D BELOV AND G MCDOUGAL

58A REDINGTON ROAD

GROUND MOVEMENT IMPACT ASSESSMENT

REVISION 1

October 2018

GEOTECHNICAL CONSULTING GROUP
52A Cromwell Road
London SW7 5BE
United Kingdom
Tel: +44 (0) 20 7581 8348
Fax: +44 (0) 20 7584 0157
Email: admin@gcg.co.uk

Geotechnical Consulting Group LLP is a partnership registered in England No OC356005 the registered address of which is as above.

D BELOV AND G MCDOUGAL

58A REDINGTON ROAD

GROUND MOVEMENT IMPACT ASSESSMENT

REVISION 1

October 2018

DISCLAIMER

REVISION HISTORY

Revision	Date	Description	Produced by	Reviewed by
Rev 0	09/18	First Issue	A.Gasparre Dott Ing. PhD DIC CEng MICE	Mike Crilly BSc MSc DIC
Rev 1	10/18	Typos amended	A.Gasparre Dott Ing. PhD DIC CEng MICE	Mike Crilly BSc MSc DIC

D BELOV AND G MCDOUGAL

58A REDINGTON ROAD

GROUND MOVEMENT IMPACT ASSESSMENT

REVISION 1

OCTOBER 2018

EXECUTIVE SUMMARY

A ground movement impact assessment has been undertaken for the site at 58a Redington Road, where the existing house is to be demolished and replaced with a new structure with basement.

The proposed basement will be constructed by underpinning the perimeter walls.

Some ground movements are inevitable when the ground is excavated, but it is concluded that movements of the ground around the surrounding structures will be tolerable, and that as a result, predicted building damage will not exceed Category 1: very slight.

D BELOV AND G MCDOUGAL

58A REDINGTON ROAD

GROUND MOVEMENT IMPACT ASSESSMENT

REVISION 1

October 2018

TABLE OF CONTENTS **Page No.**

LIST OF FIGURES

Page No.

1 Introduction

It is proposed to demolish the existing building at 58a Redington Road and construct a new structure with a basement that extends underneath the footprint of the existing house and the patio at the rear.

Geotechnical Consulting Group LLP (GCG) have been commissioned to assess the impact of the proposed basement construction on the surrounding structures.

The expected movements around the site have been estimated using linear elastic analyses and an empirical approach that is based on field measurements of movements from a number of basement constructions across London (CIRIA C760).

Information on the project has been provided by Elite Designers, the structural engineers for the project.

2 The site and the proposed redevelopment

The site lies within the Belsize Camden Administrative Boundary and is located on the east side of Redington Road, at approximately 200m to the south of West Heath (Figure 1a).

It stretches approximately 75m along a north-west to south-east direction and it is approximately 7.5m wide. At its rear end it widens to approximately 22m over the width of the adjacent 58b Redington Road.

The site includes an 8m long paved driveway at the front, a semidetached mansion house with lower ground floor and a rear garden. Figure 1b shows a layout of the site.

The house is approximately 15m long and 6m wide, but it widens to 7.5m at the rear to abut the eastern boundary of the site. This house is believed to be a late addition to the adjacent 58b Redington Road, with which it shares a party wall.

The house has a light well at the front and a patio at the rear that is 4.5m below the level of the front driveway.

The lower ground floor extends underneath the whole footprint of the house. At the front it is approximately 2m below ground (i.e. finished floor level of +109.3mOD) and it steps down to approximately +107mOD at the rear to reach the level of the patio. There is a also a 3m deep basement underneath the driveway (i.e. finished floor level at approximately +108mOD)

Figure 2 shows a plan of the existing lower ground floor and a north-west to south-east structural section through the house. The figure also shows the scheme of the existing foundations, which is based on archive drawings and the results of site investigation.

It is proposed to demolish the internal structure of the existing house and create a new basement underneath its original footprint and the existing rear patio. Figure 3 shows a plan of the proposed basement and a section through the site.

The finished floor level of the new basement will be approximately +104.1mOD and will require approximately 5m of excavation underneath the front of the original footprint of the house (assumed foundation level at +103.6mOD) and 2.5m excavation underneath the rear part of the original house and the patio.

The basement will be formed by underpinning the perimeter walls.

3 The surrounding structures

The proposed basement construction could cause ground movements that extend to the surrounding structures. Those that could be most affected are the adjacent houses on No. 60 and No. 58b Redington Road.

3.1 No. 60 Redington Road

The property is to the north-east of the site. It includes a four storey masonry house with mansard roof and front and rear gardens. There is a two storey wing on the south-west of the existing house and a prefabricated garage is at the front of this that abuts the boundary with 58a Redington Road

The house appears to have been constructed in the early 1900s, when Redington Road was developed. The main section of the house is approximately 12m x 15m in plan and the southern extension is approximately 4m x 7m in plan (Figure 4). This extends to approximately 0.6m from the boundary with 58a Redington Road.

The ground level on the front garden is approximately +111.5mOD and it is +107mOD at the rear of the house. The level of the garage is approximately +109.7mOD and a ramp runs along the south-western boundary of the site to connect the garage to street level.

For the purposes of this assessment it is assumed that the property is in good structural condition.

3.2 58 and 58b Redington Road

These properties include the ground and first floor level of the masonry house with front and rear gardens adjacent to No.58a.

The house is approximately 10m x 12m in plan and is set about 8m back from Redington Road (Figure 1b).

A review of historical maps shows that the house was constructed in the early 1900s and originally extended further to the west over the western part of the current 58a Redington Road. At this time it was the only property on the area of 58 and 58a Redington Road.

The house is known to have undergone several alterations over the years. Between 1936 and 1954, it was extended to the northeast, and it is believed that at this time it was split into two separate properties, Nos 58 and 58a.

The house on No. 58 was then divided into two maisonettes in 1954 and in flats in 1962 (GEA, 2018).

Information from archive drawings indicate that the party wall between 58a and 58/58b Redington Road is founded on concrete underpinnings stepping down from front to rear to follow the ground level, as shown in Figure 2.

4 Ground Conditions

The site is on ground sloping to the south at an approximate gradient of 1:15 (Figure 1a). The ground level at the front of the site is approximately +111.3mOD and about +107mOD at the rear.

The ground and groundwater conditions have been established on the basis of record information (British Geological Survey, BGS, maps and record boreholes) and a site-specific ground investigation carried out by Geotechnical & Environmental Associates, (GEA, 2018).

The 1:50,000 scale geological map (BGS, 1994, Sheet 256 – North London, Figure 5 shows that the site is on Bagshot Sand Formation at its boundary with the Claygate Member outcrop. The Bagshot Sand Formation includes horizontally bedded sands with occasional thin gravel beds and lenses of silt and clay, while Claygate Member is composed of interbedded layers of fine-grained sands, silts and clays.

It should be noted that the geological boundaries in the BGS maps are based on information combined from borehole logs, topography and features on the ground surface. The exact location of the geological boundaries provided in these maps is therefore only approximate.

There are no BGS record boreholes in the immediate vicinity of the site, but borehole logs in the GCG's database show that on Templewood Avenue, about 120m to the east of the site, Claygate Member is present from the ground surface, approximately 105mOD.

Below the Claygate Member the stratigraphy of the site includes London Clay, Lambeth Group, Thanet Sand and Chalk.

The London Clay outcrops at about 300m to the south of the site at levels that appear to be approximately +90mOD. The thickness of the London Clay in this area is expected to exceed 60m.

The site specific ground investigation included the sinking of a total of four boreholes and five trial pits. Three boreholes to 15m depth were sunk in the rear patio and in the garden, at the back of the main house, and one borehole to 15m was sunk in the light well at the front of the house. The location of the investigation holes is shown in Figure 6.

All borehole logs consistently identify the presence of a thin layer of Made Ground or Top Soil over a deposit of grey silty clay with bands of greenish silt and sand. This is identified as Claygate Member.

There is no evidence of Bagshot Formation being present at the site, although the construction of the existing house has required the excavation of approximately 3m of the original ground.

In all boreholes the upper part of the Claygate Member, down to a level of approximately +100 - +101mOD is described as *'firm brown and grey mottled silty sandy clay'*. Below this level, *'firm, grey silty Clay'* is identified. In the front borehole a 1.1m thick layer of sand is also recorded from +104.7mOD.

5 Ground movement analyses

5.1 Background

The construction method for the redevelopment envisages that, having demolished the existing structure, the party walls and the perimeter walls of the existing lower ground floor will be underpinned and the excavation will then be carried out installing temporary props for the walls to complete the construction in a bottom up sequence.

Inside and outside the basement area ground movements during and after the works would be due mainly to:

- Demolition of the existing house
- Underpinning of the perimeter walls
- Excavation for the extension of the basement, which would induce a reduction of vertical and lateral stresses in the ground along the excavation boundaries.

The magnitude and distribution of the ground movements caused by these operations are a function of changes of load in the ground and workmanship. The way that the existing buildings around the site respond to these movements is dependent on their current conditions and the precautions that are taken to reduce the risk of building movements.

Ground movements inside the basement area should be accounted for in the design of the new basement structure.

5.2 Estimated ground movements

5.2.1 Movements due to the demolition of the existing house

The demolition of the existing house would relieve pressures on the ground, which would tend to swell under the reduced pressures.

Horizontal movements are expected to be low and mostly movements in the vertical direction can be expected.

These movements have been estimated using the OASYS program PDisp®. The program assumes a linear elastic behaviour of the soil and determines the changes in the vertical stresses and settlement/heave using a Boussinesq approach. Elastic vertical strains are calculated on the basis of the calculated stress changes and then integrated to obtain vertical movements. The calculations represent free field movements unaffected by the stiffness of structures and therefore are likely to be conservative. The soil parameters used for the analyses are summarised in Appendix 1.

The loads removed during demolition have been provided by Elite Designers and are shown in Figure 7.

The structural arrangement of the house is such that there is little load on the party walls, while at the rear of the house loads are carried on flank walls. For the analyses, the demolition has been simulated as a removal of uniform pressures across the front part of the house and as pressures on 0.65m wide strips across the rear part of the house.

Although the foundations of the house step down as the ground level reduces across the site, the analyses have conservatively assumed that the loads on the front of the house are removed from +108mOD, while the loads on the rear of the house are assumed to be removed from +106.5mOD.

The load changes on the party wall with 58b Redington Road are in the order of 2kN/m and, given the conservative nature of the analyses, they are ignored at this stage.

The results of the analyses show that the demolition of the existing structure could induce ground heave up to 4mm in the middle of the main house and 5 to 7mm along the line of the flank walls (Figure 8). In fact the effective movements along the boundary of the site are likely to be smaller than predicted because they would be restricted by the stiffness of the party walls and the boundary walls.

5.2.2 Underpinning along party walls and secant piles along other sides

Archive drawings indicate that the levels of the existing foundations step down, front to rear, from approximately +107.5mOD to +106.5mOD (Figure 2b). Across the front of the house the underpinning will be between 3m and 4m depth, while at the rear it will be approximately 3m deep.

Groundwater across the site has been measured to be approximately 4m below ground level (bgl), hence the toe of the underpins will be over 1m above the measured groundwater level at the rear of the site, but about 1m below the groundwater level at the front, where the excavation is deeper. Measures will need to be adopted around the front of the new basement to ensure that the underpinning is carried out in the dry as water ingress could obstruct the works and cause uncontrolled ground movements.

The construction of the underpinning would induce ground movements due to the transfer of vertical loads from the current to deeper foundation levels and to the sequential excavation of underpinning slots.

Given that no significant load changes would occur during this process and that the self-weight of the wall is not high (64kN/m), it is likely that most of the ground movements due to underpinning would be due to its construction.

Experience suggests that shallow underpinning of relatively lightly loaded carried out with good workmanship and in the dry can induce localised settlements of the wall only in the order of 5-10mm.

Considering the depth of the proposed underpinning, at 58a Redington Road and assuming that the works will be carried out with good workmanship and in the dry the expected settlements could be limited to 5mm.

Any damage caused by these movements will be localised to the underpinned walls and should be capable of being repaired afterwards.

The new walls will have to be designed to retain the ground accounting for the surcharge of the structures behind.

5.2.3 Movements due to excavation

The excavation would cause upward ground movements inside the excavated area as a result of the vertical change (reduction) of loads on the excavated surface and downwards movements outside the excavated area as a result of the deflections of the retaining walls due to the loss of horizontal support in front of them.

The ground movements inside the excavated area have been estimated using PDisp. The pressures removed as a result of excavation are approximately 100kPa across the front of the house and 50kPa across the rear. The results of the analyses show that at the end of the excavation the ground would move upwards by 10-15mm in the central part of the site and 3-4mm along the edges (Figure 9). These upward movements of the underpinned walls would tend to compensate for the settlements occurred during the underpinning process.

Behind the retaining walls the ground would settle and move towards the excavation as the walls bend due to the reduction of lateral support in front of them. Empirical data based on the movements of ground behind retaining walls as a result of excavations in typical London ground conditions (CIRIA C760) show that the ground movements behind the excavation depend on the propping sequence and on the depth of the excavation (Figure 10). At the site Claygate Members are present, which are not typically found in Central London. However, the nature of the soil is such that the CIRIA's database is believed to be applicable. It should also be noted that the CIRIA's database refers to embedded retaining walls, but there is a lack of reliable data on ground movements behind underpinning so the same plots are typically used also for underpinning.

Assuming a stiff support for the walls, the data in Figure 10 suggest that for a 5m deep excavation the maximum settlements are in the order of 4mm and the maximum horizontal movements are approximately 7.5mm. Across the rear of the house, where the excavation is limited to approximately 2.5m, the maximum settlements due to the excavation would be expected to be approximately 2mm and the maximum horizontal movements would be expected to be just under 4mm.

These movements would occur behind long sections, at the corners they would be restricted to about half of the predicted values.

The ground behind the walls would tend to sag and therefore the maximum settlements would occur at approximately 1.5-2.5m behind the walls.

The ground movements due to excavation would add to those due to the construction of the underpinning.

Contour plots of the total predicted ground movements due to excavation only around the new basement area have been constructed and are shown in Figures 11 and 12. It should be noted that these movements have been calculated considering the existing levels of the lower ground floor and the ground around the site.

5.2.4 Long term movements

The loads of the new structure would be taken on the new underpinnings connected to a ground slab. As the new loads are applied they will reduce the initial swelling of the ground caused by the unloading due to demolition and excavation. The proposed loads are shown in Figure 13. It should be noted that these loads also include the self weight of the existing walls, which are not to be changed.

Assuming that the new loads will spread over a width of 1m along the line of the underpinned walls, the expected ground movements at the end of construction are shown in Figure 14a.

In the long term the ground will continue to swell as an effect of the net unload of pressures caused by the redevelopment. Figure 14b shows the expected long term movements. In the central part of the site the movements could be up to 20mm, while along the walls they will reduce to approximately 5mm.

The basement slab should be designed for the swelling pressures associated with the above movements and suitable water pressures.

6 Discussion of results

6.1 Effects of ground movements on adjacent structures

The predicted ground movements due to the redevelopment of the site will cause distortions of the ground that could affect the surrounding structures. The potential damage to these structures can be estimated as suggested in CIRIA C760 by looking at the combined effects of the horizontal strains and the deflection ratio, which is the ratio between the maximum distortion of a structure and its length.

These effects are discussed below:

60 Redington Road

The demolition of the existing house on 58a and the underpinning of the perimeter walls are unlikely to affect the main house on 60 Redington Road, which, at its closest approach is 0.6m away from the site boundary.

The movements associated with these activities could extend to the southern part of the garage, which is immediately adjacent to the wall to be underpinned. However, these are unlikely to have adverse effects on the prefabricated structure of the garage.

During excavation ground movements will extend further across 60 Redington Road as shown in Figures 11 and 12. The garage would tend to tilt away from the excavation experiencing distortions that would give rise to deflection ratio of approximately 0.025% and horizontal strains of less than 0.04%. On a masonry structure these strains would cause damage that could be classified well within Category 1 (very slight) in the Damage Category Chart shown in Figure 15. However, on the prefabricated structure of the garage they are likely to have an even lower impact.

The main house and its extension would tend to tilt slightly towards the excavated area. The extension could also experience tensile strains in the order of 0.05%, while the tensile strains on the main house that are unlikely to exceed 0.04%. The potential damage could be classified as Category 1 for the extension and Category 0 for the main house.

In reality the pattern of strains is such that distortions would end to occur along the longitudinal walls of the house and the extension and would be restrained by the stiffness of these walls.

58 and 58b Redington Road

The results of the assessment show that the party wall of this house would tend to heave slightly during the demolition of the existing house on 58a Redington Road and settle as the wall is underpinned. These movements could cause cracks to develop at the junctions of this wall. During excavation the expected ground movements would tend to cause distortions across the house in the order of 0.02% and tensile strains of approximately 0.04%. These would induce a potential damage that can be classified as well within Category 1

In the long term no significant ground movements are expected that can be of concern for the existing structure.

6.2 Monitoring

It would be prudent to monitor movements during construction. Monitoring targets could be installed on the walls of the existing house and on the adjacent properties and on the retained structures. These could be supplemented by precise levelling points that tend to show less scatter that the monitoring targets. Base readings should be taken before work commences.

In the different stages of the construction movements could be small and maybe within the limits of the measurement accuracy. Therefore it is suggested that only overall trigger levels are applied to movements of the walls.

Based on the predictions discussed above, the following trigger levels on the horizontal and vertical movements of the retaining structure are suggested:

Trigger Level	Movements [mm]
green	<7
amber	7-10
red	>10

7 Slope stability issues

The Hampstead area and the surroundings are considered to be vulnerable to slope instability due to the ground conditions and the sloping gradient of the ground.

Potential land instability has generally been associated to slopes of 8° or greater both in the London Clay and in the Claygate Member (Deness et al., 1976; Ellison et al. 2004) although the mechanisms that could drive the potential instability are different in the two types of soils.

Figure 16 shows the areas that are prone to slope stability issues as mapped by the British Geological Survey (BGS) (Arup, 2010). The BGS mapping is based on factors such as geology and groundwater conditions, in addition to the slope angle.

The specific site conditions at 58a Redington Road do not suggest that issues with general land stability exist.

The original maximum slope of the ground across the site was approximately 10°, but it has already been cut by the existing structure. The uphill part of the existing retaining structure (i.e. the existing basement under the front driveway) will not be altered and a new basement box will be formed below existing structures.

The new retaining walls will be designed for the surcharge of the existing structures and the ground behind.

During construction the walls will be propped and "out of balance forces" will be partly resisted by the ground in direct bearing and sliding ("passive" resistance) of the opposing wall or transmitted through the side walls to the soil in shear.

In the permanent condition there will be no additional global "out of balance forces" over and above those present in the temporary condition. Loads will be transferred from the temporary to the permanent propping system which will lead to small redistributions in the resistance offered by the ground behind the retaining walls.

Given the hydrological conditions of the site, it is unlikely that pore water pressure increase in the clayey units of the Claygate Member could cause instability of the ground.

8 Conclusions

The impact of the proposed basement construction on the surrounding structures has been assessed using empirical methods and linear elastic analyses.

The excavated area will be subjected to upward movements due to the net load changes following the demolition of the existing house and the basement excavation. The design of the basement foundation should be carried out considering these load changes and the associated movements.

Providing that good workmanship and a robust construction sequence are used and that full support from high level is provided to the retaining walls during excavations, the basement construction is unlikely to cause settlements and horizontal strains that would induce other than limited damage to the surrounding structures.

Monitoring of movement during construction is recommended.

9 REFERENCES

Arup (2010) Camden geological hydrogeological and hydrological study , London Borough of Camden

British Geological Survey (1998). North London, England and Wales Sheet 256. Solid and Drift Geology 1: 50,000.

CIRIA C760 (2017). Guidance on embedded retaining wall design

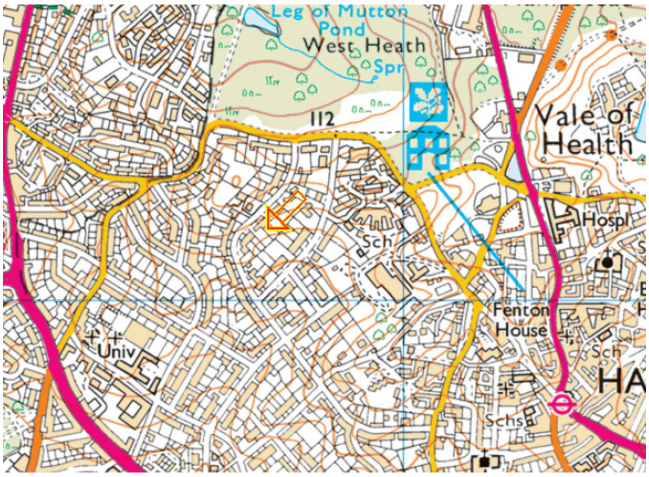
GEA (2018). Desk Study & Ground Investigation Report– 58a Redington Road

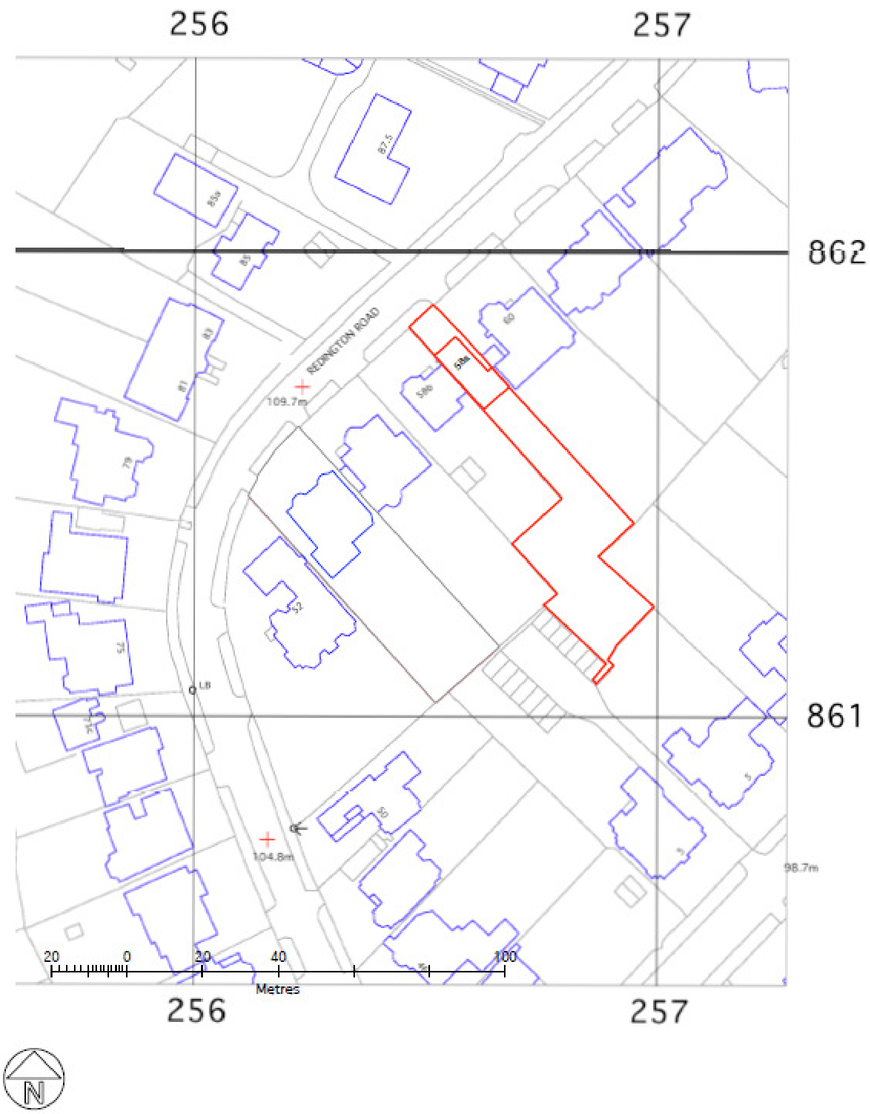
Ellison, R.A., Woods, M.A., Allen, D.J., Forester, A., Pharoah, T.C., and King, C. 2004. Geology of London: Special memoir for 1:50000 Geological sheets 256 (North London), 257 (Romford), 270 (South London), 271 (Dartford). British Geological Survey.

Denness, B and Riddols, B W., 1976. The influence of geological factors on slope stability in the London clay of south Essex, England. Bulletin of Engineering Geology and the Environment. Volume 13, Number 1, 37-40.

FIGURES

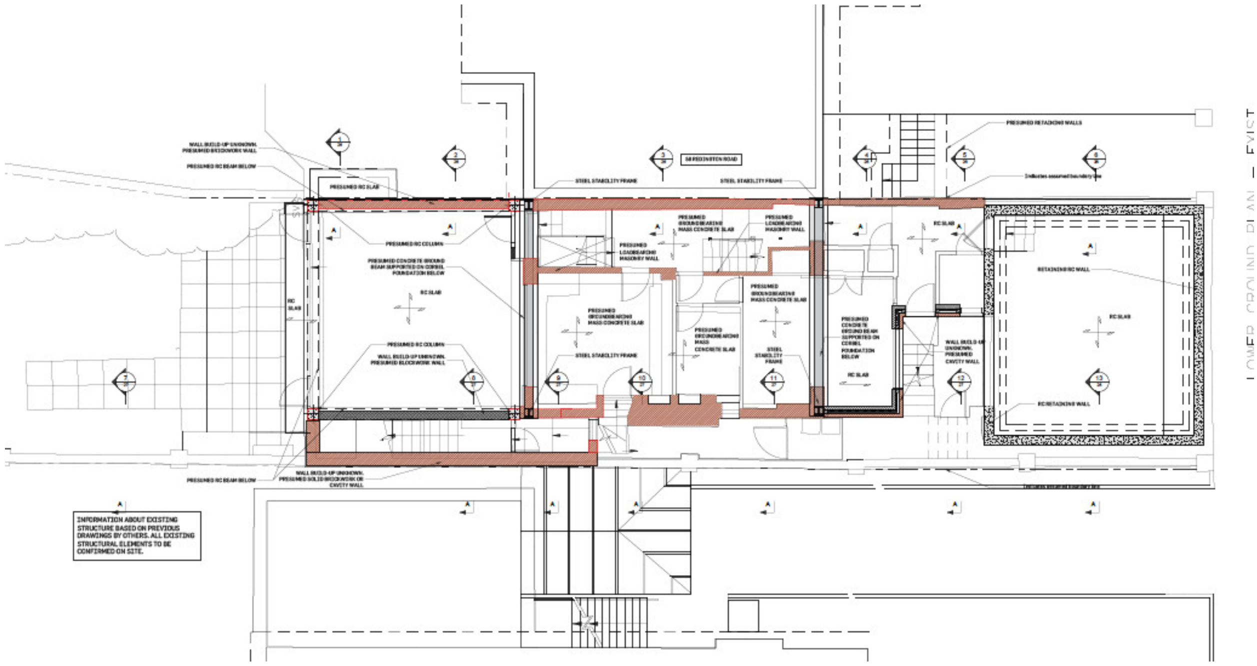
(a)



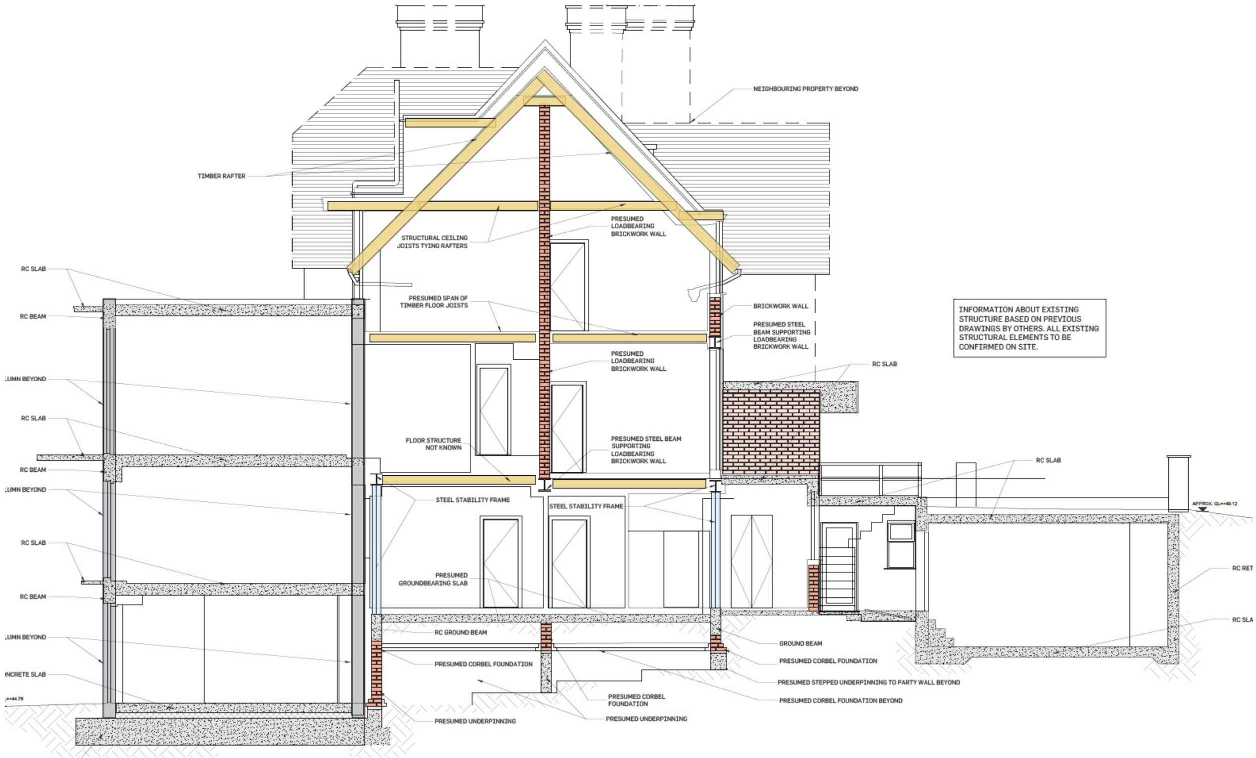


(b)

GCG	**D Belov and G McDougal** 58a Redington Road	**Figure** **1**
	The Site a) Location b) site layout	

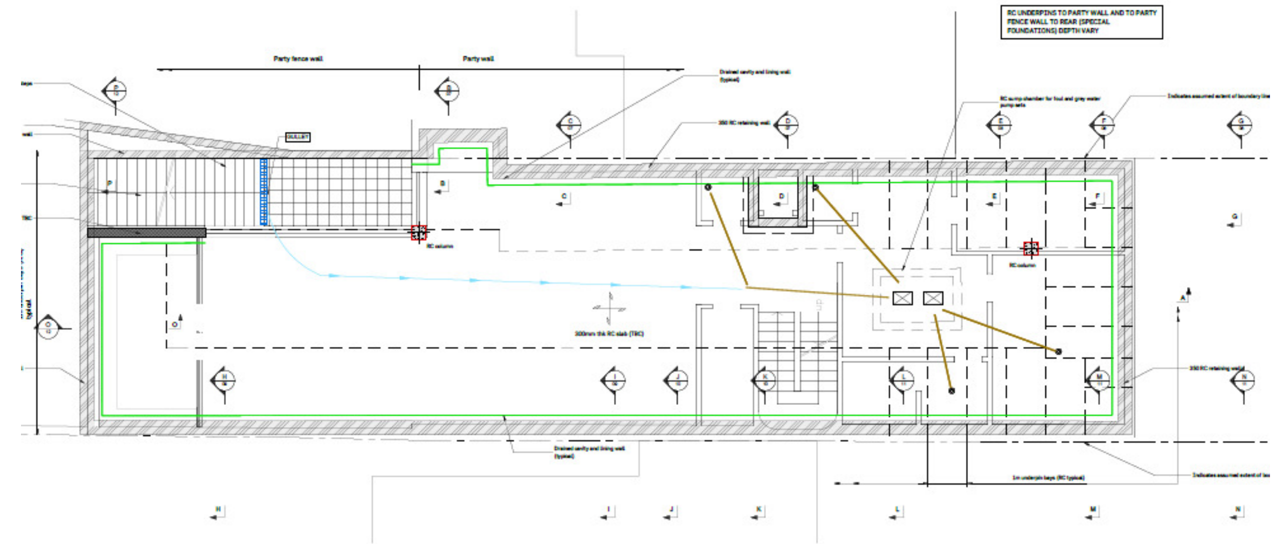


(a)

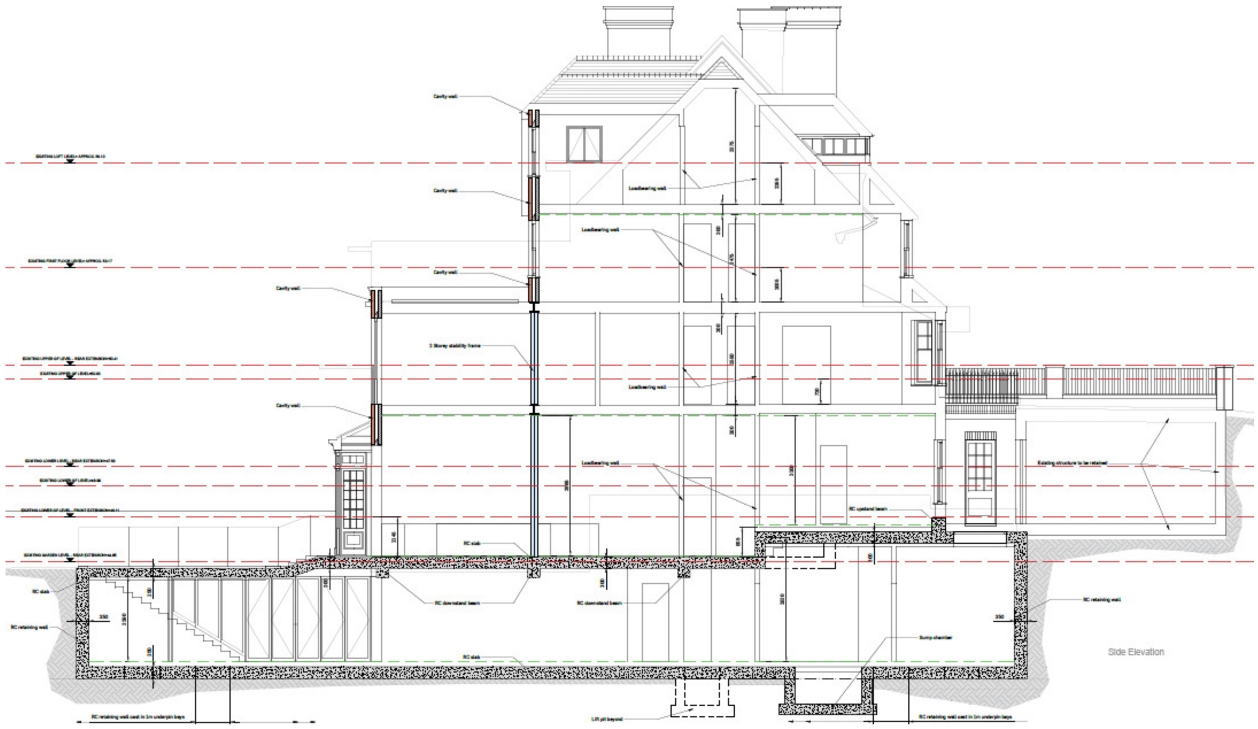


(b)

GCG	**D Belov and G McDougal** 58a Redington Road	**Figure**
	The existing property (a) Plan of lower ground floor (b) north-west to south-east structural section	**2**



(a)



(b)

D Belov and G McDougal

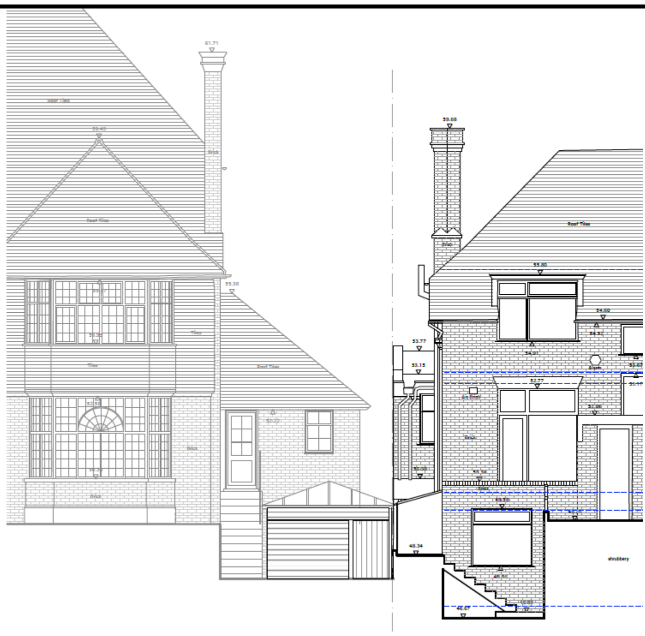
58a Redington Road

The proposed structure

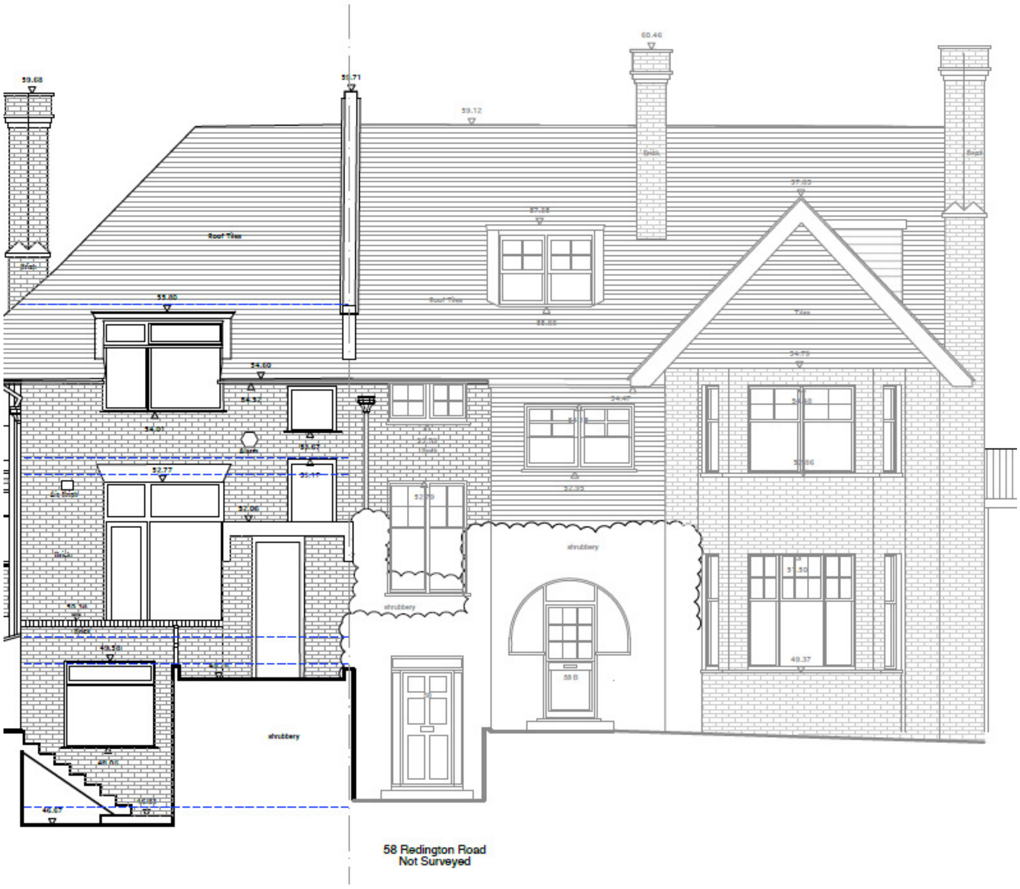
(a) Plan of basement (b) north-west to south-east section

Figure

3

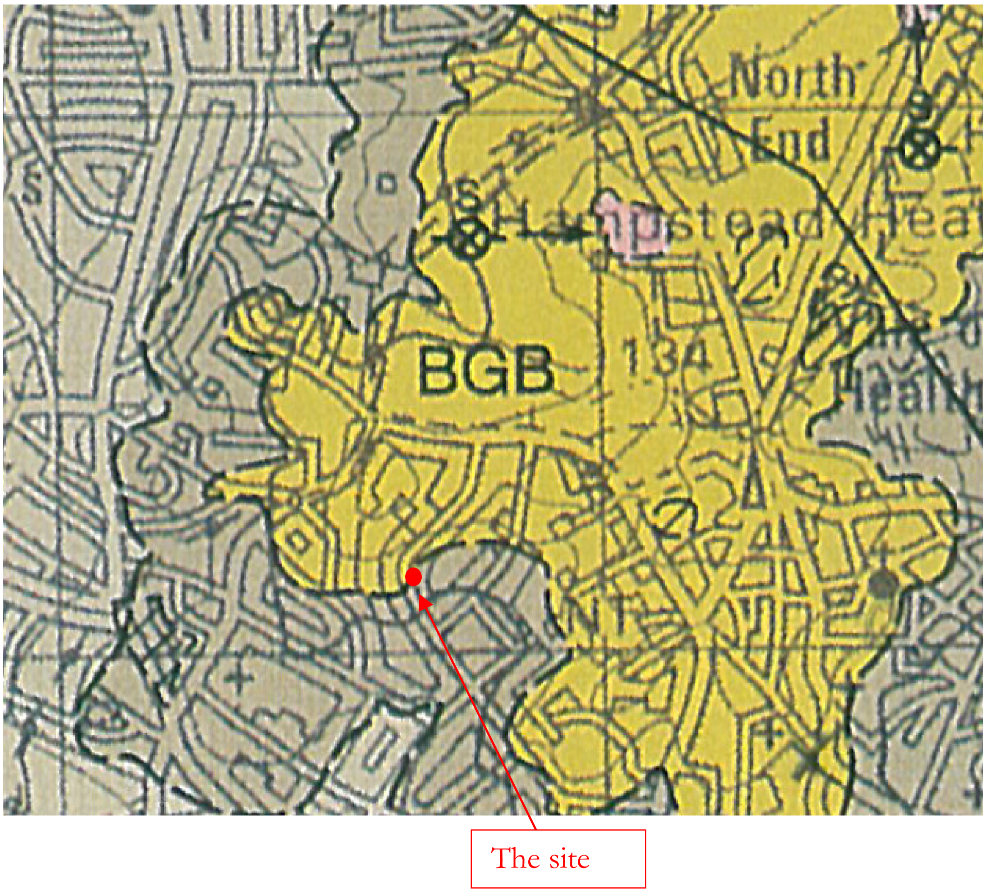


(a)

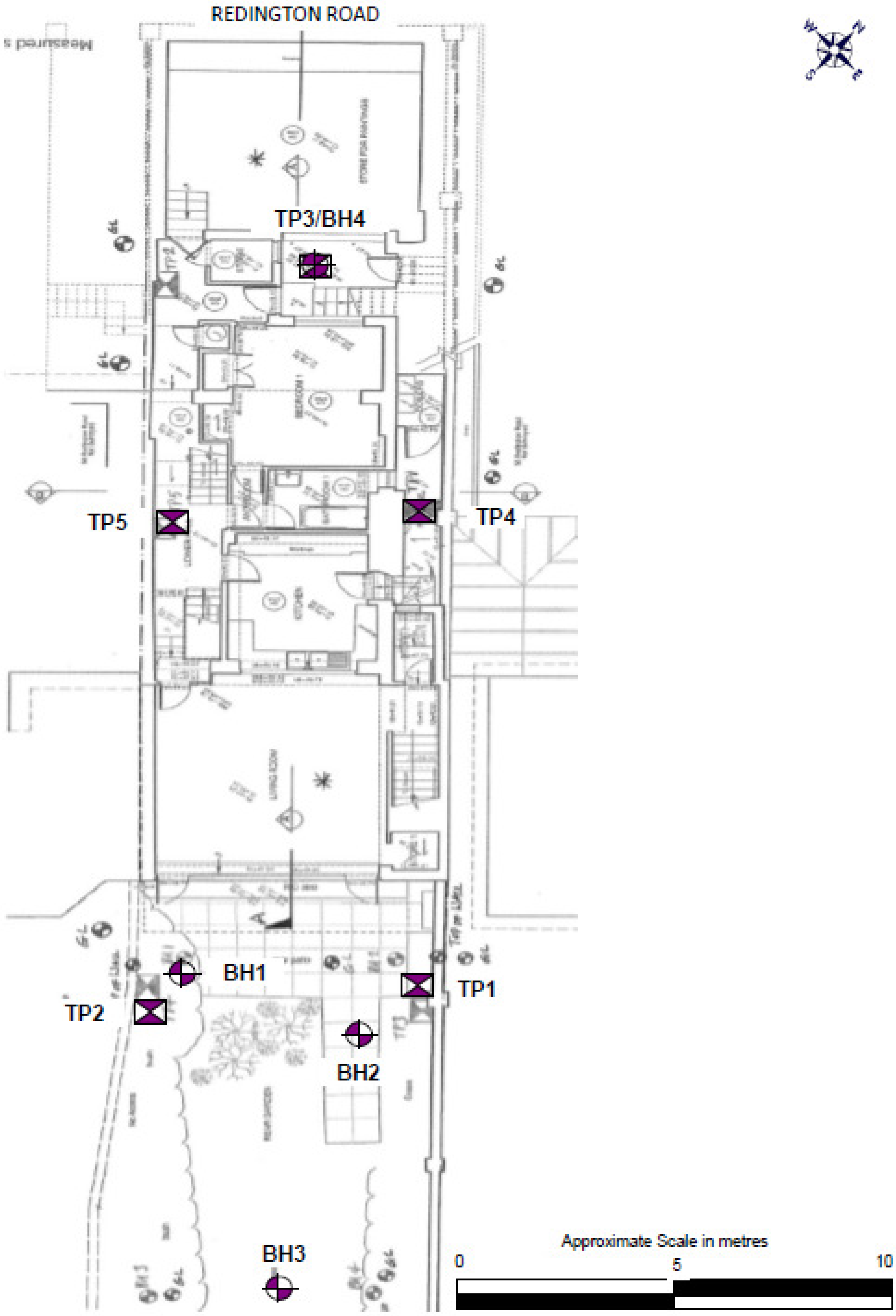


(b)

GCG	**D Belov and G McDougal** 58a Redington Road	**Figure** **4**
	The adjacent properties on Redington road a) No.60: section through the garage b) No.58b Redington Road	



	D Belov and G McDougal 58a Redington Road	**Figure** **5**
	Extract from The BGS Map North London, England and Wales Sheet 256. Solid and Drift Geology 1: 50,000.	

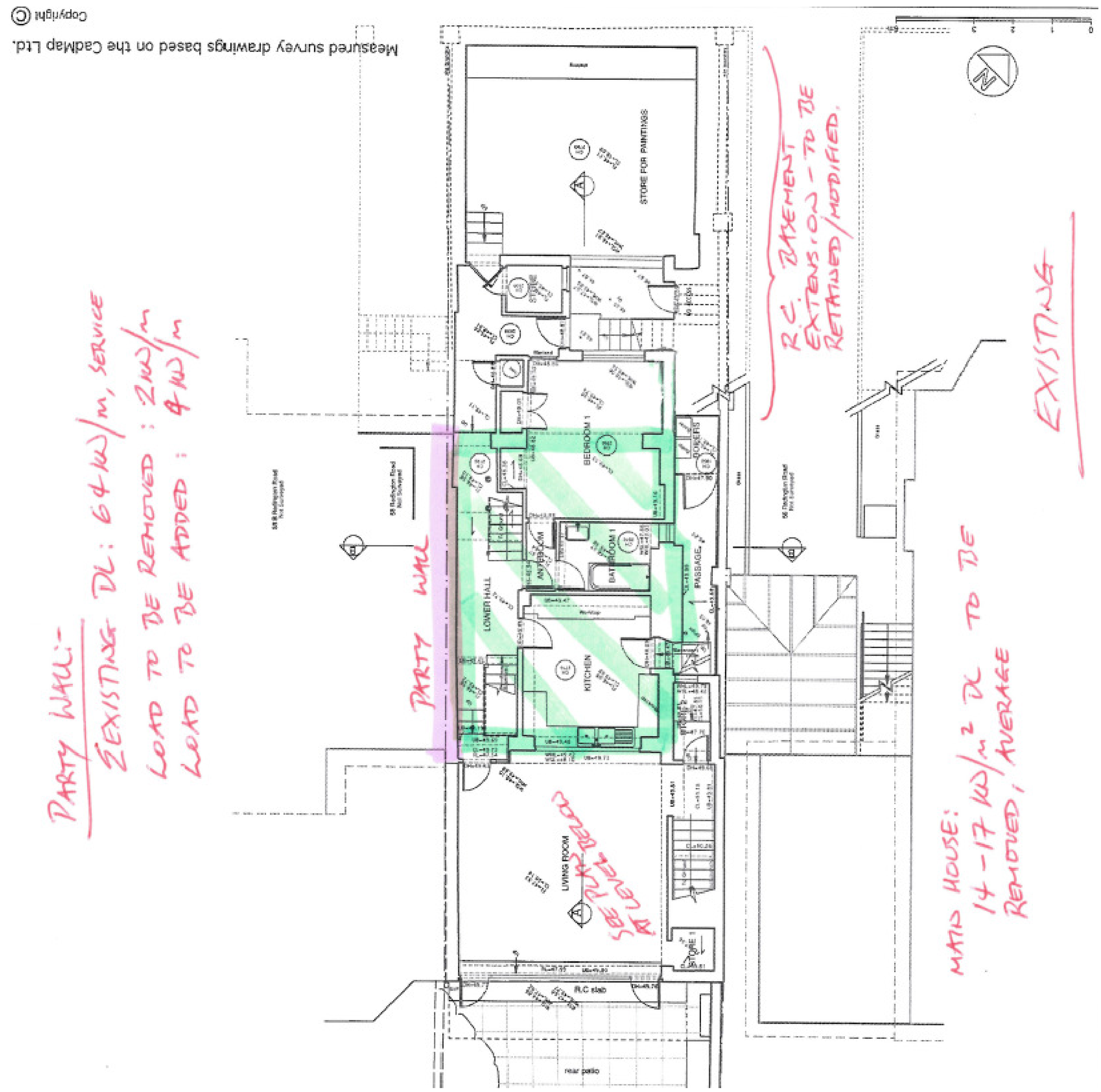


D Belov and G McDougal

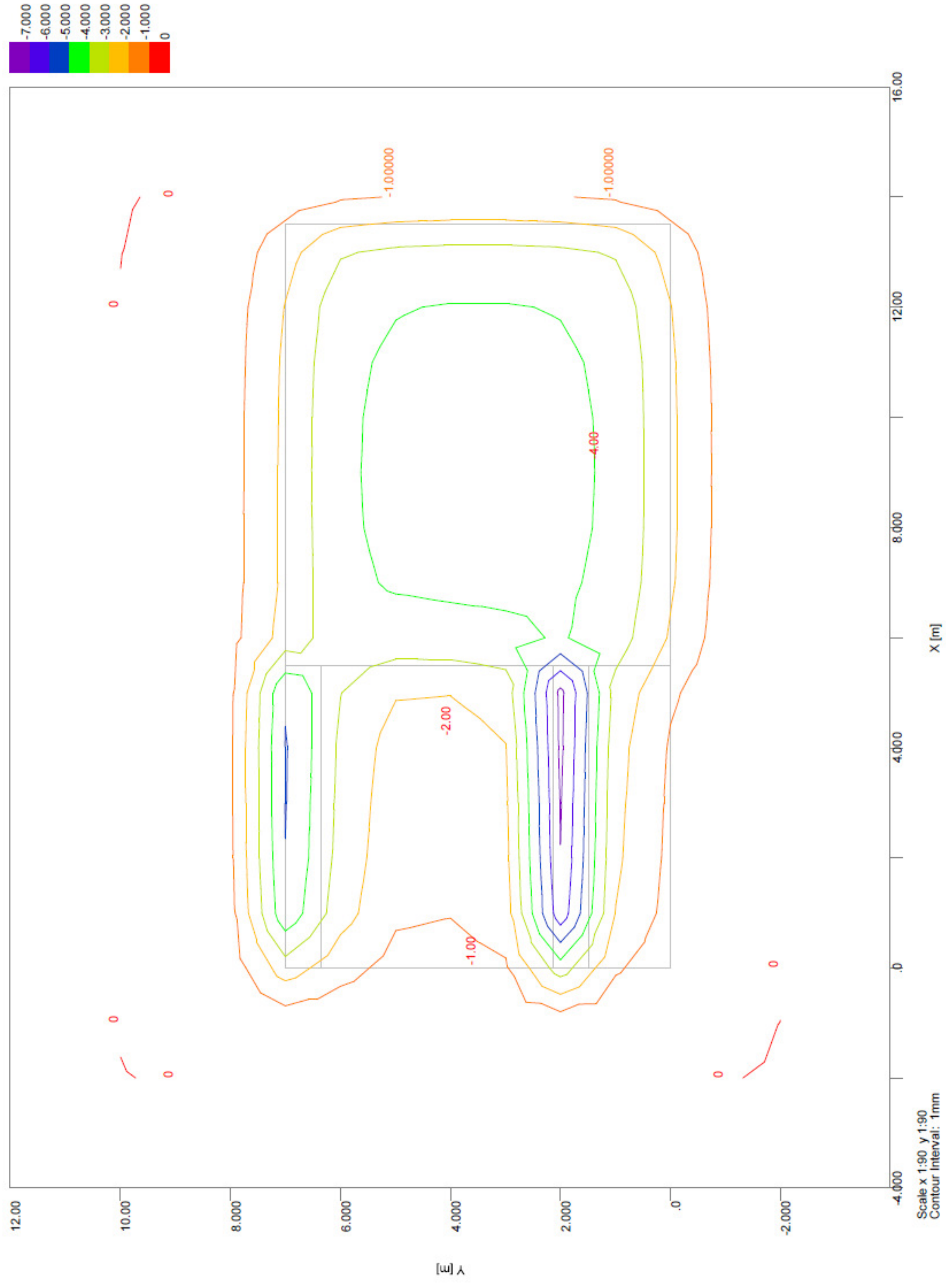
58a Redington Road

Location of investigation holes

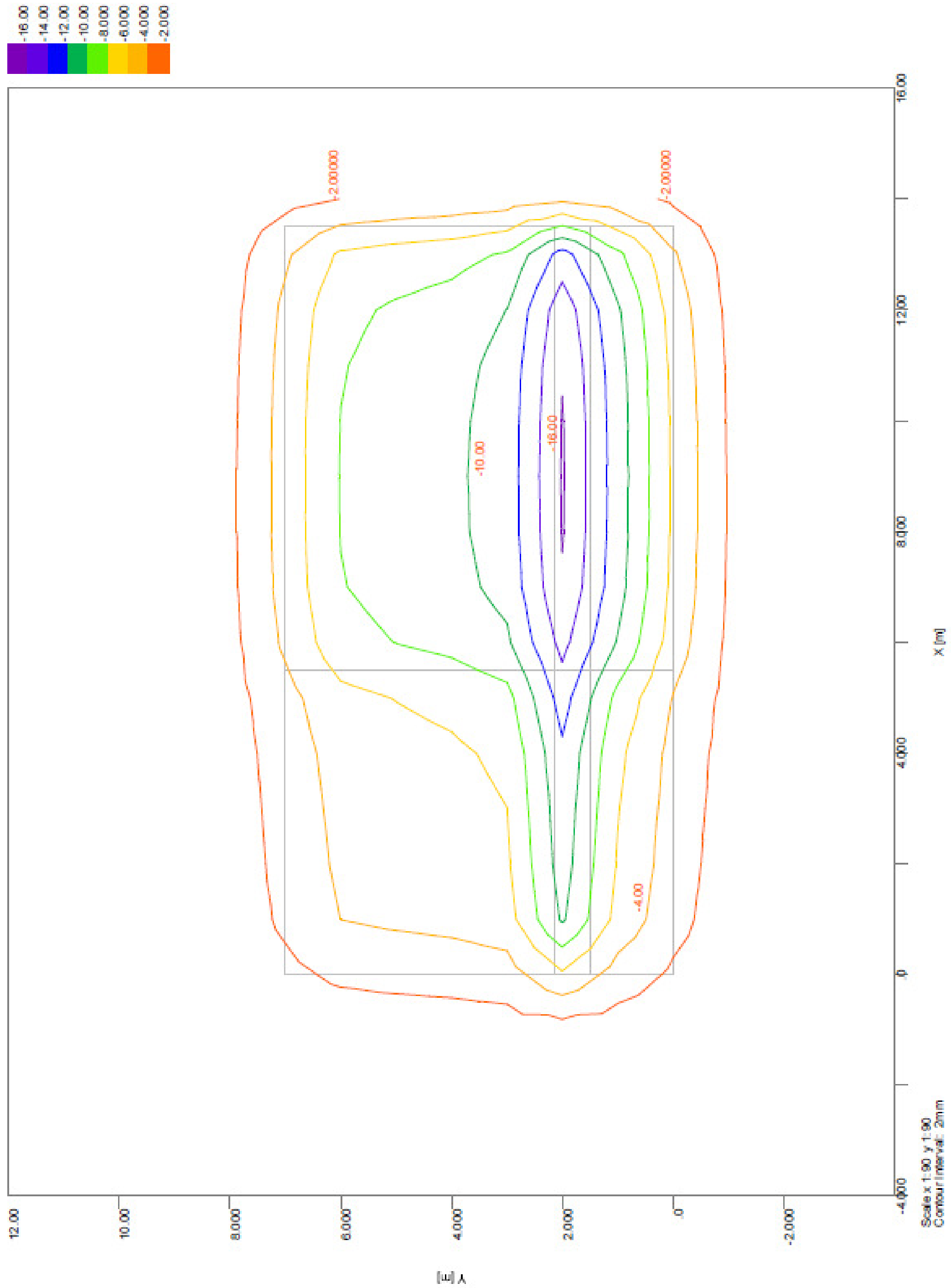
Figure 6



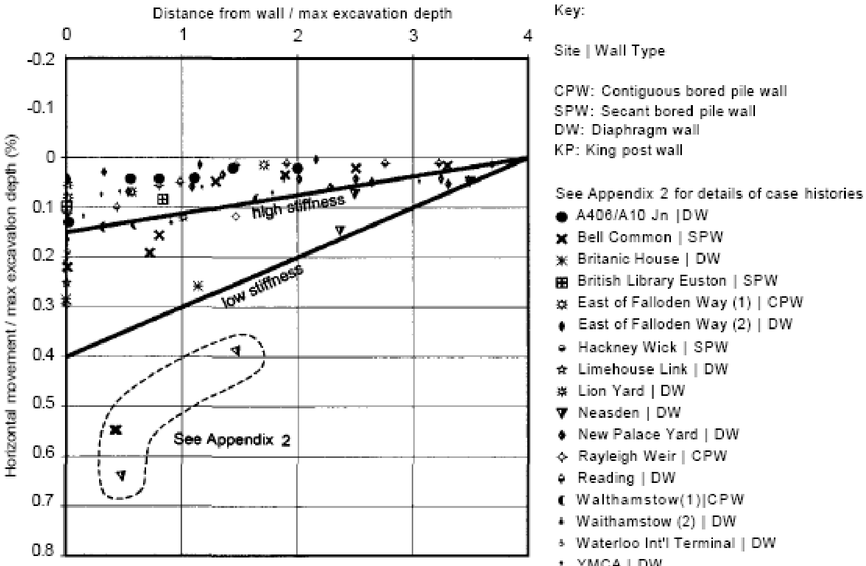
GCG	**D Belov and G McDougal** 58a Redington Road	**Figure**
	Estimated loads on the existing foundations	**7**



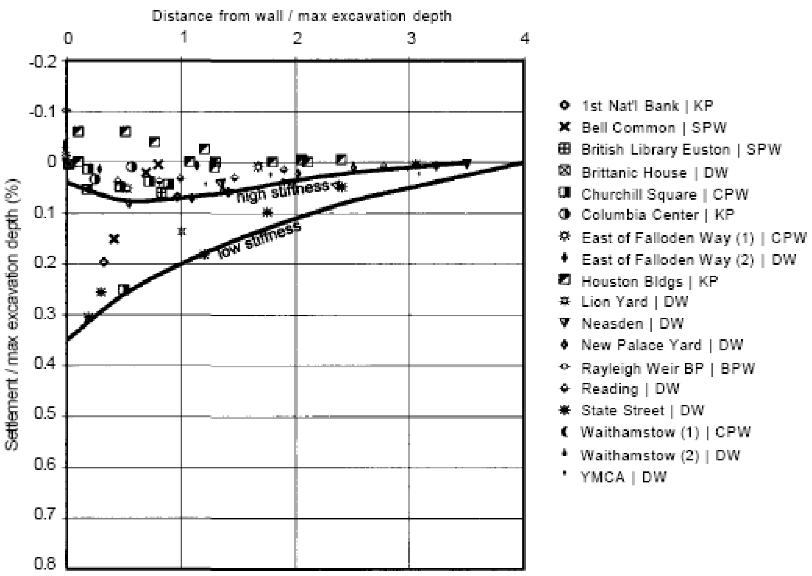
GCG	**D Belov and G McDougal** 58a Redington Road	**Figure** **8**
	Estimated ground movements due to the demolition of the existing house	



	D Belov and G McDougal 58a Redington Road	**Figure** **9**
	Estimated ground movements at completion of excavation for the new basement	

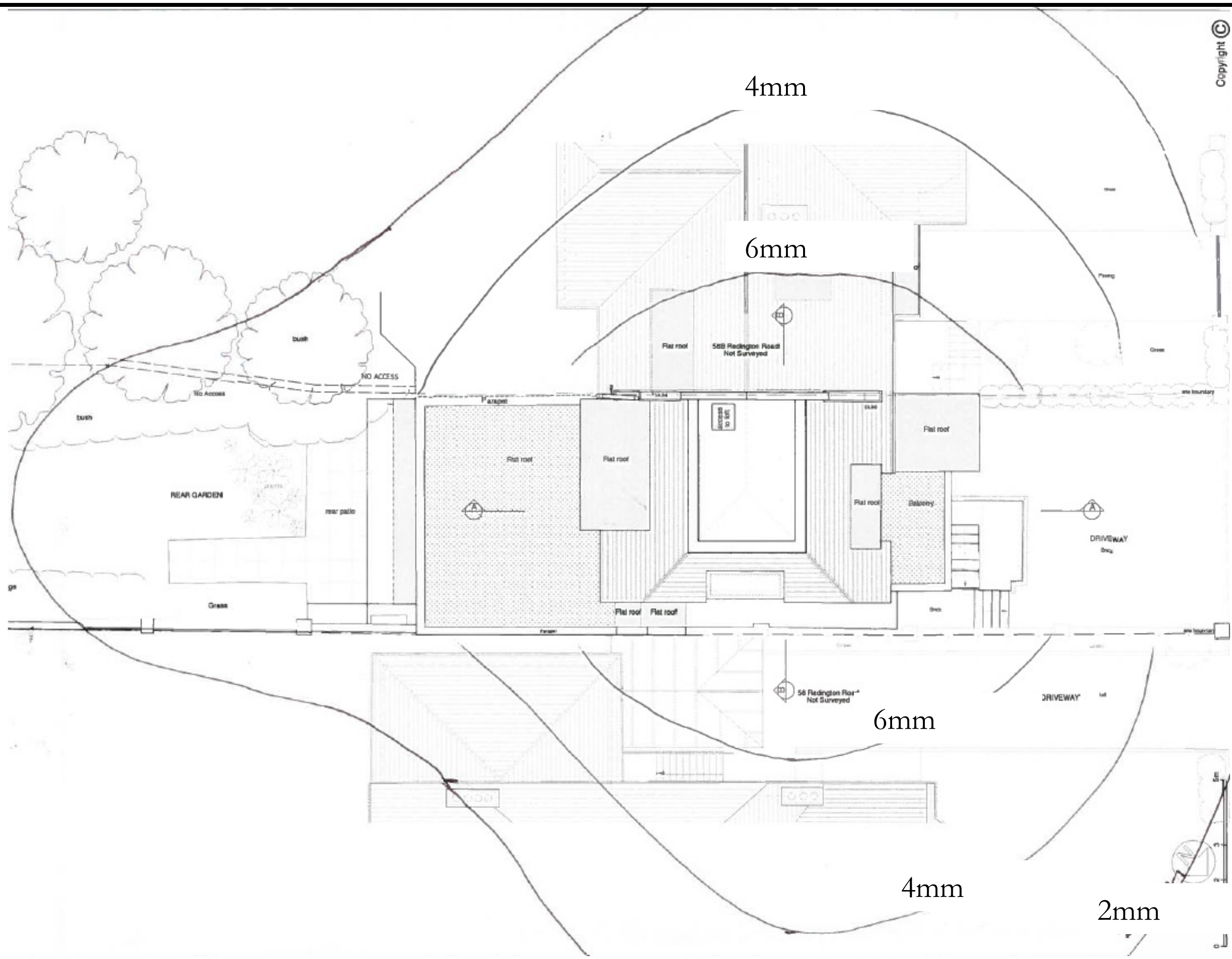


(a) Horizontal movements



(b) Vertical movements

GCG	**D Belov and G McDougal** 58a Redington Road	**Figure** **10**
	Field measurements of ground movements due to excavation in front of wall in stiff clay (CIRIA C760)	



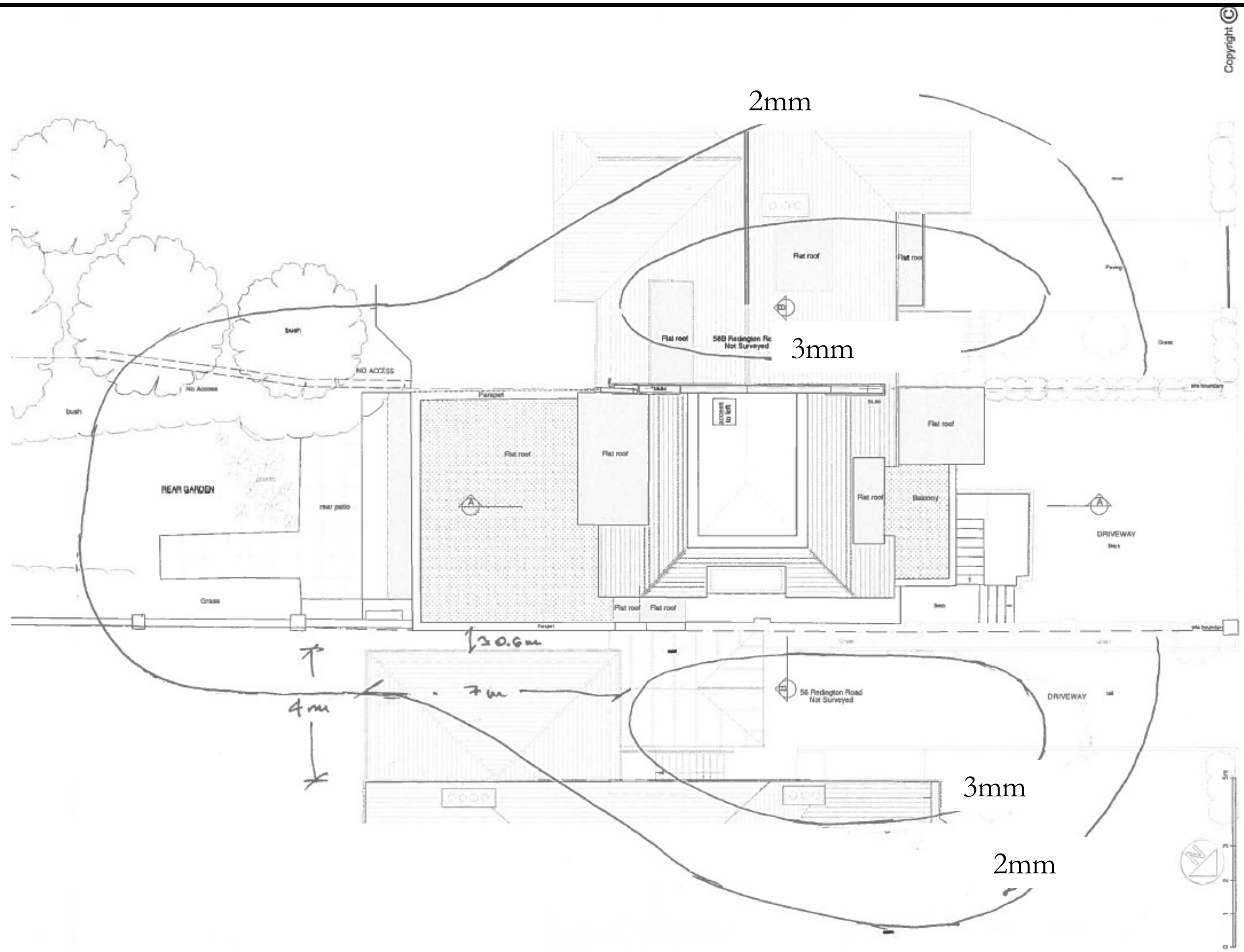
D Belov and G McDougal

58a Redington Road

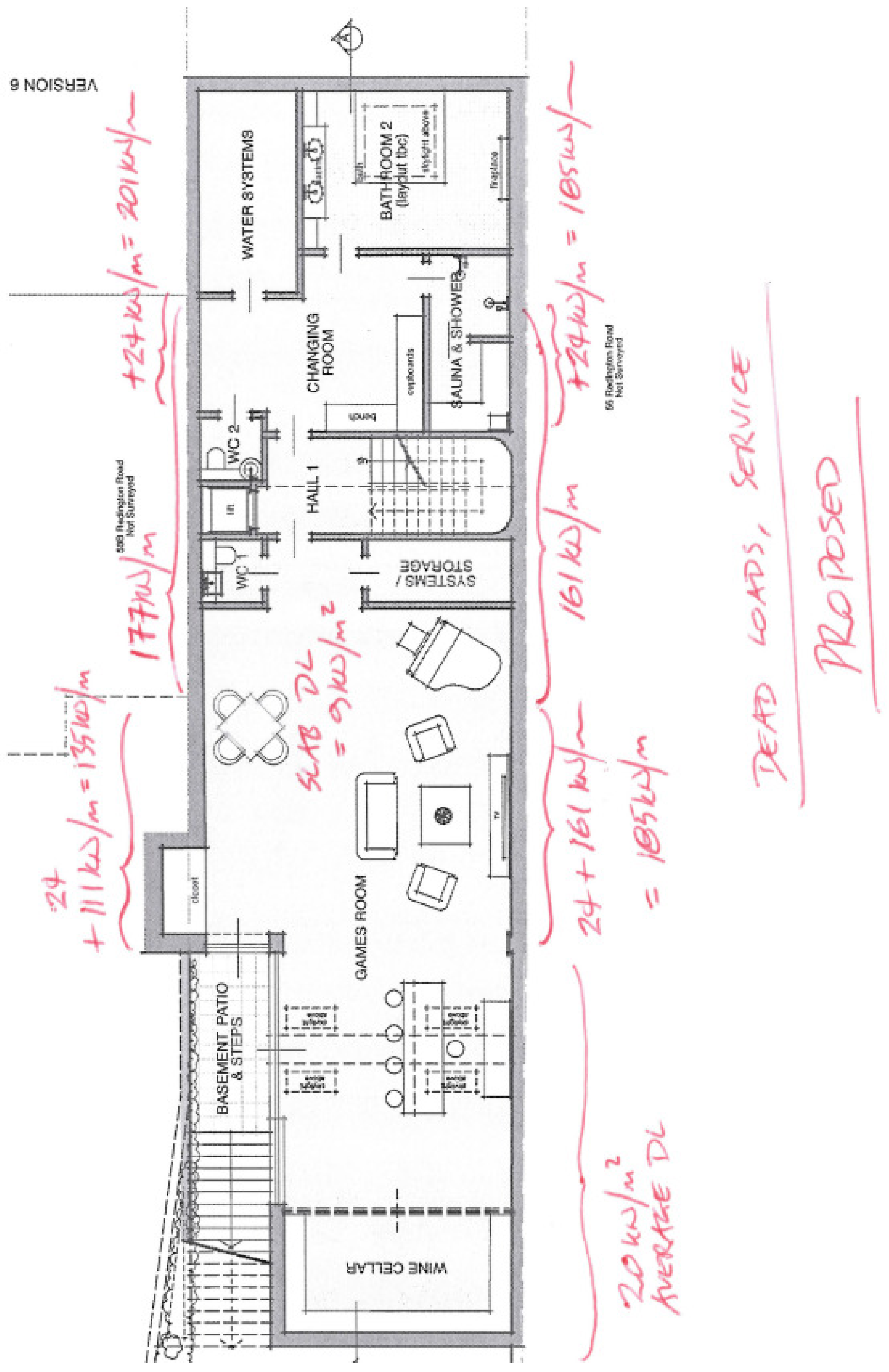
Ground movements induced around the site

Total vertical movements behind retaining walls

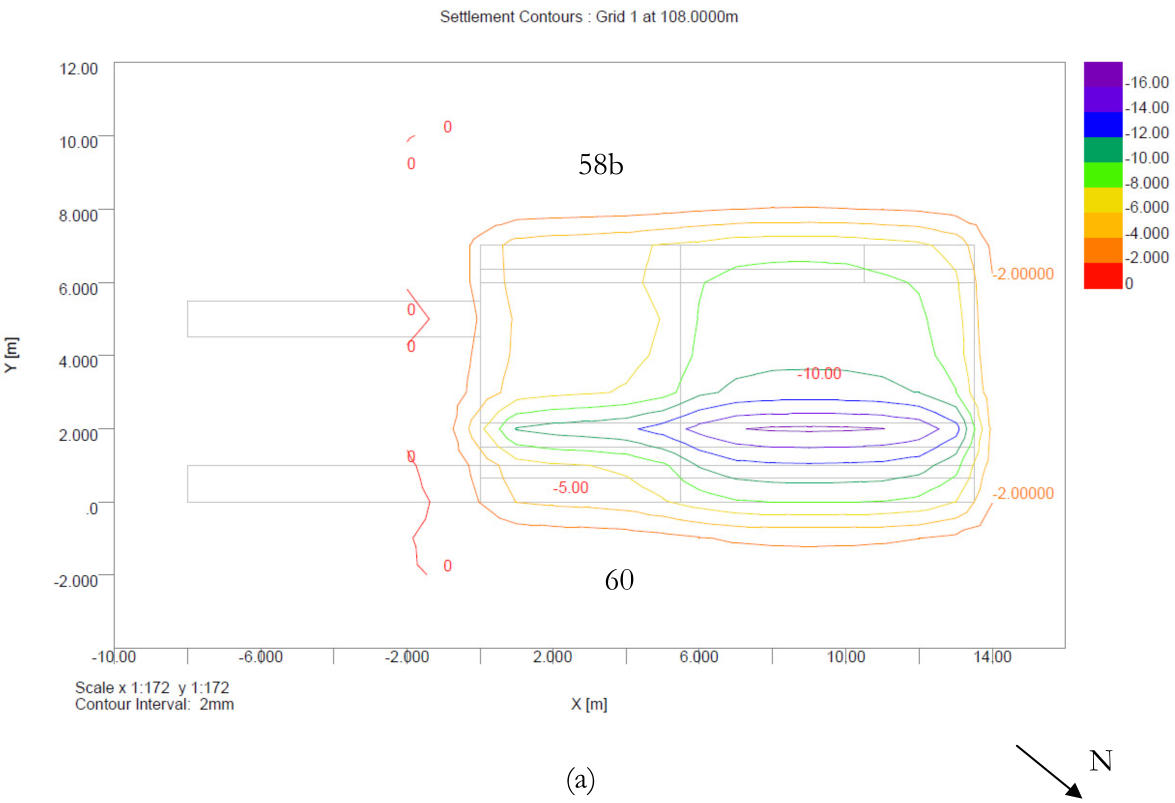
Figure 11



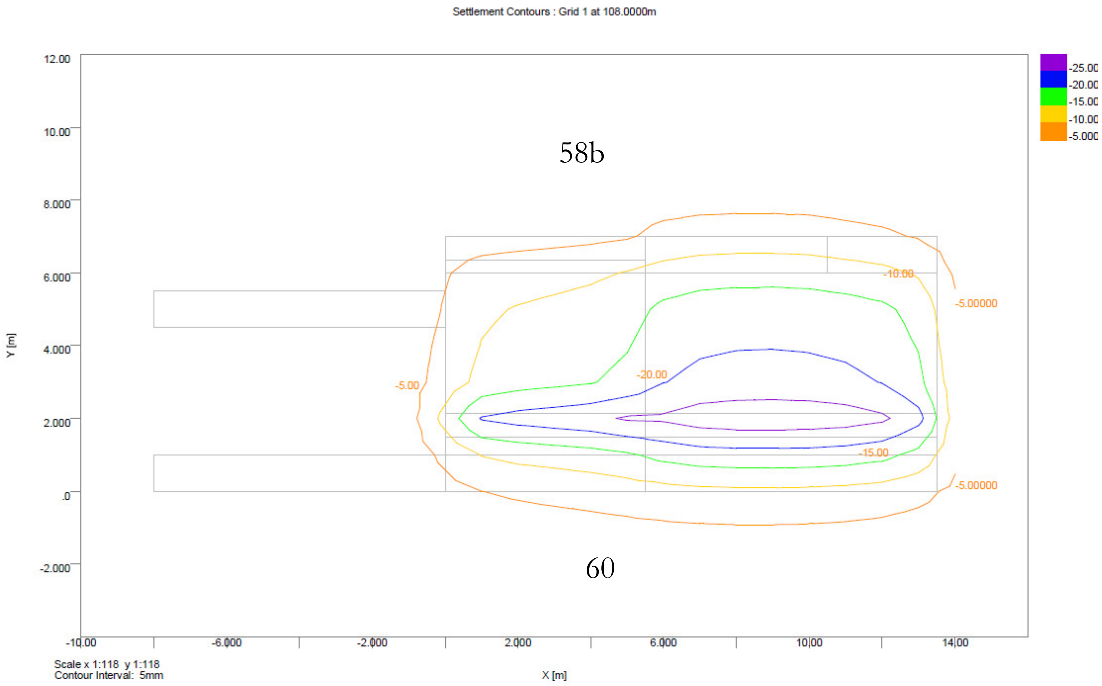
	D Belov and G McDougal 58a Redington Road	**Figure** **12**
	Ground movements induced around the site Total horizontal movements	



GCG	**D Belov and G McDougal** 58a Redington Road	**Figure** **13**
	Proposed loads on new foundations	



(a)

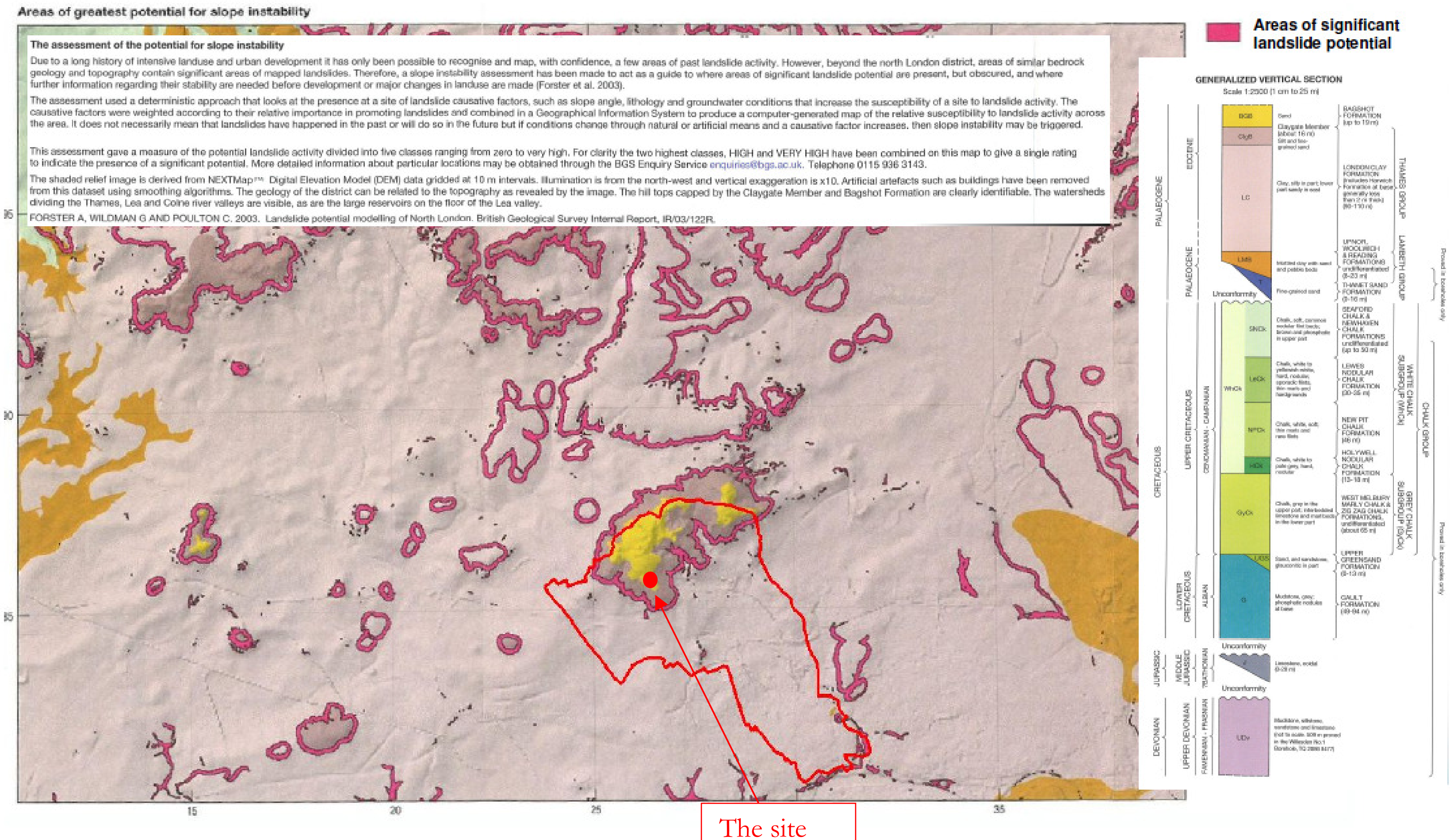


(b)

	D Belov and G McDougal 58a Redington Road	**Figure**
	Estimated loads at completion of construction. a) End of construction b) long term after completion	**14**

Category of damage	Description of typical damage (ease of repair is underlined)	Approximate crack width (mm)	Limiting tensile strain ε_{lim} (per cent)
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 linings. 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.	

GCG	**D Belov and G McDougal** 58a Redington Road	**Figure**
	Damage Category Table, Ciria C760	**15**



Source - British Geological Society, 1:50,000 Series
England and Wales Sheet 256 – North London

Camden Geological, Hydrogeological and Hydrological Study

	D Belov and G McDougal 58a Redington Road	**Figure**
	Areas of significant landslide potential (Arup 2010)	**16**

A.1 Appendix A- Soil parameters used for PDisp calculations

The soil parameters for the ground movements analyses have been selected based on experience and on published information on the mechanical behaviour of the soil at the site (High et al. 2007, Gasparre et al. 2014).

Given the limited information on the stiffness response of Claygate Members, it has been assumed that it is similar to the stiffness response of the upper lithological units of the London Clay Formation.

For the purposes of the ground movement analysis based on an isotropic soil model, the elastic (small strain) undrained stiffness of the London Clay (E_{uo}) can be taken as:

$$E_{uo}=975p' \qquad (1)$$

where the mean effective stress p' has conservatively been calculated considering a coefficient of earth pressure at rest Ko equal to 1.

The elastic drained stiffness (E'_o) of the Claygate Member has been estimated from the relationship:

$$E'_o= 0.75Eu \qquad (2)$$

For the analysis it has been assumed that the proposed works will give rise to strains in the more superficial strata of the Claygate Members, which will reduce its elastic stiffness. The stiffness reduction has been calculated based on the magnitude of the applied loads.

In summary, the following soil conditions and soil parameters have been assumed in the analyses:

Stratum	Level at top [mOD]	Undrained Stiffness Eu [MN/m^2]	Drained Stiffness E' [MN/m^2]
Made Ground	+111	-	10
Claygate Members	+107	5.8 +8z	0.75 Eu
London Clay	+90	14+6z	0.75 Eu
Lambeth Group	+30	-	400
Rigid boundary	+20		

Where z is the depth below the top level of the London Clay, z_1 is the depth below the Lambeth Group.