Part 3: GROUND MOVEMENT ASSESSMENT

This section of the report comprises an analysis of the ground movements arising from the proposed basement and foundation scheme discussed in Part 2 and the information obtained from the investigation, presented in Part 1 of the report.

9.0 INTRODUCTION

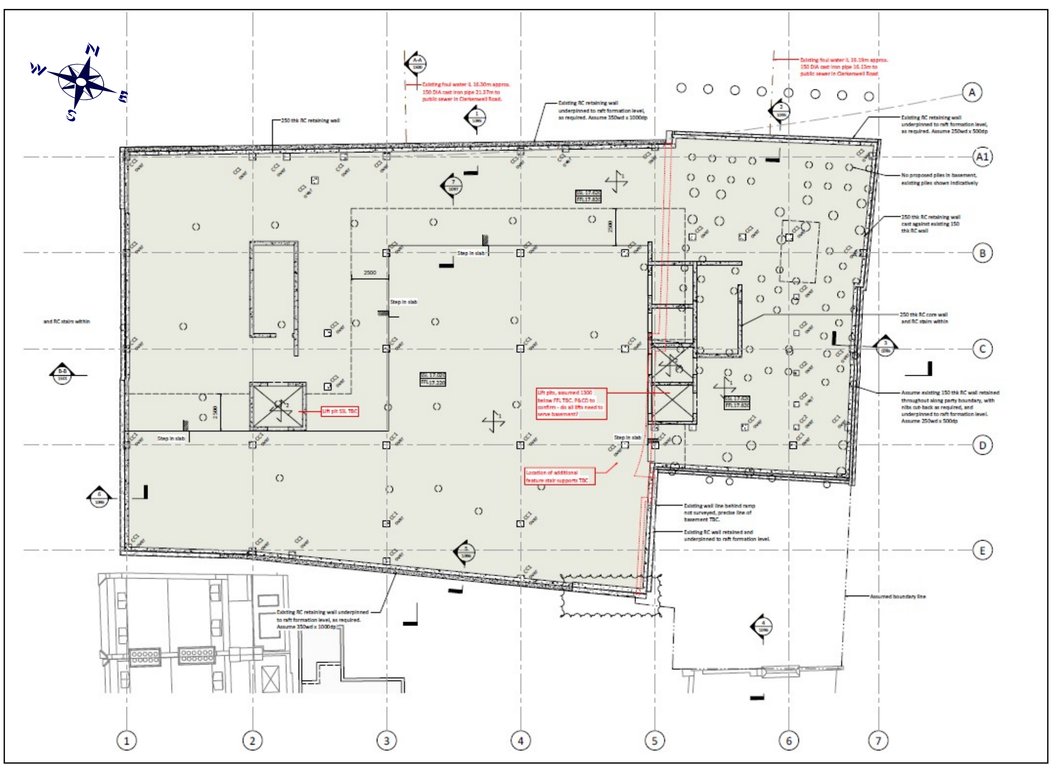
The sides of an excavation will move to some extent regardless of how they are supported. The movement will typically be both horizontal and vertical and will be influenced by the engineering properties of the ground, groundwater level and flow, the efficiency of the various support systems employed during underpinning and the efficiency or stiffness of any support structures used.

An analysis has been carried out of the likely movements arising from the proposed basement excavation and the results of this analysis have been used to predict the effect of these movements on surrounding sensitive structures.

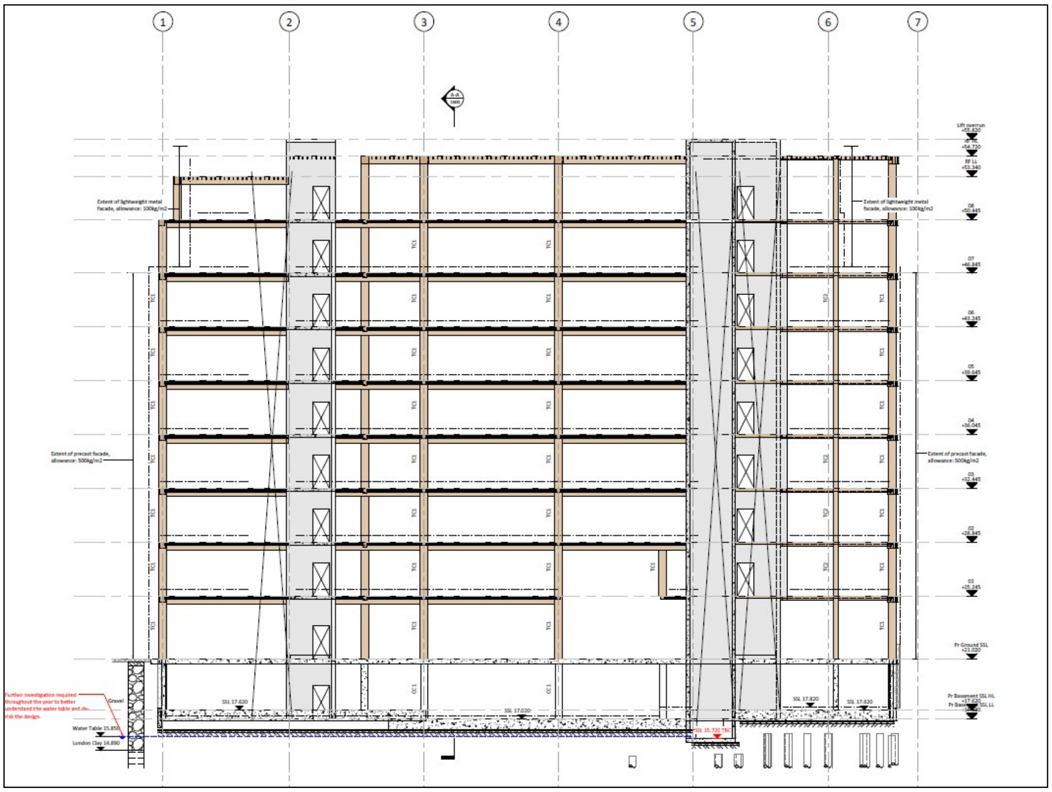
9.1 Proposed Excavation

Consideration is being given to the redevelopment of the site, which will include deepening of the existing basement by 0.5 m to 1.0 m; formation level for the new basement should therefore be within the Lynch Hill Gravel at a level of approximately 17.0 m OD to 16.5 m OD.

It is understood that deepening of the existing basement retaining walls will be achieved by traditional underpinning, with the proposed basement shown on the drawing extract below.



It is understood that the proposed loads will be distributed onto a proposed basement raft foundation, as shown on the section extract below.



9.2 Construction Sequence

The following sequence of operations has been derived to enable analysis of the ground movements around the basement, both during and after construction, and is based on drawings provided by the consulting engineer, copies of which are included in the appendix.

Essentially the sequence may be considered as two groups of activities, the first comprising the short-term temporary works, whilst the second represents the construction of the permanent works.

The detail of the support provided to adjacent walls is beyond the scope of this report and the structural engineer will be best placed to agree the methodology with the chosen contractor(s) once appointed.

9.2.1 Temporary Support to Underpinned Walls

It is understood that underpinning will take place in a ‘hit and miss’ sequence, in stages to be agreed with the temporary works engineer and under party wall agreement.

Underpinning is to be undertaken in short sections not exceeding 1.0 m in length, with no adjacent pin to be excavated until a minimum of 48 hours after the adjacent pin has been cast and dry-packed placed, with the sides of the excavation adequately shored and propped.

The underpins will be adequately laterally propped and sufficiently dowelled together, and the concrete will be cast and adequately cured prior to excavation of the basement and removal of the formwork and supports.

9.2.2 Permanent Works

When the final excavation depths have been reached the permanent works will be formed which, from the information provided, are understood to comprise reinforced concrete walls with a drained cavity lining discharging to a sump pit.

Reinforced concrete will be used for the proposed basement raft slab.

10.0 GROUND MOVEMENTS

10.1 Basis of Ground Movement Assessment

An assessment of ground movements within and surrounding the excavation has been undertaken using the X-Disp and P-Disp computer programs licensed from the OASYS suite of geotechnical modelling software from Arup. These programs are commonly used within the ground engineering industry and are considered to be appropriate tools for this analysis.

The X-Disp and P-Disp programs have been used to predict ground movements likely to arise from the construction of the proposed basement. This includes the heave / settlement of the ground (vertical movement) and the lateral movement of soil behind the proposed retaining walls (horizontal movement).

For the purpose of these analyses, the corners have been defined by x and y coordinates, with the x-direction parallel with Clerkenwell Road, whilst the y direction is parallel with Grays Inn Road. Vertical movement is in the z-direction.

The basement has been modelled as a regular polygon, with maximum dimensions of approximately 50 m by 30 m. For simplicity, it has been assumed that all underpinning will extend to a depth of 1.0 m to the lower excavation level of 16.56 m OD.

The analysis has been undertaken in a series of three stages, the first two of which represent the likely short-term (undrained) movements and broadly correspond with the principal elements of the proposed construction sequence, namely underpinning installation and lowering of the existing basement (Analysis Stage 1) and construction and loading of the proposed raft foundations (Analysis Stage 2). The final stage, Stage 3, does not correspond to any specific ‘stage of construction’, but reflects the total (drained) movements that are likely to occur as a result of the entire construction process.

The proposed basement footprint contains adopted within the model includes a re-entrant corner, which, due to limitations within the software, causes a doubling up of movements, creating an issue for any analysis, as in reality the opposite is likely to be the case, with an overall reduction in ground movements in these areas due to the increased stiffness of the structure at these points. For the purpose of this assessment, no correction and / or reduction has been made account for the re-entrant corners, such that the analysis can be considered extremely conservative in these areas.

It is assumed that suitable propping will be provided during the construction of the basement and in the permanent condition, such that the walls can be considered to be stiff for the purpose of the ground movement modelling.

The full inputs of all the analyses, along with selected movement contour plots and tabular outputs are included within the appendix.

10.2 P-Disp Model

Unloading of the Lynch Hill Gravel and underlying London Clay will take place as a result of the excavation of the proposed basement and the reduction in vertical stress will cause heave to take place. Undrained soil parameters have been used to estimate the potential short-term movements, which include the "immediate" or elastic movements as a result of the basement excavation. Drained parameters have been used to provide an estimate of the total movement.

The elastic analysis requires values of soil stiffness at various levels to calculate displacements. Values of stiffness for the soils at this site are readily available from published data and we have used a well-established method to provide our estimates. This relates values of E_u and E', the drained and undrained stiffness respectively, to values of undrained cohesion, as described by Padfield and Sharrock[22] and Butler[23] and more recently by O'Brien and Sharp[24]. More recent published data[25] for the London Clay indicates stiffness values of 600 to 750 x Cu for E_u, and a ratio of E' to E_u of 0.75 should be appropriate. However, for the purpose of this initial assessment lower relationships of $E_u = 500\ C_u$ and $E' = 300\ C_u$ have been adopted as it is considered that the use of the more conservative values provides a sensible approach for this stage in the design.

A relationship of 2000 x SPT N (estimated from soil description) has been used to obtain values of Young's modulus for the granular soils of the Lynch Hill Gravel.

The soil parameters used in this assessment have been taken from those presented in Section 7.1, and are tabulated below for completeness.

Stratum	Base of Stratum (m OD)	Eu (KN/m²)	E'(KN/m²)
Made Ground	17.0 (varies)	12,500	7,500
Lynch Hill Gravel	14.5	-	60,000
London Clay	-1.0	25,000 to 125,000	15,000 to 75,000
Lambeth Group	-7.0⁺	160.000 to 200,000	96,000 to 120,000
	-14.0*	200,000 to 230,000	120,000 to 138,000

⁺Maximum depth of investigation. *Estimated base of Lambeth Group form nearby BGS data.

The excavation of between 0.5 m to 1.0 m of soil to deepen the existing basement is likely to result in an unloading of between 10 kN/m² and 20 kN/m².

A rigid boundary for the analysis has been set at a depth of approximately 35 m (approx. -14 m OD), at which point nearby previous BGS archive records indicate the base of Lambeth Group is likely to be encountered and below which, essentially incompressible soils of the Thanet Sand are expected to be present.

Information provided by the consulting engineer indicates that the likely bearing pressure over the footprint of the basement raft is likely to be in the region of 80 kN/m².

22 Padfield CJ and Sharrock MJ (1983) *Settlement of structures on clay soils*. CIRIA Special Publication 27
23 Butler FG (1974) *Heavily overconsolidated clays: a state-of-the-art review.* Proc Conf Settlement of Structures, Cambridge, 531-578, Pentech Press, London.
24 O'Brien AS and Sharp P (2001) *Settlement and heave of overconsolidated clays - a simplified non-linear method.* Part Two, Ground Engineering, Nov 2001, 48-53
25 Burland JB, Standing, JR, and Jardine, FM (2001) Building response to tunnelling, case studies from construction of the Jubilee Line Extension. CIRIA Special Publication 200

An assessment of the potential behaviour of these foundations has been included within the analysis, with a staged approach to the modelling adopted to reflect the change in the way the loads are applied during the course of construction.

10.3 Ground Movements – Surrounding the Excavation

The magnitude of the settlement resulting from the proposed basement construction will be controlled to a large extent by the quality of workmanship, particularly with respect to walls constructed by underpinning techniques.

For the purpose of this assessment a high quality of construction has been assumed, with continued loading from the existing building, such that potential movements are expected to be kept to a minimum.

10.3.1 X-Disp Model

For the X-Disp analysis, the soil movement relationships used for the embedded retaining walls are the default values within CIRIA report C760[26], which were derived from a number of historic case studies.

Installation of Proposed Underpinning: On this site it is assumed that the proposed underpinning will be supported or propped in the temporary condition to maintain stability during the excavation and that reinforced concrete retaining walls will be cast at a later stage in the appropriate areas.

Whilst it might appear reasonable to adopt the ground movement curves for ‘no horizontal and vertical movement’ for this analysis, in practice there will always be a potential for some movement to take place and the installation curves for the panel-like planar diaphragm wall have therefore been adopted to capture the likely constructed related movements for walls installed by underpinning techniques.

Excavation Phase: Published data for ground movements associated with underpinned retaining walls and the subsequent excavation of a new basement is limited compared to other types of retaining wall, although it is possible to use the well-documented predictions and movement curves for embedded retaining walls contained within CIRIA C760.

It is generally accepted that movements from underpinning would be expected to be in the order of 5 mm for a single stage underpin with a retained height of about 3.0 m, equivalent to a normalised relationship of 0.15%, with movement that diminishes with distance from the wall, similar to the trend line set by a wall within clay (see Fig 6.15a of CIRIA C760). As movements are intrinsically linked to retained height, it therefore follows that there would be a corresponding increase or decrease in movements, reflecting any changes in the height of the proposed underpinning, i.e., a relatively limited underpin of up to 1.0 m in height, as proposed for the deepening of the basement, would experience proportionally less movement than the full height underpins proposed to support the party wall with the adjoining property to the northwest of the site.

Ground movement curves with a normalised relationship of 0.15% have therefore been adopted, as this provides a conservative assessment of the likely vertical and horizontal movements as a result of the proposed deepening of the existing basement.

[26] Gaba, A, Hardy, S, Powrie, W, Doughty, L and Selemetas, D (2017) *Embedded retaining walls – guidance for economic design* CIRIA Report C760

The vertical movements obtained from the corresponding P-Disp analysis (Analysis Stages 1 to 3), have also been imported into the corresponding X-Disp models to account for any additional vertical movement from unloading due to excavation and subsequent settlement of the proposed raft foundation, to enable a damage assessment to be undertaken of all the potential movements for each stage of the analysis.

10.3.2 Results

The movements predicted by the combined X-Disp and P-Disp analysis are summarised in the table below; the results are presented below and in subsequent tables to the degree of accuracy required to allow predicted variations in ground movements around the structure(s) to be illustrated but may not reflect the anticipated accuracy of the predictions.

It is important to note that the movements in each table reflect those that will have occurred by the end of that stage, and together represent the cumulative progression of potential ground movements from the early stages of underpinning construction, through excavation of the proposed basement and the application of the proposed loads onto the basement raft slab, with the final stage displaying the 'Total' (short-term + long-term) movements that will occur as a result of the development.

Analysis Stage 1 (Short-term movements from retaining wall construction & deepening of the existing basement)

Location	Wall Movement (mm)*	
	Vertical Heave / Settlement	Horizontal Movement
Immediately behind wall	1.0 to 2.0	2.0 to 3.0
At 5 m from wall	0.0	0.0
At 10 m from wall	0.0	0.0

**A positive number denotes settlement, whilst a negative number denotes heave.*

Analysis Stage 2 (Short-term movements following construction & loading of the proposed raft foundation)

Location	Wall Movement (mm)*	
	Vertical Heave / Settlement	Horizontal Movement
Immediately behind wall	10.0 to 12.0	2.0 to 3.0
At 5 m from wall	<2.0	0.0
At 10 m from wall	0.0	0.0

**A positive number denotes settlement, whilst a negative number denotes heave.*

Analysis Stage 3 (Total movements from proposed development)

Location	Wall Movement (mm)*	
	Vertical Heave / Settlement	Horizontal Movement
Immediately behind wall	22.0 to 26.0	2.0 to 3.0
At 5 m from wall	<6.0	0.0
At 10 m from wall	<2.0	0.0

**A positive number denotes settlement, whilst a negative number denotes heave.*

The estimated movements are considered to represent a worst-case scenario, particularly as the movements resulting from basement excavation will be minimised due to control of the propping in the temporary works and a regime of monitoring.

10.4 Ground Movements within the Excavation (Heave / Settlement)

10.4.1 Results

The P-Disp analysis indicates that short-term heave resulting from deepening of the existing basement is likely to be in the order of 2 mm to 5 mm, which is likely to be recovered following construction of the proposed raft foundation, with up to 12 mm to 14 mm of short-term settlement anticipated by the end of Stage 2.

In the long term, following completion of the basement construction, a further 20 mm of settlement is expected, as a result of long-term consolidation of the underlying clay soils.

The potential movements are summarised in the table overleaf.

Location	Short-term Movements (mm)*		Total Movements (mm)*
	Stage 1	Stage 2	Stage 3
Centre of proposed basement excavations	-3.0 to -4.0	12.0 to 14.0	32.0 to 34.0
Edge of proposed basement	-1.0 to -2.0	4.0 to 6.0	16.0 to 18.0

Stage 1 = Underpinning & deepening of existing basement; Stage 2 = Raft construction and loading; Stage 3 = Total (short term + long term) movements from development. *Negative values indicate heave and positive indicates settlement

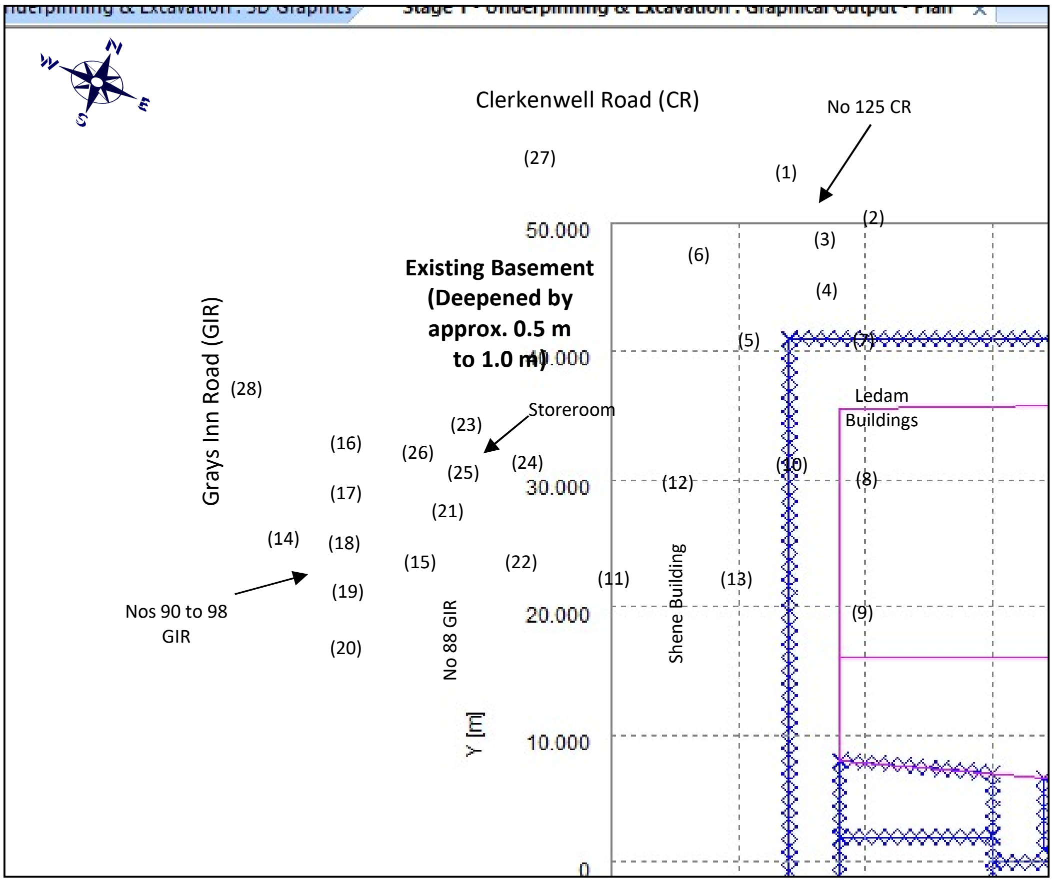
11.0 BUILDING DAMAGE ASSESSMENT

In addition to the assessment of the likely movements that will result from the proposed development, some of the neighbouring structures have been set as sensitive structures, requiring Building Damage Assessments, on the basis of the classification given in Table 6.4 of C760, as follows:

- the adjoining building of No to 125 Clerkenwell Road, to the west;
- the northern parts of Ledam and Shene Buildings, to the southeast and south-southeast of the site;

- the adjoining storeroom building and northern part of No 88 Grays Inn Road, to the south;
- Nos 90 to 98 Grays Inn Road, to the south-southwest; and
- the adjoining roadways of Clerkenwell Road and Grays Inn Road, to the north and south, respectively.

The sensitive structures outlined above have been modelled as lines in the analysis and are the lines along which the damage assessment has been undertaken. For clarity, these critical lines and the specific reference numbers used in the assessment are shown on the plan below.



These lines are expected to be sensitive at their foundation level, which in the absence of specific information have generally been assumed to be at a depth of 1.0 m below existing ground level, which is likely to be highly conservative as the majority are likely to include some form of basement structures.

Building heights have been derived from information contained within the site survey drawings, or from the number of storeys, as observed during the site walkover and reference to Google maps.

11.1 Damage to Neighbouring Structures

The combined movements resulting from piling, underpinning and excavation of the proposed basement, estimated using the X-Disp and P-Disp modelling software have been used to carry out an assessment of the likely damage to adjacent properties for each stage of the development, and the critical results are summarised in the table below.

Sensitive Structure	Ref No / Elevation	Max Tensile Strain (%)			Category of Damage*
		Stage 1	Stage 2	Stage 3	
No 125 Clerkenwell Road	1	0.04	0.04	0.03	Category 0 - Negligible
	2	<0.01	<0.01	<0.01	Category 0 - Negligible
	3	<0.01	<0.01	<0.01	Category 0 - Negligible
	4	<0.01	<0.01	<0.01	Category 0 - Negligible
	5	0.06	0.05	0.06	Category 1 – Very Slight
	6	0.02	0.02	0.03	Category 0 - Negligible
Ledam Building	7	<0.01	<0.01	<0.01	Category 0 – Negligible
	8	<0.01	<0.01	<0.01	Category 0 - Negligible
	9	-$^{+}$	<0.01	-$^{+}$	Category 0 - Negligible
	10	<0.01	<0.01	<0.01	Category 0 - Negligible
Shene Building	11	<0.01	<0.01	<0.01	Category 0 - Negligible
	12	<0.01	<0.01	<0.01	Category 0 - Negligible
	13	<0.01	<0.01	<0.01	Category 0 - Negligible
Nos 90 to 98 Grays Inn Road	14	0.06	0.07	0.07	Category 1 – Very Slight
	15	0.04	0.07	0.05	Category 1 – Very Slight
	16	<0.01	0.02	0.04	Category 0 - Negligible
	17	-$^{+}$	<0.01	<0.01	Category 0 - Negligible
	18	<0.01	<0.01	<0.01	Category 0 - Negligible
	19	<0.01	<0.01	<0.01	Category 0 - Negligible
	20	<0.01	<0.01	<0.01	Category 0 - Negligible
No 88 Grays Inn Road & Storeroom	21	-$^{+}$	<0.01	<0.01	Category 0 - Negligible
	22	<0.01	<0.01	<0.01	Category 0 - Negligible
	23	<0.01	0.02	0.03	Category 0 - Negligible
	24	0.05	0.05	0.06	Category 1 – Very Slight
	25	-$^{+}$	<0.01	<0.01	Category 0 - Negligible
	26	0.06	0.07	0.07	Category 1 – Very Slight
Clerkenwell Road	27	<0.01	<0.01	<0.01	Category 0 - Negligible
Grays Inn Road	28	<0.01	<0.01	<0.01	Category 0 - Negligible

*From Table 6.4 of C760: Classification of visible damage to walls. $^{+}$Less than limit of sensitivity

The building damage reports in the above table predict that the damage to the adjoining structures would generally be Category 0 (negligible), with limited sections of Category 1 (Very Slight) damage to the rear elevation of No 125 Clerkenwell Road, the frontage of Nos 90 to 98 Grays Inn Road and the rear elevation / party wall with No 88 Grays Inn Road, along with the east and west elevations of the storeroom building of No 88 Grays Inn Road.

The results discussed above are based on individual building lines, or walls, that have been further divided up into a series of segments that the software used assumes can move independently of one another, with the most critical segment determining the result for the entire wall. In reality, this is unlikely to be the case as the walls will behave as single elements that are also joined continuously with the rest of the structure. The above results therefore provide a conservative estimate of the behaviour of each of the sensitive structures and are likely to overestimate the degree of damage, although they provide a useful indication of the most critical structures within the adjoining properties.

11.2 Monitoring of Ground Movements

The predictions of ground movement based on the ground movement analysis should be checked by monitoring of adjacent properties and structures. The structures to be monitored during the construction stages should include the existing building and neighbouring structures. Condition surveys of the existing structures should be carried out before, during and after the proposed works.

The precise monitoring strategy will be developed at a later stage, and it will be subject to discussions and agreements with the owners of the adjacent properties and structures. Contingency measures will be implemented if movements of the adjacent structures exceed predefined trigger levels. Both contingency measures and trigger levels will need to be developed within a future monitoring specification for the works.

12.0 GROUND MOVEMENT ASSESSMENT CONCLUSIONS

The analysis has concluded that the predicted damage to the neighbouring properties from the construction of the basement retaining walls and excavation would be generally ‘Negligible’ to ‘Very Slight’. On this basis, the damage that has been predicted to occur as a result of the construction of the proposed basement falls within the acceptable limits, although careful construction, including the careful control of the proposed underpinning, will be required to ensure that no excessive movements occur that would lead to damage in excess of these limits.

Whilst it is recommended that movement monitoring is carried out on all structures prior to and during the proposed excavation and construction, it is unlikely that specification of these works will be required as part of the planning conditions but may be required in order to satisfy party wall awards.