Design Note

A-squared I Studio

Project	32 Percy Street, London W1T 2DE
Project no.	0341
Subject	Ground Movement Assessment (GMA)

Status	Date	Ref	Issued by	Checked by	Approved by
Ground Movement Assessment (GMA) – supporting design note	09/12/16	0341-TN-01-00	Silvia Autuori	Alex Nikolic	Tony Suckling
	15/12/16	0341-TN-01-01	Silvia Autuori	Alex Nikolic	Tony Suckling

1. Introduction

A ground movement and impact assessment has been carried out in order to estimate the potential damage induced by the proposed redevelopment of 32 Percy Street on selected surrounding properties.

Above ground, the scheme comprises the redevelopment/refurbishment of the existing terraced property and partial demolition and redevelopment of the extension to the rear of the property. Below ground, the scheme includes a new basement at the rear of the property comprising both the deepening of existing basement elements and construction of new below ground space in areas where no existing basement is present.

The assessment includes properties located within the zone of influence of the proposed scheme. As part of the ground movement assessment (GMA), *greenfield* ground movements have been considered.

The assessment and findings presented herein have been prepared in support of the existing Basement Impact Assessment (BIA) prepared by others. It is intended for this GMA to be read in conjunction with the relevant submissions and documentation, including but not limited to the *Desk Study, Ground Investigation and Basement Impact Assessment* prepared by Jomas Associates Ltd (V1.1, dated 1st July 2016, document job number P9273J732) *and Description of Existing Structure & Method Statement for carrying out Internal Alterations and Extensions* (dated August 2016).

2. Impact assessment evaluation

The assessment has been undertaken using proprietary spreadsheets and the commercially available software Oasys Pdisp and Xdisp, which consider the three dimensional ground movement field induced by the proposed works.

Ground movements will arise as a result of various mechanisms which are mobilised as part of the implementation of the proposed scheme. In the first instance, the works will involve the partial demolition of the existing rear extension alongside selected below ground elements. The demolition phase will be followed by basement excavation operations and the construction of the proposed substructure and application of the permanent works building loadings. The basement excavation process will induce ground movements arising from the overburden removal. The permanent condition loading will partially reinstate a portion of the removed overburden, yielding settlements across the foundation system.

These ground movements will extend over a given zone of influence surrounding the building footprint. The assessment presented herein adopts the normalised ground displacement curves reported in CIRIA C580 and general principles of elasticity. This procedure comprises the current industry standard/best practice for this type of analytical assessment.

A series of three dimensional models of the proposed scheme have been developed in both software packages outlined previously and have been combined by means of superposition in order to represent the various ground displacement fields summarised above. An indicative plot of the analytical model is presented below in Figure 1.

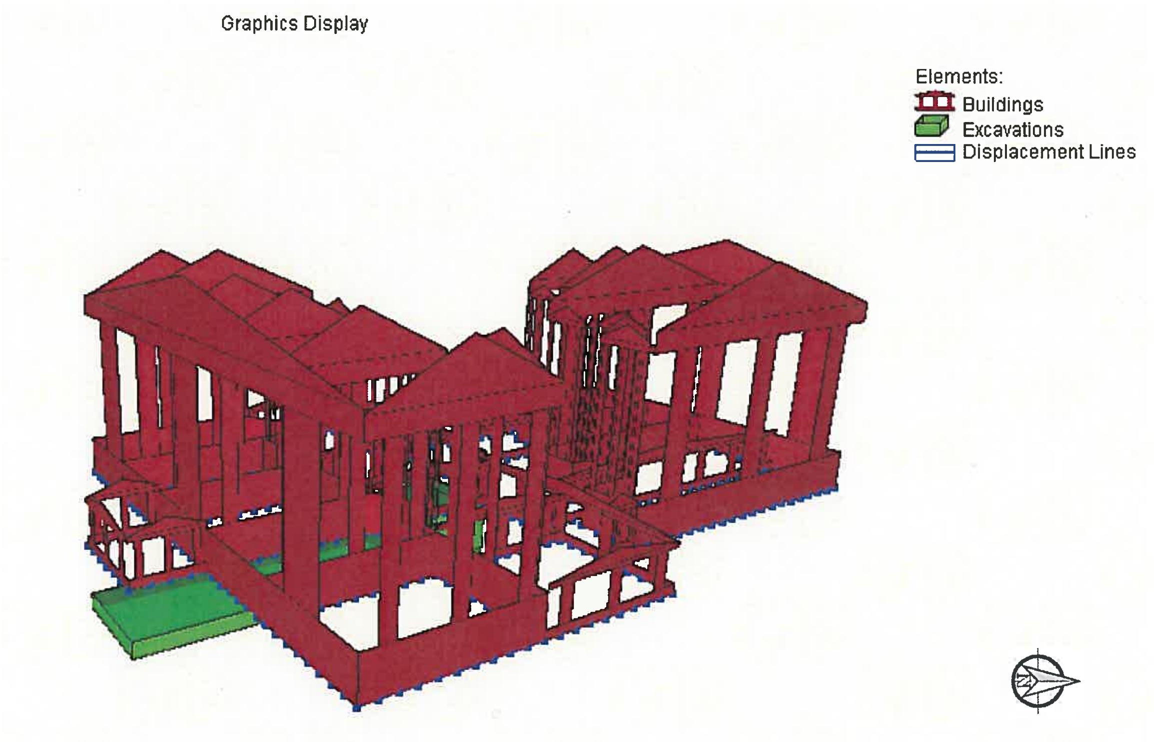

Figure 1 - Indicative plot of the three-dimensional analytical model using the Oasys software suite (soil removed for clarity of presentation).

An idealised ground model has been evaluated based on the site specific investigation information reported in the site investigation report prepared by Jomas Associates Ltd (as referenced previously in section 1).

Table 1 summarises the representative ground model adopted for ground movement assessment purposes.

Table 1 - Ground model summary and key geotechnical parameters adopted for analysis purposes

Stratum	Top of stratum (m bgl)	Assumed undrained strength, S_u (kPa)	Undrained Young's Modulus, E_u (MPa)	Drained Young's Modulus, E' (MPa)
Made Ground	0.00	-	-	10
Soft to very gravelly sandy silty CLAY	-4.20	75	30	24
Medium dense very sandy silty GRAVEL	-6.25	-	-	24
Silty gravelly sandy CLAY	-8.35	75	30	24
Stiff slightly gravelly sandy CLAY	-9.00	50 + 6 z[1]	20 + 2.4 z[1]	16 + 1.9 z[1]
Thanet Sand	-39.60	-	-	300

Notes:
1. z is the depth in metres below top of stratum concerned.
2. *Rigid boundary* assumed at -45.40 m AOD for analytical purposes.
3. Refer to ground investiagtion report prepatred by Jomas for further supporting information.
4. The stiffness data (E_u and E') has been evaluated empirically taking into consideration the nature of the geotechnical/soil-structure interaction mechanisms and level of anticipated strain within the soil mass.

The following primary construction stages have been discretised and included in the assessment:

- **Partial demolition of the existing single storey rear extension**

  The demolition of the existing rear extension has been modelled in Pdisp adopting an average representative uniformly distributed load (UDL) of 10kPa, whilst the demolition of the brick vault area has been modelled considering an enhanced average representative UDL of 20kPa. The effects of the evaluated displacement field on the existing structure and nearby buildings have been considered with the aid of Xdisp.

- **Basement excavation condition**

  The excavation has been considered from the presumed existing ground floor elevation of approximately -3.13mAOD for the main building and from -0.60mAOD for the existing rear extension down to the formation level (adopting a level of -4.20mAOD). The proposed basement excavation is simulated by means of two alternative methods (in order to capture and bind the differing mechanisms, which may arise from the proposed underpinning and excavation operations):

  1. Adopting empirical analytical methods within Xdisp, thus capturing horizontal and vertical ground movement fields (method 1). The assessment adopts an empirical database of ground movement information, which is readily adopted for impact assessment purposes of this type. The excavation analysis adopts the normalised ground movement data curves presented in CIRIA C580 for *excavation in front of a high stiffness wall in stiff clay* (CIRIA C580, Figure 2.11 a/b). The stiffening effect provided by the building structures and any other built

elements was neglected. It is acknowledged that this methodology does not reflect the precise means and methods proposed, however it is considered this provides a robust means of examining representative mechanisms alongside alternative analytical approaches undertaken.

2. Adopting an unloading/overburden removal elastic assessment using Pdisp, thus capturing the potential impact of heave movements (method 2). This alternative assessment conservatively assumes the installation means and methods do not result in lateral deflections (enabling the evaluation of peak resultant heave deflections). The excavation is modelled as an overburden removal representative UDL. The façade deflection data is imported into Pdisp in order to perform the impact/damage assessment.

- **Long term condition**

  The proposed building loadings are applied upon completion of the development (as presented in Figure 2). This phase of the assessment is undertaken using Pdisp and taking into consideration the previously reported scenario covering both the demolition and excavation phases of the project. The loading applied for ground movement and impact assessment purposes comprises an average representative UDL of 10kPa. This phase of the assessment assumes long-term (drained) conditions.

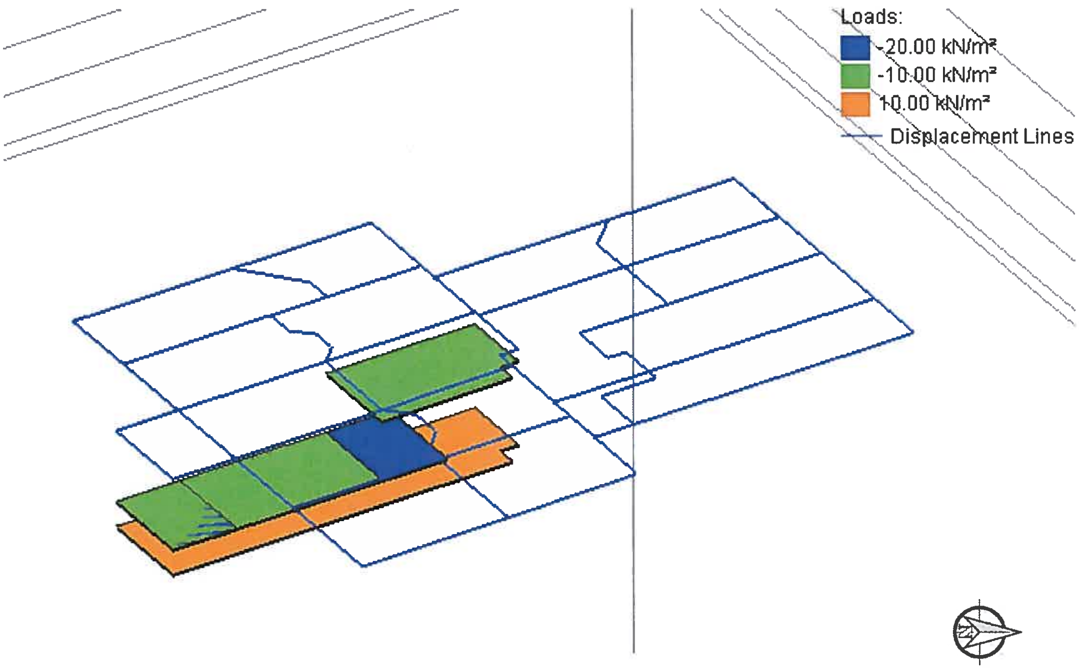

Figure 2 - Long term phase loading scheme (3D perspective view; green shading represents existing slab unloading based on average UDL; blue shading represents existing vaults unloading based on average UDL; orange shading represents proposed loading due to new basement based on average UDL; blue *displacement lines* correspond to façade lines of interest captured within the analysis).

The potential impact/damage induced on primary façade/wall elements of the buildings within the zone of influence of the proposed scheme has been evaluated on the basis of the calculated ground movement field. The masonry walls of concern are shown in Figure 3, including the wall nomenclature/reference system adopted. The arrangement is based on the currently available survey information and presents a reasonable array of primary structures both perpendicular and parallel to the proposed basement (covering the key deformation mechanisms).

Each wall has been assumed to behave as an equivalent beam subject to a bending and extension/compression deformation mechanism, based on the evaluated *greenfield* ground movement, as outlined previously.

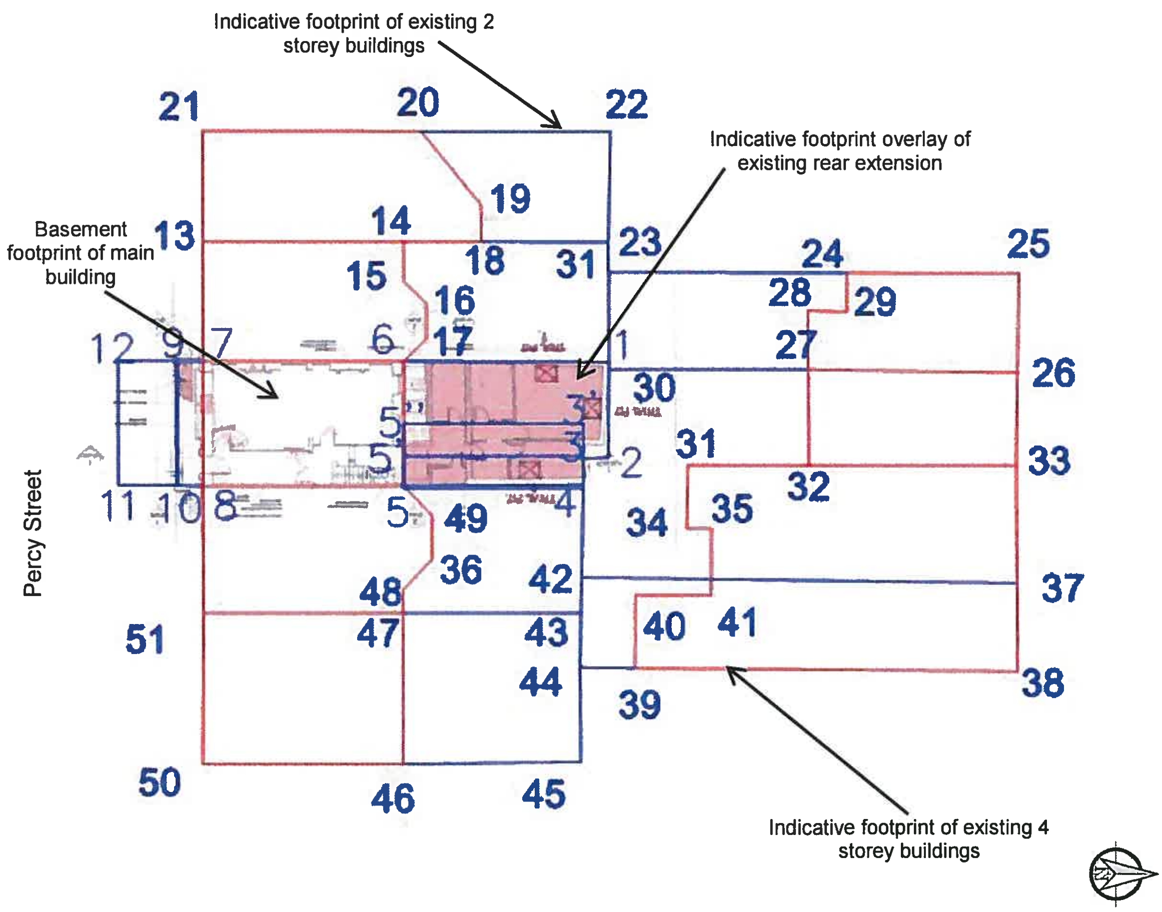

Figure 3 – Simplified scheme and nomenclature for building façade/masonry wall elements (node/intersect reference numbers denoted)

Tensile strains induced within the building masonry walls have been evaluated based on the deflection ratios Δ/L estimated from the analyses. The assessment considers the well-established Burland (1997) damage classification method, as presented and summarised in Figures 4 and 5. This method involves a simple but robust means of assessment, which widely adopted and is considered to comprise an industry standard/best practice basis for impact assessments of this typology.

Potential damage categories are directly related to the tensile strains induced by the assessed interim (short-term) and long-term phases of construction, arising from a combination of direct tension and bending induced tension mechanisms, as reported in Table 3.

Building damage classification, after Burland et al 1977 and Boscardin and Cording 1989				
Category of damage		Description of typical damage (ease of repair is underlined)	Approximate crack width (mm)	Limiting tensile strain %
0	Negligible	Hairline cracks of less than about 0.1mm are classes 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. Weather-tightness 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, floors 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	

Figure 4 – Damage categorisation - relationship between category of damage and limiting strain ε_{lim}

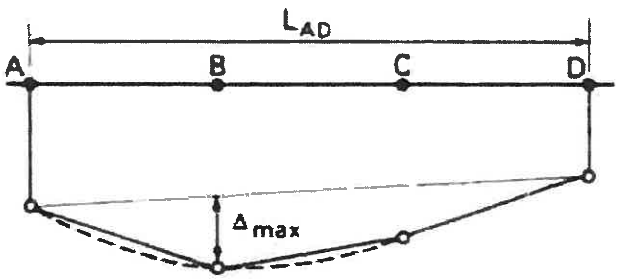

Figure 5 – Definition of relative deflection Δ and deflection ratio Δ/L

Table 3 – Evaluated damage categories for demolition, excavation and long term condition stages (refer to Figure 3 for wall nomenclature)

Method 1

Wall reference	Damage category envelope		
	Demolition	Excavation	Long term
21-20	0 (Negligible)	0 (Negligible)	0 (Negligible)
19-20	0 (Negligible)	0 (Negligible)	1 (Very Slight)
19-18	0 (Negligible)	1 (Very Slight)	1 (Very Slight)
18-13	0 (Negligible)	0 (Negligible)	0 (Negligible)
21-50	0 (Negligible)	0 (Negligible)	All settlements are less than the Settlement Trough Limit Sensitivity.
14-15	0 (Negligible)	0 (Negligible)	0 (Negligible)
15-16	0 (Negligible)	1 (Very Slight)	1 (Very Slight)
16-17	0 (Negligible)	0 (Negligible)	0 (Negligible)
17-6	0 (Negligible)	0 (Negligible)	0 (Negligible)
5-49	0 (Negligible)	0 (Negligible)	0 (Negligible)
49-36	0 (Negligible)	0 (Negligible)	0 (Negligible)
36-48	0 (Negligible)	1 (Very Slight)	1 (Very Slight)
48-47	0 (Negligible)	0 (Negligible)	0 (Negligible)
47-51	0 (Negligible)	0 (Negligible)	0 (Negligible)
50-46	All settlements are less than Settlement Trough Limit Sensitivity	All settlements are less than Settlement Trough Limit Sensitivity	All settlements are less than Settlement Trough Limit Sensitivity
46-47	0 (Negligible)	0 (Negligible)	0 (Negligible)
24-25	All settlements are less than Settlement Trough Limit Sensitivity	All settlements are less than Settlement Trough Limit Sensitivity	All settlements are less than Settlement Trough Limit Sensitivity
25-26	All settlements are less than Settlement Trough Limit Sensitivity	All settlements are less than Settlement Trough Limit Sensitivity	All settlements are less than Settlement Trough Limit Sensitivity
26-27	All settlements are less than Settlement Trough Limit Sensitivity	1 (Very Slight)	2 (Slight)
27-28	All settlements are less than Settlement Trough Limit Sensitivity	0 (Negligible)	0 (Negligible)
28-29	All settlements are less than Settlement Trough Limit Sensitivity	1 (Very Slight)	1 (Very Slight)
27-32	All settlements are less than Settlement Trough Limit Sensitivity	0 (Negligible)	0 (Negligible)
33-31	0 (Negligible)	1 (Very Slight)	1 (Very Slight)
31-34	0 (Negligible)	0 (Negligible)	0 (Negligible)
34-35	0 (Negligible)	0 (Negligible)	0 (Negligible)
35-41	0 (Negligible)	0 (Negligible)	0 (Negligible)
41-40	0 (Negligible)	0 (Negligible)	0 (Negligible)
40-39	0 (Negligible)	1 (Very Slight)	1 (Very Slight)
39-38	All settlements are less than Settlement Trough Limit Sensitivity	0 (Negligible)	0 (Negligible)
38-25	All settlements are less than Settlement Trough Limit Sensitivity	All settlements are less than Settlement Trough Limit Sensitivity	All settlements are less than Settlement Trough Limit Sensitivity
20-22	0 (Negligible)	0 (Negligible)	0 (Negligible)
22-2	0 (Negligible)	2 (Slight)	2 (Slight)
2-3	0 (Negligible)	1 (Very Slight)	1 (Very Slight)
3-45	0 (Negligible)	2 (Slight)	2 (Slight)
18-31	0 (Negligible)	0 (Negligible)	0 (Negligible)
23-24	0 (Negligible)	1 (Very Slight)	1 (Very Slight)
6-1	0 (Negligible)	2 (Slight)	2 (Slight)
42-37	0 (Negligible)	0 (Negligible)	0 (Negligible)

Wall reference	Damage category envelope		
	Demolition	Excavation	Long term
47-43	0 (Negligible)	0 (Negligible)	0 (Negligible)
44-39	0 (Negligible)	0 (Negligible)	0 (Negligible)
46-45	All settlements are less than Settlement Trough Limit Sensitivity	All settlements are less than Settlement Trough Limit Sensitivity	All settlements are less than Settlement Trough Limit Sensitivity
5-4	0 (Negligible)	0 (Negligible)	1 (Very Slight)
7-6	0 (Negligible)	2 (Slight)	2 (Slight)
6-5	0 (Negligible)	0 (Negligible)	2 (Slight)
5-8	0 (Negligible)	1 (Very Slight)	1 (Very Slight)
7-12	0 (Negligible)	0 (Negligible)	All settlements are less than the Settlement Trough Limit Sensitivity.
12-11	0 (Negligible)	0 (Negligible)	All settlements are less than the Settlement Trough Limit Sensitivity.
11-8	0 (Negligible)	0 (Negligible)	All settlements are less than the Settlement Trough Limit Sensitivity.

Method 2

Wall reference	Damage category envelope		
	Demolition	Excavation	Long term
21-20	0 (Negligible)	0 (Negligible)	0 (Negligible)
19-20	0 (Negligible)	0 (Negligible)	0 (Negligible)
19-18	0 (Negligible)	0 (Negligible)	0 (Negligible)
18-13	0 (Negligible)	0 (Negligible)	0 (Negligible)
21-50	0 (Negligible)	0 (Negligible)	0 (Negligible)
14-15	0 (Negligible)	0 (Negligible)	0 (Negligible)
15-16	0 (Negligible)	0 (Negligible)	0 (Negligible)
16-17	0 (Negligible)	0 (Negligible)	0 (Negligible)
17-6	0 (Negligible)	0 (Negligible)	0 (Negligible)
5-49	0 (Negligible)	0 (Negligible)	0 (Negligible)
49-36	0 (Negligible)	0 (Negligible)	0 (Negligible)
36-48	0 (Negligible)	0 (Negligible)	0 (Negligible)
48-47	0 (Negligible)	0 (Negligible)	0 (Negligible)
47-51	0 (Negligible)	0 (Negligible)	0 (Negligible)
50-46	All settlements are less than Settlement Trough Limit Sensitivity	0 (Negligible)	0 (Negligible)
46-47	0 (Negligible)	0 (Negligible)	0 (Negligible)
24-25	All settlements are less than Settlement Trough Limit Sensitivity	All settlements are less than Settlement Trough Limit Sensitivity	0 (Negligible)
25-26	All settlements are less than Settlement Trough Limit Sensitivity	All settlements are less than Settlement Trough Limit Sensitivity	All settlements are less than Settlement Trough Limit Sensitivity
26-27	All settlements are less than Settlement Trough Limit Sensitivity	0 (Negligible)	0 (Negligible)
27-28	All settlements are less than Settlement Trough Limit Sensitivity	0 (Negligible)	0 (Negligible)
28-29	All settlements are less than Settlement Trough Limit Sensitivity	0 (Negligible)	0 (Negligible)
27-32	All settlements are less than Settlement Trough Limit Sensitivity	0 (Negligible)	0 (Negligible)
33-31	0 (Negligible)	0 (Negligible)	0 (Negligible)
31-34	0 (Negligible)	0 (Negligible)	0 (Negligible)
34-35	0 (Negligible)	0 (Negligible)	0 (Negligible)

Wall reference	Damage category envelope		
	Demolition	Excavation	Long term
35-41	0 (Negligible)	0 (Negligible)	0 (Negligible)
41-40	0 (Negligible)	0 (Negligible)	0 (Negligible)
40-39	0 (Negligible)	0 (Negligible)	0 (Negligible)
39-38	All settlements are less than Settlement Trough Limit Sensitivity	0 (Negligible)	0 (Negligible)
38-25	All settlements are less than Settlement Trough Limit Sensitivity	0 (Negligible)	All settlements are less than Settlement Trough Limit Sensitivity
20-22	0 (Negligible)	0 (Negligible)	0 (Negligible)
22-2	0 (Negligible)	1 (Very Slight)	1 (Very Slight)
2-3	0 (Negligible)	0 (Negligible)	0 (Negligible)
3-45	0 (Negligible)	0 (Negligible)	0 (Negligible)
18-31	0 (Negligible)	0 (Negligible)	0 (Negligible)
23-24	0 (Negligible)	0 (Negligible)	1 (Negligible)
6-1	0 (Negligible)	1 (Very Slight)	1 (Very Slight)
42-37	0 (Negligible)	0 (Negligible)	0 (Negligible)
47-43	0 (Negligible)	0 (Negligible)	0 (Negligible)
44-39	0 (Negligible)	0 (Negligible)	0 (Negligible)
46-45	All settlements are less than Settlement Trough Limit Sensitivity	0 (Negligible)	0 (Negligible)
5-4	0 (Negligible)	1 (Very Slight)	1 (Very Slight)
7-6	0 (Negligible)	0 (Negligible)	0 (Negligible)
6-5	0 (Negligible)	1 (Very Slight)	1 (Very Slight)
5-8	0 (Negligible)	0 (Negligible)	0 (Negligible)
7-12	0 (Negligible)	0 (Negligible)	0 (Negligible)
12-11	0 (Negligible)	0 (Negligible)	0 (Negligible)
11-8	0 (Negligible)	0 (Negligible)	0 (Negligible)

3. Conclusions & Closing Remarks

The interaction between the proposed development and the nearby buildings has been reviewed as part of the GMA study presented herein. The proposed development construction operations comprise a series of stages, including demolition of the existing storied rear extension and vaults, basement deepening/excavation and construction of the proposed elements. The impact of the excavation stages of construction has been reviewed on the basis of two alternative methods (i.e. evaluating the excavation effect unloading the CIRIA curves in Xdisp (method 1) and overburden removal/unloading using Pdisp (method 2)). The two methods aim to capture alternative mechanisms of lateral and vertical ground movement, which will be in part dependent on construction means and methods (including workmanship).

The results from the analyses are presented in Table 3 (denoting the evaluated damage categorisation in accordance with the Burland criteria presented herein). The majority of the façades fall within Categories 0 and 1, representative of *Negligible* and *Very Slight* damage classification respectively. Selected structures/façades have been classified as Category 2, representative of *Slight* damage classification. Façade/wall elements denoted as '*all settlements are less than settlement trough limit sensitivity*' indicate that the structures concerned are located outside of the anticipated zone of influence of the proposed redevelopment works.

It is noted that the predicted ground movements, the associated wall tensile strains and level of damage categorisation are considered to be moderately conservative in view of the relatively cautious ground model assumptions and *greenfield* nature of the assessment undertaken.

It is also noted that the GMA will be supplemented by a project specific monitoring regime and Action Plan, which will delineate lines of responsibility, monitoring trigger levels and appropriate mitigation measures. The assessment presented herein is dependent and reliant on the works being undertaken by an experienced contractor, high quality workmanship and appropriate supervision of construction means and methods by experienced personnel.