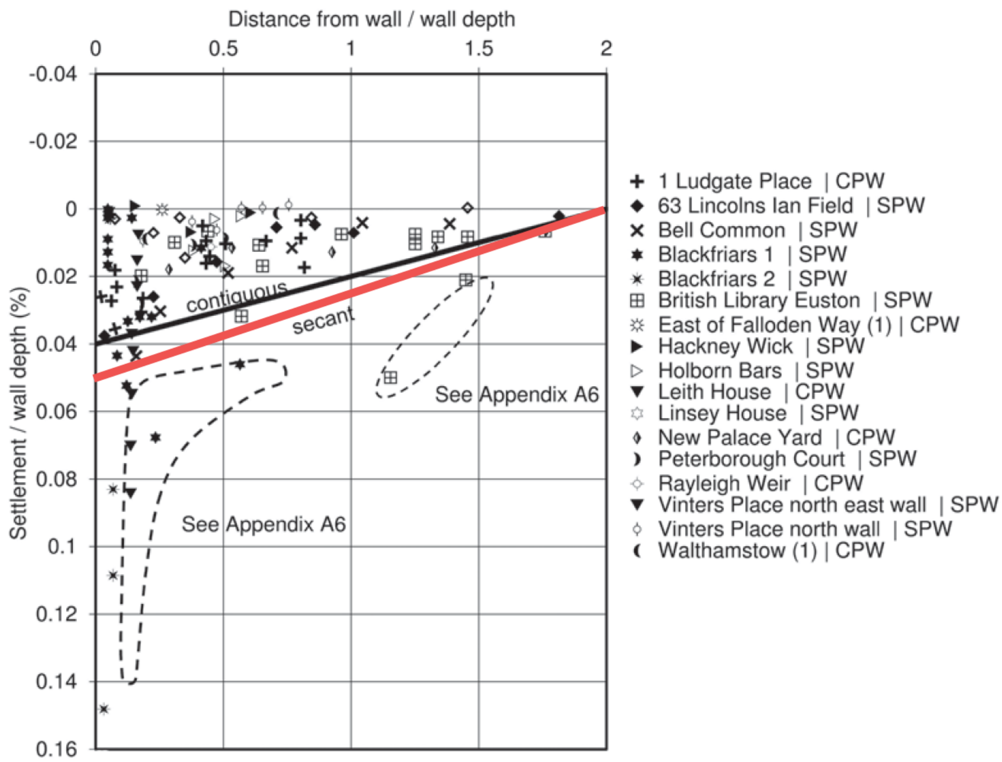
Sheet Number

MHA-ACM-XX-P1-DR-SE-001001

Scale: 1 : 100@A1 **Rev:** T1



a Horizontal movements



b Vertical movements

Figure 5: Ground surface movements due to bored pile installation in stiff clay (normalised) (CIRIA C760 Figure 6.8 (a) & (b))

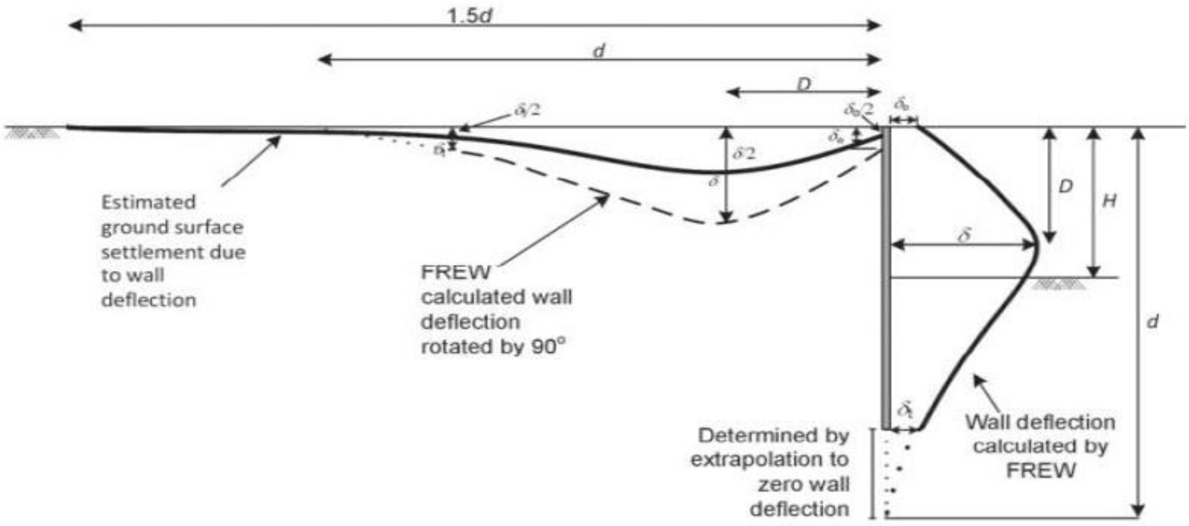


Figure 6: Figure 6.17 Relationship between analysed lateral (propped) wall deflections and predicted ground surface settlements in stiff ground (CIRIA C760 Figure 6.17)

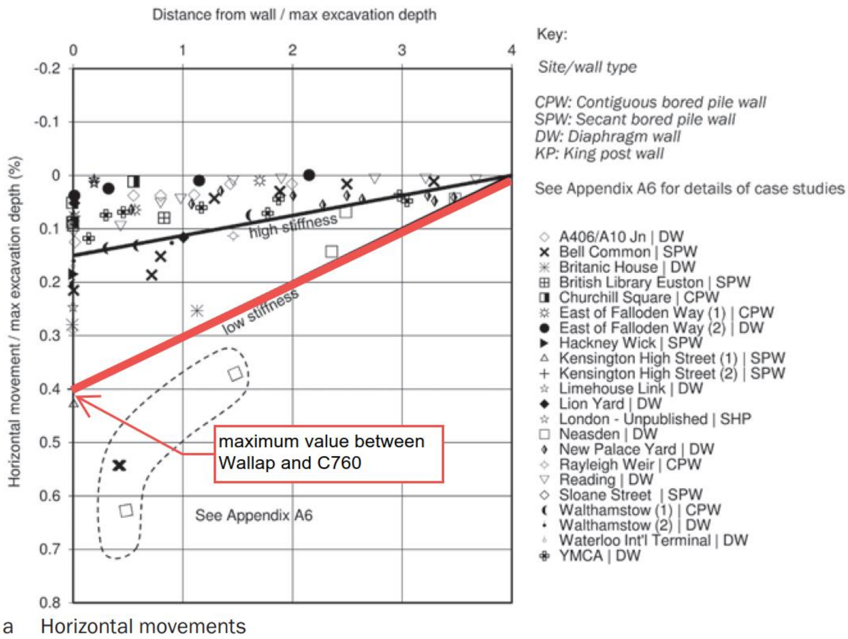


Figure 7: Ground surface movements due to excavation in front of wall embedded in stiff clay (CIRIA C760 Figure 6.15)

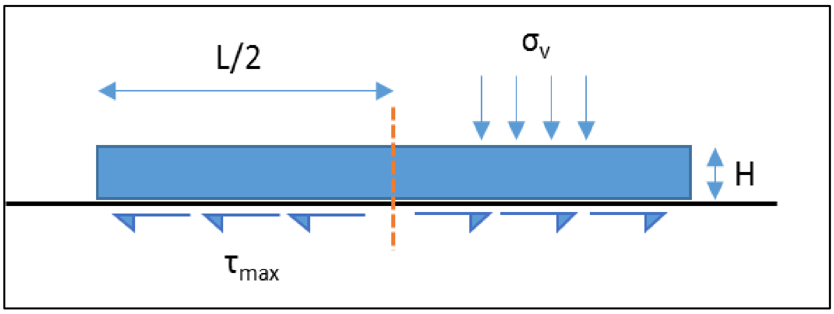


Figure 8: Axial Strain Calculation – Alternative Approach

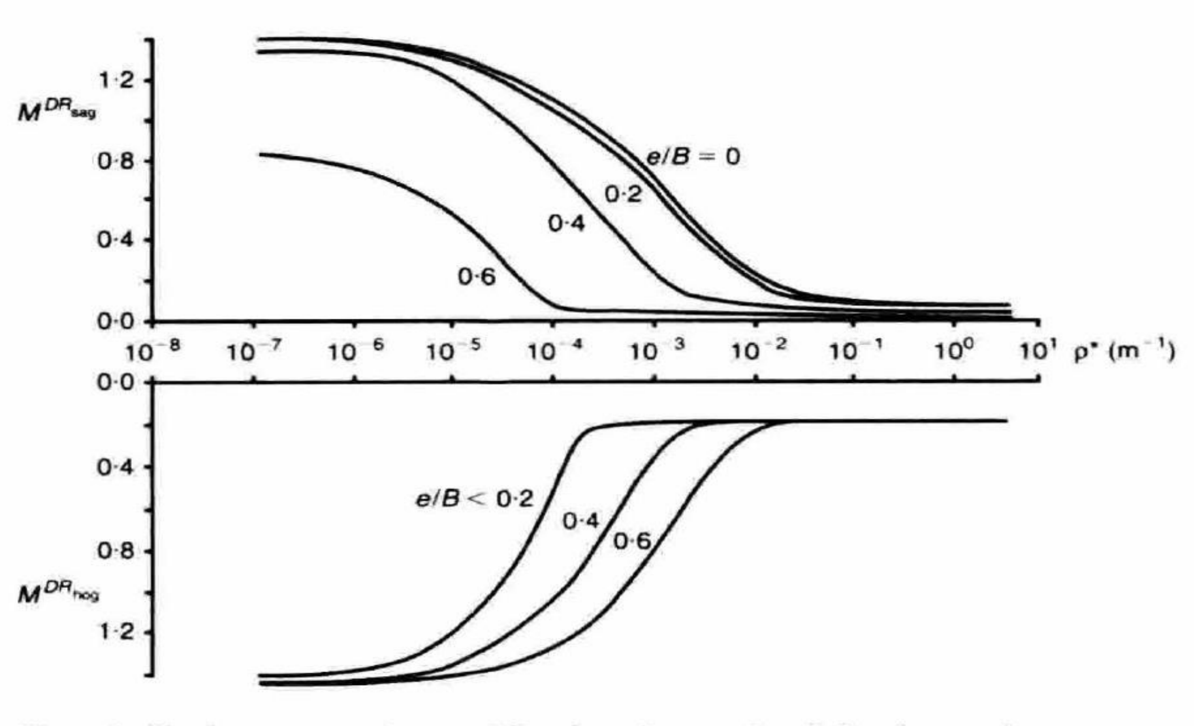


Figure 9: Modification Factors for Deflection Ratio (after Potts and Addenbrooke, 1997)

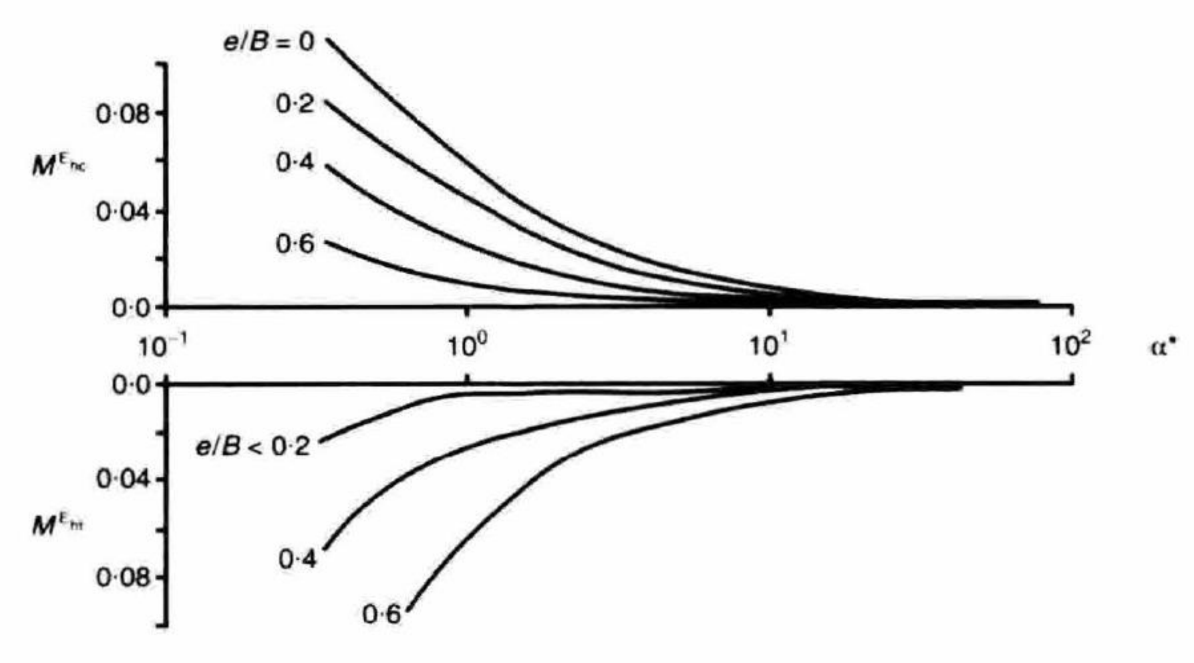
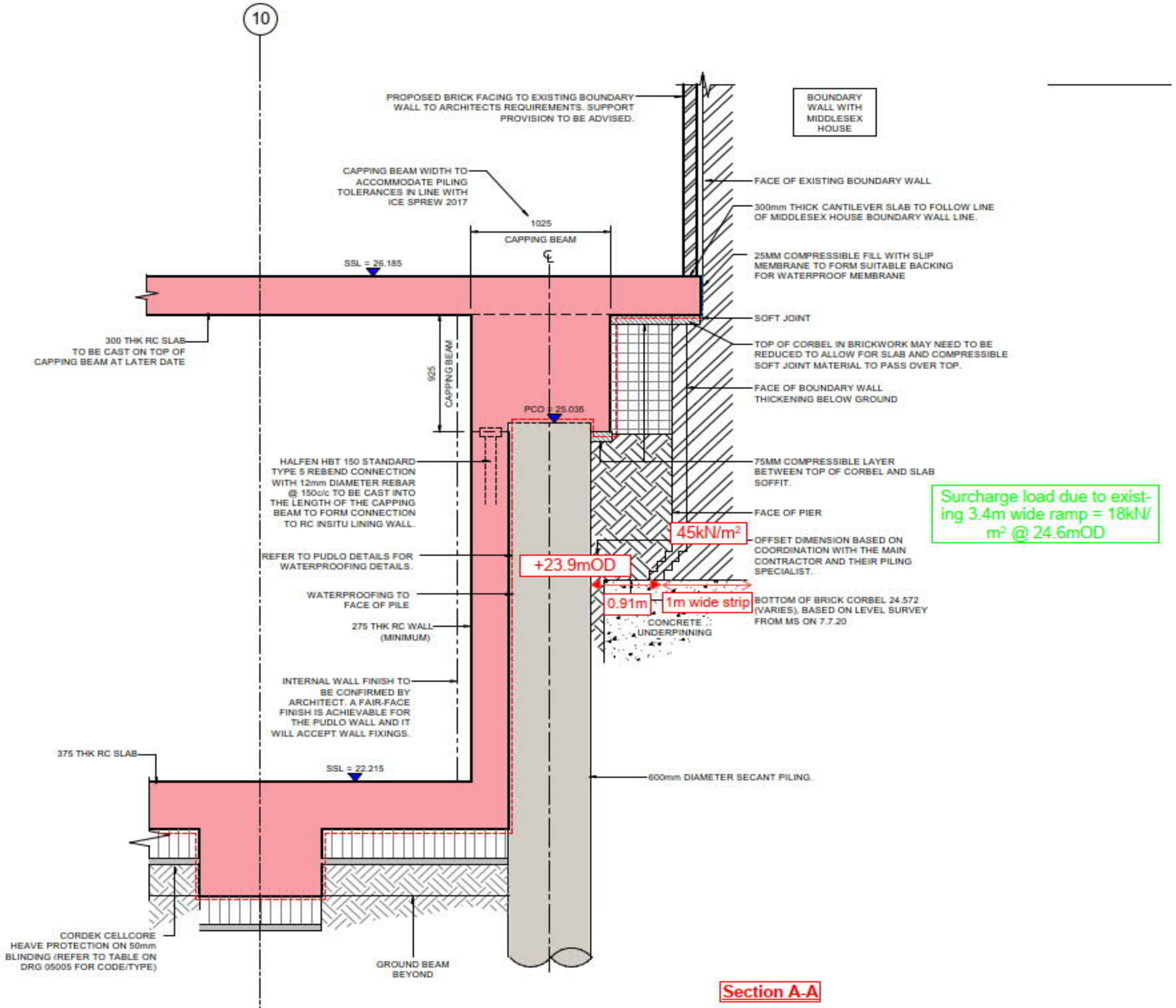


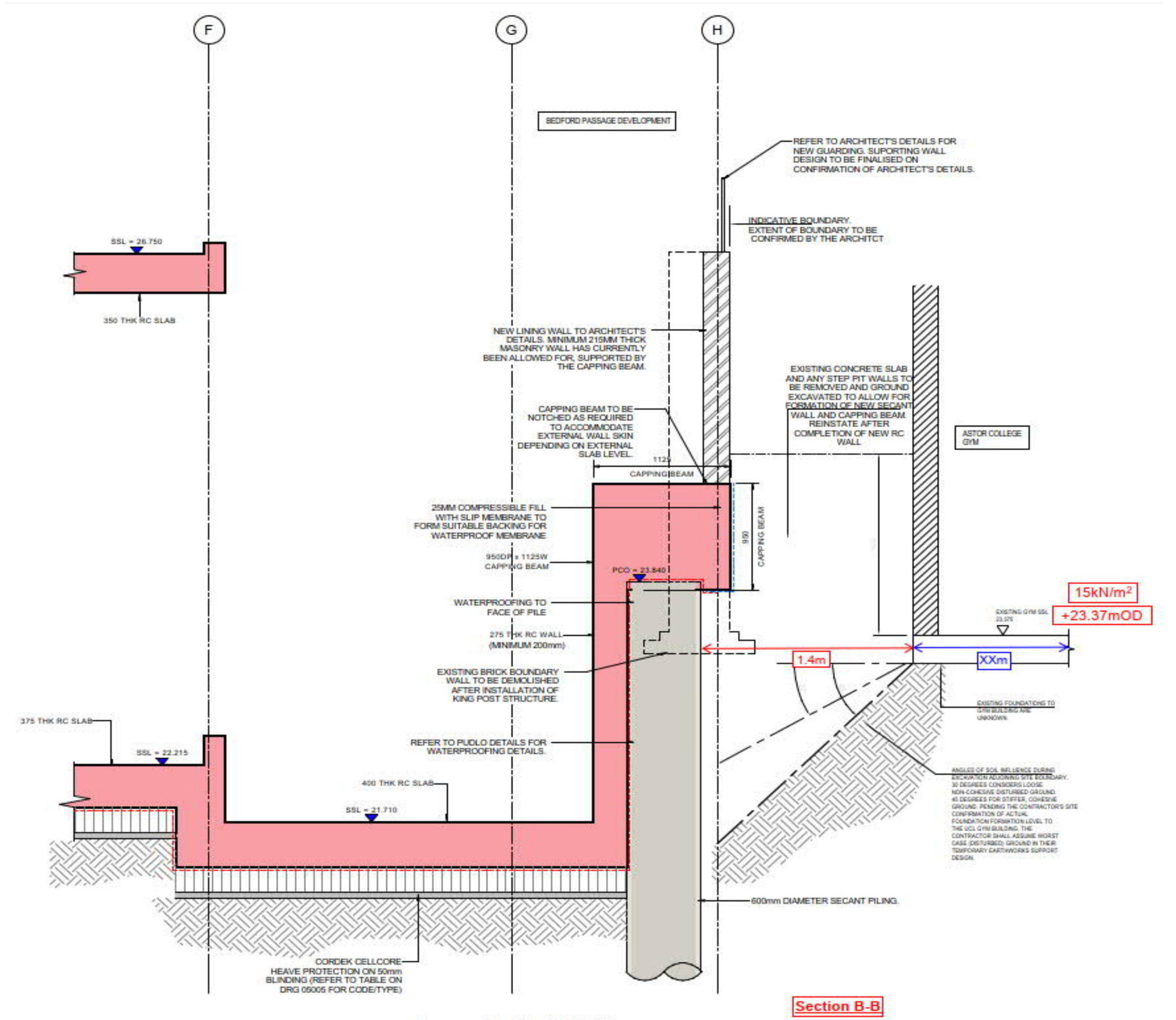
Figure 10: Modification Factor for Horizontal Strain (after Potts and Addenbrooke, 1997)

Appendix A Representative Sections for Basement Construction



Proposed Section 2-2 (BW2)
1 : 25

AECOM		Project:	**Middlesex Hospital Annexe Ground Movement Assessment**
		Title:	**Retaining Wall Sections Analysed for Ground Movement Assessment**
Job No.	60516144		

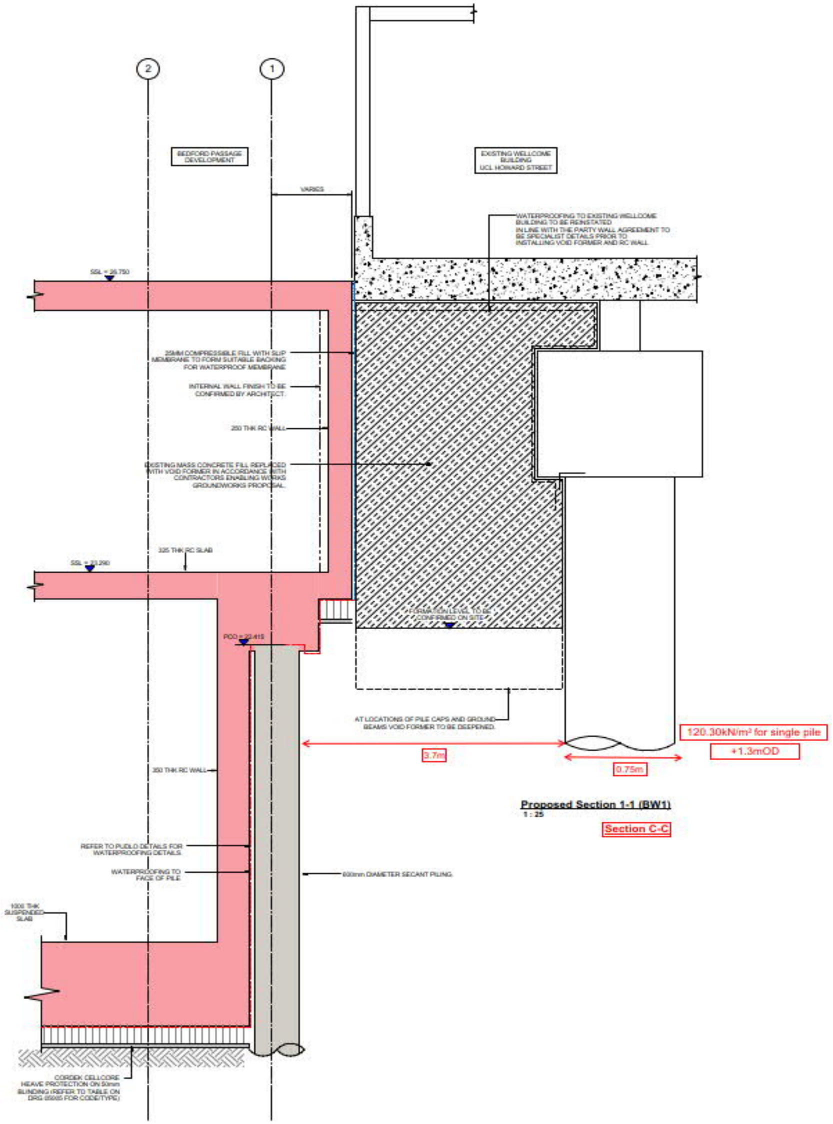


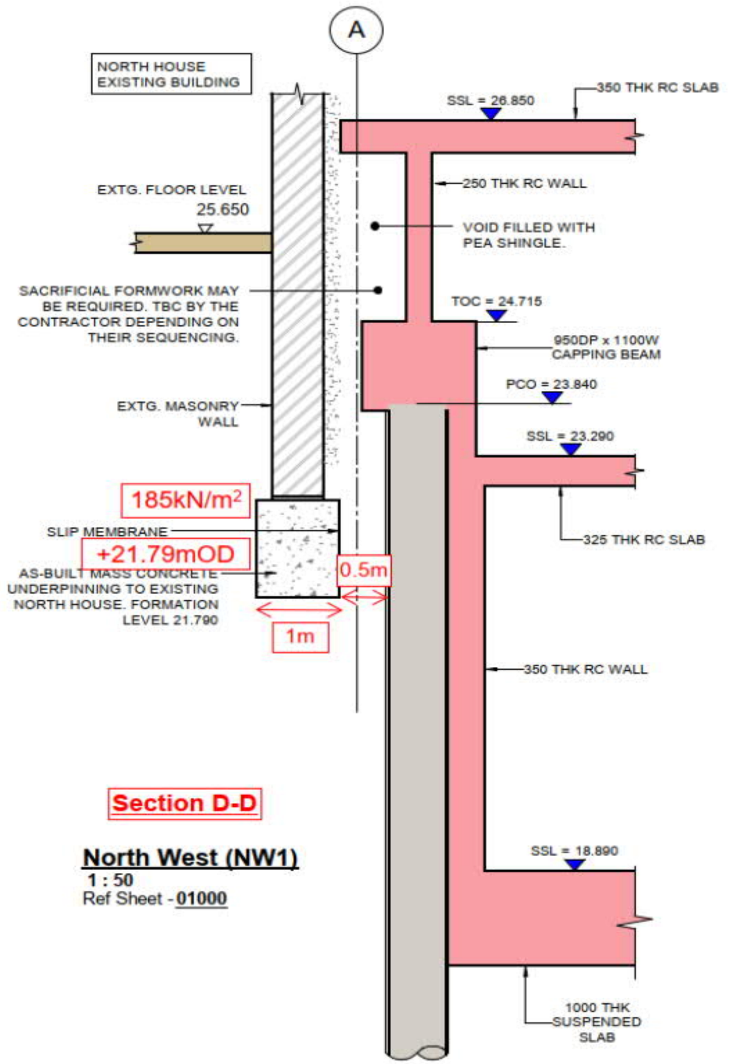
Proposed Section 5-5 (BW5)

1 : 25

AECOM

Project:	**Middlesex Hospital Annexe Ground Movement Assessment**
Title:	**Retaining Wall Sections Analysed for Ground Movement Assessment**
Job No.	60516144

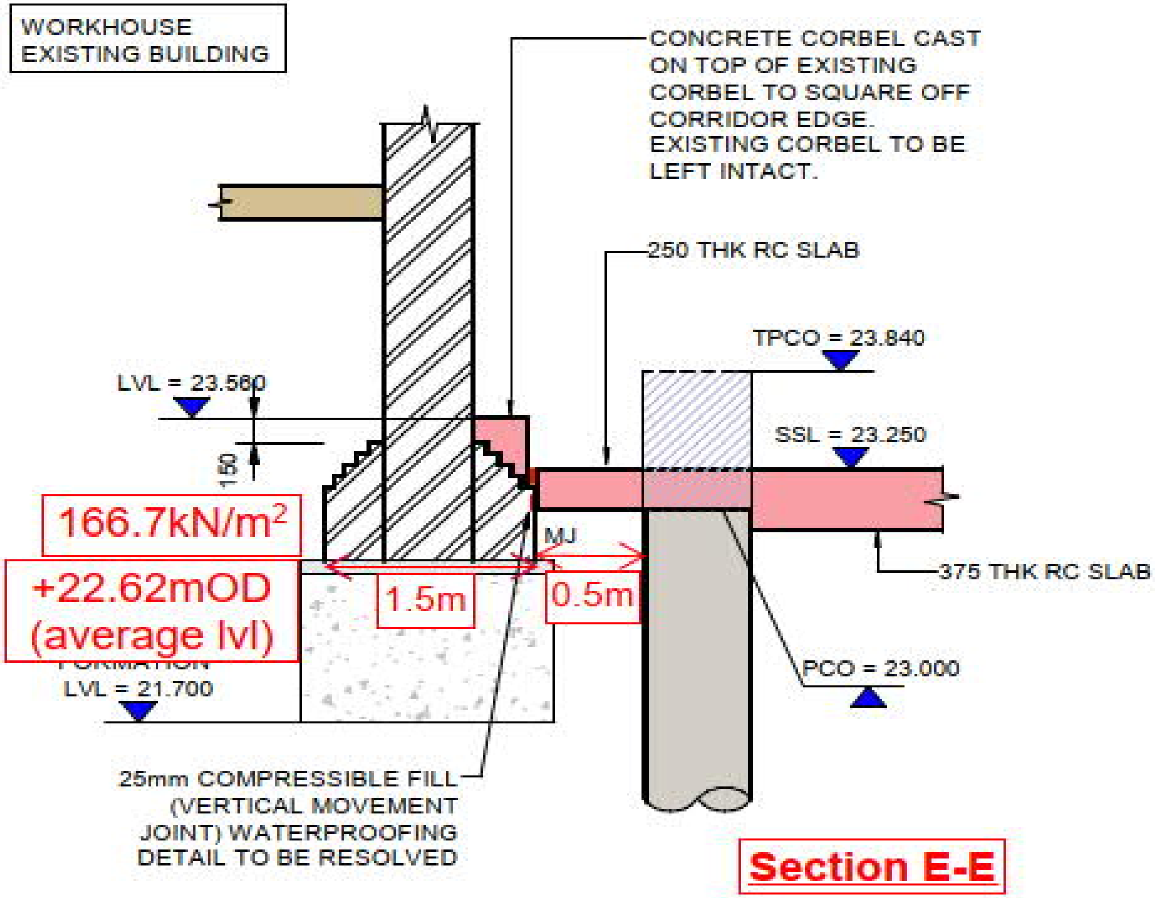




Section D-D

North West (NW1)
1 : 50
Ref Sheet - **01000**

AECOM	Project: **Middlesex Hospital Annexe Ground Movement Assessment**
	Title: **Retaining Wall Sections Analysed for Ground Movement Assessment**
Job No. 60516144	



West 2 (W2)

1 : 50

Ref Sheet - 01001

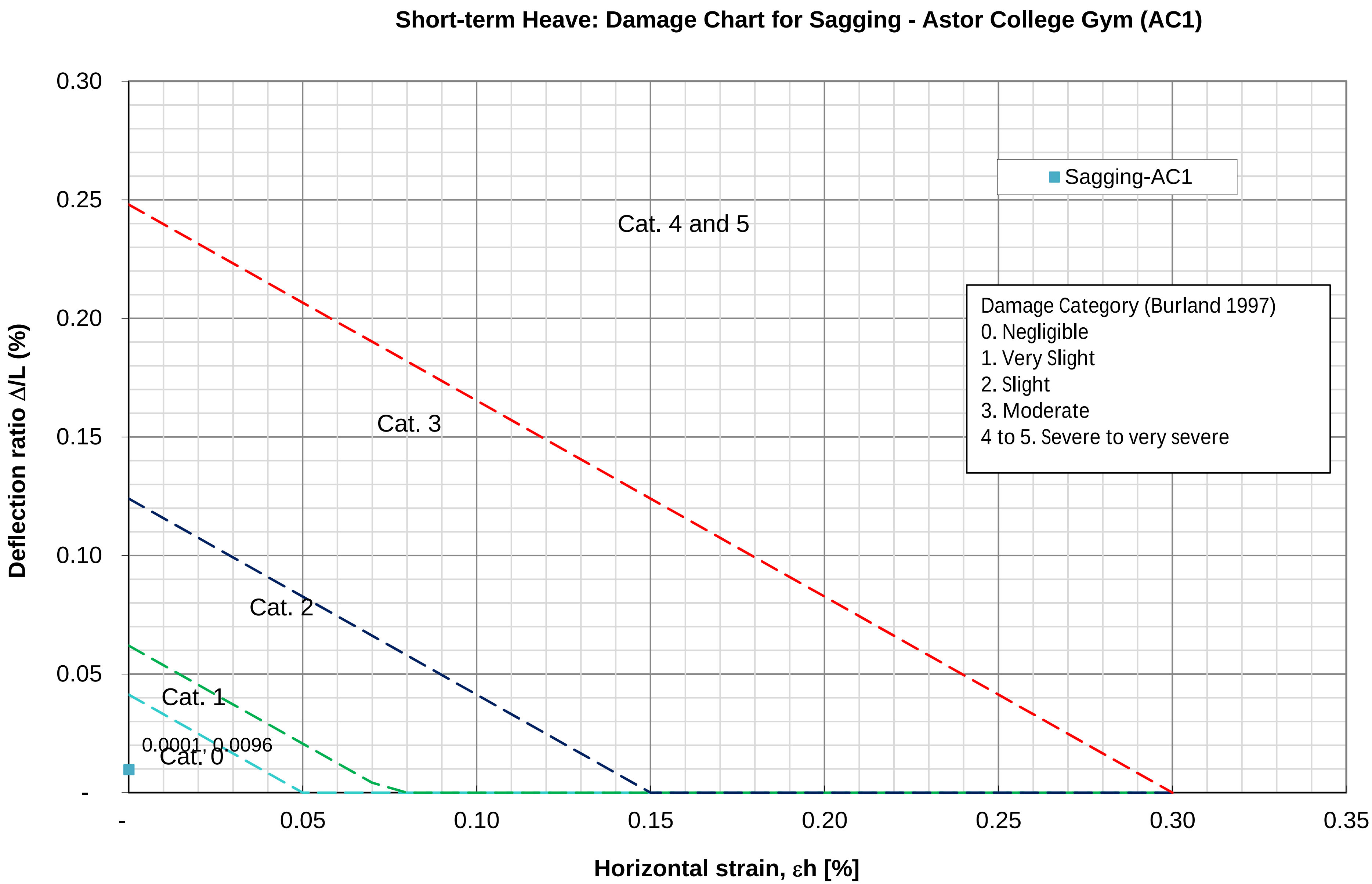
AECOM		Project:	Middlesex Hospital Annexe Ground Movement Assessment
		Title:	Retaining Wall Sections Analysed for Ground Movement Assessment
Job No.	60516144		

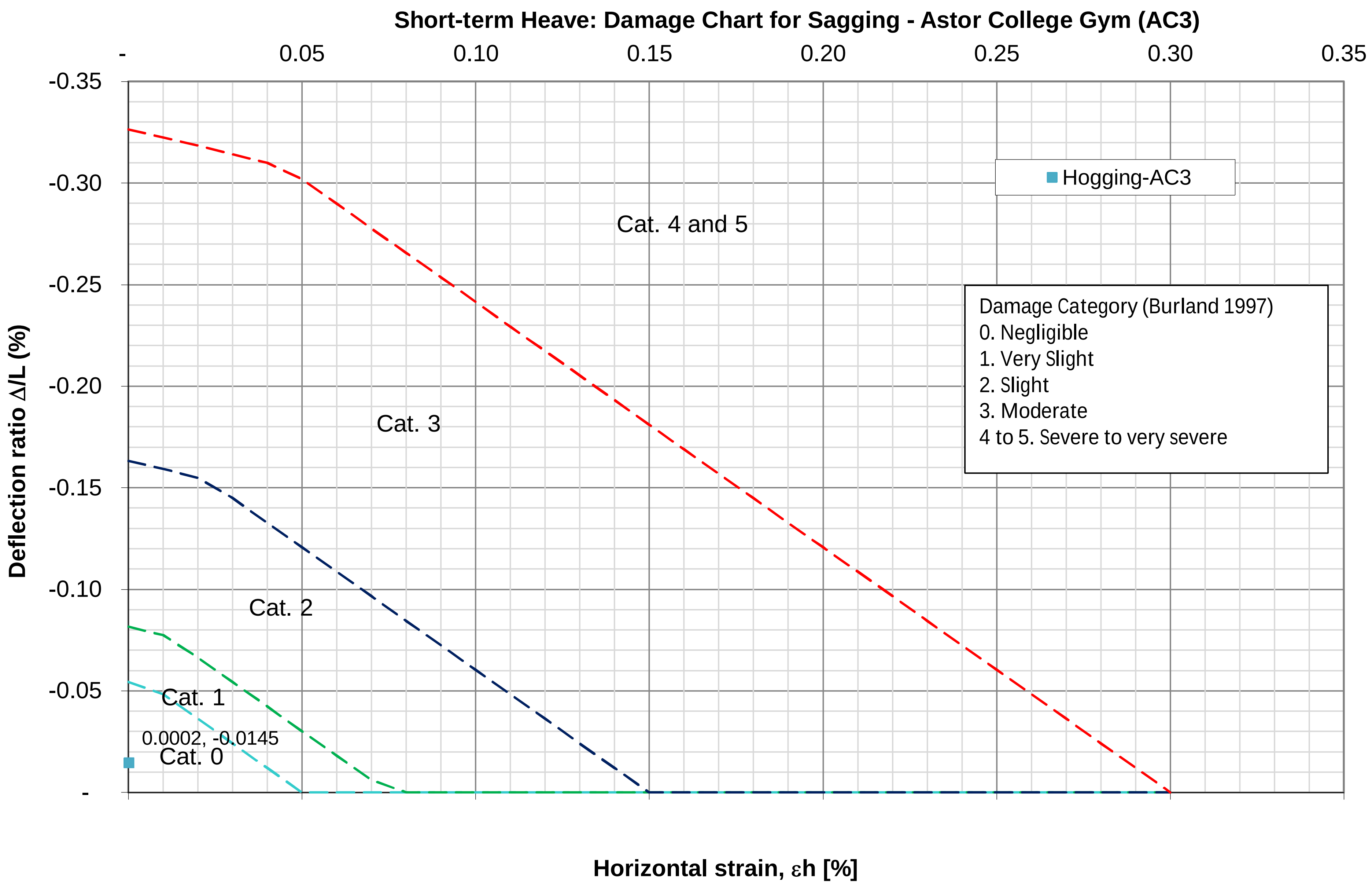
Appendix B Damage Assessment Calculation – Refinement of Results

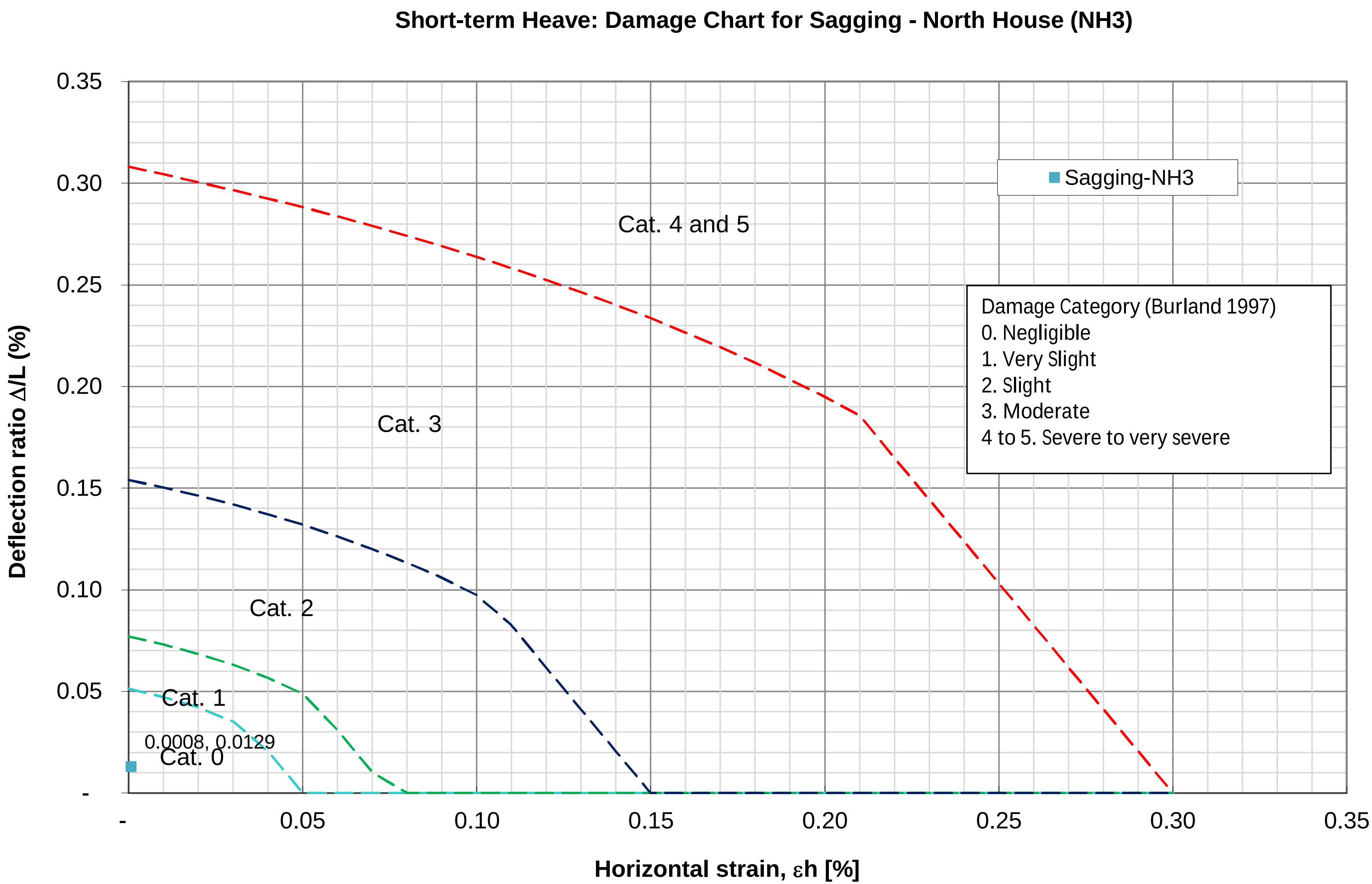
Results considering Potts and Addenbrooke (1997) method accounting for structure stiffness.

Wall ID	Wallap Section	Wall No.	Computed Deflection Ratio - greenfield (%)	Computed Horizontal Strain - greenfield (%)	Sagging/ Hogging	Tensile/ Compressive	Width, B (m)	H=L/2 (m)	E (kPa)	A (m^2)	I (m^4)	ρ*	α*	MDRsag	MDRhog	Metensile	Mecompressive	Computed Deflection Ratio - modified (%)	Computed Horizontal Strain - modified (%)
Short-Term Heave																			
Astor College	Section B-B	AC-1	0.0096131	0.083829	Sagging	Tensile	0.25	4.1	3.30E+07	2.1	12.3	5.68E+01	6.74E+02	0.1		0.003		0.00096131	0.000251487
	Section B-B	AC-3	0.014537	0.10729	Hogging	Tensile	0.25	4.9	3.30E+07	2.1	12.3	2.78E+01	5.63E+02	0.2		0.003		0	0.00032187
North House	Section D-D	NH-3	0.012896	0.07447	Sagging	Tensile	0.35	3.2	5.00E+06	6.8	214.9	4.37E+02	4.32E+02	0.1		0.003		0.0012896	0.00022341
Long-Term Net Loading																			
Tottenham Mews	Section A-A	TM-2	0.083412	0.077035	Sagging	Tensile	0.6	1.8	5.00E+06	10.9	299.0	6.23E+03	1.24E+03	0.1		0.003		0.0083412	0.000231105
Astor College	Section B-B	AC-1	0.018298	0.083539	Sagging	Tensile	0.25	4.1	3.30E+07	2.1	12.3	5.68E+01	6.74E+02	0.1		0.003		0.0018298	0.000250617
	Section B-B	AC-3	0.037626	0.13302	Sagging	Tensile	0.25	4.9	3.30E+07	2.1	12.3	2.78E+01	5.63E+02	0.1		0.003		0.0037626	0.00039906
North House	Section D-D	NH-3	0.070263	0.086117	Sagging	Tensile	0.35	3.2	5.00E+06	6.8	214.9	4.37E+02	4.32E+02	0.1		0.003		0.0070263	0.000258351
Workhouse	Section E-E	WH-3	0.083739	0.038384	Sagging	Tensile	0.6	1.5	5.00E+06	12.0	404.8	1.60E+04	1.61E+03	0.1		0.003		0.0083739	0.000115152

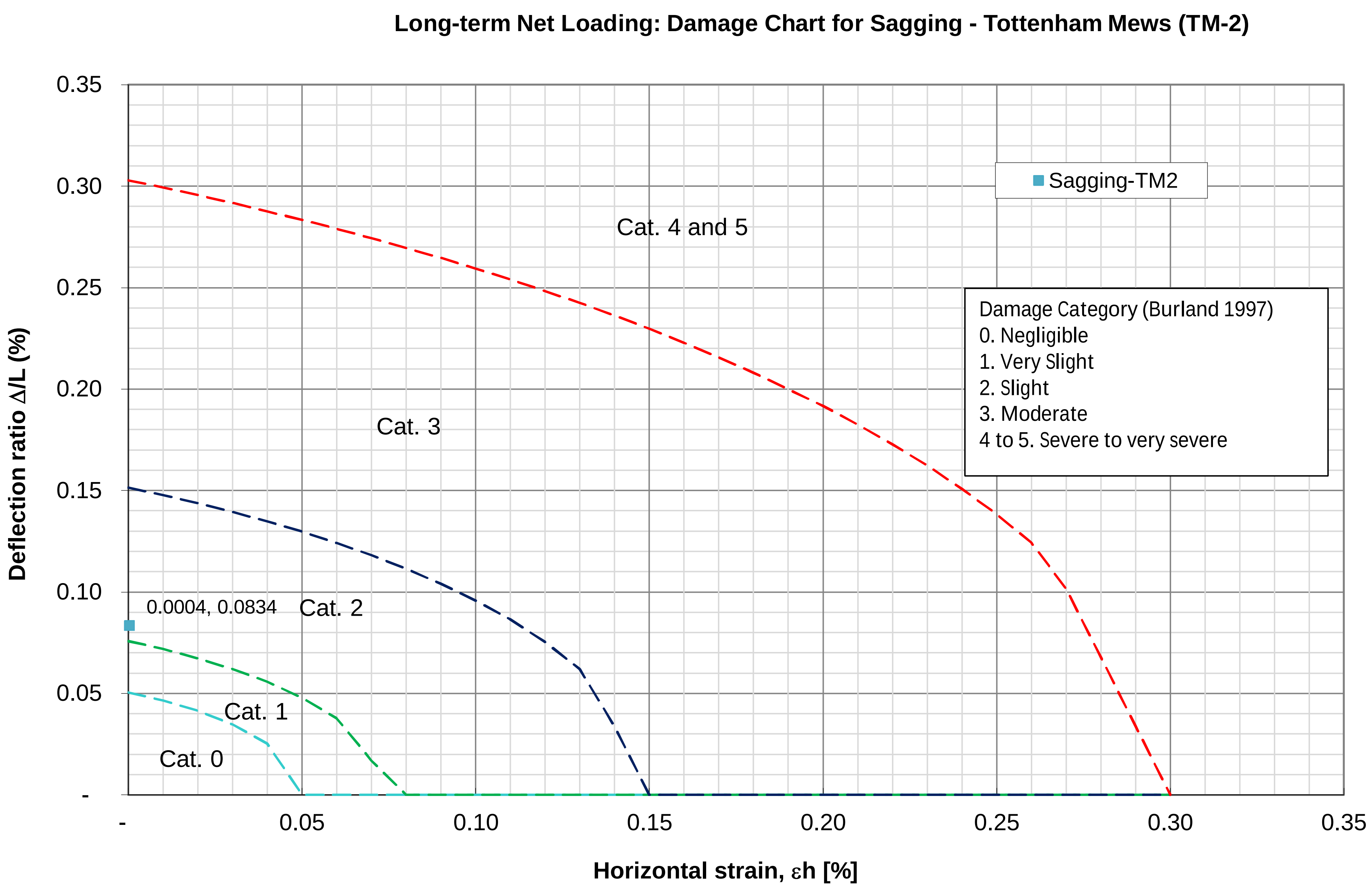
Results considering maximum tensile strain within walls.



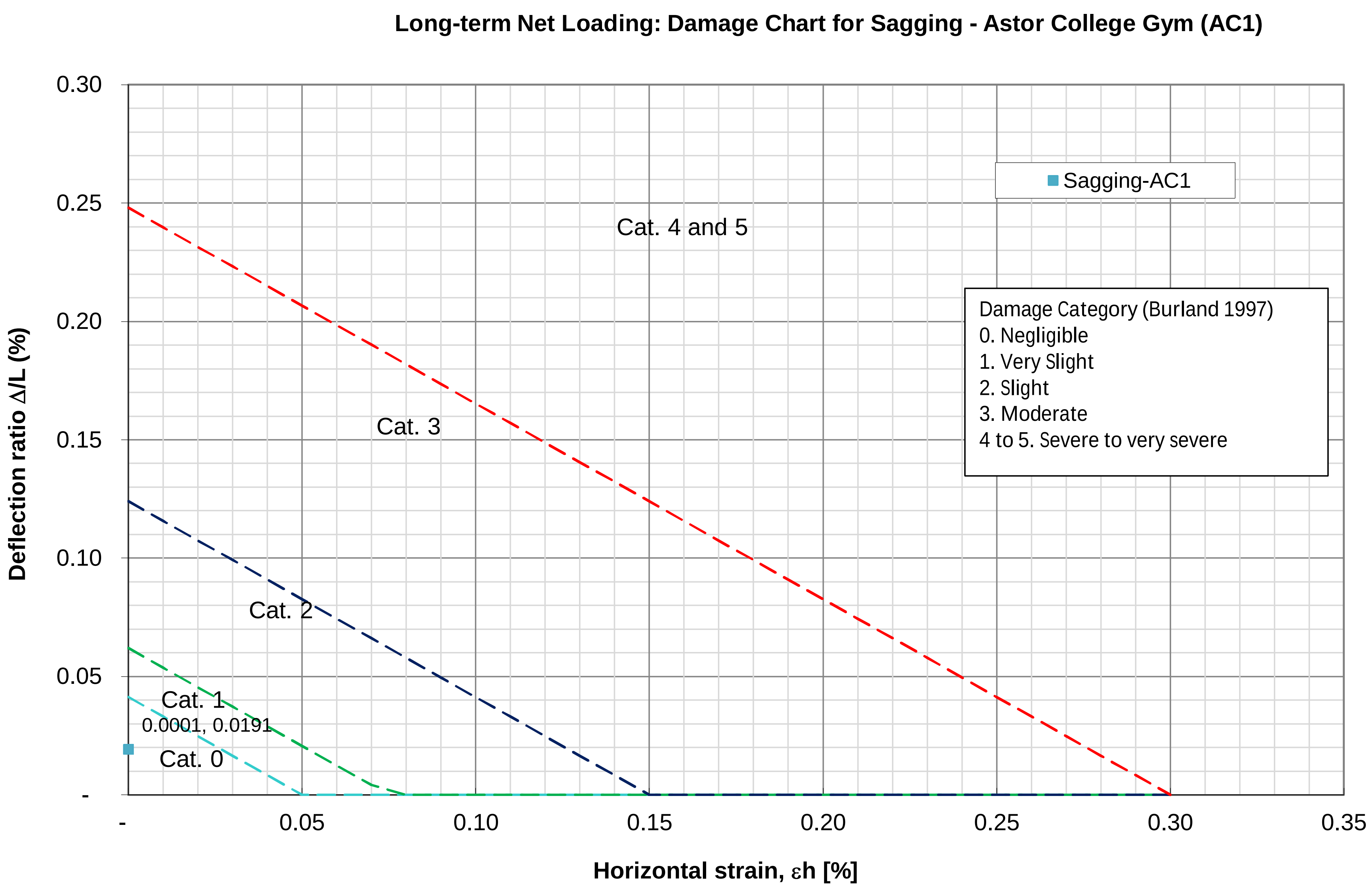

Short-term Heave: Damage Chart for Sagging - Astor College Gym (AC3)
-
0.05
0.10
0.15
0.20
0.25
0.30
0.35
-0.35
-0.30
-0.25
-0.20
-0.15
-0.10
-0.05
-
Deflection ratio Δ/L (%)
Hogging-AC3
Cat. 4 and 5
Cat. 3
Cat. 2
Cat. 1
Cat. 0
0.0002, -0.0145
Damage Category (Burland 1997)
0. Negligible
1. Very Slight
2. Slight
3. Moderate
4 to 5. Severe to very severe
Horizontal strain, εh [%]



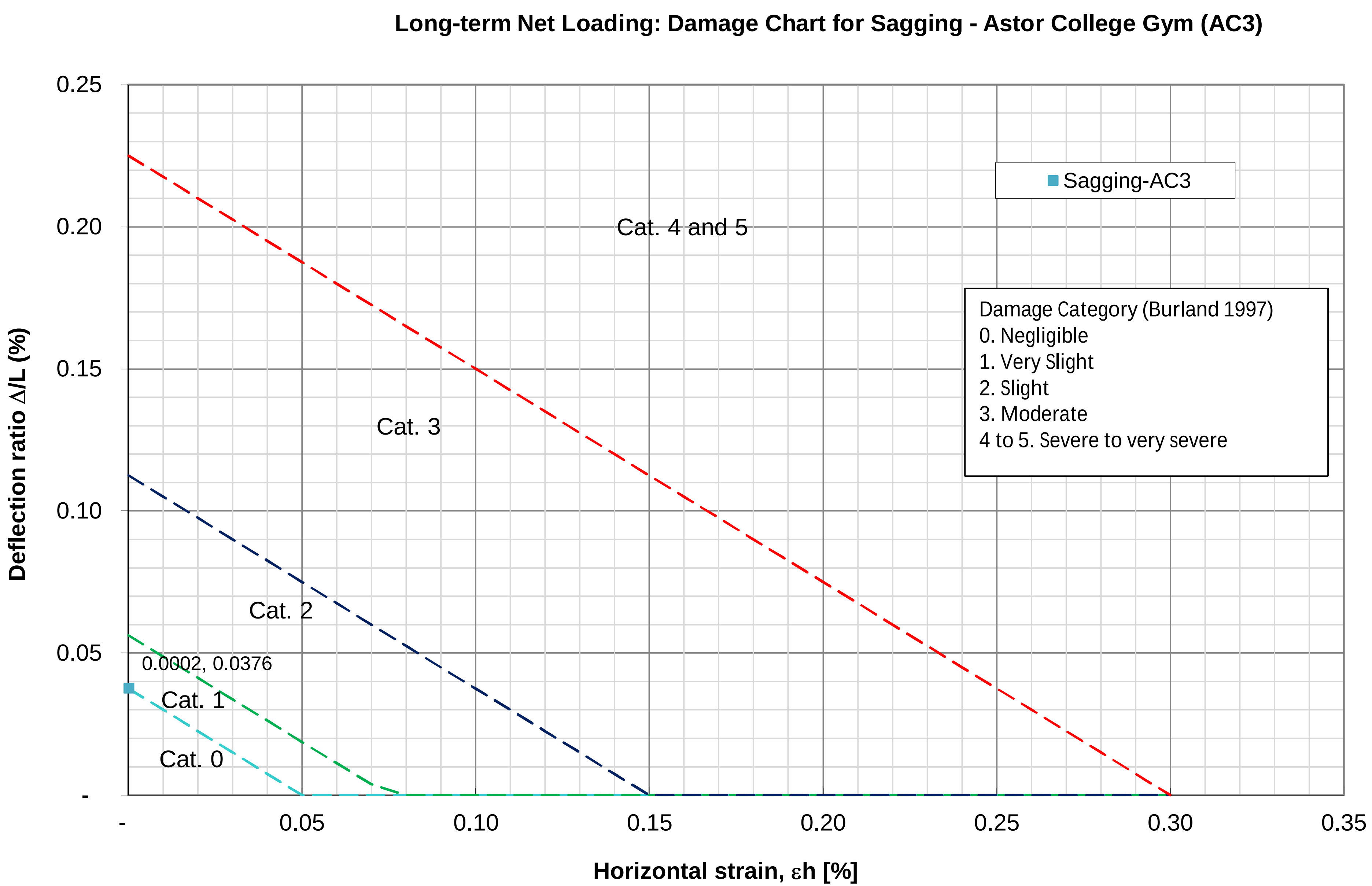
Short-term Heave: Damage Chart for Sagging - North House (NH3)
Sagging-NH3
Cat. 4 and 5
Damage Category (Burland 1997)
0. Negligible
1. Very Slight
2. Slight
3. Moderate
4 to 5. Severe to very severe
Cat. 3
Cat. 2
Cat. 1
0.0008, 0.0129
Cat. 0
Deflection ratio Δ/L (%)
0.35
0.30
0.25
0.20
0.15
0.10
0.05
-
-
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Horizontal strain, εh [%]



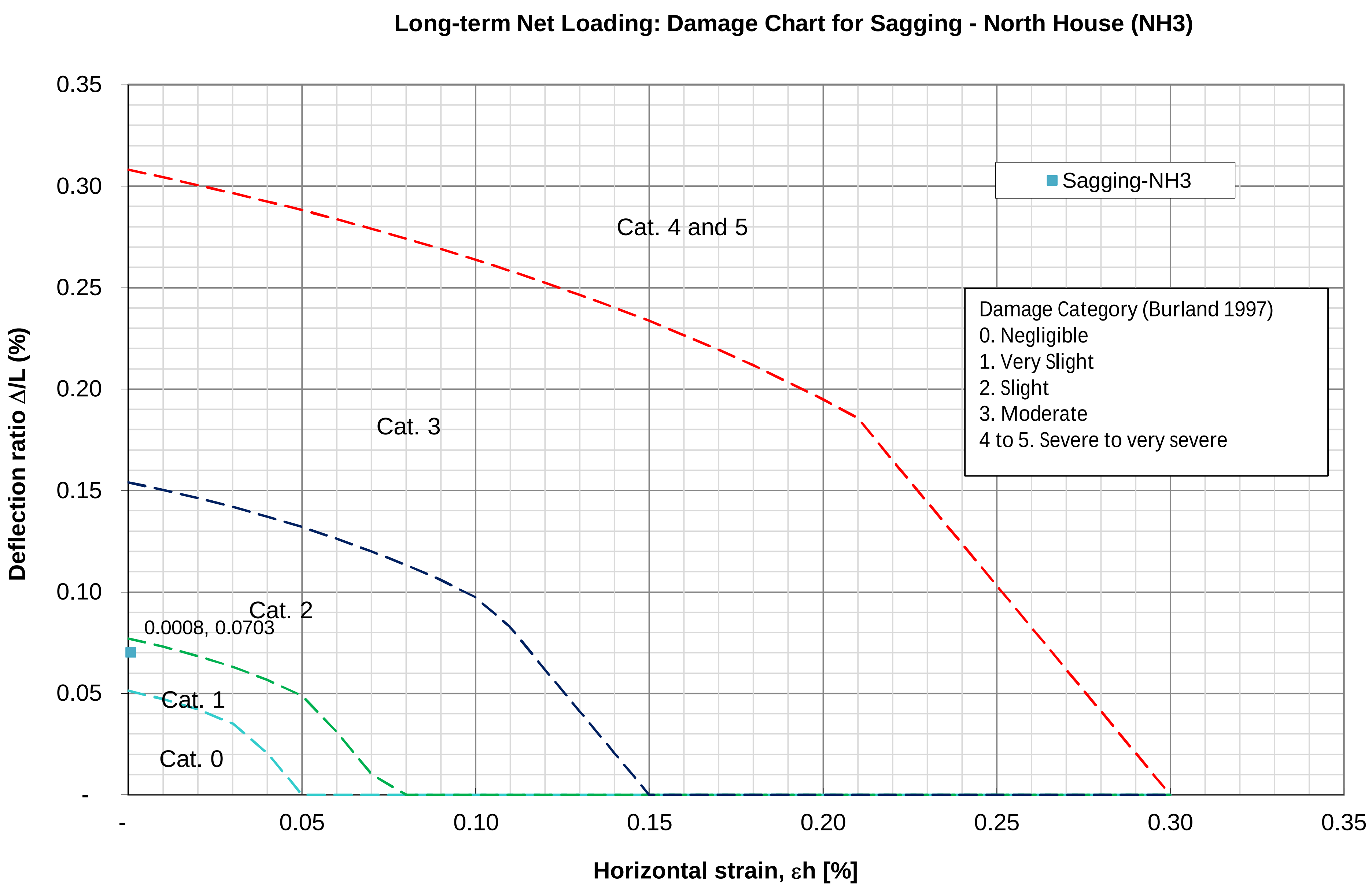
Long-term Net Loading: Damage Chart for Sagging - Tottenham Mews (TM-2)
Deflection ratio Δ/L (%)
Horizontal strain, εh [%]
0.35
0.30
0.25
0.20
0.15
0.10
0.05
-
-
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Sagging-TM2
Cat. 4 and 5
Cat. 3
Cat. 2
Cat. 1
Cat. 0
0.0004, 0.0834
Damage Category (Burland 1997)
0. Negligible
1. Very Slight
2. Slight
3. Moderate
4 to 5. Severe to very severe



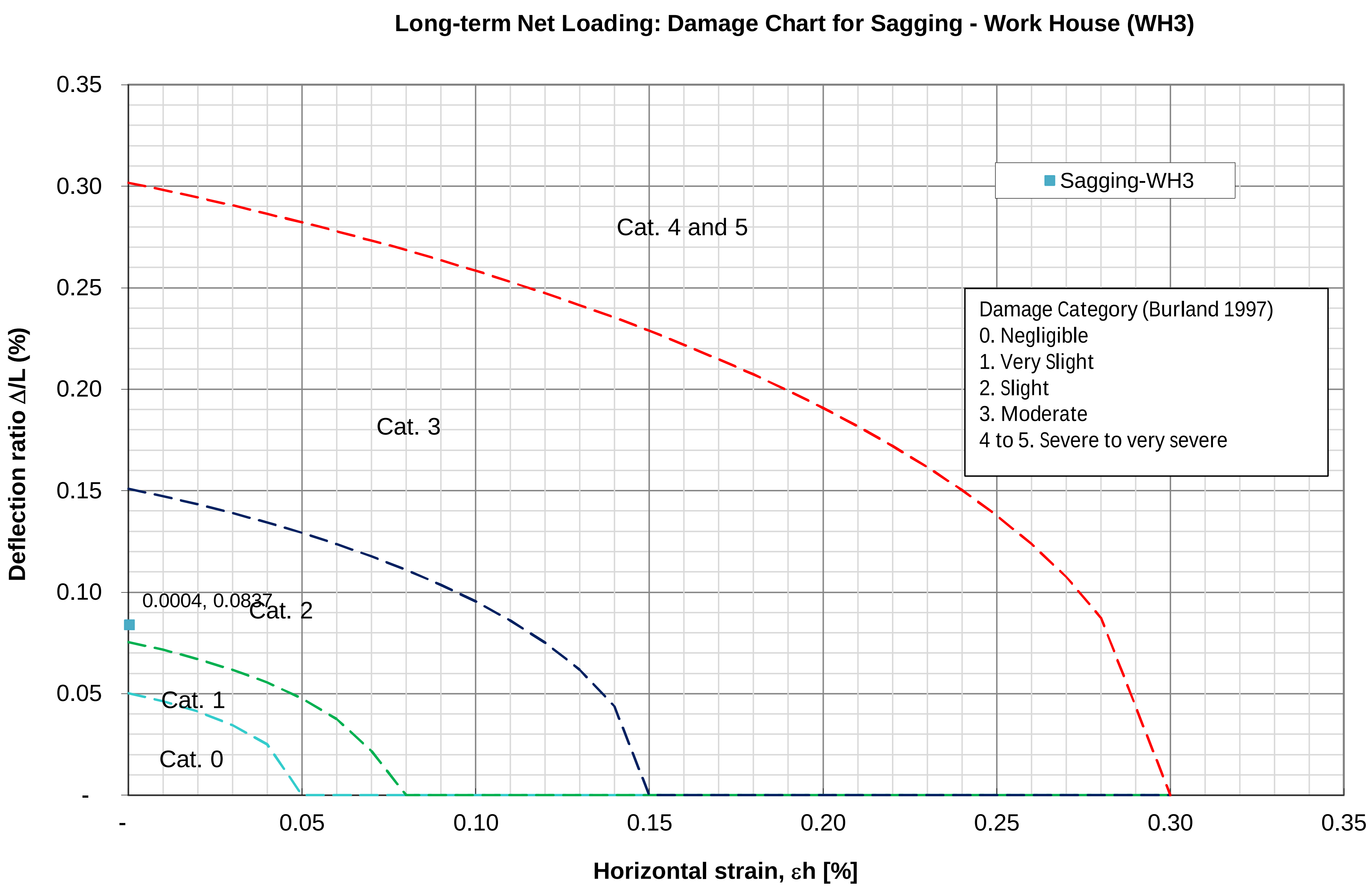
Long-term Net Loading: Damage Chart for Sagging - Astor College Gym (AC1)
0.30
0.25
0.20
0.15
0.10
0.05
-
Deflection ratio ΔL (%)
Sagging-AC1
Cat. 4 and 5
Cat. 3
Cat. 2
Cat. 1
0.0001, 0.0191
Cat. 0
Damage Category (Burland 1997)
0. Negligible
1. Very Slight
2. Slight
3. Moderate
4 to 5. Severe to very severe
-
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Horizontal strain, εh [%]



Long-term Net Loading: Damage Chart for Sagging - Astor College Gym (AC3)
Sagging-AC3
Cat. 4 and 5
Damage Category (Burland 1997)
0. Negligible
1. Very Slight
2. Slight
3. Moderate
4 to 5. Severe to very severe
Cat. 3
Cat. 2
0.0002, 0.0376
Cat. 1
Cat. 0
0.25
0.20
0.15
0.10
0.05
-
-
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Deflection ratio Δ/L (%)
Horizontal strain, εh [%]



Long-term Net Loading: Damage Chart for Sagging - North House (NH3)
Deflection ratio Δ/L (%)
0.35
0.30
0.25
0.20
0.15
0.10
0.05
-
Horizontal strain, εh [%]
-
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Sagging-NH3
Cat. 4 and 5
Cat. 3
Cat. 2
Cat. 1
Cat. 0
0.0008, 0.0703
Damage Category (Burland 1997)
0. Negligible
1. Very Slight
2. Slight
3. Moderate
4 to 5. Severe to very severe



Long-term Net Loading: Damage Chart for Sagging - Work House (WH3)
Deflection ratio Δ/L (%)
0.35
0.30
0.25
0.20
0.15
0.10
0.05
-
Horizontal strain, εh [%]
-
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Sagging-WH3
Cat. 4 and 5
Cat. 3
Cat. 2
Cat. 1
Cat. 0
0.0004, 0.0837
Damage Category (Burland 1997)
0. Negligible
1. Very Slight
2. Slight
3. Moderate
4 to 5. Severe to very severe