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Bacton Low Rise . Phase 2

Basement Impact Assessment [Addendum]

2 Mar 2017 . 2880 RPT Bacton BIA [Addendum]

90 Walcot Street . Bath BA1 5BG . 01225 444194
103 Timber Yard . Drysdale Street . London . N1 6ND. 020 7739 6939
www.momentumengineering.com

Background

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Authors
Tom Skailes
BSc (Hons) MSc DIC CGeol FGS

Richard Heath
MEng MIStructE

Authors and accreditation from previous report may be found in Appendix B.

Checked
S Fisher
BEng MIStructE

Issue History

Rev.	Date	Comments
0	02.03.17	First issue

Contents

Introduction

Introduction
This document has been prepared to address comments made by Campbell Reith Hill.

This document should be read in conjunction with the original BIA document, revision 1, dated 27th September 2016.

Site details

Updates to assessment of site geology
The bulk of the site geology (BHs 4-8 of the Geotechnics 2012 site investigation are applicable) comprises 0.9-1.7m of made ground directly overlying firm to stiff London Clay. At BH 4 to the north-east of the proposed basement, however, an intervening layer of firm gravelly clay was present to 2.0m depth which may represent weathered/reworked London Clay or some other superficial deposit, although the Camden Geological, Hydrogeological and Hydrological Study geological map of north Camden does not indicate any superficial deposits to be present in the vicinity of the site, and hence this material is not expected to be extensive or consistent. A former tributary of the River Fleet also passed through the site, and although this was first culverted and then severed by the railway line to the north of the site, alluvial deposits and more deeply weathered London Clay may be present locally across the site.

Updates to assessment of site hydrogeology
As noted above, a former tributary of the River Fleet crossed the site historically from north to south. Monitoring of the standpipes installed during the ground investigation has indicated variable groundwater levels, probably due to the standpipes being installed into very low permeability London Clay, and may therefore represent perched groundwater. The line of the former tributary may or may not provide a route for perched groundwater flow through the site, however pockets and lenses of alluvial material associated with its former route may be a source of isolated/localised perched water bodies of limited extent.

Conceptual site model
A sketch plan and section showing the conceptual site model is presented in Appendix A to this addendum document.

Preliminary assessment of appropriate geotechnical design parameters
The detailed design of the piles for the proposed retaining wall and foundations will be carried out by the piling contractor, however a preliminary assessment of applicable geotechnical design parameters is given here as guide of the types and range of parameters that are likely to be adopted.

Made ground – ground level to ~1.5m depth, γb = 17 kN/m3, c' = 0kN/m2, φ' = 24-26° (ignored in bearing pile design)

London Clay (weathered) - ~1.5m to ~3m depth, γb = 20 kN/m3, c' = 0kN/m2, φ' = 20-25° (based on BS 8002 guidance, high plasticity clay)

London Clay - >3m depth, γb = 20.5 kN/m3, c' = 2.5kN/m2, φ' = 20-25° (based on BS 8002 guidance, high plasticity clay)

London Clay undrained shear strength profile, Cu = 40 + 6z kN/m2 (where z is the depth in metres below a reference level of 2m depth – based on Geotechnics ground investigation report data)

London Clay, undrained stiffness, Eu = 1000Cu (based on CIRIA C580 guidance)

London Clay, drained stiffness, E' = 0.8Eu (based on CIRIA C580 guidance)

Potential hydrogeology/land stability issues
There are some indications that lower strength or water-bearing superficial deposits could be present locally across the basement footprint associated with a former tributary of the River Fleet. If present these could potentially affect the required depth of embedment for the retaining wall piles due to lower soil strengths to greater depth, however they are not anticipated to affect the compression piles beneath the basement area as they are considered unlikely to extend below 5m depth. In addition to the potential for reduced soil strength characteristics locally, superficial deposits may be source of localised perched water which could impact on the basement construction.

To mitigate these potential risks the contractor shall excavate a series of trial pits to 2-3m depth close to the line of the proposed retaining wall at various points around the basement footprint to assess whether any superficial deposits are present between the made ground and the London Clay, and, if present, their strength characteristics and whether they are water-bearing.

If superficial materials are found present and are water-bearing it is anticipated that for standard bored piles a temporary casing will in any case be used through the near surface materials, and if necessary a longer temporary casing could be used to allow the bored piles to be constructed without risk of water influx or collapse of water-bearing soils into the pile bore, however the temporary casings used are typically a minimum of 6m long, which is anticipated to extend well below the base of any superficial materials that might be present. If CFA piling is used the presence of water-bearing strata will not be an issue for their construction.

In the permanent construction case the retaining wall/basement structure will be waterproofed, however, if evidence is found of the significant presence of groundwater-bearing superficial strata crossing the basement footprint, this may suggest the potential for perched water flow across the site, and in that case some means of diverting any potential groundwater flows around the basement would be incorporated into the design, perhaps by including a drainage trench around the basement wall, or linking around the basement at a greater distance. Any such measures would be subject to the findings of the supplementary investigation works noted above and would be the subject of detailed design.

If soft/loose materials are encountered locally to greater depths than currently envisaged this may result in a need for some of the retaining wall piles to be taken a few metres deeper than might otherwise be the case. This requirement would be assessed by the piling contractor based on the findings of the trial pitting, with the pile design adjusted accordingly for the affected piles. If increased pile lengths are required over a short section of wall this is not anticipated to have any impact on the predicted ground movements and associated building damage categories.

If the trial pit findings indicate a wider need for longer piles for the basement retaining wall this would extend the potential zone of influence of ground movements associated with the basement construction. The predicted damage assessment would therefore have to be re-assessed accordingly if the piled retaining wall as designed is deeper than 10m below general ground levels.

Updated ground movements assessments

The CIRIA C580 case study data has been used as the basis for an analysis of the potential short-term ground movements associated with the installation of the piled retaining wall and the excavation of the basement. In this assessment, the following assumptions have been made:

- A 5m depth of dig is required to form the bulk of the basement, and this excavation depth has been assumed
- It is estimated that the bored piles of the retaining wall will extend to 10m below ground surface level, which equates to 6m depth of embedment below dig level, however this will be subject to specialist contractor design
- The temporary and permanent support system is of HIGH stiffness (bored pile retaining wall propped in the temporary case, single storey of basement excavation)

The case study data indicates that ground movements due to installation of the retaining wall could extend to around 20m from the edge of the excavation, and ground movements due to excavation could also extend to around 20m, which takes in 113 Wellesley Road and part of St Martin's Church, both to the north-east of the excavation. A 300mm diameter Thames Water sewer runs parallel to the basement excavation within Wellesley Road at a distance of 4.5m away has also been considered in the assessment. In the nearby properties, the external and internal walls running perpendicular to the edge of the excavation are at greater risk of potential damage than walls running parallel to the excavation. In the analysis, therefore, only the external walls running perpendicular to the edge of the excavation, have been considered. A key plan showing the buildings considered is presented in Appendix B.

The assessment of the potential damage resulting from the predicted short term ground movements has been based on the method proposed by Burland (1995) which built upon the work of Boscardin and Cording (1989) and uses the predicted ground deflections to assess the cumulative effects of bending and diagonal strain on adjacent structures using the limiting tensile strain approach, as summarised in the table below.

Category of damage	Description of typical damage	Approximate crack width (mm)	Limiting tensile strain ε_{lim} (%)
0 Negligible	Hairline cracks of less than about 0.1 mm are classed as negligible	<0.1	0.0-0.05
1 Very slight	Fine cracks that can easily be treated during normal decoration. Perhaps isolated slight fracture in building. Cracks in external brickwork visible on inspection	<1	0.05-0.075
2 Slight	Cracks easily filled. Redecoration probably required. Several slight fractures showing inside of building. Cracks are visible externally and some repointing may be required externally to ensure weathertightness. Doors and windows may stick slightly.	<5	0.075-0.15
3 Moderate	The cracks require some opening up and can be patched by a mason. Recurrent cracks can be masked by suitable lining. Repointing of external brickwork and possibly a small amount of brickwork to be replaced. Doors and windows sticking. Service pipes may fracture. Weathertightness often impaired.	5-15 or a number of cracks > 3	0.15-0.3
4 Severe	Extensive repair work involving breaking-out and replacing sections of walls, especially over doors and windows. Windows and frames distorted, floor sloping noticeably. Walls leaning or bulging noticeably, some loss of bearing in beams. Service pipes disrupted.	15-25 but also depends on number of cracks	>0.3
5 Very severe	This requires a major repair involving partial or complete rebuilding. Beams lose bearings, walls lean badly and require shoring. Windows broken with distortion. Danger of instability.	Usually > 25 but depends on number of cracks	

The Burland building damage assessment method only provides charts for a structure with a length to height wall ratio of 1, and only in the hogging deflection mode and this was used in the preliminary ground movement assessment carried out in September 2016. Since the preliminary ground movement assessment was completed we have developed an in-house spreadsheet that allows any L/H ratio of wall to be assessed. The spreadsheet calculates the diagonal and bending strains in the building wall based on Burland's methodology and can therefore be used to assess the potential degree of damage to walls experiencing hogging or sagging, or a mix of the two modes. For ease of use Burland developed simple charts to aid damage category assessment, and the spreadsheet reproduces charts of the same form, however, because the spreadsheet calculates the diagonal and bending strains directly it also examines the higher of the two strain elements to determine the worst case tensile strain and then compares this to the damage categories directly. The spreadsheet therefore plots the strain data on charts in the forms presented by Burland and also presents the worst case tensile strain directly compared against the limiting strains for the various damage categories, as tabulated below. In all cases a wall E/G ratio of 2.6 has been used in the analyses, which is appropriate for masonry structures.

The table below summarises the findings of the short-term ground movements analysis. The detailed spreadsheet outputs are presented in Appendix B.

Feature	**Length/height/distance**	**Deflection ratio**	**Horiz. strain**	**Deflection mode**	**Tensile strain**	**Damage category**
113 Wellesley Road	7.45m/9.2m/12.2m	0.0036%	0.0426%	hog	0.0448%	0 – *negligible*
St Martin's Church	12.4m/7.5m/16.4m	0.0066%	0.0375%	hog	0.0436%	0 – *negligible*
Thames Water sewer	66m/0.3m/4.5m	0.0103%	0.000005%	sag	0.0003%	0 – *negligible*

Updated basement impact assessment

"Excavation of basement within 20m of neighbouring buildings resulting in structural damage to neighbouring properties"

There are two potentially affected structures and one potentially affected buried service/utility:

- St Martin's Church
- 113 Wellesley Road
- Thames Water sewer in Wellesley Road

St Martin's Church and 113 Wellesley Road
With reference to the analysis sheets presented in Appendix B, based on case study data, the estimated ground movements anticipated at St Martin's Church and 113 Wellesley Road, located 12-16m from the perimeter of the proposed basement, are of the order of 1.0-2.5mm vertical settlement, and 1.5-3.0mm horizontal movement towards the basement, with angular rotations of 1 in 2200.

The limiting tensile stress analysis presented in Appendix B concludes that the potential damage to 113 Wellesley Road and St Martin's Church will be negligible.

Thames Water sewer in Wellesley Road
"Excavation of basement within 5m of highway, with possible damage to the pavement, road or to buried services"

Design of the retaining walls will take account of the associated highway loading.

The ground movement analysis of the Thames Water sewer presented in Appendix B indicates anticipated ground movements of 6-7mm (vertical) and ~8mm (horizontal) at 4.5m from the back of the retaining wall. The zone of influence of the ground movement has been assumed to be ~66m long at 4.5m parallel from the excavation (excavation length of 26m plus a fall off zone to zero deflection extending 3 x excavation depth beyond each end of the excavation). Although not strictly applicable to a buried service, as an initial indicator, a Burland-style damage assessment has been carried out assuming this length of service, with an estimated sewer diameter of 600mm. The calculated deflection ratio and tensile strain fall well within the negligible damage category. The spreadsheet indicates less than 0.005mm of total length extension over the 66m length due to the predicted lateral deflections. Movements of this magnitude are therefore not expected to have any adverse effect on the road or buried services beneath it.

Monitoring of the basement capping beam and ground behind will be carried out to ensure that movements are within the expected limits.

Impact Assessment Summary [updated]
The majority of structures surrounding this basement will be new buildings supported on reinforced concrete piles. The basement can therefore only affect the nearby highway (Wellesley Road), the services in that highway, St Martin's Church and the residential block at 113 Wellesley Road.

The new basement will be single storey and constructed using large diameter, reinforced concrete bored piles propped near the top in the temporary case, and at the top and lower down in the permanent case. The piles will create a cut-off wall limiting any immediate heave of ground outside the basement area due to the unloading of the ground, and the retaining wall support system will behave very stiffly, limiting any deflections and associated settlements behind the wall.

The small amount of short-term ground movements arising from the retaining wall installation and basement excavation is anticipated to result in negligible damage to the church and 113 Wellesley Road. Over the medium- to long-term the longer-term heave beyond the proposed basement will tend to cancel out the short-term ground movements. The ground movement assessment also suggests negligible damage will occur to the Thames Water sewer that runs in Wellesley Road 4.5m away from the bored pile retaining wall.

If the findings of the proposed trial pitting to assess if the former tributary of the River Fleet affects the site indicate a wider need for longer piles for the basement retaining wall this would extend the potential zone of influence of ground movements associated with the basement construction. As the current levels of predicted damage to the nearby structures are negligible, but relatively close to very slight, it is possible that the predicted damage may creep into the lower end of the very slight damage category. The predicted damage assessment would therefore have to be re-assessed accordingly if the piled retaining wall as designed is deeper than 10m below general ground levels. A quick check using the spreadsheet indicates that for 113 Wellesley Road for a 12m deep wall the predicted tensile strain would increase from 0.0448% to 0.0525% (10% into the bottom end of very slight damage), which is such a minor incursion into the very slight damage category that it would not be considered significant.

Structural survey of adjacent properties

Although only small ground movements are considered likely to extend beyond ~15m across Wellesley Road, structural surveys will be carried out of St Martin's Church and 113 Wellesley Road before and after the basement works.

The nature of the London Clay, coupled with the likely foundation depths of the church and 113 Wellesley Road and the anticipated high support stiffness of the basement piled retaining wall mean that ground movements will be very small, particularly when compared to the seasonal movements experienced in such ground conditions

Monitoring

Prior to commencement of the works, a monitoring system may be set up in order to record any movement taking place. This work will be carried out by third party specialist surveyor using appropriately precise survey techniques. Monitoring will consist of:

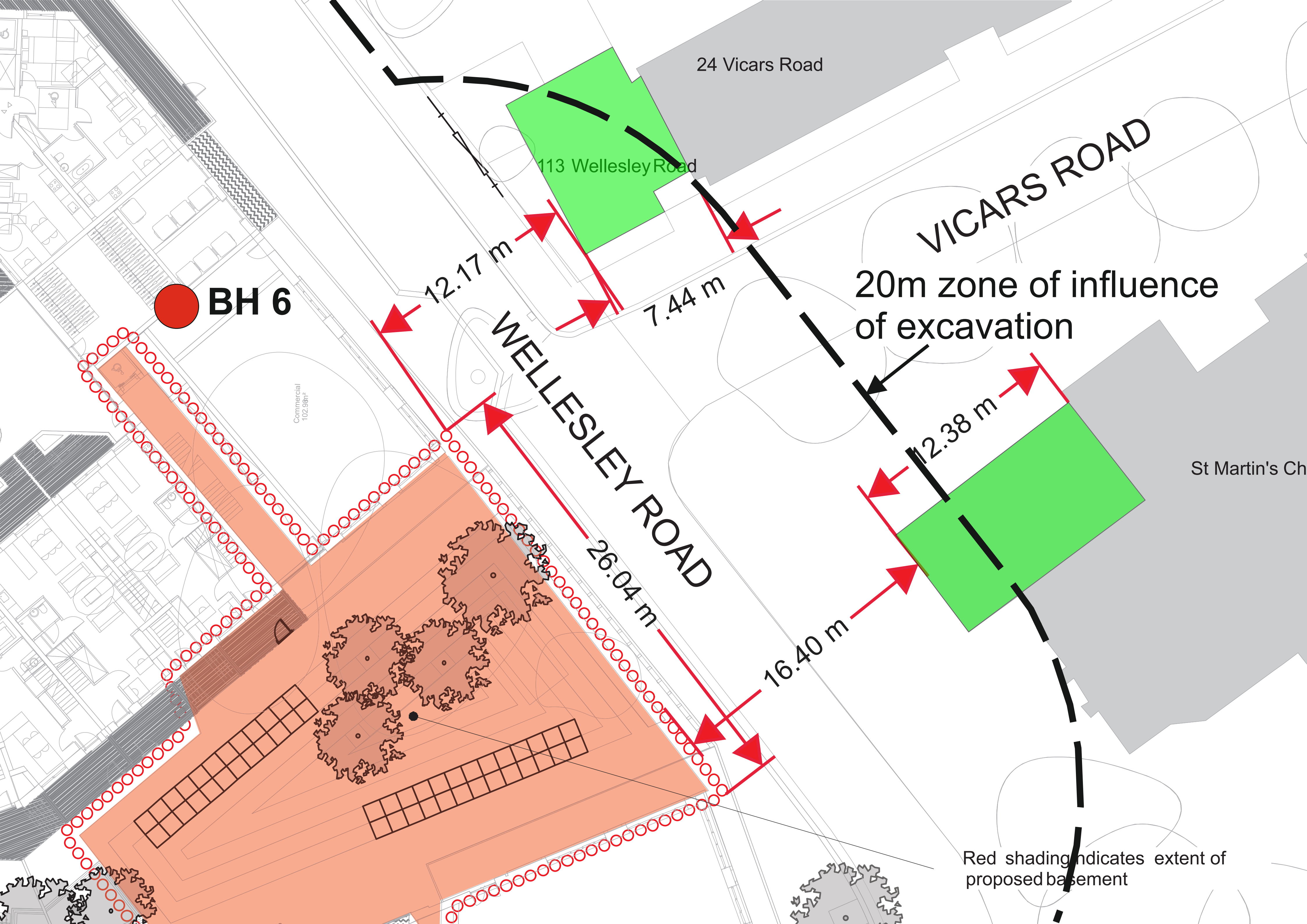
- Weekly monitoring of vertical and horizontal displacements (perpendicular to the elevation at each of the locations shown on the drawings opposite. Readings will be forwarded to all interested parties in the form of a movement/ timeline which will also record the key activities on site. Monitoring tolerances of +/-0.5mm will be specified.
- A traffic light system will be used to raise alerts to excessive deflection ratios. Deflection information taken on site will be processed in a spreadsheet and the deflection ratios established for each of the wall elevations considered. The amber limit will be set at 60% of the relevant criteria (0.4x 10-3 for sagging and 0.2 x 10-3 for hogging). The red limit will be set at 80% of these values. In the event that these criteria are exceeded an assessment of the reasons why these values may have occurred will be carried out. More frequent monitoring may be advised subject to the phase of construction.
- In addition, trigger levels will be set for overall horizontal and vertical movement at Amber - 1mm and Red - 2mm, for the church and 113 Wellesley Road.
- In both cases, should the Red conditions be met, work would be stopped on site until such time that remedial actions have been evaluated.

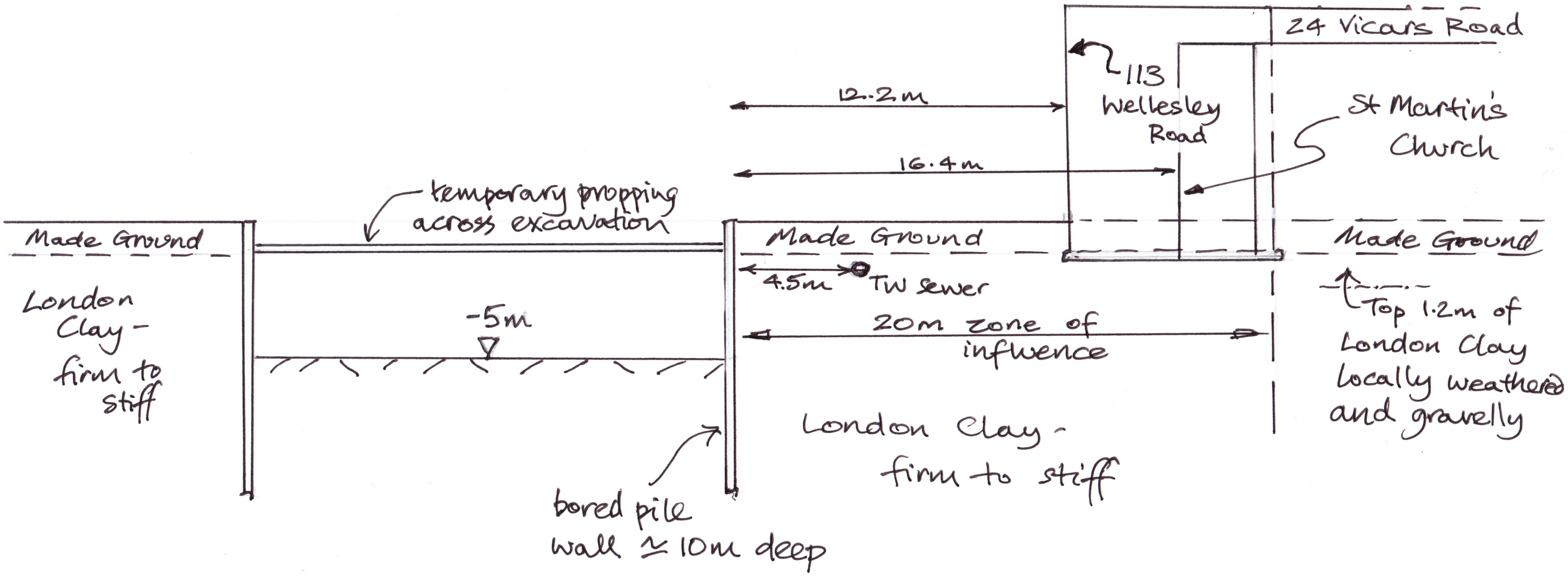
It is anticipated that monitoring will be limited to St Martin's Church, 113 Wellesley Road and the ground immediately behind the retaining wall.

Preliminary BIA Summary

Due to the relatively shallow depth of the basement, the high support stiffness of the proposed construction method and the relatively remote distance from nearby structures, the effect of ground movements are expected to be minimal resulting in neglible damage generally, with a very low risk of slight damage locally.

Appendix A . Appendix A: conceptual site plan and section


24 Vicars Road
113 Wellesley Road
BH 6
12.17 m
7.44 m
VICARS ROAD
20m zone of influence
of excavation
WELLESLEY ROAD
12.38 m
St Martin's Ch
26.04 m
16.40 m
Red shading indicates extent of
proposed basement



BACTON BIA - Conceptual Sketch section

Not to scale

Appendix B . Updated ground movement assessment

Bacton - CIRIA C580 case study short term ground movement analysis

113 Wellesley Road

Distance of wall from excavation:	12.20	m
Length of wall:	7.45	m
Height of wall:	9.20	m
Retaining wall type:	contiguous	
Retaining wall pile length (m):	10.00	m
Average max. excavation depth (m):	5.00	m
Support system stiffness:	HIGH	(Multi-level - top-down construction, temporary props installed before permanent props at high level; Single storey - temporary props of high stiffness installed before permanent high level props)
Distance to negligible movement:	20.00	m
Length of wall in influence zone:	7.45	m

Wall installation ground movements

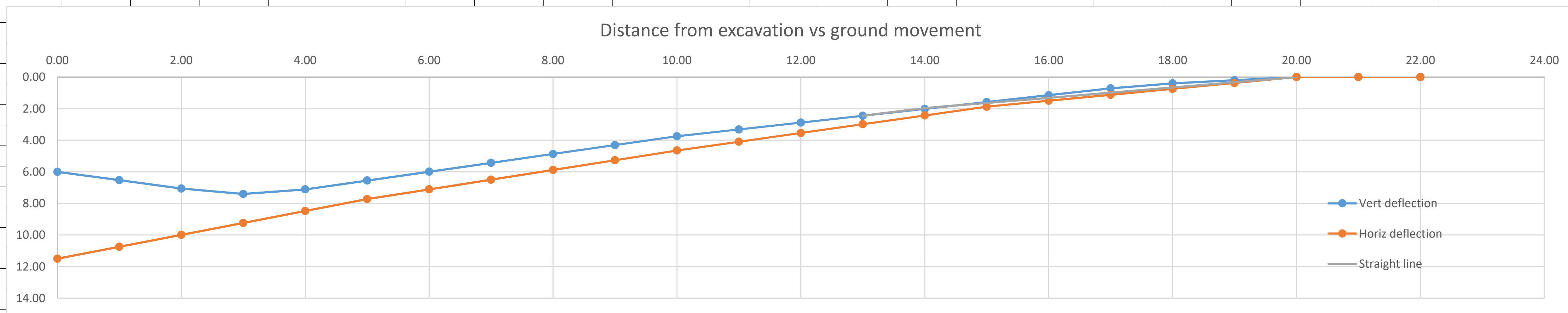
Distance from retaining wall (m)	0.00	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	19.00	20.00	21.00	22.00
Vertical movement (mm)	4.00	3.80	3.60	3.40	3.20	3.00	2.80	2.60	2.40	2.20	2.00	1.80	1.60	1.40	1.20	1.00	0.80	0.60	0.40	0.20	0.00	0.00	0.00
Horizontal movement (mm)	4.00	3.62	3.24	2.86	2.48	2.10	1.86	1.62	1.38	1.14	0.90	0.72	0.54	0.36	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Basement excavation ground movements

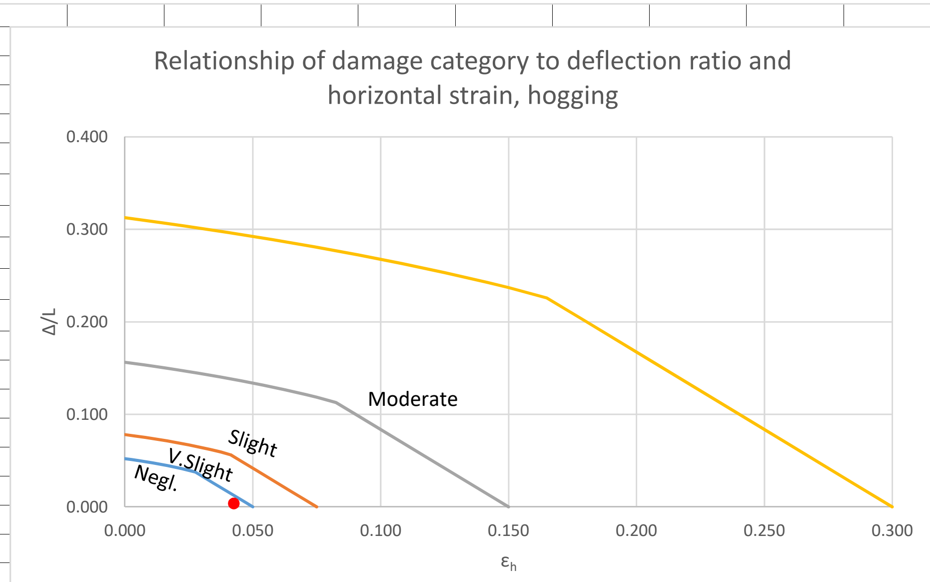
Distance from retaining wall (m)	0.00	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	19.00	20.00	21.00	22.00
Vertical movement (mm)	2.00	2.73	3.45	4.00	3.91	3.55	3.19	2.83	2.47	2.11	1.75	1.52	1.28	1.05	0.82	0.58	0.35	0.12	0.00	0.00	0.00	0.00	0.00
Horizontal movement (mm)	7.50	7.13	6.75	6.38	6.00	5.63	5.25	4.88	4.50	4.13	3.75	3.38	3.00	2.63	2.25	1.88	1.50	1.13	0.75	0.38	0.00	0.00	0.00

Total ground movements

Distance from retaining wall (m)	0.00	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	**13.00**	**14.00**	**15.00**	**16.00**	**17.00**	**18.00**	**19.00**	**20.00**	21.00	22.00
Vertical movement (mm)	6.00	6.53	7.05	7.40	7.11	6.55	5.99	5.43	4.87	4.31	3.75	3.32	2.88	**2.45**	**2.02**	**1.58**	**1.15**	**0.72**	**0.40**	**0.20**	**0.00**	0.00	0.00
Horizontal movement (mm)	11.50	10.75	9.99	9.24	8.48	7.73	7.11	6.50	5.88	5.27	4.65	4.10	3.54	**2.99**	**2.43**	**1.88**	**1.50**	**1.13**	**0.75**	**0.38**	**0.00**	0.00	0.00
Slope, 1 in		-1897	-1897	-2895	3448	2353	1786	1786	1786	1786	1786	2308	2308	**2308**	**2308**	**2308**	**2308**	**2308**	**3158**	**5000**	**5000**		
Movement		HOG	HOG	HOG	HOG	HOG	HOG	HOG	HOG	HOG	HOG	HOG	HOG	**HOG**	**HOG**	**HOG**	**HOG**	**HOG**	**HOG**	**HOG**	**HOG**	HOG	HOG
Wall perpendicular, straight line														**2.45**	**1.97**	**1.64**	**1.32**	**0.99**	**0.66**	**0.33**	**0.00**		
Wall perpendicular, Δmax (-ve = hogging)														**0.00**	**0.04**	**-0.06**	**-0.17**	**-0.27**	**-0.26**	**-0.13**	**0.00**		
Horizontal strain (%)														**0.0555**	**0.0555**	**0.0555**	**0.0375**	**0.0375**	**0.0375**	**0.0375**	**0.0375**		



Worst case wall deflection ratio (%)	0.0036
Average horizontal strain in wall (%)	0.0426
ε_{max} check (assuming hog/bottom n.a.)	
Calculated ε_{bmax}	0.0022
Calculated ε_{br}	0.0448
Calculated ε_{dmax}	0.0035
Calculated ε_{dr}	0.0429
ε_{max}	**0.0448**
Damage Category	**0 - Negligible <0.05%**



Deflection ratio/ L/H, ε_{lim} and ε_h relationships based on Burland & Wroth 1974 and Burland 1995
113 Wellesley Road

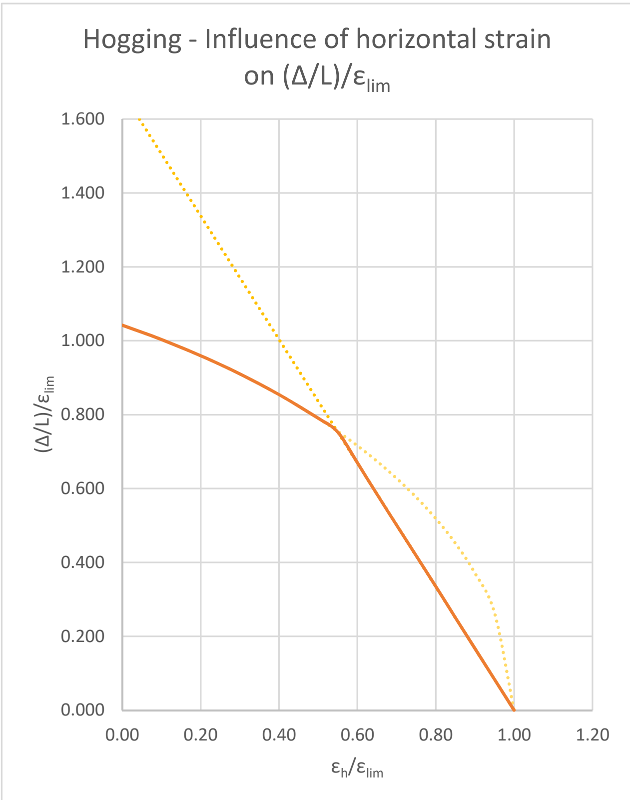
L (effective)	7.45				
H	9.20				
L/H	0.81				
I	483.435				
I bottom n.a.	1933.742				
E/G	2.6				
Poisson's ratio, v	0.3	A	0.35	B	0.65

Hogging, bottom neutral axis

bending	1.67285
diagonal	1.04204

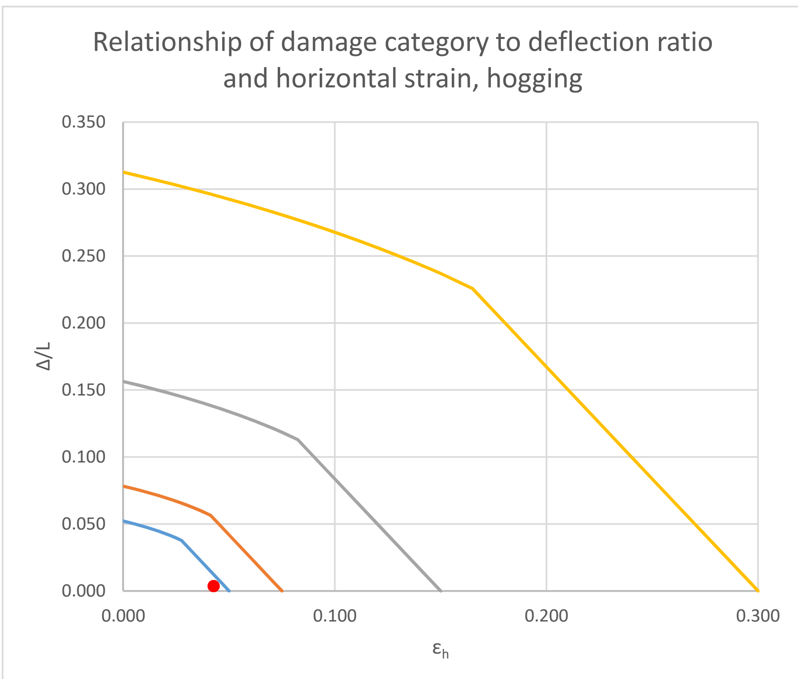
Hogging

$\varepsilon_h/\varepsilon_{lim}$	Bending $(\Delta/L)/\varepsilon_{lim}$	Diagonal $(\Delta/L)/\varepsilon_{lim}$	Lowest $(\Delta/L)/\varepsilon_{lim}$
0.00	1.673	1.042	1.042
0.05	1.589	1.023	1.023
0.10	1.506	1.003	1.003
0.15	1.422	0.982	0.982
0.20	1.338	0.960	0.960
0.25	1.255	0.936	0.936
0.30	1.171	0.910	0.910
0.35	1.087	0.883	0.883
0.40	1.004	0.854	0.854
0.45	0.920	0.823	0.823
0.50	0.836	0.790	0.790
0.55	0.753	0.754	0.753
0.60	0.669	0.716	0.669
0.65	0.585	0.674	0.585
0.70	0.502	0.628	0.502
0.75	0.418	0.577	0.418
0.80	0.335	0.519	0.335
0.85	0.251	0.452	0.251
0.90	0.167	0.371	0.167
0.95	0.084	0.264	0.084
1.00	0.000	0.000	0.000



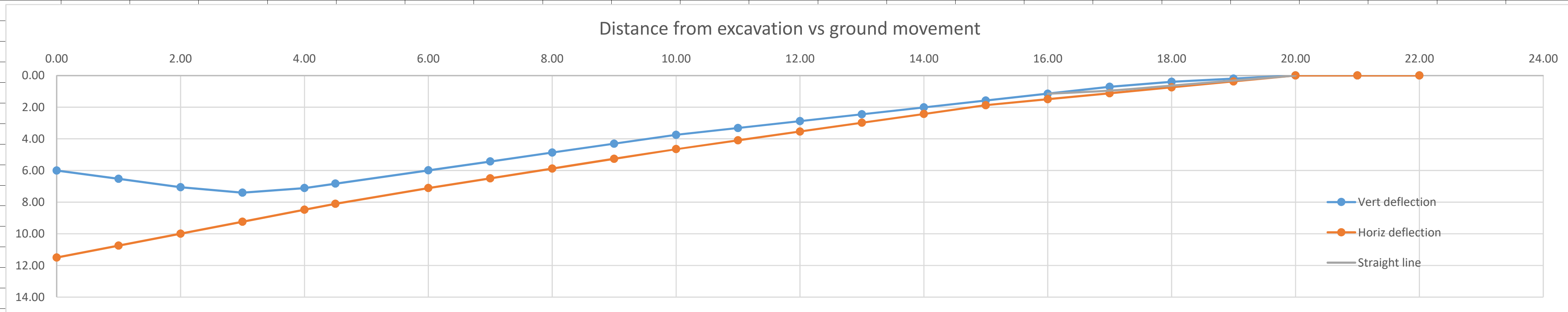
Damage category vs ε_h chart for L/H= 0.81

$\varepsilon_h/\varepsilon_{lim}$	0.050 Δ/L		0.075 Δ/L		0.150 Δ/L		0.300 Δ/L	
0.00	0.000	0.052	0.000	0.078	0.000	0.156	0.000	0.313
0.05	0.003	0.051	0.004	0.077	0.008	0.153	0.015	0.307
0.10	0.005	0.050	0.008	0.075	0.015	0.150	0.030	0.301
0.15	0.008	0.049	0.011	0.074	0.023	0.147	0.045	0.295
0.20	0.010	0.048	0.015	0.072	0.030	0.144	0.060	0.288
0.25	0.013	0.047	0.019	0.070	0.038	0.140	0.075	0.281
0.30	0.015	0.046	0.023	0.068	0.045	0.137	0.090	0.273
0.35	0.018	0.044	0.026	0.066	0.053	0.132	0.105	0.265
0.40	0.020	0.043	0.030	0.064	0.060	0.128	0.120	0.256
0.45	0.023	0.041	0.034	0.062	0.068	0.123	0.135	0.247
0.50	0.025	0.040	0.038	0.059	0.075	0.119	0.150	0.237
0.55	0.028	0.038	0.041	0.056	0.083	0.113	0.165	0.226
0.60	0.030	0.033	0.045	0.050	0.090	0.100	0.180	0.201
0.65	0.033	0.029	0.049	0.044	0.098	0.088	0.195	0.176
0.70	0.035	0.025	0.053	0.038	0.105	0.075	0.210	0.151
0.75	0.038	0.021	0.056	0.031	0.113	0.063	0.225	0.125
0.80	0.040	0.017	0.060	0.025	0.120	0.050	0.240	0.100
0.85	0.043	0.013	0.064	0.019	0.128	0.038	0.255	0.075
0.90	0.045	0.008	0.068	0.013	0.135	0.025	0.270	0.050
0.95	0.048	0.004	0.071	0.006	0.143	0.013	0.285	0.025
1.00	0.050	0.000	0.075	0.000	0.150	0.000	0.300	0.000

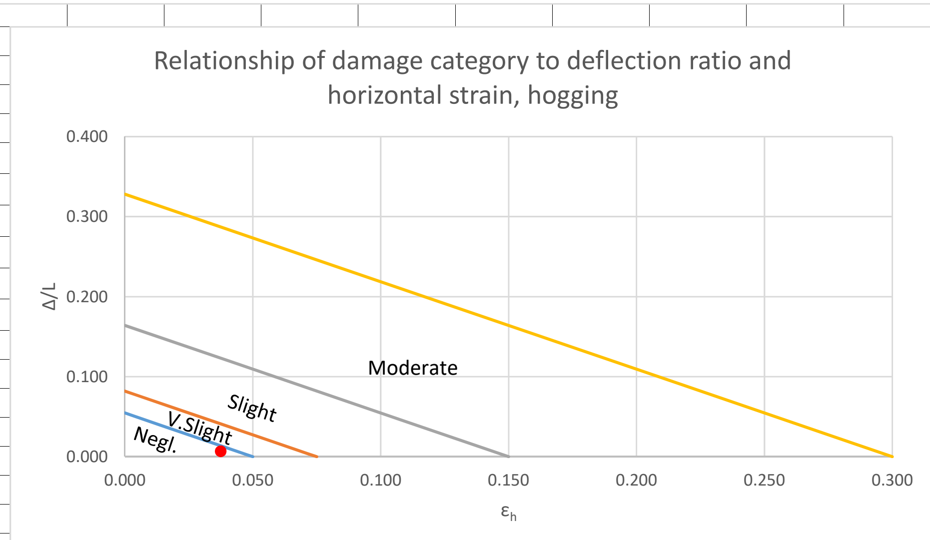


Bacton - CIRIA C580 case study short term ground movement analysis		
St Martin's Church		
Distance of wall from excavation:	16.40	m
Length of wall:	12.40	m
Height of wall:	7.50	m
Retaining wall type:	contiguous	
Retaining wall pile length (m):	10.00	m
Average max. excavation depth (m):	5.00	m
Support system stiffness:	HIGH	(Multi-level - top-down construction, temporary props installed before permanent props at high level; Single storey - temporary props of high stiffness installed before permanent high level props)
Distance to negligible movement:	20.00	m
Length of wall in influence zone:	3.60	m

Wall installation ground movements						**SEWER**																	
Distance from retaining wall (m)	0.00	1.00	2.00	3.00	4.00	4.50	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	19.00	20.00	21.00	22.00
Vertical movement (mm)	4.00	3.80	3.60	3.40	3.20	3.10	2.80	2.60	2.40	2.20	2.00	1.80	1.60	1.40	1.20	1.00	0.80	0.60	0.40	0.20	0.00	0.00	0.00
Horizontal movement (mm)	4.00	3.62	3.24	2.86	2.48	2.29	1.86	1.62	1.38	1.14	0.90	0.72	0.54	0.36	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Basement excavation ground movements																							
Distance from retaining wall (m)	0.00	1.00	2.00	3.00	4.00	4.50	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	19.00	20.00	21.00	22.00
Vertical movement (mm)	2.00	2.73	3.45	4.00	3.91	3.73	3.19	2.83	2.47	2.11	1.75	1.52	1.28	1.05	0.82	0.58	0.35	0.12	0.00	0.00	0.00	0.00	0.00
Horizontal movement (mm)	7.50	7.13	6.75	6.38	6.00	5.81	5.25	4.88	4.50	4.13	3.75	3.38	3.00	2.63	2.25	1.88	1.50	1.13	0.75	0.38	0.00	0.00	0.00
Total ground movements																							
Distance from retaining wall (m)	0.00	1.00	2.00	3.00	4.00	4.50	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	**16.00**	**17.00**	**18.00**	**19.00**	**20.00**	21.00	22.00
Vertical movement (mm)	6.00	6.53	7.05	7.40	7.11	6.83	5.99	5.43	4.87	4.31	3.75	3.32	2.88	2.45	2.02	1.58	**1.15**	**0.72**	**0.40**	**0.20**	**0.00**	0.00	0.00
Horizontal movement (mm)	11.50	10.75	9.99	9.24	8.48	8.10	7.11	6.50	5.88	5.27	4.65	4.10	3.54	2.99	2.43	1.88	**1.50**	**1.13**	**0.75**	**0.38**	**0.00**	0.00	0.00
Slope, 1 in		-1897	-1897	-2895	3448	2632	1786	1786	1786	1786	1786	2308	2308	2308	2308	2308	**2308**	**2308**	**3158**	**5000**	**5000**		
Movement		HOG	HOG	HOG	HOG	HOG	HOG	HOG	HOG	HOG	HOG	HOG	HOG	HOG	HOG	HOG	**HOG**	**HOG**	**HOG**	**HOG**	**HOG**	HOG	HOG
Wall perpendicular, straight line																	**1.15**	**0.96**	**0.64**	**0.32**	**0.00**		
Wall perpendicular, Δmax (-ve = hogging)																	**0.00**	**-0.24**	**-0.24**	**-0.12**	**0.00**		
Horizontal strain (%)																	**0.0375**	**0.0375**	**0.0375**	**0.0375**	**0.0375**		



Worst case wall deflection ratio (%)	0.0066
Average horizontal strain in wall (%)	0.0375
ε_{max} check (assuming hog/bottom n.a.)	
Calculated ε_{bmax}	0.0061
Calculated ε_{br}	0.0436
Calculated ε_{dmax}	0.0060
Calculated ε_{dr}	0.0382
ε_{max}	**0.0436**
Damage Category	**0 - Negligible <0.05%**



Deflection ratio/ L/H, ε_{lim} and ε_h relationships based on Burland & Wroth 1974 and Burland 1995
St Martin's Church

L (effective)	16.40		
H	12.40		
L/H	1.32		
I	2605.719		
I bottom n.a.	10422.878		
E/G	2.6		
Poisson's ratio, v	0.3	A 0.35	B 0.65

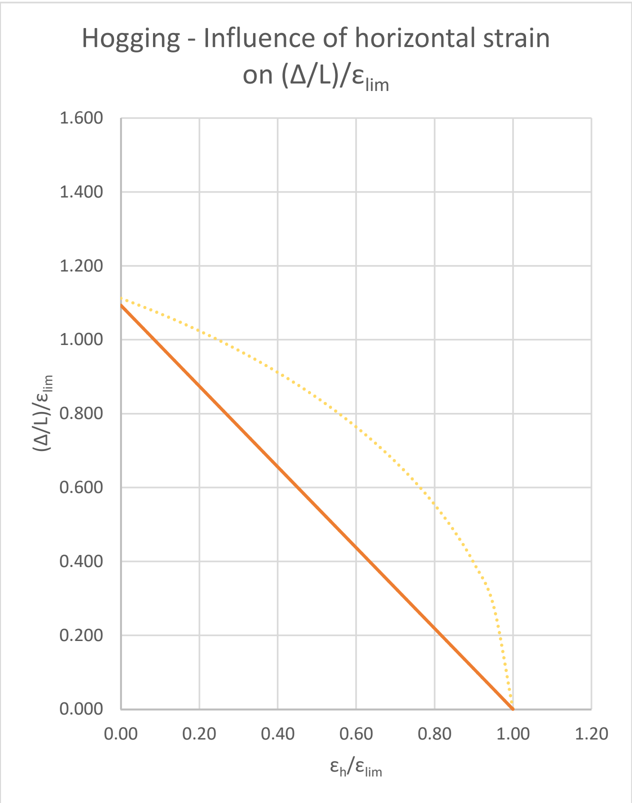
Hogging, bottom neutral axis

bending	1.09314
diagonal	1.11213

SEWER
4.5

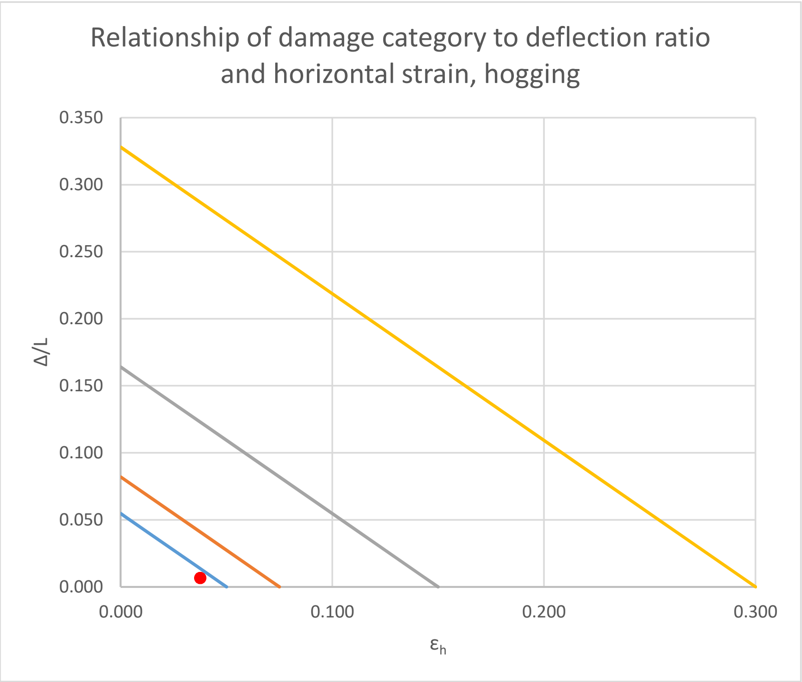
Hogging

$\varepsilon_h/\varepsilon_{lim}$	Bending $(\Delta/L)/\varepsilon_{lim}$	Diagonal $(\Delta/L)/\varepsilon_{lim}$	Lowest $(\Delta/L)/\varepsilon_{lim}$
0.00	1.093	1.112	1.093
0.05	1.038	1.092	1.038
0.10	0.984	1.071	0.984
0.15	0.929	1.048	0.929
0.20	0.875	1.024	0.875
0.25	0.820	0.999	0.820
0.30	0.765	0.971	0.765
0.35	0.711	0.943	0.711
0.40	0.656	0.912	0.656
0.45	0.601	0.879	0.601
0.50	0.547	0.843	0.547
0.55	0.492	0.805	0.492
0.60	0.437	0.764	0.437
0.65	0.383	0.719	0.383
0.70	0.328	0.670	0.328
0.75	0.273	0.615	0.273
0.80	0.219	0.554	0.219
0.85	0.164	0.483	0.164
0.90	0.109	0.396	0.109
0.95	0.055	0.282	0.055
1.00	0.000	0.000	0.000



Damage category vs ε_h chart for L/H= 1.32

$\varepsilon_h/\varepsilon_{lim}$	0.050 Δ/L		0.075 Δ/L		0.150 Δ/L		0.300 Δ/L	
0.00	0.000	0.055	0.000	0.082	0.000	0.164	0.000	0.328
0.05	0.003	0.052	0.004	0.078	0.008	0.156	0.015	0.312
0.10	0.005	0.049	0.008	0.074	0.015	0.148	0.030	0.295
0.15	0.008	0.046	0.011	0.070	0.023	0.139	0.045	0.279
0.20	0.010	0.044	0.015	0.066	0.030	0.131	0.060	0.262
0.25	0.013	0.041	0.019	0.061	0.038	0.123	0.075	0.246
0.30	0.015	0.038	0.023	0.057	0.045	0.115	0.090	0.230
0.35	0.018	0.036	0.026	0.053	0.053	0.107	0.105	0.213
0.40	0.020	0.033	0.030	0.049	0.060	0.098	0.120	0.197
0.45	0.023	0.030	0.034	0.045	0.068	0.090	0.135	0.180
0.50	0.025	0.027	0.038	0.041	0.075	0.082	0.150	0.164
0.55	0.028	0.025	0.041	0.037	0.083	0.074	0.165	0.148
0.60	0.030	0.022	0.045	0.033	0.090	0.066	0.180	0.131
0.65	0.033	0.019	0.049	0.029	0.098	0.057	0.195	0.115
0.70	0.035	0.016	0.053	0.025	0.105	0.049	0.210	0.098
0.75	0.038	0.014	0.056	0.020	0.113	0.041	0.225	0.082
0.80	0.040	0.011	0.060	0.016	0.120	0.033	0.240	0.066
0.85	0.043	0.008	0.064	0.012	0.128	0.025	0.255	0.049
0.90	0.045	0.005	0.068	0.008	0.135	0.016	0.270	0.033
0.95	0.048	0.003	0.071	0.004	0.143	0.008	0.285	0.016
1.00	0.050	0.000	0.075	0.000	0.150	0.000	0.300	0.000



Bacton - CIRIA C580 case study short term ground movement analysis
TW service: Sewer in Wellesley Road

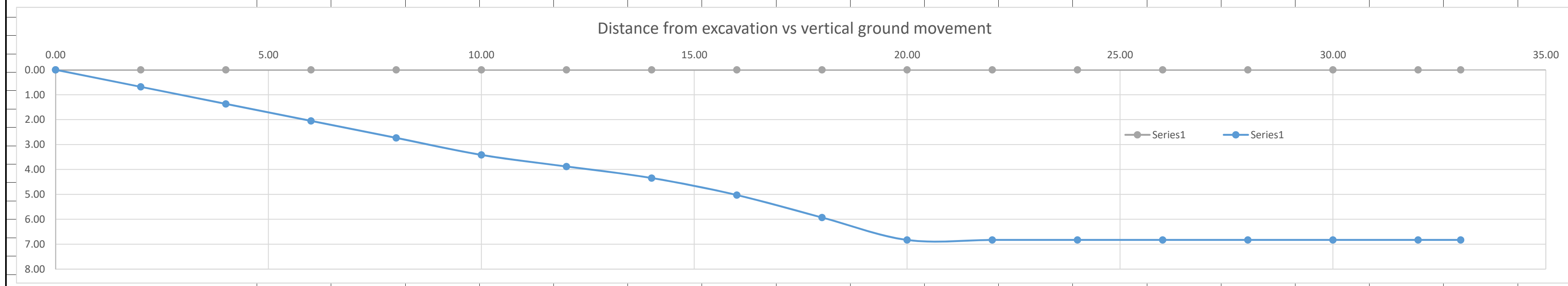
Distance of service from excavation:	4.50	m	
Affected length of service:	66.00	m	
Service diameter:	0.30	m	
Retaining wall type:	contiguous		
Retaining wall pile length (m):	10.00	m	
Average max. excavation depth (m):	5.00	m	
Support system stiffness:	HIGH	(Multi-level - top-down construction, temporary props installed before permanent props at high level; Single storey - temporary props of high stiffness installed before permanent high level props)	
Distance to negligible movement:	20.00	m	
Estimated distance from corner to no corner effect:		5.00	m

Total ground movements taken from St Martin's Church spreadsheet

Distance from retaining wall (m)	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50
Distance along service E to W	0.00	2.00	4.00	6.00	8.00	10.00	12.00	14.00	16.00	18.00	20.00	22.00	24.00	26.00	28.00	30.00	32.00	33.00
Unfactored Vertical movement (mm)	6.83	6.83	6.83	6.83	6.83	6.83	6.83	6.83	6.83	6.83	6.83	6.83	6.83	6.83	6.83	6.83	6.83	6.83
Unfactored Horizontal movement (mm)	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10
Corner adjustment (calculated)	0.00	10.00	20.00	30.00	40.00	50.00	56.80	63.60	73.60	86.80	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Factored vertical movement (mm)	0.00	0.68	1.37	2.05	2.73	3.42	3.88	4.34	5.03	5.93	6.83	6.83	6.83	6.83	6.83	6.83	6.83	6.83
Factored horizontal movement (mm)	0.00	0.81	1.62	2.43	3.24	4.05	4.60	5.15	5.96	7.03	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10

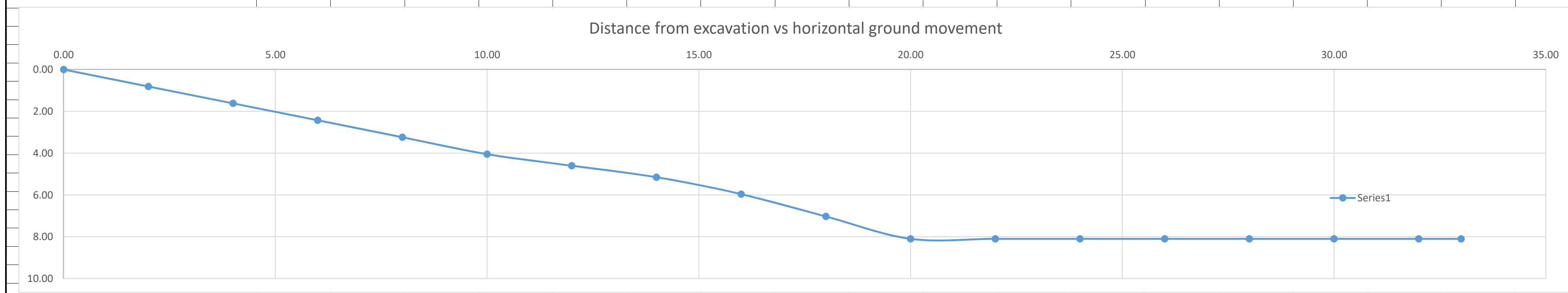
Vertical deflections

Slope, 1 in		-2928	-2928	-2928	-2928	-2928	-4306	-4306	-2928	-2218	-2218	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Vert - Wall parallel, straight line	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Differential vertical movement (mm)	0.00	0.68	1.37	2.05	2.73	3.42	3.88	4.34	5.03	5.93	**6.83**	6.83	6.83	6.83	6.83	6.83	6.83	6.83



Horizontal deflections

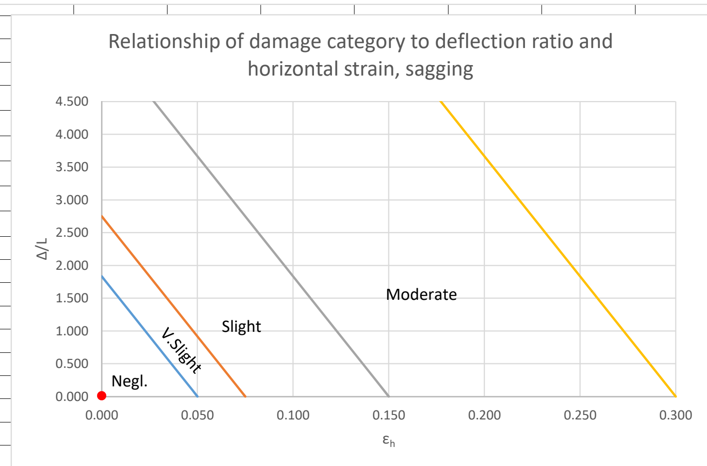
Horizontal extensions (mm)		0.0001640	0.0001640	0.0001640	0.0001640	0.0001640	0.0000758	0.0000758	0.0001640	0.0002858	0.0002858	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
Sum of horizontal extensions (mm)		0.003415																



Worst case vertical deflection ratio (%)	0.0103
Average horizontal strain in service (%)	0.0000052

ε_{max} check (assuming sag/central n.a.)

Calculated ε_{bmax}	0.0003
Calculated ε_{br}	0.0003
Calculated ε_{dmax}	0.0000
Calculated ε_{dr}	0.0000
ε_{max}	**0.0003**
Damage Category	0 - Negligible <0.05%



Deflection ratio/ L/H, ε_{lim} and ε_h relationships based on Burland & Wroth 1974 and Burland 1995
TW service: Sewer in Wellesley Road

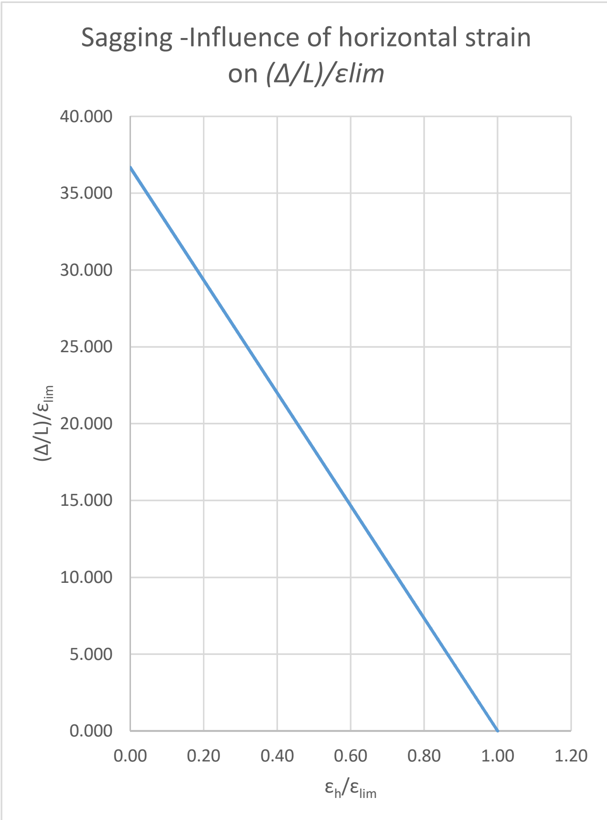
L	66.00			
H	0.30			
L/H	220.00			
I	0.149			
I bottom n.a.	0.594			
E/G	2.6			
Poisson's ratio, v	0.3	A 0.35	B 0.65	

Sagging, central neutral axis

bending	36.66962
diagonal	12411.25641

Sagging

	Bending	Diagonal	Lowest
$\varepsilon_h/\varepsilon_{lim}$	$(\Delta/L)/\varepsilon_{lim}$	$(\Delta/L)/\varepsilon_{lim}$	$(\Delta/L)/\varepsilon_{lim}$
0.00	36.670	12411.256	36.670
0.05	34.836	12187.386	34.836
0.10	33.003	11949.662	33.003
0.15	31.169	11697.239	31.169
0.20	29.336	11429.143	29.336
0.25	27.502	11144.244	27.502
0.30	25.669	10841.216	25.669
0.35	23.835	10518.494	23.835
0.40	22.002	10174.203	22.002
0.45	20.168	9806.071	20.168
0.50	18.335	9411.301	18.335
0.55	16.501	8986.384	16.501
0.60	14.668	8526.813	14.668
0.65	12.834	8026.639	12.834
0.70	11.001	7477.718	11.001
0.75	9.167	6868.372	9.167
0.80	7.334	6180.756	7.334
0.85	5.500	5384.969	5.500
0.90	3.667	4423.007	3.667
0.95	1.833	3145.954	1.833
1.00	0.000	0.000	0.000



Damage category vs ε_h chart for L/H= 220.00

$\varepsilon_h/\varepsilon_{lim}$	0.050	Δ/L	0.075	Δ/L	0.150	Δ/L	0.300	Δ/L
0.00	0.000	1.833	0.000	2.750	0.000	5.500	0.000	11.001
0.05	0.003	1.742	0.004	2.613	0.008	5.225	0.015	10.451
0.10	0.005	1.650	0.008	2.475	0.015	4.950	0.030	9.901
0.15	0.008	1.558	0.011	2.338	0.023	4.675	0.045	9.351
0.20	0.010	1.467	0.015	2.200	0.030	4.400	0.060	8.801
0.25	0.013	1.375	0.019	2.063	0.038	4.125	0.075	8.251
0.30	0.015	1.283	0.023	1.925	0.045	3.850	0.090	7.701
0.35	0.018	1.192	0.026	1.788	0.053	3.575	0.105	7.151
0.40	0.020	1.100	0.030	1.650	0.060	3.300	0.120	6.601
0.45	0.023	1.008	0.034	1.513	0.068	3.025	0.135	6.050
0.50	0.025	0.917	0.038	1.375	0.075	2.750	0.150	5.500
0.55	0.028	0.825	0.041	1.238	0.083	2.475	0.165	4.950
0.60	0.030	0.733	0.045	1.100	0.090	2.200	0.180	4.400
0.65	0.033	0.642	0.049	0.963	0.098	1.925	0.195	3.850
0.70	0.035	0.550	0.053	0.825	0.105	1.650	0.210	3.300
0.75	0.038	0.458	0.056	0.688	0.113	1.375	0.225	2.750
0.80	0.040	0.367	0.060	0.550	0.120	1.100	0.240	2.200
0.85	0.043	0.275	0.064	0.413	0.128	0.825	0.255	1.650
0.90	0.045	0.183	0.068	0.275	0.135	0.550	0.270	1.100
0.95	0.048	0.092	0.071	0.138	0.143	0.275	0.285	0.550
1.00	0.050	0.000	0.075	0.000	0.150	0.000	0.300	0.000