Appendix H

Ground Movement & Damage Impact Assessment

BRITISH MUSEUM

EAST ROAD BUILDING REDEVELOPMENT

BUILDING DAMAGE ASSESSMENT

Rev 1

December 2023

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DISCLAIMER

REVISION HISTORY

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1 INTRODUCTION

It is proposed to redevelop the East Road Building (ERB), which is part of the complex of buildings owned by the British Museum, located at a site in the London Borough of Camden at National Grid Reference TQ 30079 81806. This will include demolition of the existing building and the construction of a three-storey structure including a single level basement, largely supported by a raft foundation.

A number of existing buildings are present in the vicinity of the development. Geotechnical Consulting Group LLP (GCG) has been instructed by the British Museum, to conduct a ground movement assessment and a building damage assessment to determine the impact of the proposed works on the existing surrounding buildings.

All information used in this report was provided to GCG by Alan Baxter Ltd, the structural engineers involved in the design. It is outside the scope of this report to consider the adequacy of works as proposed.

2 EXISTING SITE AND PROPOSED REDEVELOPMENT

The site is located in central London, in the London Borough of Camden. It is bounded by the rear garden of 43 Russell Square to the north, a single-storey 20th Century rear extension of the Grange Hotel on Montague Street to the south, the rear of 8 to 11 Montague Street buildings to the east and by the East Road and the East Wing of the British Museum to the west (see Figure 1).

The site is currently occupied by the existing East Road Building (ERB), which is a single-storey workshop building that is to be demolished. The building is a load-bearing masonry structure supported on mass concrete strip foundations around 0.8m to 2.3m below ground level, corresponding to a foundation level of approximately +23.7mOD (see Figure 2).

The ground level in the vicinity of the existing ERB varies approximately between +24.5mOD (East Road to the west of the ERB) and +26mOD (rear gardens of the Montague Street buildings).

The site redevelopment will involve the demolition of the existing ERB and the construction of a new building accommodating technical services for the museum, see Figure 3. The proposed building will be a reinforced concrete framed structure consisting of a single storey above ground with a local area extending to two stories. A single-storey basement is also proposed. The basement will consist of a reinforced concrete box constructed within a secant piled retaining wall made of 450mm bored piles. Although the design of these piles is not finalised, it is understood that they will be approximately 9.2 m long, from a cutoff level of approximately +23.7mOD to a toe level of approx. +14.5mOD. The retained excavation height is approximately 5m (i.e. from an average ground level of +24.8mOD to the excavation level of +19.8mOD). A stiff propping system is assumed to be adopted across the excavation between the secant piles. The structure will be supported by a raft foundation constructed from a formation level of approximately +19.8mOD and six 450mm diameter CFA piles along the northwestern side of the building. The footprint of the proposed building (about 30m long x 13m wide) will be approximately the same as the existing building, although the basement will be smaller (about 24.5m long x 13m wide).

Key drawings of the existing & proposed structures are included in Appendix A.

3 THE SURROUNDING ASSETS

3.1 Structures

A number of non-residential buildings are present in the vicinity of the ERB (see Figure 4) that can be potentially affected by the site redevelopment. These include: the Grange Hotel Extension to the south, the East Wing of the British Museum to the west, a stanchion supporting the Jade Gallery to the north-west and the Montague Street properties to the east. In addition, three structures that are understood to act as bin storage and that will be demolished prior to the construction of the proposed building are present to the north-east.

The Grange Hotel Extension consists of a single storey load-bearing brick wall building which shares a party wall with the existing ERB. It is understood that this wall will be retained and supported on temporary works and then re-supported on the new building. No signs of structural damage have been observed for this building. The foundation level of the shared party wall is at +23.5mOD.

The external walls of the East Wing of the British Museum facing the ERB, named East Range, consist of load bearing brick walls on concrete strip foundations located at a level of approximately +21.8mOD.

The column located to the north-west of the ERB (see Figure 5) is part of a goalpost frame with a top beam that runs under the Jade Gallery tunnel and supports it and a second column present next to the museum East Wing. This column is founded on a concrete pad located at a level of approx. +23.8mOD.

The Montague Street properties are early 1800s Georgian terraced houses (apart from the hotel rear extension) and are Grade II listed. They consist of load-bearing masonry structures with four storeys above ground level and single level basements. The basements extend under the rear gardens of the properties and are founded on brick corbelled footings at approx. 3m bgl, i.e. at a level of approx. +22.6mOD. Cracking to the render of the garden room of the 8 Montague Street property has been reported but appears to be of non-structural nature.

Little information is available about the three structures present to the north-west corner of the ERB. They appear to consist of a timber first floor cabin structure on top rendered brick walls (see Figure 5) and appear to be founded at approx. 0.6m bgl, i.e. at a level of approx. +24.2mOD. It is proposed to demolish these building prior to the redevelopment of the East Road Building.

3.2 Underground Utilities

There are a few underground utilities under the service road between the proposed ERB and the East Wing of the British Museum. As indicated by the information provided to GCG by Alan Baxter Ltd, there are three utilities that would remain functioning and should be included as part of the assessment. They are:

(i) 1 No. 9" cast-iron (CI) water main and 1 no. of 4" CI water main

(ii) 1 No. 100mm to 300mm drain

There is no clear indication of the material of the 100mm to 300mm drainage pipes. For the purpose of the assessment, they are assumed to be CI pipes.

The depths of water mains are generally 0.7m to 1m depth below ground, and the drain is at about 2.5m to 2.8m depth below ground.

4 GROUND CONDITIONS

The geology of the area shown on the British Geological Survey (BGS) maps suggests that the site is generally underlain by River Terrace Deposits (Lynch Hill Gravel Member) above London Clay (see Figure 7 and Figure 8).

Historical records of boreholes in the vicinity of the site available in the BGS database (see Figure 9) and borehole records and geological sections in the area of the British Museum provided by Alan Baxter (see Figure 10; Reference [7]) confirm the above stratigraphy and indicate the presence of Made Ground and a stiff clay layer above the River Terrace Deposits, and Lambeth Group underlying the London Clay. The above records indicate that the bottom of the London Clay, and hence the top of Lambeth Group, is approximately at a level of +4.7mOD in the vicinity of the site. The Lambeth Group is underlain by Chalk at an elevation of around -14mOD.

Harrison Group Environmental Ltd carried out a geotechnical and geoenvironmental investigation for the site in January 2023 (Reference [8]). This site investigation comprised 2No cable percussive boreholes to a maximum depth of 15m bgl with undisturbed sampling, disturbed sampling and Standard Penetration Tests (SPTs), and 5No trial pits to a maximum depth of 3.8m bgl. The locations of these exploratory holes are as shown in Figure 11. In addition to SPTs, monitoring wells for gas and groundwater monitoring were installed. Various laboratory tests were also conducted including unconsolidated undrained triaxial tests for characterization of undrained shear strength. The two boreholes BHA and BHB confirm the stratigraphy indicated by historical records and show the presence of the following strata, listed from the ground level (+24.8mOD) downwards: Made Ground (1.9m-thick), stiff clay (0.65 to 0.9m thick), River Terrace Deposits (3.3 to 3.6 m thick) and London Clay down to the end of the boreholes.

The Made Ground comprised sandy clayey gravel to sandy gravelly clay, where the gravel components variously comprised flint, brick, concrete, clinker and animal bones. The layer underling the Made Ground consisted of firm to stiff slightly sandy slightly gravelly clay. The River Terrace Deposits comprised sand and gravel of flint. The London Clay was described as stiff clay with occasional possible presence of fine selenite (at 9.5m bgl) and bands of fine sand (at 11.0m bgl).

Based on the ground investigation undertaken by Harrison Group Environmental combined with the published BGS maps and historical boreholes and borehole records and geological sections provided by Alan Baxter, the following idealised stratigraphy has been assumed for the assessment herein:

Made Ground (MG)	+24.8 to +22.9mOD (1.9m thick)
Clay (Cl)	+22.9 to +22.1mOD (0.8m thick)
River Terrace Deposits (RTD)	+22.1 to +18.2mOD (4.3m thick)
London Clay (LC)	+18.2 to +4.7mOD (13.5m thick)
Lambeth Group (LG)	+4.7 to -14.0mOD (18.7m thick)
Chalk	from -14.0mOD

Groundwater level monitoring undertaken by Harrison Group Environmental suggests that the average groundwater level is located approximately 4m bgl, i.e. at around +20.8mOD, that is within the River Terrace Deposits.

5 SOIL STIFFNESS PARAMETERS

The soil parameters adopted for the analyses carried out to assess ground movements have been chosen based on site-specific GI data (Reference [8]) and literature data for the same materials.

Made Ground

Considering that the Made Ground will only undergo unloading due to demolition and that the induced swelling deformations are expected to be little or negligible (i.e. the Made Ground is expected to exhibit a stiff response upon unloading), a constant stiffness of 30MPa was assumed for the Made Ground. A Poisson's ratio of 0.2 has been assumed for this layer assuming that its response is drained.

Clay layer

Only two SPT tests are available for the Clay layer underlying Made Ground and both resulted in test refusal, i.e. SPT N > 50. This confirms the stiff nature of this layer, which has been modelled considering an undrained elastic stiffness E_u of 62.5 MPa. The corresponding drained stiffness has been assessed as $E' = 0.8xE_u = 50$ MPa.

River Terrace Deposits

SPT data available for the River Terrace Deposits vary between 26 and refusal (i.e. > 50) with an average in the order of 36, indicating the dense to very dense nature of this material. A constant drained stiffness of 50 MPa has therefore been adopted to model the River Terrace Deposits.

London Clay

The stiffness of the London Clay has been calculated considering that 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:

$$E_{uo}=800p' \qquad (1)$$

where the mean effective stress p' has been calculated considering the geological history of the clay to derive the coefficient of earth pressure at rest K_0 at the top and at the bottom of the stratum (Mayne & Kulhawy, 1982; Reference [9]).

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

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

For the analyses it has been assumed that the proposed works will give rise to strains in the more superficial strata of the London Clay, which will reduce the elastic soil stiffness. Assuming that the strains are in the order of 0.05% the operational stiffnesses at the top of the clay have been assumed to be 1/4 E_{uo} and 1/4 E'_o.

Half of the elastic stiffness values have been assumed for the bottom of the London Clay because it is only 13.5m thick and relatively high levels of strains can still occur at its base.

The relationships used in the analyses yield an operative stiffness of $Eu=12+7z$ [MPa], where z is the depth below the top of London Clay.

This relationship leads to slightly higher values than those calculated using the relationship proposed by Burland and Kalra (1986; Reference [10]) ($Eu=10+5.2z$), but is believed to be more appropriate for the problem as they account for the presence of gravel above the top of the clay and for the amount of stresses and strains involved in the specific case.

Lambeth Group

In the absence of additional information on the nature of this deposit, drained values have been adopted.

Using record data on laboratory triaxial tests across central London the elastic (small strain) undrained stiffness of the clay layers of the Lambeth Group can be taken as:

$$Eu_o=1100p' \qquad (3)$$

where the mean effective stress p' can be calculated using the equations proposed by Mayne & Kulhawy (1982; Reference [9]).

The elastic drained stiffness of the clay has been estimated from the relationship:

$$E'_o= 0.8Eu_0 \qquad (4)$$

The elastic values at the top of the stratum have been halved to account for the strains at this level. This results in an operative stiffness $E'=124+14.2z_1$, where z_1 is the depth below the top of the Lambeth Group.

Table 1 presents a summary of soil parameters adopted for the elastic ground movement analysis. The corresponding Young's modulus profiles and the basis of the parameters (where appropriate) are presented in Figure 12.

6 GROUND MOVEMENT ASSESSMENT

6.1 Background

The proposed redevelopment of the East Road Building will involve the following main activities:

- Demolition of the existing ERB and the three structures to its north-west corner;
- Installation of new secant pile retaining walls and CFA piles;
- Excavation of the basement;
- Construction of the new structure.

Figure 13 shows the footprints of the different areas involved in the various works listed above.

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 demolition of the existing structures would relieve pressures on the ground, which would tend to swell. Horizontal movements are expected to be low and movements mostly in the vertical direction can be expected during these works.

The installation of secant pile walls can result in vertical and horizontal ground movements, directed towards the pile walls. However, these are likely to be confined to the soil volumes around the pile walls and the ground above the toe of the pile walls.

Bulk excavation for the basements causes unloading of the underlying ground resulting in stress reduction and heave. Also, the bulk excavation causes the ground behind the retaining wall to move towards the excavation, due to the reduction in lateral support, resulting in vertical and horizontal movements of the ground behind.

Construction of the new structure causes reloading of the underlying ground resulting in stress increase and settlement.

The following construction stages have been considered for the analyses:

- Stage 1: Demolition
- Stage 2: Wall and pile installation and excavation
- Stage 3: Construction of the new structure
- Stage 4: Long-term

6.2 Stage 1: Demolition of existing structures

As discussed in Section 6.1, the demolition of the existing structures would relieve pressures on the ground, which would tend to swell. Horizontal movements are expected to be low and movements mostly in the vertical direction can be expected during these works.

These ground 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 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 Table 1. Assuming no significant delays in construction, the excavations were modelled using short-term parameters.

The demolition is simulated in the analyses as a reduction of pressures on the ground at the level of the existing foundations. According to the loads provided by Alan Baxter, the demolition of the existing ERB will cause 28 kPa of unloading within its footprint whereas the demolition of the three structures located to the north-west corner will cause 15 kPa of unloading within their footprint. Demolitions were thus modelled in the PDisp analyses as negative pressures (28 kPa for the ERB and 15 kPa for the structures to the north-west corner) applied at the foundation levels (+23.7mOD for the ERB and +24.2mOD kPa for the structures to the north-west corner).

6.3 Stage 2: Wall and pile installation and excavation

As discussed in Section 6.1, the pile wall and CFA pile installation will cause movements in the surrounding ground and the excavation will cause vertical unloading of underlying ground and reduction of lateral support to the secant pile wall. As a result, it is anticipated that the ground within the footprint of excavation will heave and the ground adjacent to the excavation will move towards the excavation. The ground movements associated with these are discussed in the following subsections, as appropriate.

6.3.1 Installation of secant pile wall and CFA piles

A retaining wall system will need to be installed around the perimeter of the proposed ERB to enable the construction of the basement underneath the footprint of building. Although the design of this retaining system has not been finalised, it is understood that a system of secant pile walls including 10.3m long piles, from existing ground level of approximately +24.8mOD to a toe level of approx. +14.5mOD, will be installed to retain the ground prior to excavation.

Record data of movements due to wall installation (CIRIA C760; Reference [11]) are shown in Figure 14 and can be used to estimate the expected movements at and above the existing ground level around the site (+24.8mOD). Figure 14a shows data of normalised horizontal displacement plotted against the normalised distance from the wall and Figure 14b shows data of normalised vertical displacement (settlement) plotted against the normalised distance from the wall.

Figure 14a shows that horizontal movements are limited and very scattered and in practice could be ignored. Settlements (Figure 14b) show a large scatter over a distance of about 0.2 times the wall length behind the wall. Behind that all but a very few measurements show that the settlements are less than 0.02% of the wall length. The movements are highly dependent on the piling method and the care taken. Ball et al (2014; Reference [12]) showed that, with good construction control, piled wall installation movements would be significantly smaller than those indicated by the upper bound envelope of the CIRIA C760 guidelines. The fit to the CIRIA C760 database (see red curve in Figure 14b), rather than the upper bound envelope, was considered to be a more realistic ground movement curve. Nevertheless, the C760 upper bound envelope is adopted as the conservative prediction for the purpose of this assessment.

A row of six CFA piles will be installed along the north-western side of the building to support the superstructure loading. For the purpose of ground movement assessment, the envelope curve for contiguous pile wall in CIRIA C760 (Figure 14) are conservatively adopted.

Ground movements due to the installation of the secant pile wall were determined using the computer program Oasys Xdisp, incorporating the above-mentioned approach.

It should be noted that the displacement profiles shown in Figure 14 refer to the ground surface. The displacement profiles at the foundation levels of the structures and levels of underground utilities surrounding the piles were estimated by projecting at depth with an angle of 45° the surface movements calculated from Figure 14.

6.3.2 Effect of reduction in lateral support caused by excavation

Bulk excavation for the new basement causes the ground outside the footprint of the excavation to move towards the excavation inducing vertical and horizontal movements. This is due to the reduction of lateral support to the secant pile wall.

The retained height of excavation is estimated to be approximately 5m, i.e. from the existing ground level at about +24.8mOD to the formation level of about +19.8mOD. This depth has been considered for determining the ground movements.

Figure 15 shows empirical data based on the movements of ground surface behind retaining walls as a result of excavations in typical London ground conditions. The CIRIA guide indicates that for a rectangular excavation with high support stiffness, the maximum ground movements are 0.15% of the excavation depth horizontally and 0.075% vertically. Also, the CIRIA guide indicates that maximum vertical movements do not occur immediately adjacent to the wall, but at a distance approximately half the excavation depth away from the wall. The vertical movement immediately adjacent to the wall is 0.05% of the excavation depth. These movements do not allow for the stiffening effects of corners which typically reduces movements around the corners of the excavation.

Vertical movements due to excavation become negligible beyond 3.5 times the excavation depth from the wall whereas the horizontal movements become negligible beyond 4 times the excavation depth.

The ground movements were determined assuming a high support stiffness system (secant pile wall with early, high-level propping). Corner stiffening effects were considered for the assets, where they are relevant.

Ground movements due to the excavation were determined using the computer program Oasys Xdisp, incorporating the above-mentioned CIRIA C760 approach.

Since the foundation levels of the structures surrounding the pile walls and levels of underground utilities are deeper than the retained ground surface level, the movements behind the retaining walls were estimated using the curves shown in Figure 15 and projecting them at depth as described in Section 6.3.1.

6.3.3 Effect of vertical unloading caused by the excavation

The basement of the proposed ERB requires removal of approximately 3.9m of soil approx. from +23.7mOD (the founding level of the existing ERB) to +19.8mOD. Assuming that the unit weight of the excavated material is 17 kN/m^3, these excavations are estimated to cause vertical unloading of 66.3kPa at the corresponding formation level. The idealised footprint of excavation for the basement and the corresponding loading footprint that was modelled are shown in Figure 13. As a consequence of the pressure relief, the ground within the footprint of the excavation would tend to swell.

Assuming no significant delays in construction, the excavations were modelled in PDisp analyses using short-term parameters.

It is worth highlighting that the predicted heave induced by the above excavation is only relevant to within the footprint of the excavation as the movements outside the retaining walls are predicted as explained in Section 9.

6.4 Stage 3: Construction of the new structure

The construction of the proposed ERB would cause settlements as a result of the increase of vertical loads on the ground.

Alan Baxter Ltd supplied the loading imposed by construction as unfactored loads at the formation level of the basement (+19.8mOD) and at each CFA pile. The loading resulting from the construction of the basement and the superstructure were modelled in the PDisp as a uniform pressure of 125.6kPa applied to the basement footprint (a total unfactored load of 35,800kN) at +19.8mOD and a load of 250kN at each of the six CFA piles at a level of 2/3 assumed pile length (i.e. 17.9 mOD) with a 1H:4V load spread (i.e. approx.. 20.9 kPa over a circular area of 12 m^2).

This construction stage was modelled using short-term parameters.

It is worth highlighting that the movements predicted for the structures surrounding the ERB at the end of the construction stage were obtained by adding the movements induced by construction only to the movements obtained from demolition and those obtained from the CIRIA C760 approach for pile wall installation and excavation (see Sections 6.3.1 and 6.3.2).

6.5 Stage 4: Long-term

The ground within the footprint of the development and its vicinity will continue to move in the long-term as a result of the ground consolidation. This stage has been modelled in a similar way to Stage 3 but using long-term soil parameters (see Table 1).

It is worth highlighting that the movements predicted for the structures surrounding the development in the long term were obtained by adding the PDisp time dependent movements to the movements obtained from previous stages.

7 RESULTS AND DISCUSSION

For the purpose of this assessment, ground movements were assessed at the locations of the structures and utilities located in the vicinity of the proposed redevelopment. Figure 13 shows the assessed locations in blue. Contours of ground movements induced at ground level are shown in Appendix B.

7.1 Structures

The ground movements that will be experienced by the Montague Street properties to the east of the ERB were assessed considering seven profiles. Section A-A approximately corresponds to the rear façade of the properties. Section B-B approximately corresponds to the outer retaining wall of the property basements. Sections C-C, D-D, E-E, F-F, G-G and H-H correspond to the party walls dividing the different properties. All the movements for these sections were considered at the foundation level of the Montague Street properties, which is approximately +22.6 mOD.

The ground movements that will be experienced by the Grange Hotel extension to the south of the ERB were assessed considering two profiles. Section I-I corresponds to the party wall between the ERB and the Grange Hotel extension, that will be retained during redevelopment of the ERB. Section J-J is perpendicular to the above party wall and covers the footprint of the Grange Hotel extension. All the movements for these sections were considered at the foundation level of the Grange Hotel extension, which is approximately +23.5 mOD.

The ground movements that will be experienced by the British Museum East Wing to the west of the ERB were assessed considering two profiles. Section K-K corresponds to the east façade of the building. Section L-L corresponds to one of the internal walls perpendicular to the external façade. The other internal walls are expected to experience similar or lower movements. All the movements for these sections were considered at the foundation level of the British Museum East Wing, which is approximately +21.8 mOD.

The ground movements experienced by the stanchion were considered at its foundation level which is approximately +23.8 mOD.

Figures 16 to 27 show the vertical ground movements predicted at the end of the different construction stages for Section A-A to Section L-L. Figures 30 to 41 show the horizontal ground movements in the direction parallel and perpendicular to the assessed profiles, at the end of the excavation stage for Section A-A to Section L-L. No further noticeable horizontal ground movements are expected to occur in the subsequent construction stages.

Table 2 summarises the ground movements predicted at the location of the Jade Gallery stanchion's foundation.

The results of the analyses show that the demolition of the existing structures (Stage 1) could induce ground heave up to 3 mm under the foundations of the Montague Street properties (see Figure 21), less than 4 mm under the foundations of the Grange Hotel extension (see Figure 24), less than 1 mm under the foundations of the British Museum East Wing (see Figure 26) and 1 mm under the stanchion's foundation (see Table 2).

The pile wall installation and excavation in front of the wall are predicted to be the activities that will induce the larger ground movements. At the end of the excavation stage (Stage 2), all the surrounding structures are predicted to experience settlements of up to about 6 mm (see Figures 21, 25, Figure 26 and 27), except for the stanchion's foundation that is predicted to experience settlement of approx. 3 mm (see Table 2). The horizontal ground movements, which are directed towards the excavation, are predicted to be up to 11 mm under the foundations of the Montague Street properties (see Figure 33), up to about 12 mm under the foundations of the Grange Hotel extension (see Figure 38), up to about 9 mm under the foundations of the British Museum East Wing (see Figure 41) and approx. 5 mm under the stanchion's foundation (see Table 2).

Settlements are predicted to slightly increase in the vicinity of the ERB between the end of excavation and the end of construction (Stage 3), resulting in values of up to about 8 mm under the foundations of the Montague Street properties (see Figure 20), up to about 9 mm under the foundations of the Grange Hotel extension (see Figure 24), up to 7 mm under the foundations of the British Museum East Wing (see Figure 27) and approx. 6 mm under the stanchion's foundation (see Table 2).

In the long term (Stage 4), the ground in the vicinity of the ERB will tend to settle due to the effect of consolidation and overall increase of the stress induced in the ground by the ERB redevelopment. Such consolidation will therefore result in a slight increase of the settlements experienced at the end of construction.

The potential damage due to the ground movements described above can be estimated as suggested in CIRIA C760 (Reference [11]) 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. The assessment was conducted by splitting each assessed section into different segments delimited by the points of inflection in the vertical ground movement profiles, so that sagging and hogging movements were considered separately; however, horizontal strains were averaged over the whole section. The beneficial effect of any compressive horizontal strains was conservatively neglected. The following structure heights from the foundation level were considered in the assessment: 18.7 m for the Montague Street properties (except for Section B-B representing only the basements of the properties for which a heigh of 3.5 m was considered), 6.1 m for the Grange Hotel extension and 23.2 m for the British Museum East Wing.

Table 3 summarises the results of the building damage assessment in terms of deflection ratio Δ/L, average horizontal strain ε_h, maximum tensile strain ε_t and damage category. The damage category was established as a function of the maximum tensile strain, according to the classification proposed by Burland (1995; Reference [13]), see Table 4. According to this classification, the ground movements induced by the redevelopment of ERB will cause damage that could be classified well within Category 2 (slight) for the Grange Hotel extension, within Category 1 (very slight) for the Montague Street properties and within Category 0 (negligible) for the British Museum East Wing.

The potential movements of the stanchion supporting the Jade Gallery are relatively small (up to 8 mm of settlement and about 5 mm of horizontal movements), and might result in a minor rotation and twist of the goalpost structure. However, such movements are not considered likely to cause significant damage.

7.2 Grange Hotel extension

As the only structure that results in a Damage Category greater than Category 1, the Grange Hotel extension is considered in more detail here. It should be noted that for this building the damage category is almost entirely a result of the predicted horizontal strains.

The predicted Category 2 damage is an inevitable consequence of using the full CIRIA upper bound envelope of movements during wall installation. The horizontal strain induced by these movements when combined with the horizontal strain caused by excavation will, for structures which are wholly within a given distance from the wall (1.5 x pile length and 4 x excavation depth), result in a horizontal strain greater than 0.075%, and consequently Category 2 damage or greater. As discussed above, the installation horizontal movements given by C760 for secant pile walls are considered to be highly conservative and are driven by the results from one case study (Bell Common tunnel). If a more reasonable profile or horizontal movements were applied (such as either the C760 profile for contiguous pile walls or the or the Ball et al (2014) profile), the predicted damage to this building becomes Category 1. This is considered to be a more realistic estimate of potential damage.

Additionally, it is understood that the basement will be constructed by a suitable experienced contractor, utilising extensive movement monitoring, which could be used to confirm that the wall installation movements are significantly smaller than the C760 upper bound values.

The Grange Hotel extension is also understood to be within the Museum's freehold, so that arranging any repairs that might be required would be relatively straightforward.

7.3 Underground Utilities

Sections M-M and N-N correspond to the 9" CI water main and the 100mm to 300mm drain respectively. The 9" CI water main is the water main closest to the proposed ERB and is more sensitive to movement (in terms of flexural strain and joint rotation) due to its larger diameter. It is therefore considered a conservatively representation of both water mains for the purpose of this assessment. For the same reason, 300mm diameter has been adopted as a conservative representation of the 100mm to 300mm drain for assessing the potential impacts. The movements along the 9" water main and the 300mm drain are conservatively considered to be at the ground surface and at a level of +22.5 mOD (i.e. 2.3m below ground) respectively.

Figure 28 and Figure 29 show the vertical ground movements predicted at the end of the different construction stages for Section M-M to Section N-N. Figure 42 and Figure 43 show the horizontal ground movements in the direction parallel and perpendicular to the assessed profiles, at the end of the excavation stage for Section M-M and Section N-N. No further noticeable horizontal ground movements are expected to occur in the subsequent construction stages.

In order to assess any adverse effects to the water mains and the drain, Thames Water's criteria considering allowable increase in compressive and tensile strain (<100με in tension and 1200με in compression) and allowable increase in joint rotation between consecutive pipe sections (< 0.1°) of CI pipes were considered. For the purpose of this assessment, the CI pipes are assumed to have been constructed using 3.66m long pipe sections.

Figure 44 to Figure 47 show the profiles of predicted cumulative flexural displacement (a vector sum of vertical movement and horizontal movement perpendicular to the section), the radius of curvature, bending strains and joint rotation along the 9" CI water main respectively at the end of Stages 1 to 4. The maximum flexural displacement is about 21mm considering all the construction stages. The minimum induced radius of curvature is 3km. The maximum compressive/tensile strain is 87με, which is within the allowable limit of 100 με. The maximum joint rotation is about 0.08°, which is within the allowable limit of 0.1°.

For the 100mm to 300mm drain, the profiles of predicted cumulative flexural displacement, the radius of curvature, bending strains and joint rotation are shown in Figure 48 to Figure 51. The maximum flexural displacement is about 15mm considering all the construction stages. The minimum induced radius of curvature is 4.6km. The maximum compressive/tensile strain is 65με, which is within the allowable limit of 100 με. The maximum joint rotation is about 0.05°, which is within the allowable limit of 0.1°.

8 CONCLUSIONS AND RECOMMENDATIONS

This report presents an assessment of the ground movements induced by the proposed redevelopment of the East Road Building and its impact on the surrounding structures (none of which are residential) and underground utilities. It describes the analyses undertaken, outlines the underlying assumptions and presents the results of the analyses and the assessments at the end of the different work stages.

The proposed redevelopment of the East Road Building is unlikely to cause significant impacts at the locations of the surrounding structures and underground utilities. The damage to the structure of the British Museum East Wing to the west of the ERB is classified within Category 0 (negligible) and the damage caused to the Montague Street properties to the east is within Category 1. The damage to the Grange Hotel extension to the south of the ERB is predicted by the analysis to be within Category 2 (slight), however, for reasons outlined above, this is considered to be an inevitable consequence of the type of assessment carried out and that, in reality, the damage to this building is unlikely to exceed Category 1 (very slight).

The proposed works are not expected to have an adverse impact on the structural integrity of the adjacent underground services, on the basis of the predicted ground movements and associated assessment parameters presented in this report.

The assessments above assume that the works will be carried out with high levels of workmanship and attention to detail. In particular it is recommended that the party wall shared between the existing ERB and the Grange Hotel extension is adequately protected and supported during all the construction stages given its vicinity to the ERB, and that care is taken to avoid undermining the foundation by temporary excavations.

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TABLES

Table 1. Soil stratigraphy and stiffness parameters adopted for elastic analysis

Strata	*Level at top of stratum (mOD)*	*Short-term (undrained)*			*Long-term (drained)*		
		E_u *(top), kPa*	E_u *(base), kPa*	*Poisson's ratio*	*E' (top), kPa*	*E' (base), kPa*	*Poisson's ratio*
Made Ground (MG)	+24.8	Drained parameters used			30,000	30,000	0.2
Clay (Cl)	+22.9	62,500	62,500	0.5	50,000	50,000	0.2
River Terrace Deposits (RTD)	+22.1	Drained parameters used			50,000	50,000	0.2
London Clay (LC)	+18.2	12,000	106,000	0.5	9,600	85,000	0.2
Lambeth Group (LG)	+4.7	Drained parameters used			124,000	390,000	0.2

Note: Rigid boundary is taken as -14.0mOD

Table 2. Ground movements predicted at the location of the stanchion supporting the Jade Gallery

Stage	Vertical movement (mm)	Horizontal movement – west to east (mm)	Horizontal movement – north to south (mm)
Stage 1 (Demolition)	1	0	0
Stage 2 (Excavation)	-3	0	5
Stage 3 (Construction)	-6	0	5
Stage 4 (Long term)	-8	0	5

Table 3. Summary of predicted strains and associated potential building damage

Stage	*Section*	*Segment*	*Start (m)*	*End (m)*	*Length L (m)*	*Structure height, H (m)*	*L/H*	*Type*	*Deflection ratio Δ/L (%)*	*Average horizontal strain, ε_b (%)*	*Max tensile strain, ε_t (%)*	*Damage category*
1 (Demolition)	A-A	1	0.00	23.46	23.46	18.7	1.3	Hogging	0.0005	0.0000	0.0005	0 (Negligible)
1 (Demolition)	A-A	2	23.46	43.43	19.97	18.7	1.1	Sagging	0.0003	0.0000	0.0004	0 (Negligible)
2 (Excavation)	A-A	1	0.00	32.45	32.45	18.7	1.7	Sagging	0.0068	-0.0009	0.0102	0 (Negligible)
2 (Excavation)	A-A	2	32.45	43.43	10.98	18.7	0.6	Hogging	0.0031	-0.0009	0.0031	0 (Negligible)
3 (Construction)	A-A	1	0.00	32.45	32.45	18.7	1.7	Sagging	0.0070	-0.0009	0.0105	0 (Negligible)
3 (Construction)	A-A	2	32.45	43.43	10.98	18.7	0.6	Hogging	0.0032	-0.0009	0.0031	0 (Negligible)
4 (Long term)	A-A	1	0.00	32.45	32.45	18.7	1.7	Sagging	0.0075	-0.0009	0.0114	0 (Negligible)
4 (Long term)	A-A	2	32.45	43.43	10.98	18.7	0.6	Hogging	0.0032	-0.0009	0.0031	0 (Negligible)
1 (Demolition)	B-B	1	0.00	22.04	22.04	3.5	6.3	Hogging	0.0029	0.0000	0.0039	0 (Negligible)
1 (Demolition)	B-B	2	22.04	33.05	11.01	3.5	3.1	Sagging	0.0015	0.0000	0.0020	0 (Negligible)
2 (Excavation)	B-B	1	0.00	21.03	21.03	3.5	6.0	Sagging	0.0115	-0.0123	0.0104	0 (Negligible)
2 (Excavation)	B-B	2	21.03	33.05	12.02	3.5	3.4	Sagging	0.0153	-0.0123	0.0200	0 (Negligible)
3 (Construction)	B-B	1	0.00	21.03	21.03	3.5	6.0	Sagging	0.0181	-0.0123	0.0163	0 (Negligible)
3 (Construction)	B-B	2	21.03	33.05	12.02	3.5	3.4	Sagging	0.0109	-0.0123	0.0143	0 (Negligible)
4 (Long term)	B-B	1	0.00	21.03	21.03	3.5	6.0	Sagging	0.0208	-0.0123	0.0188	0 (Negligible)
4 (Long term)	B-B	2	21.03	33.05	12.02	3.5	3.4	Sagging	0.0095	-0.0123	0.0125	0 (Negligible)
1 (Demolition)	C-C	1	0.00	19.37	19.37	18.7	1.0	Sagging	0.0050	0.0000	0.0063	0 (Negligible)
2 (Excavation)	C-C	1	0.00	13.91	13.91	18.7	0.7	Hogging	0.0042	0.0203	0.0226	0 (Negligible)
2 (Excavation)	C-C	2	13.91	19.37	5.46	18.7	0.3	Sagging	0.0116	0.0203	0.0254	0 (Negligible)
3 (Construction)	C-C	1	0.00	13.91	13.91	18.7	0.7	Hogging	0.0044	0.0203	0.0227	0 (Negligible)
3 (Construction)	C-C	2	13.91	19.37	5.46	18.7	0.3	Sagging	0.0072	0.0203	0.0235	0 (Negligible)
4 (Long term)	C-C	1	0.00	13.91	13.91	18.7	0.7	Hogging	0.0045	0.0203	0.0228	0 (Negligible)
4 (Long term)	C-C	2	13.91	19.37	5.46	18.7	0.3	Sagging	0.0063	0.0203	0.0230	0 (Negligible)
1 (Demolition)	D-D	1	0.00	19.37	19.37	18.7	1.0	Sagging	0.0064	0.0000	0.0080	0 (Negligible)
2 (Excavation)	D-D	1	0.00	13.41	13.41	18.7	0.7	Hogging	0.0068	0.0560	0.0597	1 (Very Slight)

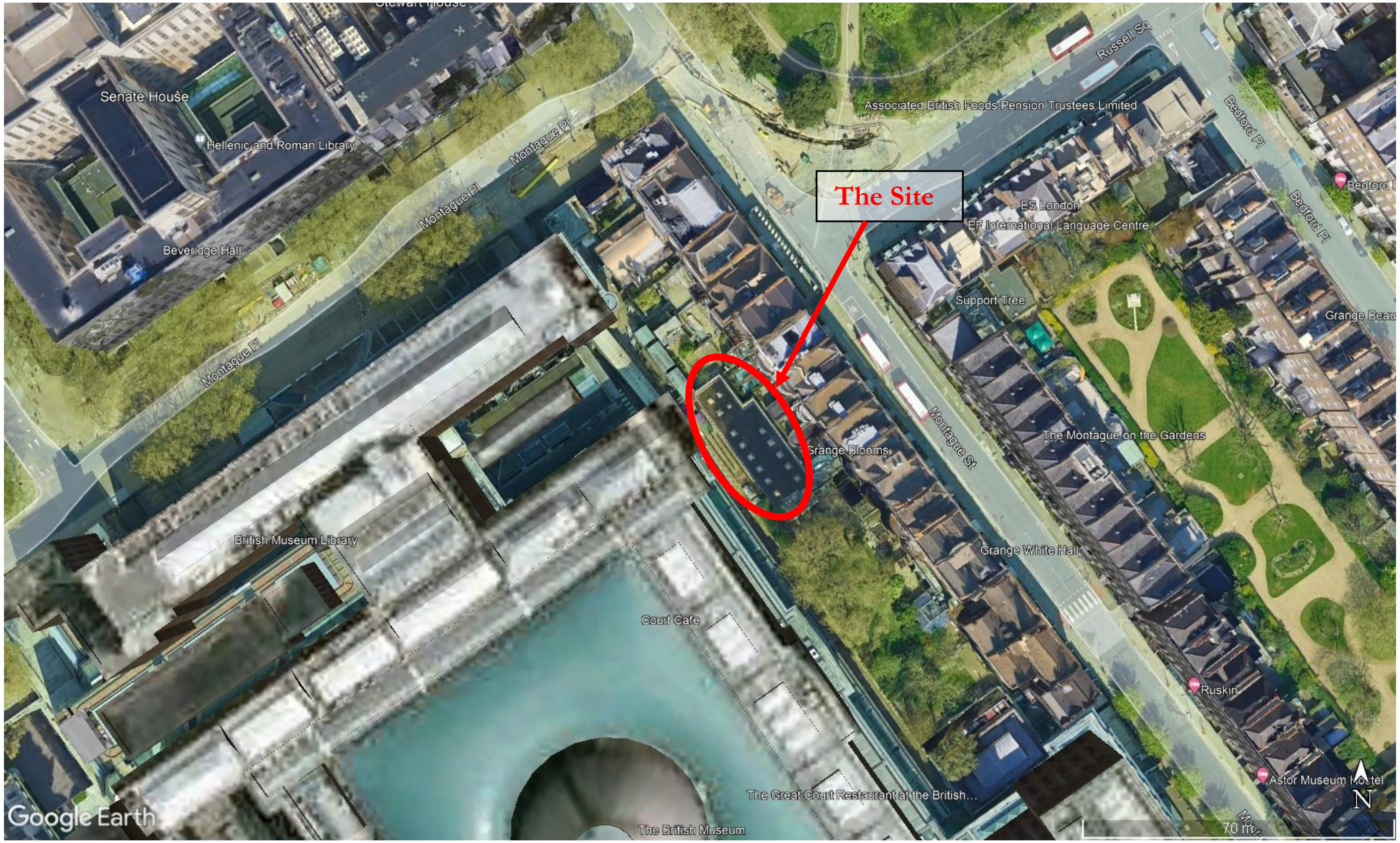
Stage	*Section*	*Segment*	*Start (m)*	*End (m)*	*Length L (m)*	*Structure height, H (m)*	*L/H*	*Type*	*Deflection ratio Δ/L (%)*	*Average horizontal strain, ε_h (%)*	*Max tensile strain, ε_t (%)*	*Damage category*
2 (Excavation)	D-D	2	13.41	19.37	5.96	18.7	0.3	Sagging	0.0104	0.0560	0.0610	1 (Very Slight)
3 (Construction)	D-D	1	0.00	19.37	19.37	18.7	1.0	Hogging	0.0085	0.0560	0.0624	1 (Very Slight)
4 (Long term)	D-D	1	0.00	19.37	19.37	18.7	1.0	Hogging	0.0119	0.0560	0.0649	1 (Very Slight)
1 (Demolition)	E-E	1	0.00	19.33	19.33	18.7	1.0	Sagging	0.0067	0.0000	0.0083	0 (Negligible)
2 (Excavation)	E-E	1	0.00	13.38	13.38	18.7	0.7	Hogging	0.0068	0.0565	0.0601	1 (Very Slight)
2 (Excavation)	E-E	2	13.38	19.33	5.95	18.7	0.3	Sagging	0.0109	0.0565	0.0617	1 (Very Slight)
3 (Construction)	E-E	1	0.00	19.33	19.33	18.7	1.0	Hogging	0.0086	0.0565	0.0629	1 (Very Slight)
4 (Long term)	E-E	1	0.00	19.33	19.33	18.7	1.0	Hogging	0.0125	0.0565	0.0658	1 (Very Slight)
1 (Demolition)	F-F	1	0.00	21.57	21.57	18.7	1.2	Sagging	0.0069	0.0000	0.0091	0 (Negligible)
2 (Excavation)	F-F	1	0.00	14.55	14.55	18.7	0.8	Hogging	0.0055	0.0473	0.0504	1 (Very Slight)
2 (Excavation)	F-F	2	14.55	21.57	7.02	18.7	0.4	Sagging	0.0115	0.0473	0.0537	1 (Very Slight)
3 (Construction)	F-F	1	0.00	21.57	21.57	18.7	1.2	Hogging	0.0066	0.0473	0.0527	1 (Very Slight)
4 (Long term)	F-F	1	0.00	21.57	21.57	18.7	1.2	Hogging	0.0068	0.0473	0.0528	1 (Very Slight)
1 (Demolition)	G-G	1	0.00	22.20	22.20	18.7	1.2	Sagging	0.0033	0.0000	0.0045	0 (Negligible)
2 (Excavation)	G-G	1	0.00	16.28	16.28	18.7	0.9	Hogging	0.0051	0.0073	0.0106	0 (Negligible)
2 (Excavation)	G-G	2	16.28	22.20	5.92	18.7	0.3	Sagging	0.0058	0.0073	0.0100	0 (Negligible)
3 (Construction)	G-G	1	0.00	16.78	16.78	18.7	0.9	Hogging	0.0053	0.0073	0.0108	0 (Negligible)
3 (Construction)	G-G	2	16.78	22.20	5.43	18.7	0.3	Sagging	0.0091	0.0073	0.0128	0 (Negligible)
4 (Long term)	G-G	1	0.00	16.78	16.78	18.7	0.9	Hogging	0.0054	0.0073	0.0109	0 (Negligible)
4 (Long term)	G-G	2	16.78	22.20	5.43	18.7	0.3	Sagging	0.0138	0.0073	0.0171	0 (Negligible)
1 (Demolition)	H-H	1	0.00	26.47	26.47	18.7	1.4	Sagging	0.0005	0.0000	0.0008	0 (Negligible)
2 (Excavation)	H-H	1	0.00	16.48	16.48	18.7	0.9	Hogging	0.0012	0.0002	0.0012	0 (Negligible)
2 (Excavation)	H-H	2	16.48	26.47	9.99	18.7	0.5	Sagging	0.0015	0.0002	0.0014	0 (Negligible)
3 (Construction)	H-H	1	0.00	16.48	16.48	18.7	0.9	Hogging	0.0012	0.0002	0.0012	0 (Negligible)
3 (Construction)	H-H	2	16.48	26.47	9.99	18.7	0.5	Sagging	0.0013	0.0002	0.0013	0 (Negligible)
4 (Long term)	H-H	1	0.00	16.48	16.48	18.7	0.9	Hogging	0.0012	0.0002	0.0012	0 (Negligible)
4 (Long term)	H-H	2	16.48	26.47	9.99	18.7	0.5	Sagging	0.0014	0.0002	0.0013	0 (Negligible)

Stage	Section	Segment	Start (m)	End (m)	Length L (m)	Structure height, H (m)	L/H	Type	Deflection ratio Δ/L (%)	Average horizontal strain, ε_b (%)	Max tensile strain, ε_t (%)	Damage category
1 (Demolition)	I-I	1	0.00	11.87	11.87	6.1	1.9	Hogging	0.0134	0.0000	0.0161	0 (Negligible)
2 (Excavation)	I-I	1	0.00	4.45	4.45	6.1	0.7	Hogging	0.0050	-0.0336	0.0048	0 (Negligible)
2 (Excavation)	I-I	2	4.45	9.40	4.95	6.1	0.8	Sagging	0.0083	-0.0336	0.0088	0 (Negligible)
2 (Excavation)	I-I	3	9.40	11.87	2.47	6.1	0.4	Hogging	0.0341	-0.0336	0.0337	0 (Negligible)
3 (Construction)	I-I	1	0.00	3.96	3.96	6.1	0.6	Hogging	0.0019	-0.0336	0.0018	0 (Negligible)
3 (Construction)	I-I	2	3.96	9.40	5.44	6.1	0.9	Sagging	0.0185	-0.0336	0.0211	0 (Negligible)
3 (Construction)	I-I	3	9.40	11.87	2.47	6.1	0.4	Hogging	0.0394	-0.0336	0.0390	0 (Negligible)
4 (Long term)	I-I	1	0.00	4.45	4.45	6.1	0.7	Hogging	0.0014	-0.0336	0.0014	0 (Negligible)
4 (Long term)	I-I	2	4.45	9.40	4.95	6.1	0.8	Sagging	0.0189	-0.0336	0.0202	0 (Negligible)
4 (Long term)	I-I	3	9.40	11.87	2.47	6.1	0.4	Hogging	0.0408	-0.0336	0.0404	0 (Negligible)
1 (Demolition)	J-J	1	0.00	5.18	5.18	6.1	0.8	Sagging	0.0140	0.0000	0.0155	0 (Negligible)
2 (Excavation)	J-J	1	0.00	5.18	5.18	6.1	0.8	Sagging	0.0210	0.0939	0.1170	2 (Slight)
3 (Construction)	J-J	1	0.00	5.18	5.18	6.1	0.8	Hogging	0.0026	0.0939	0.0954	2 (Slight)
4 (Long term)	J-J	1	0.00	5.18	5.18	6.1	0.8	Hogging	0.0066	0.0939	0.0979	2 (Slight)
1 (Demolition)	K-K	1	0.00	24.08	24.08	23.2	1.0	Hogging	0.0004	0.0000	0.0004	0 (Negligible)
1 (Demolition)	K-K	2	24.08	36.12	12.04	23.2	0.5	Sagging	0.0004	0.0000	0.0003	0 (Negligible)
2 (Excavation)	K-K	1	0.00	22.07	22.07	23.2	1.0	Hogging	0.0076	-0.0015	0.0071	0 (Negligible)
2 (Excavation)	K-K	2	22.07	36.12	14.05	23.2	0.6	Sagging	0.0046	-0.0015	0.0042	0 (Negligible)
3 (Construction)	K-K	1	0.00	22.07	22.07	23.2	1.0	Hogging	0.0095	-0.0015	0.0090	0 (Negligible)
3 (Construction)	K-K	2	22.07	36.12	14.05	23.2	0.6	Sagging	0.0065	-0.0015	0.0059	0 (Negligible)
4 (Long term)	K-K	1	0.00	22.07	22.07	23.2	1.0	Hogging	0.0117	-0.0015	0.0110	0 (Negligible)
4 (Long term)	K-K	2	22.07	36.12	14.05	23.2	0.6	Sagging	0.0076	-0.0015	0.0069	0 (Negligible)
1 (Demolition)	L-L	1	0.00	23.65	23.65	23.2	1.0	Sagging	0.0010	0.0000	0.0012	0 (Negligible)
2 (Excavation)	L-L	1	0.00	23.65	23.65	23.2	1.0	Hogging	0.0106	0.0358	0.0435	0 (Negligible)
3 (Construction)	L-L	1	0.00	23.65	23.65	23.2	1.0	Hogging	0.0134	0.0358	0.0456	0 (Negligible)
4 (Long term)	L-L	1	0.00	23.65	23.65	23.2	1.0	Hogging	0.0157	0.0358	0.0473	0 (Negligible)

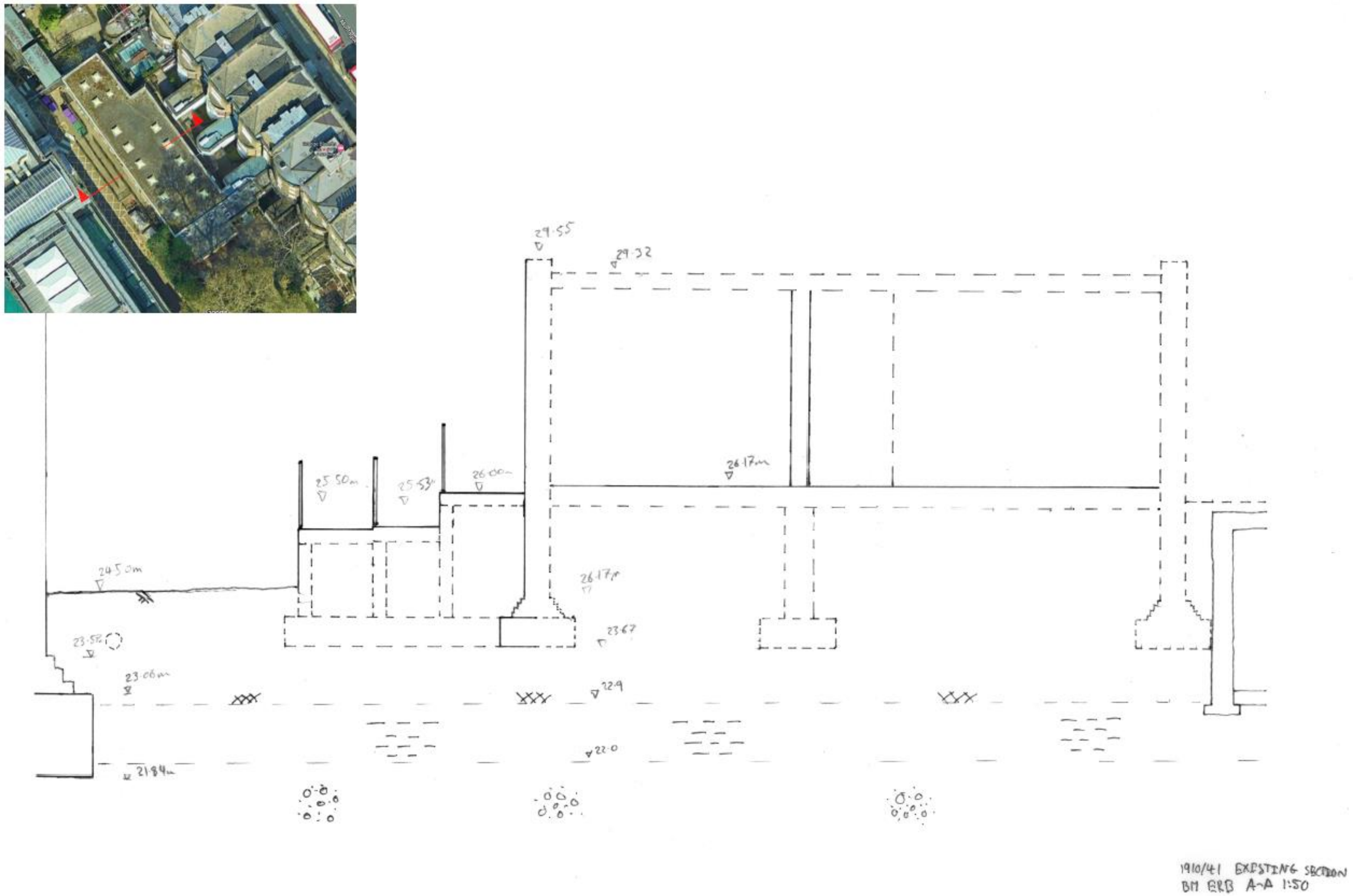
Table 4. Damage category classifications (Burland, 1995; Reference [13])

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 weather tightness. 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	

FIGURES



British Museum East Road Building redevelopment		**Figure 1**
Site location plan From Google Earth		



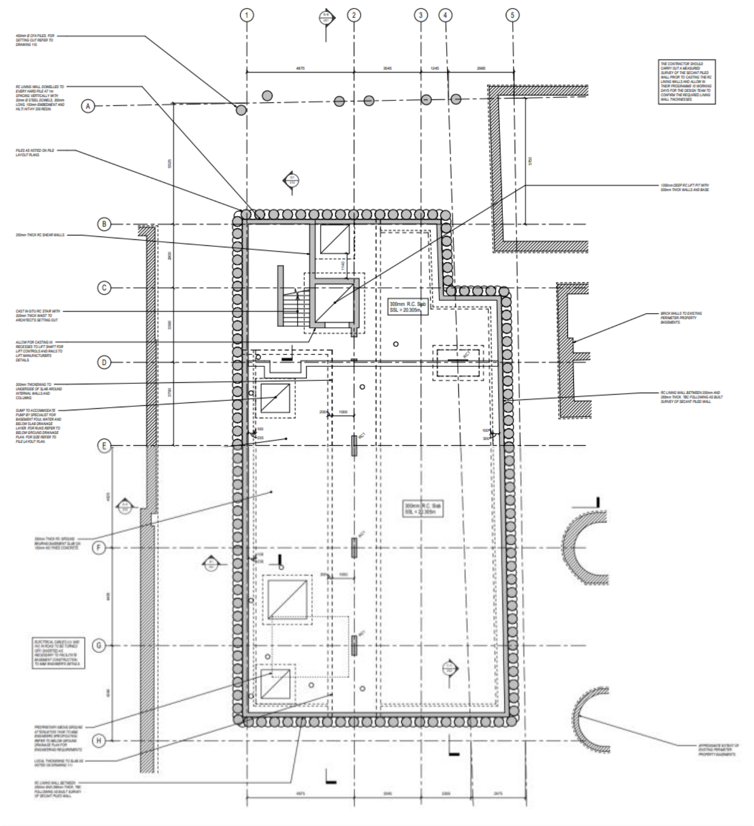
British Museum

East Road Building redevelopment

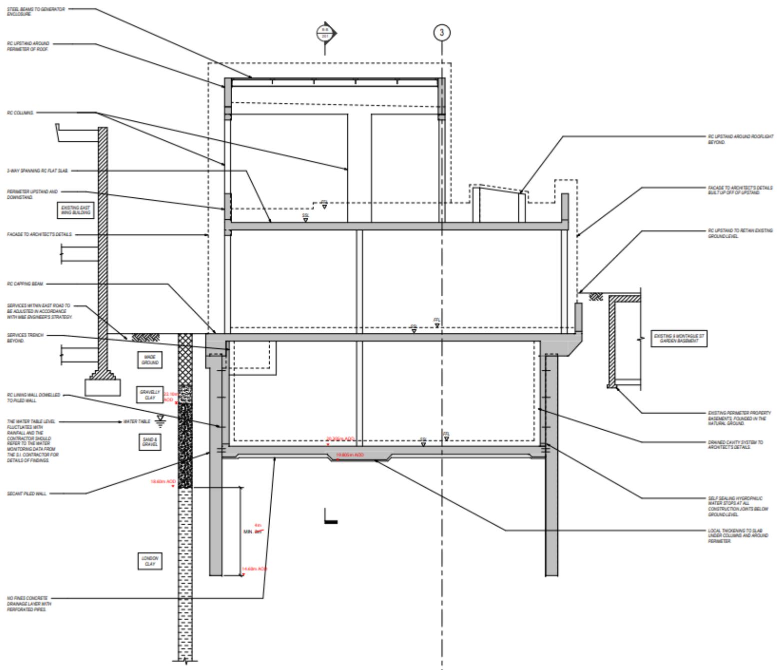
Existing East Road Building

From Alan Baxter, Reference [1]

Figure 2



(a)



(b)

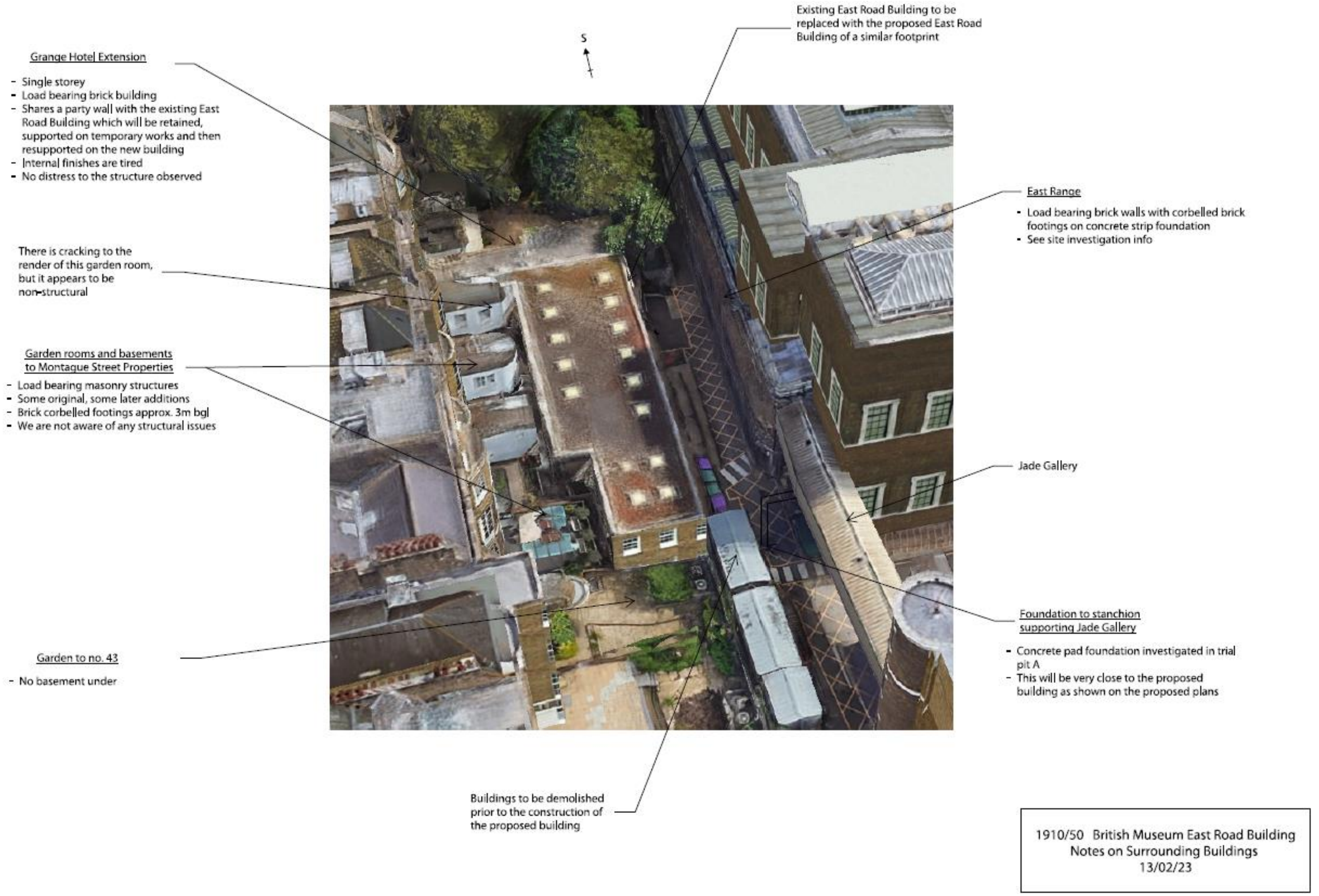
British Museum

East Road Building redevelopment

Proposed development layout: (a) basement plan, (b) vertical cross section

Extract from References [2], [3] and [4]

Figure 3



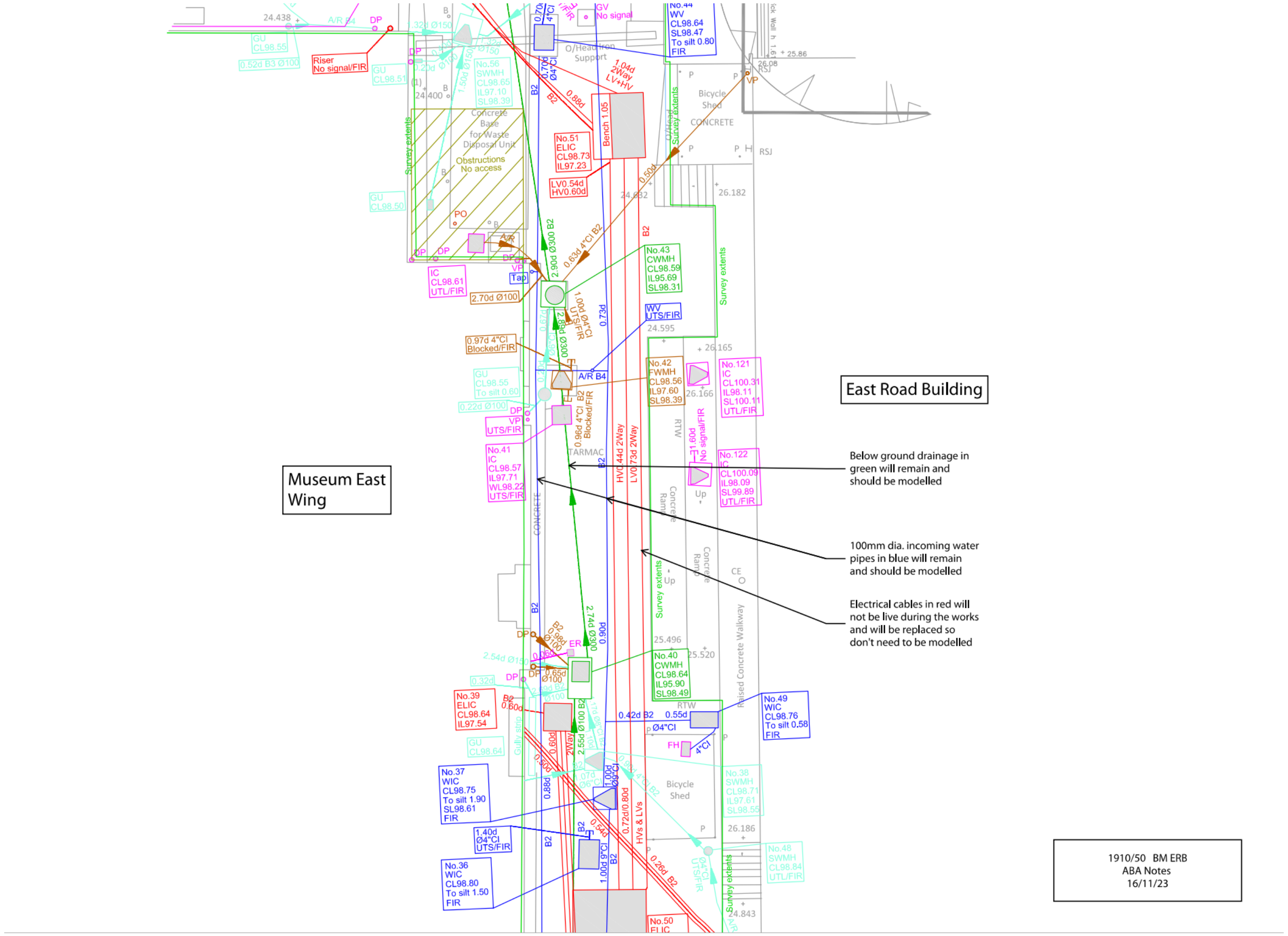
British Museum East Road Building redevelopment	**Figure 4**
Buildings surrounding the East Road Buildings From Alan Baxter, Reference [5]	

British Museum

East Road Building redevelopment

Photos of frame supporting the Jade Gallery and structures to the north-west corner of the East Road Building

Figure 5



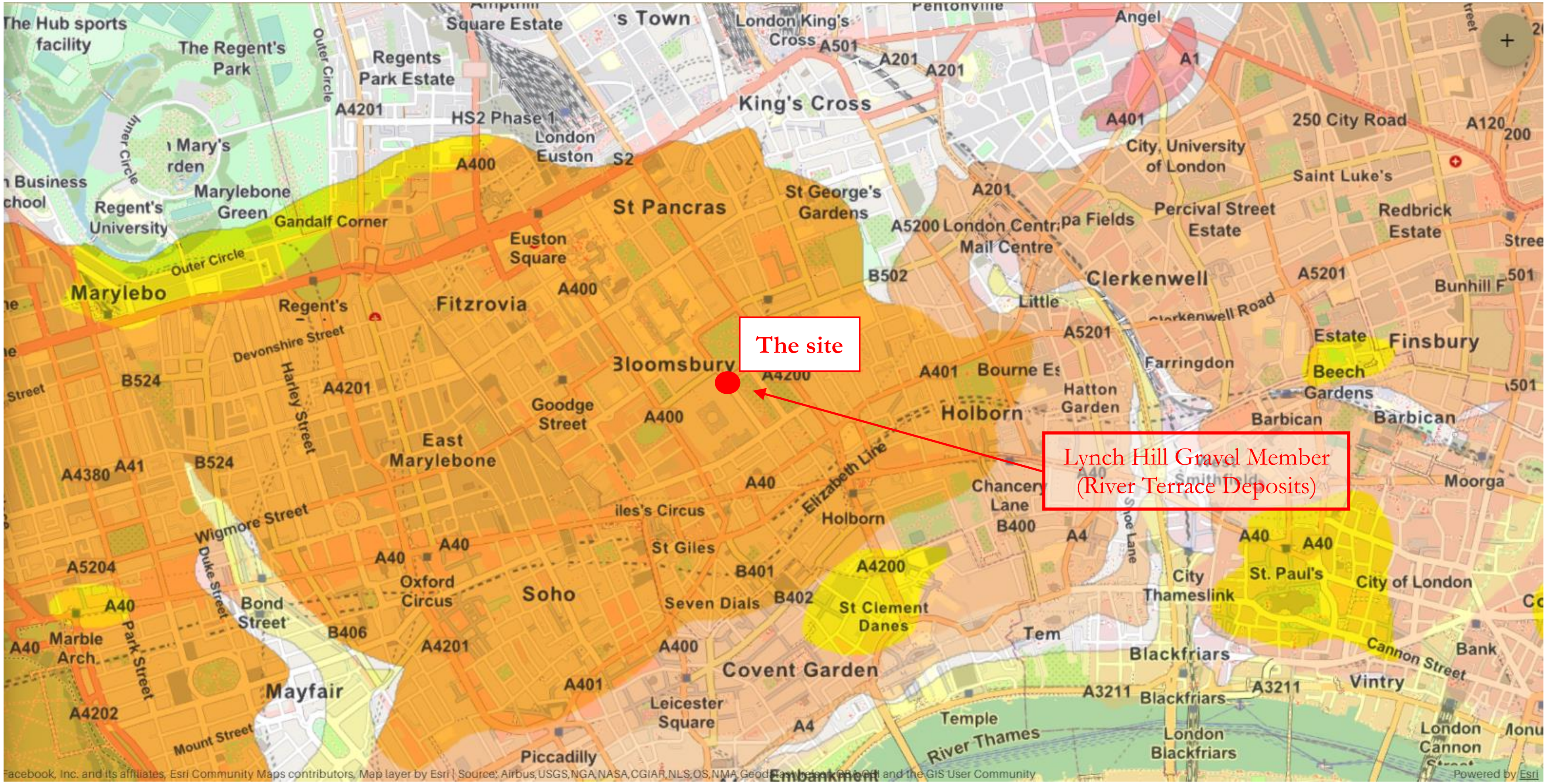
British Museum

East Road Building redevelopment

Underground utilities under the service road considered in the assessment

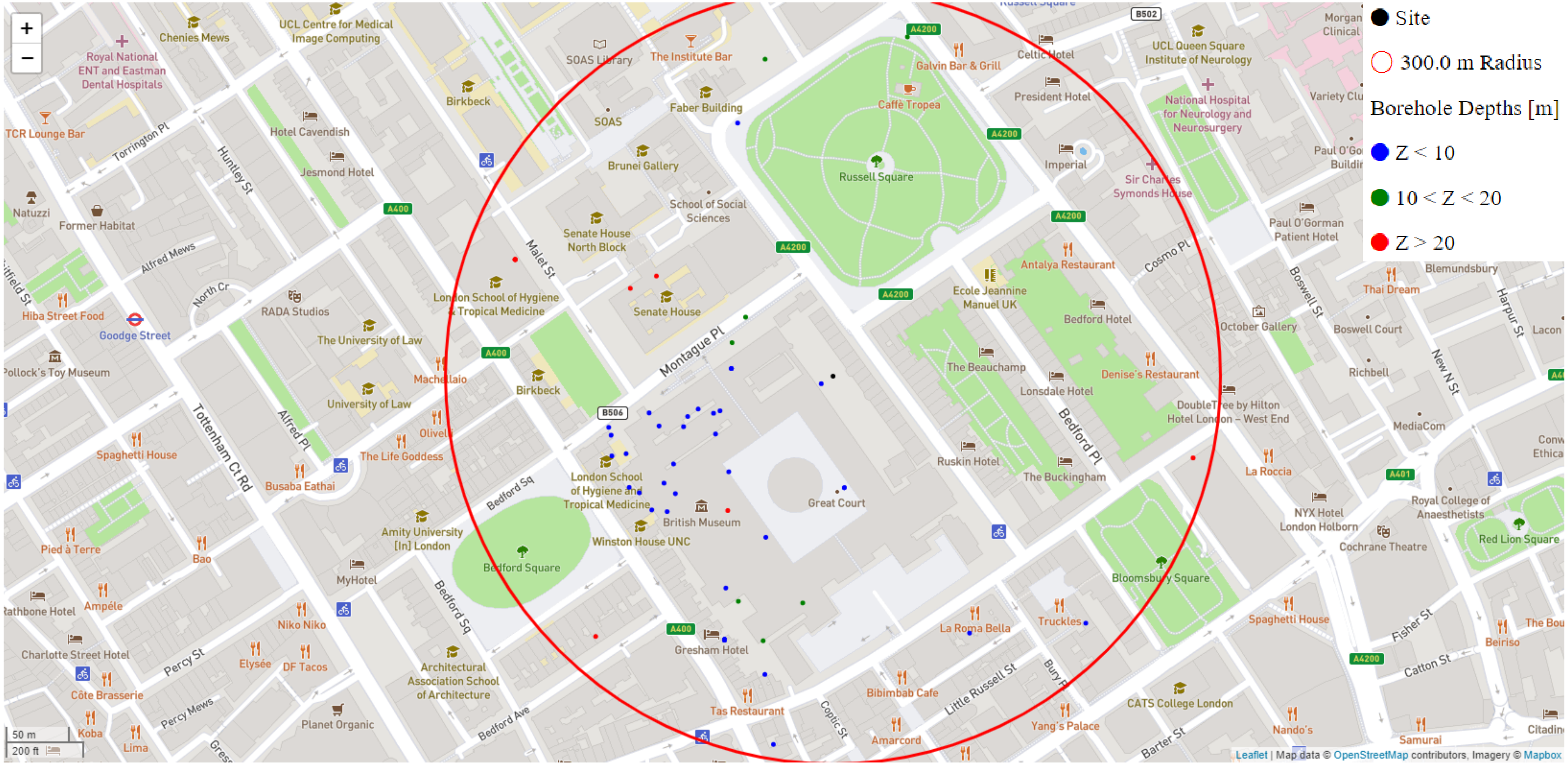
From Alan Baxter, Reference [5]

Figure 6



British Museum East Road Building redevelopment	**Figure 7**
Geology of the area shown on BGS maps – Superficial deposits http://mapapps.bgs.ac.uk/geologyofbritain/home.html	

	British Museum East Road Building redevelopment	**Figure 8**
	Geology of the area shown on BGS maps – Bedrock geology http://mapapps.bgs.ac.uk/geologyofbritain/home.html	

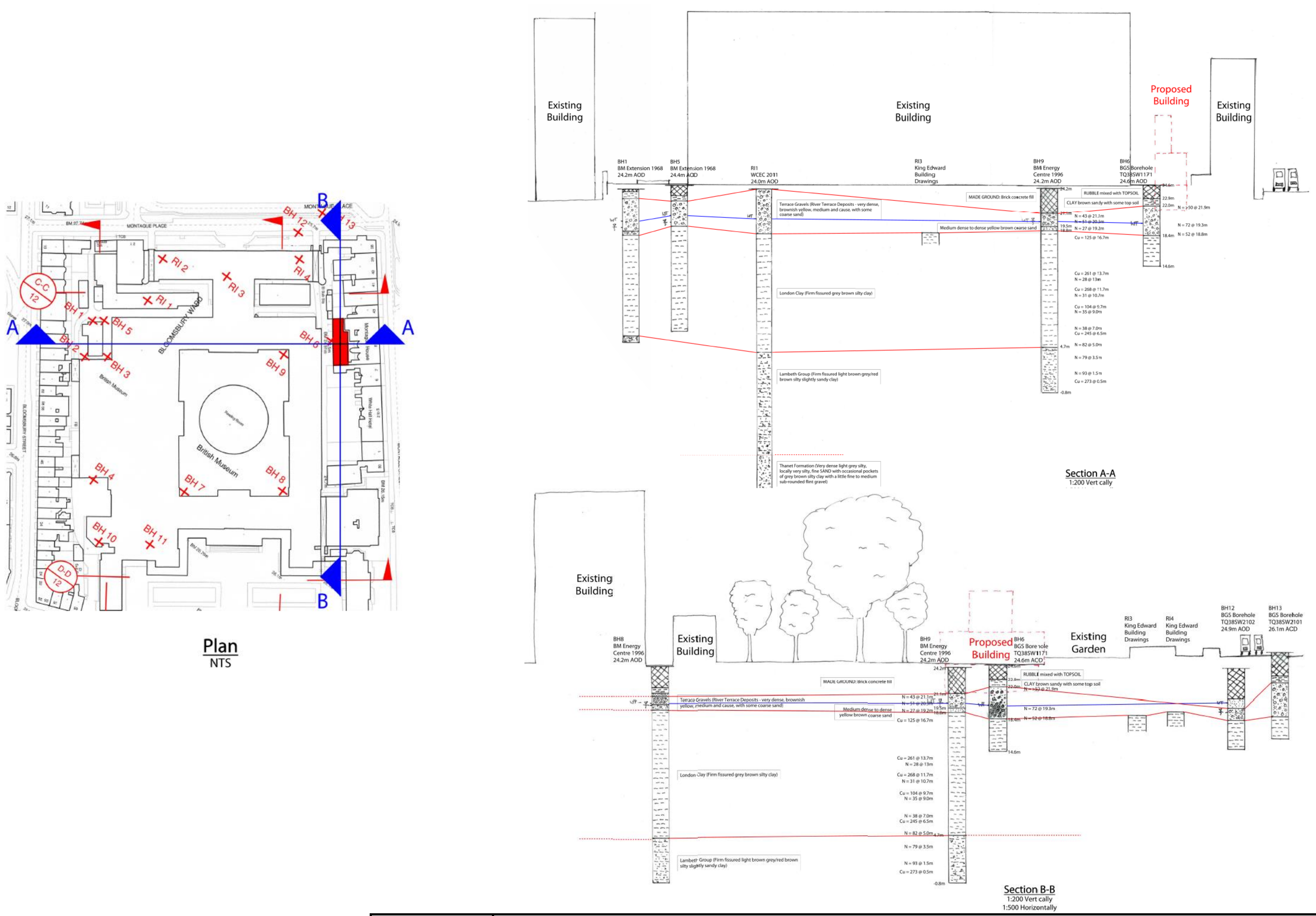


British Museum

East Road Building redevelopment

Historical borehole locations from BGS database

Figure 9



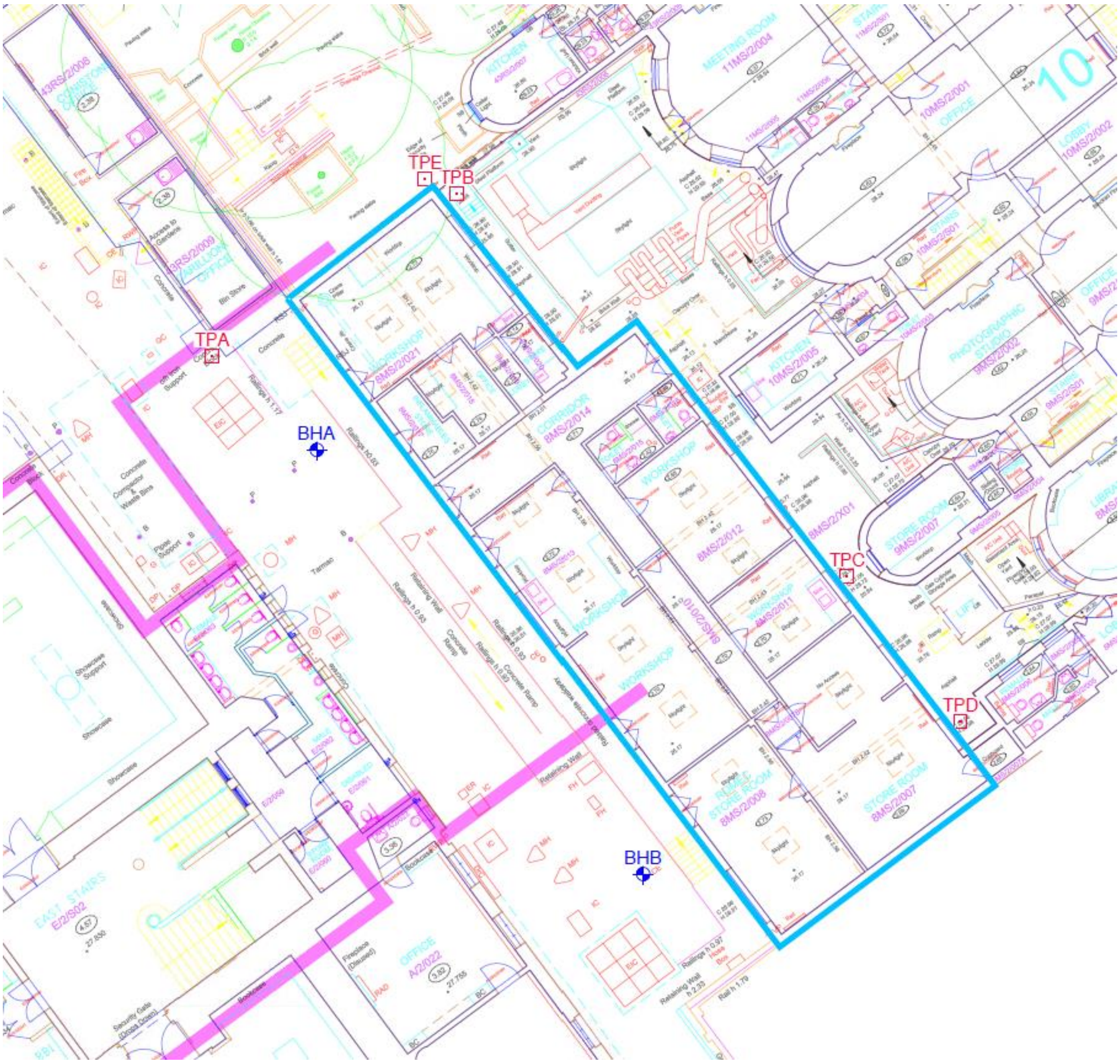
British Museum

East Road Building redevelopment

Historical boreholes and geological sections

From Reference [7]

Figure 10



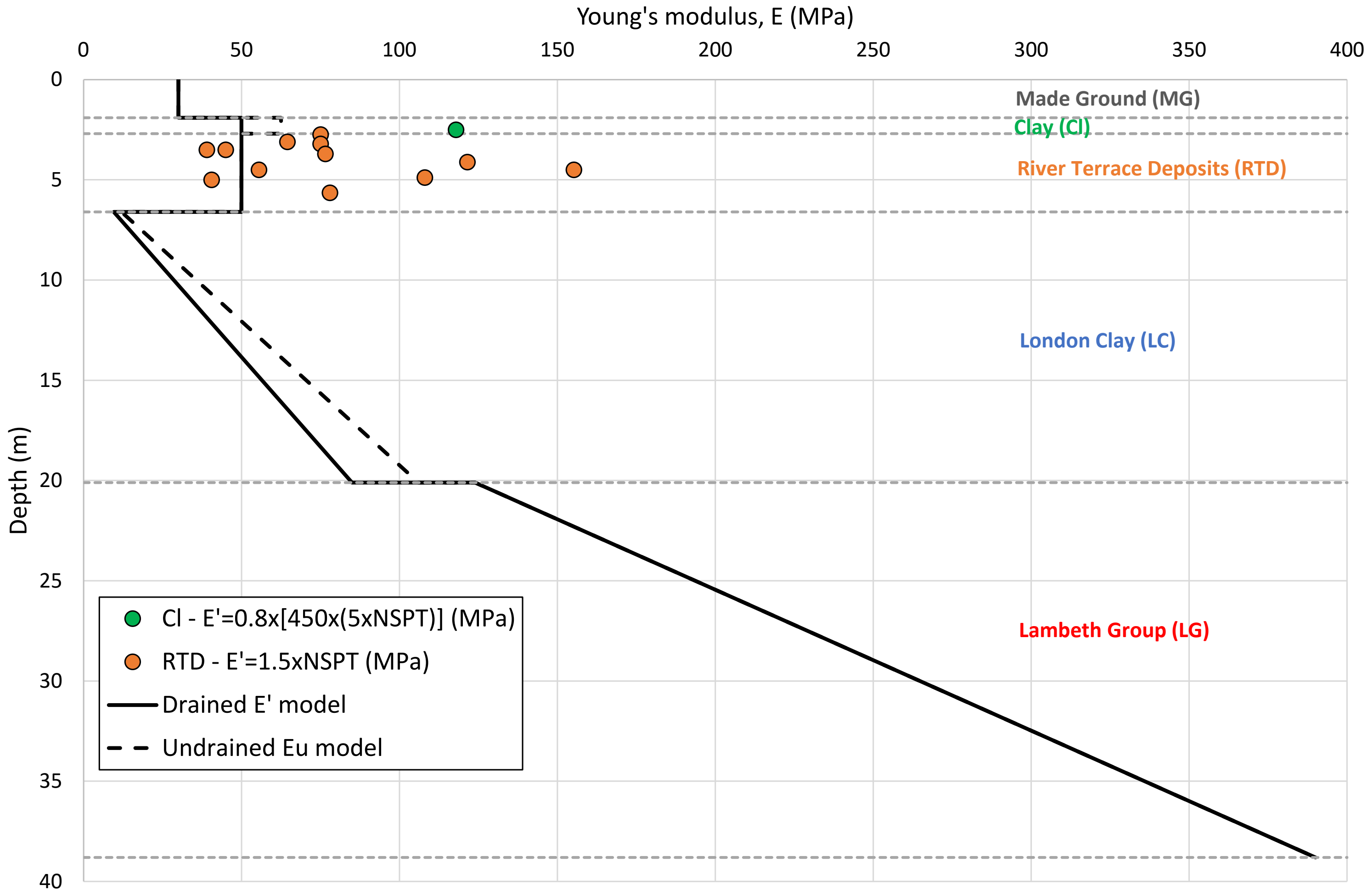
Key :

Site Boundary (Existing East Road Building)

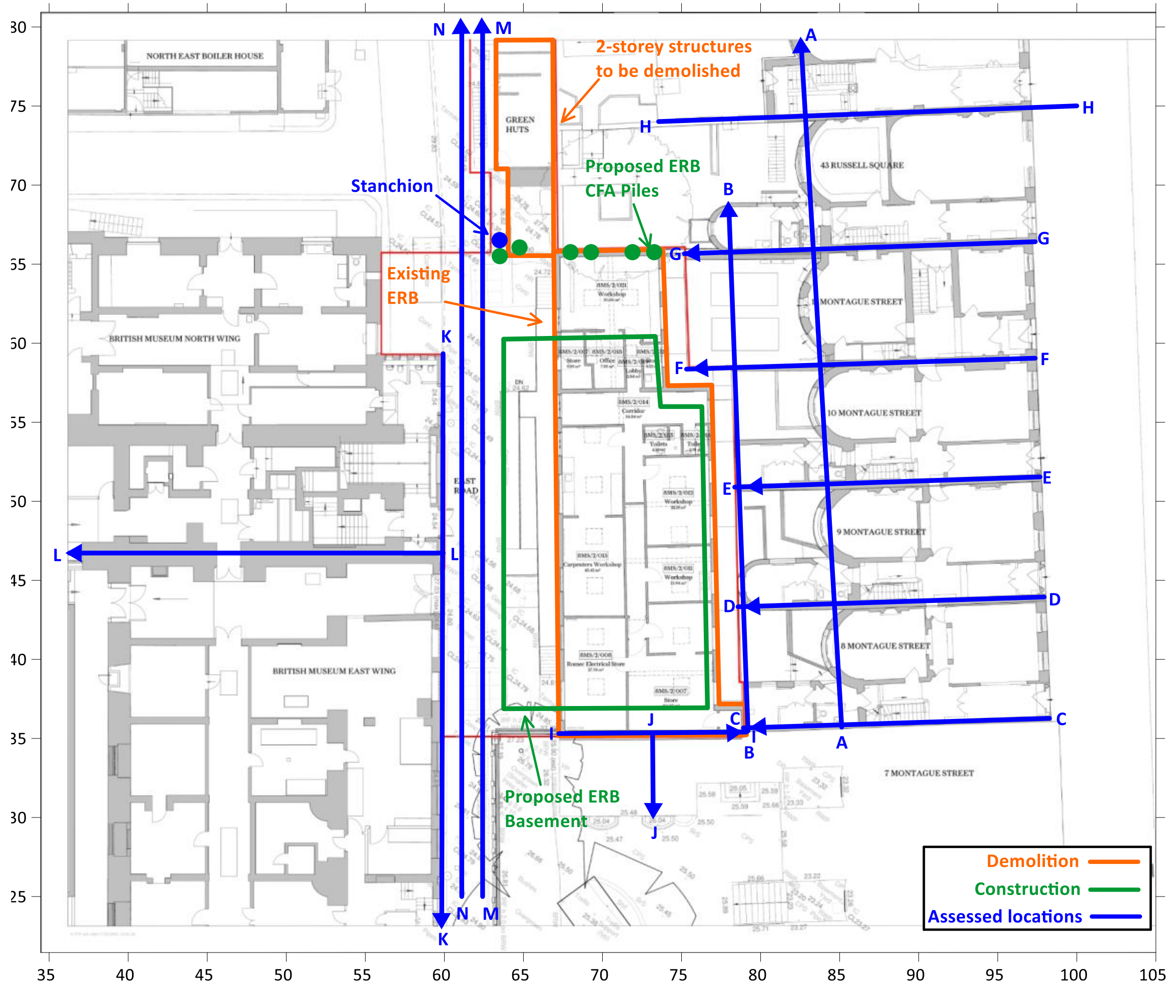
BHA Cable Percussive Borehole

TPA Foundation Inspection Pit

	British Museum East Road Building redevelopment	**Figure 11**
	Locations of boreholes and trial pits of site investigation carried out in January 2023 From Reference [8]	



British Museum East Road Building redevelopment		**Figure 12**
Young's Modulus profile adopted for elastic analyses		



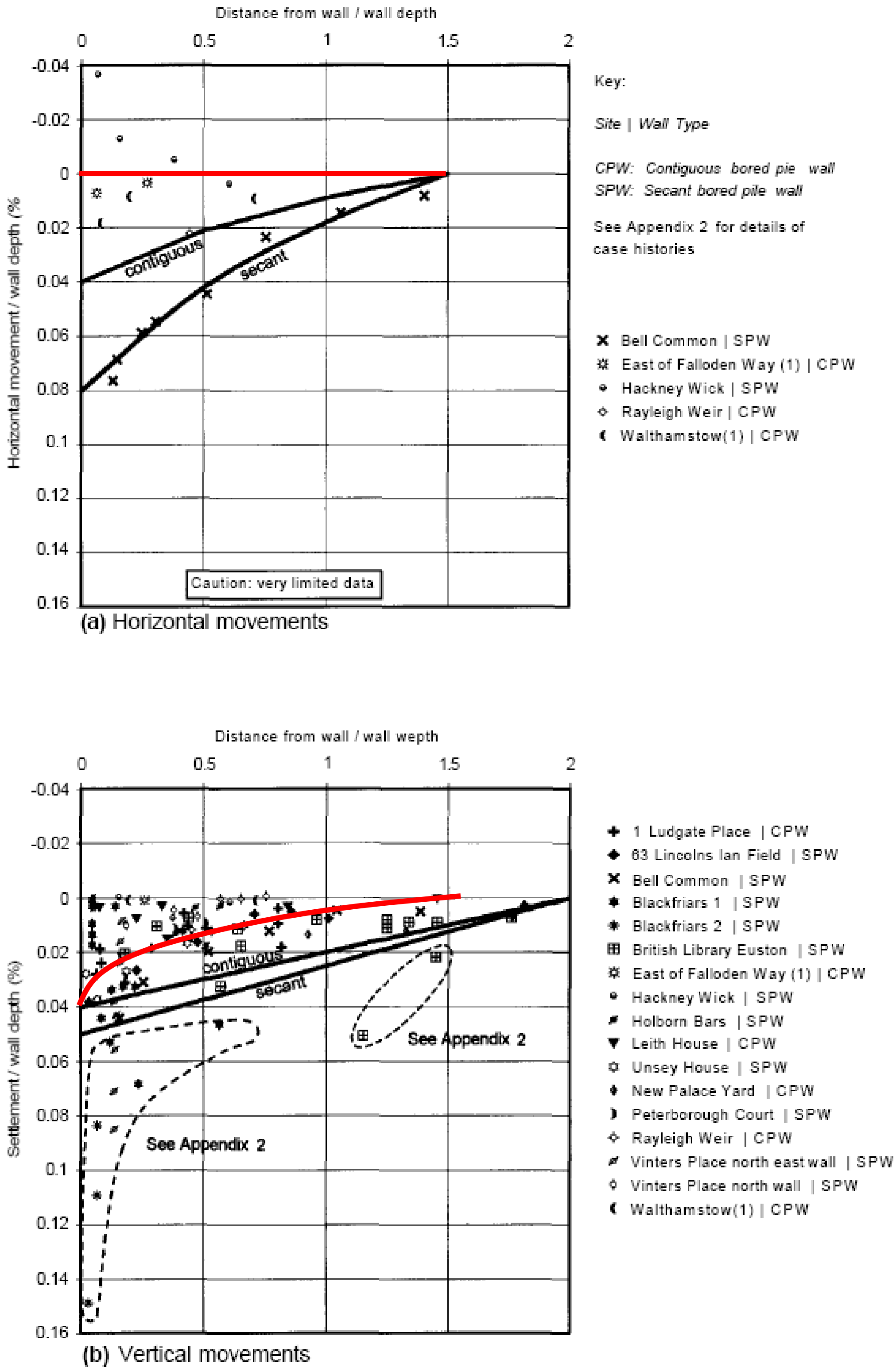
British Museum

East Road Building redevelopment

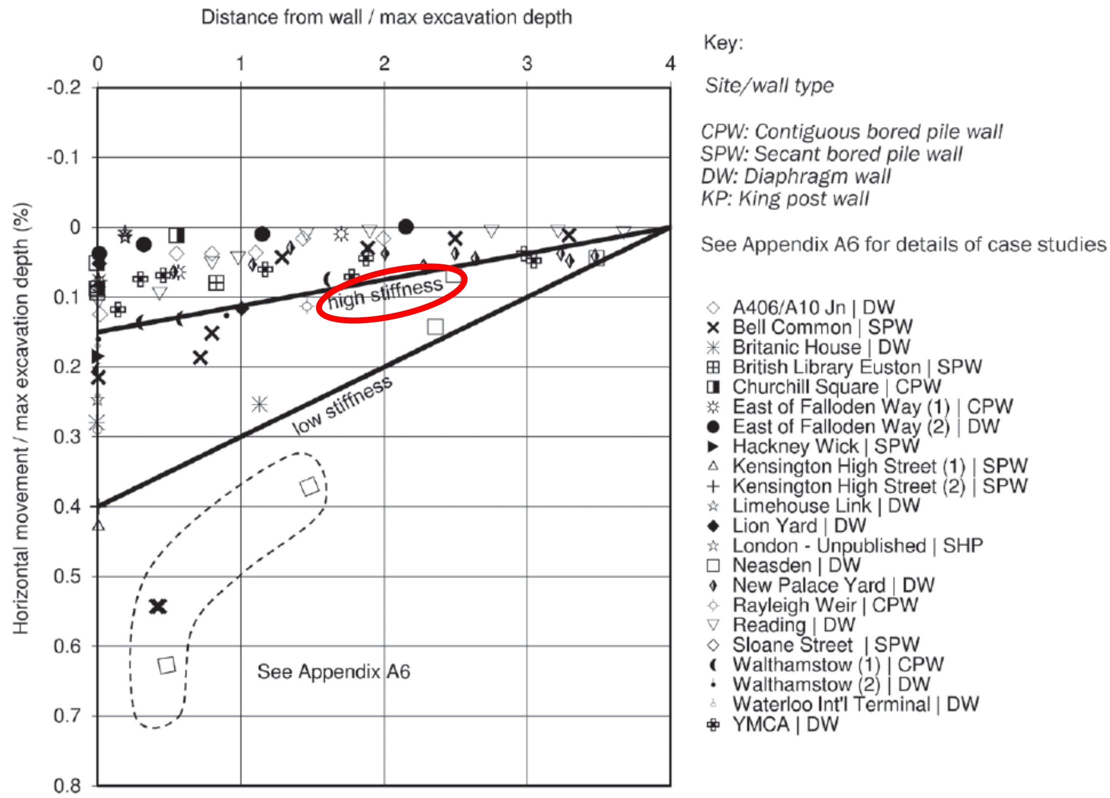
Site layout – existing structures, proposed structures and assessed structure locations

Arrows indicate direction of the assessed profiles for plotting

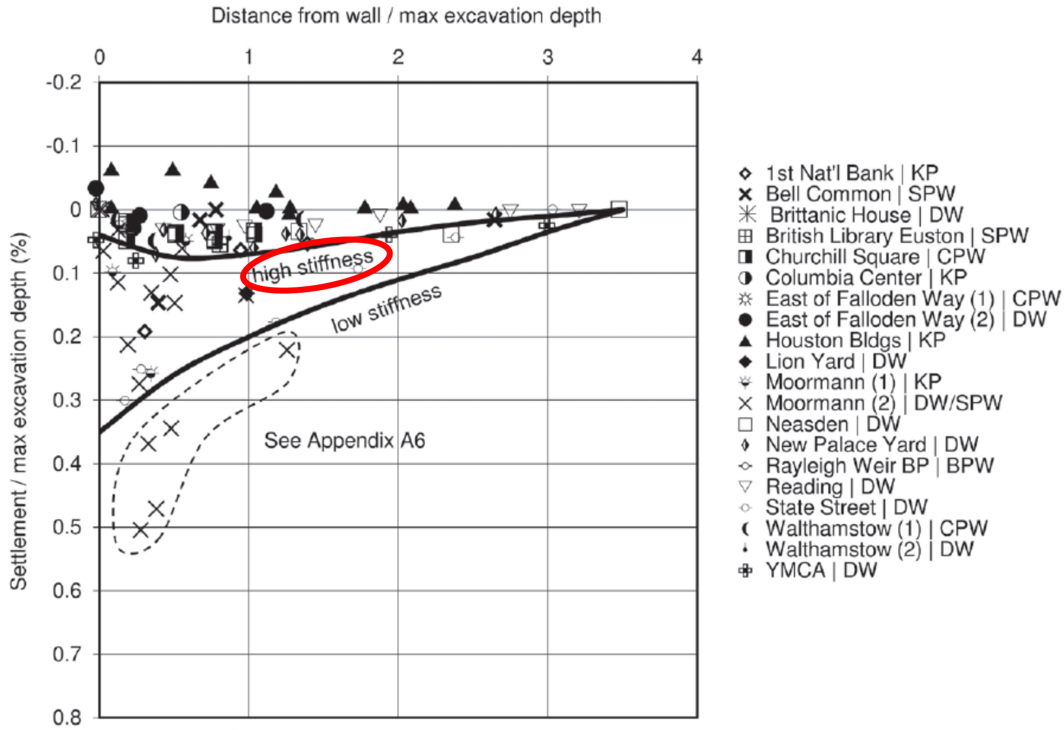
Figure 13



	British Museum East Road Building redevelopment	**Figure 14**
	Field measurements of ground movements due to bored pile wall installation in stiff clay (CIRIA C760) From Reference [11]	

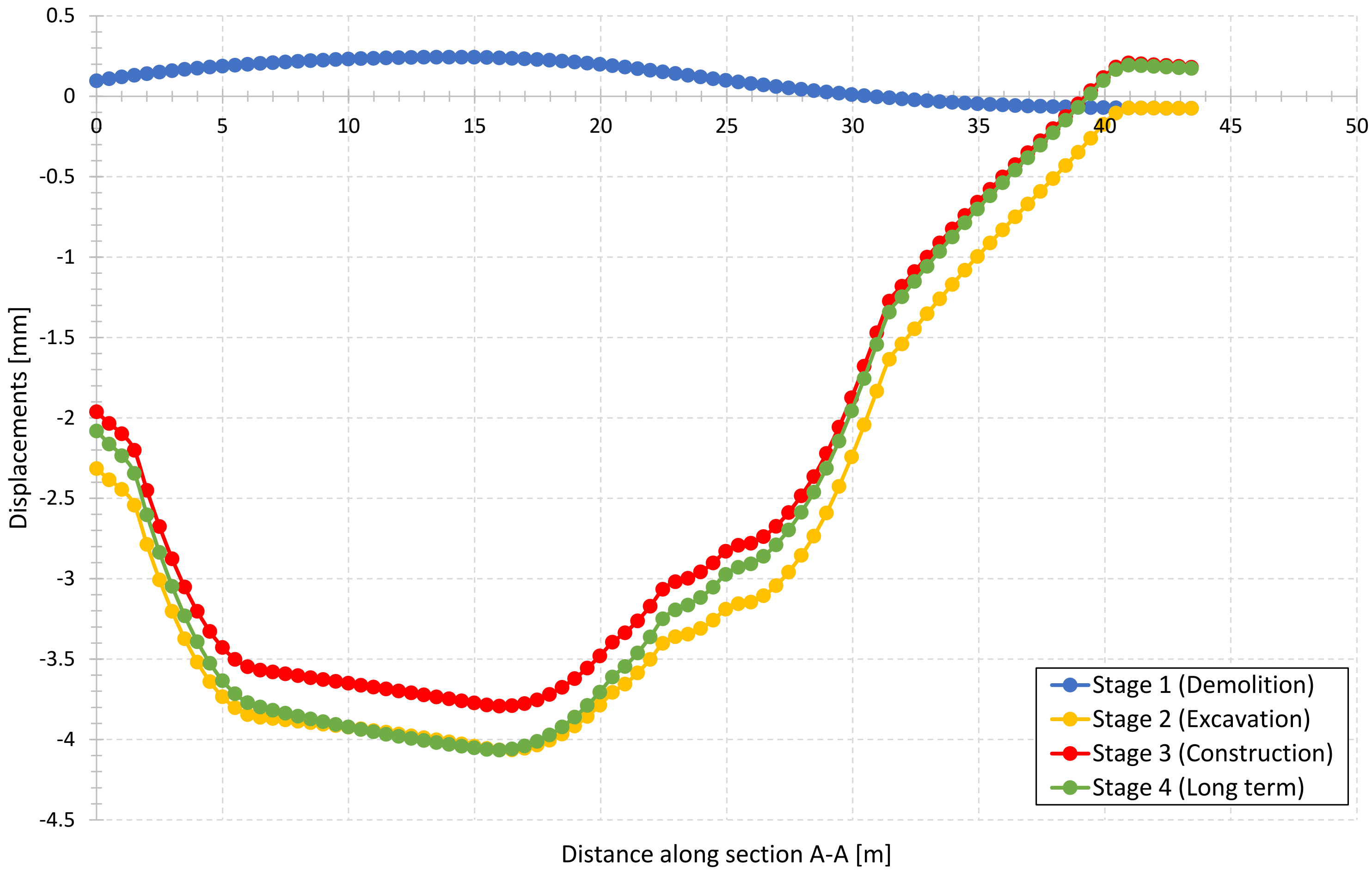


a Horizontal movements



b Vertical movements

GCG	**British Museum** East Road Building redevelopment	**Figure 15**
	Field measurements of ground movements due to excavation in front of wall embedded in stiff clay (CIRIA C760) From Reference [11]	



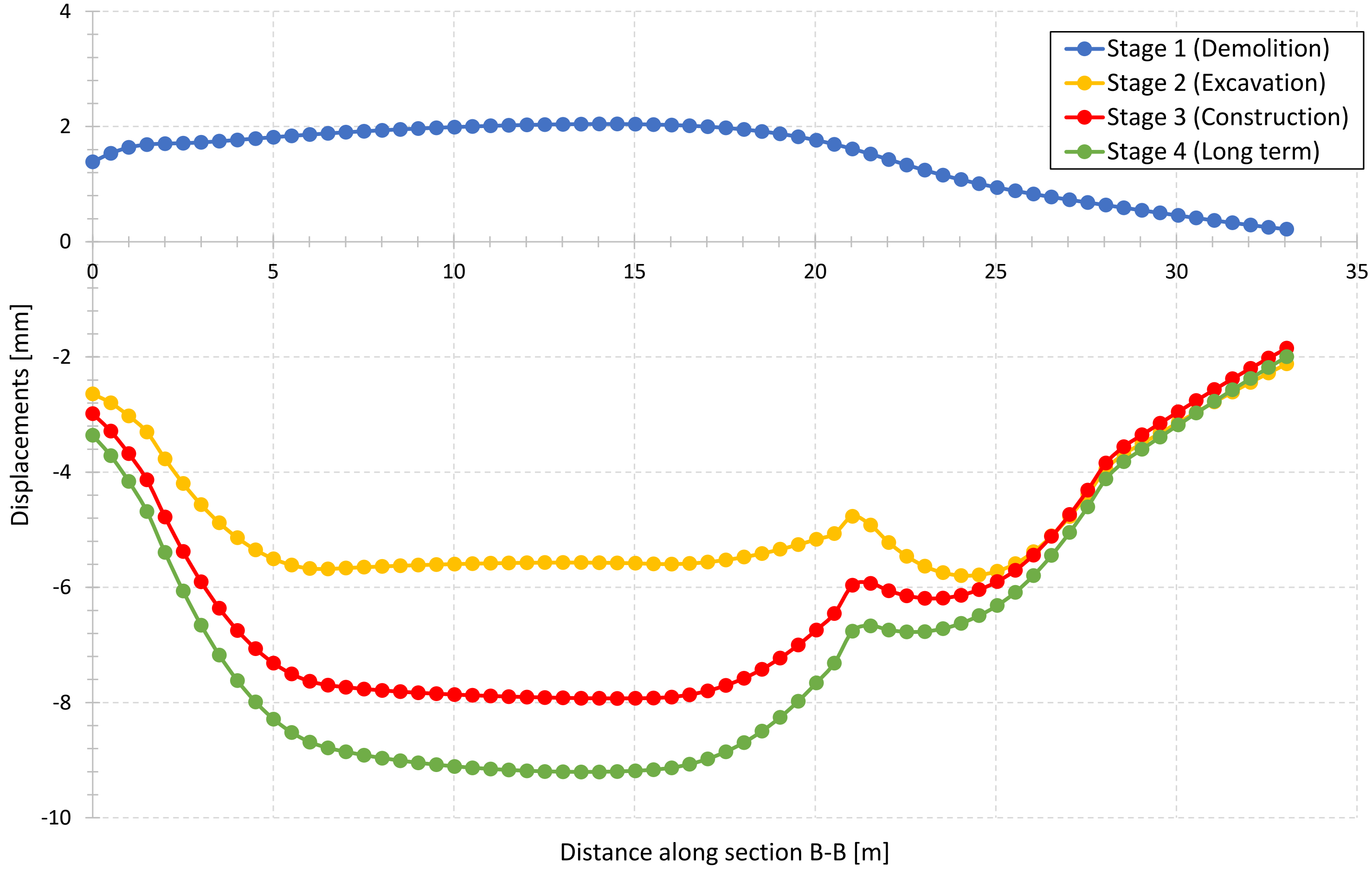
British Museum

East Road Building redevelopment

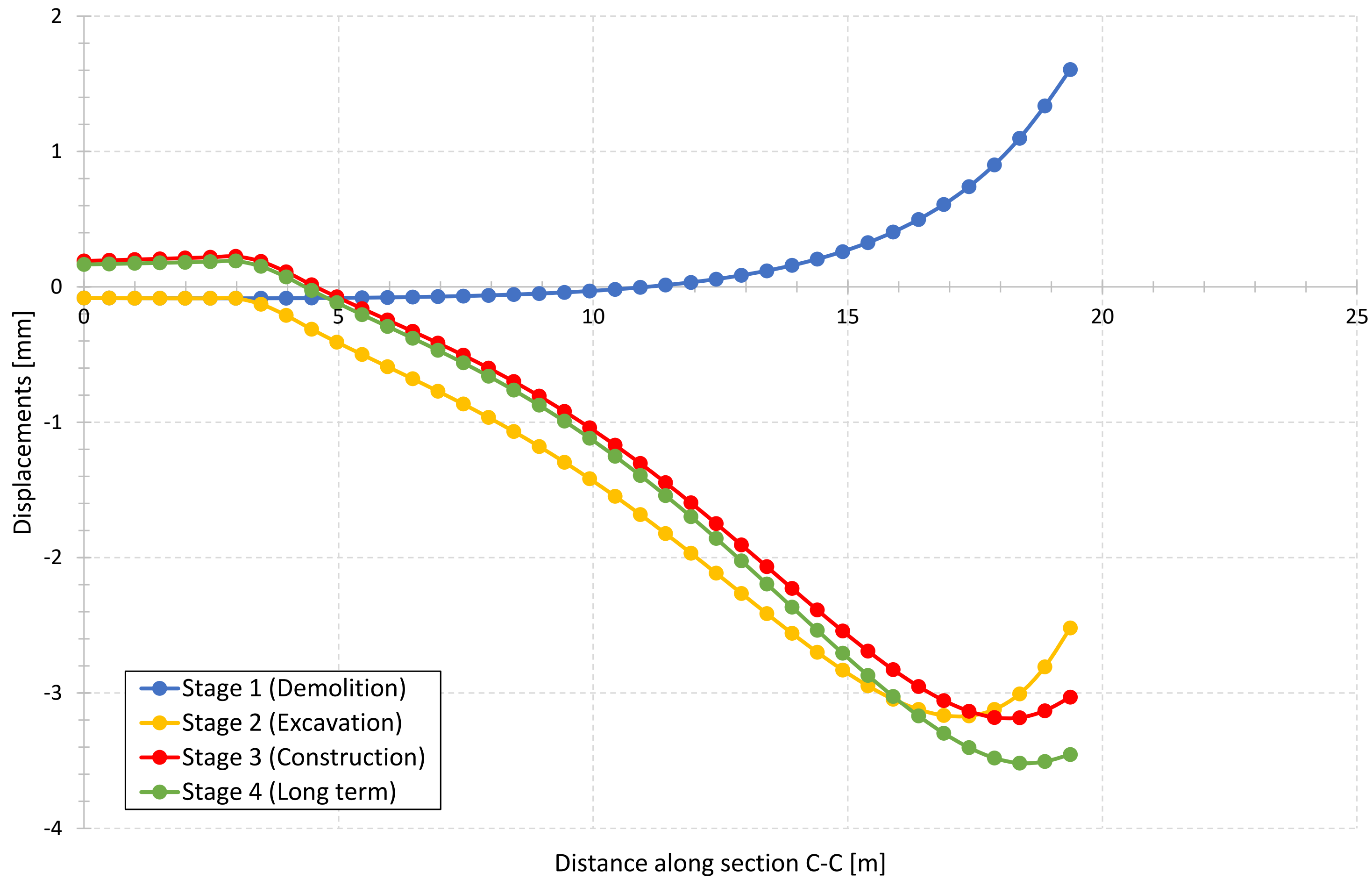
Predicted vertical movements along Section A-A

Positive sign means heave, negative sign means settlements

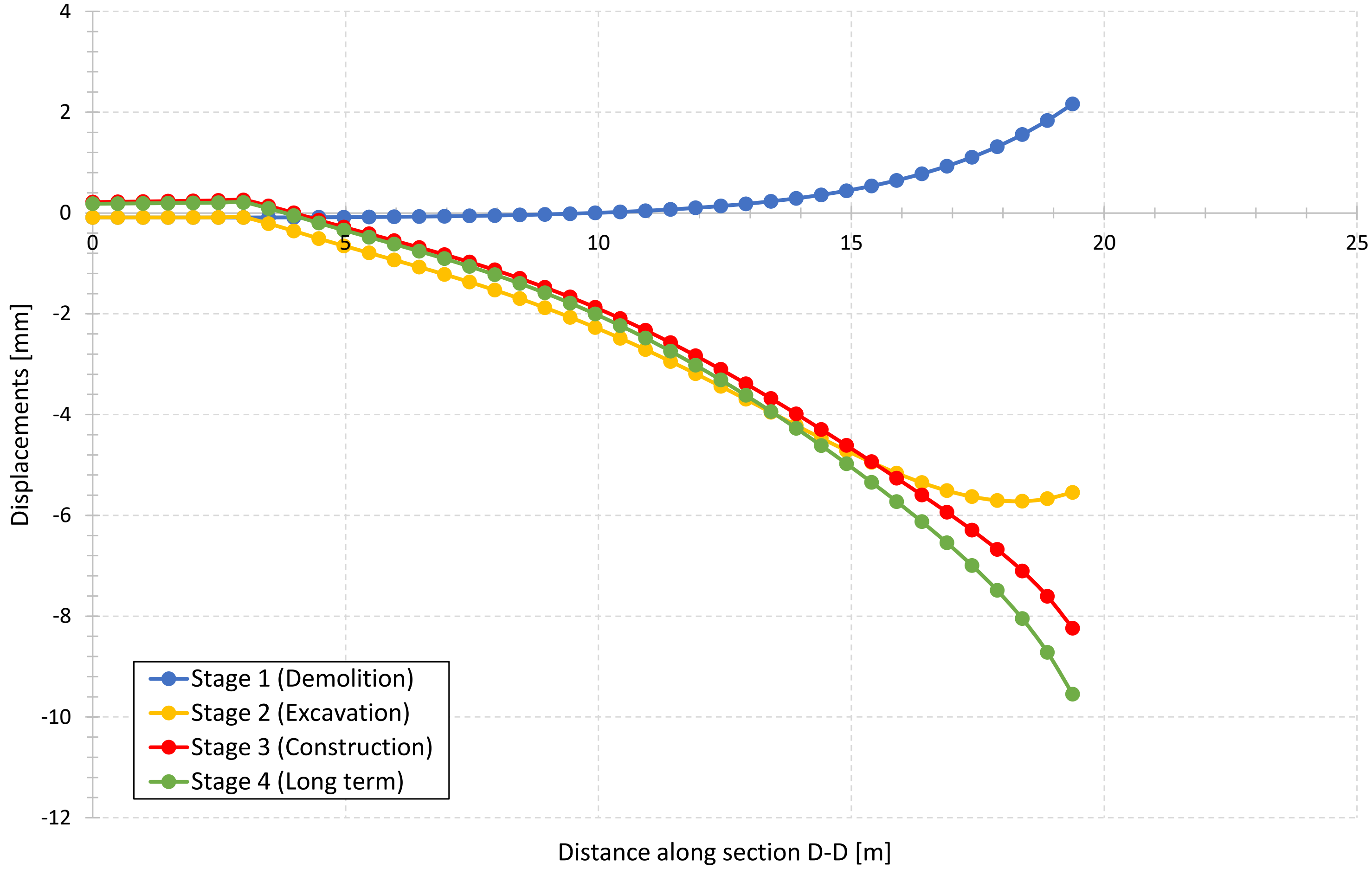
Figure 16



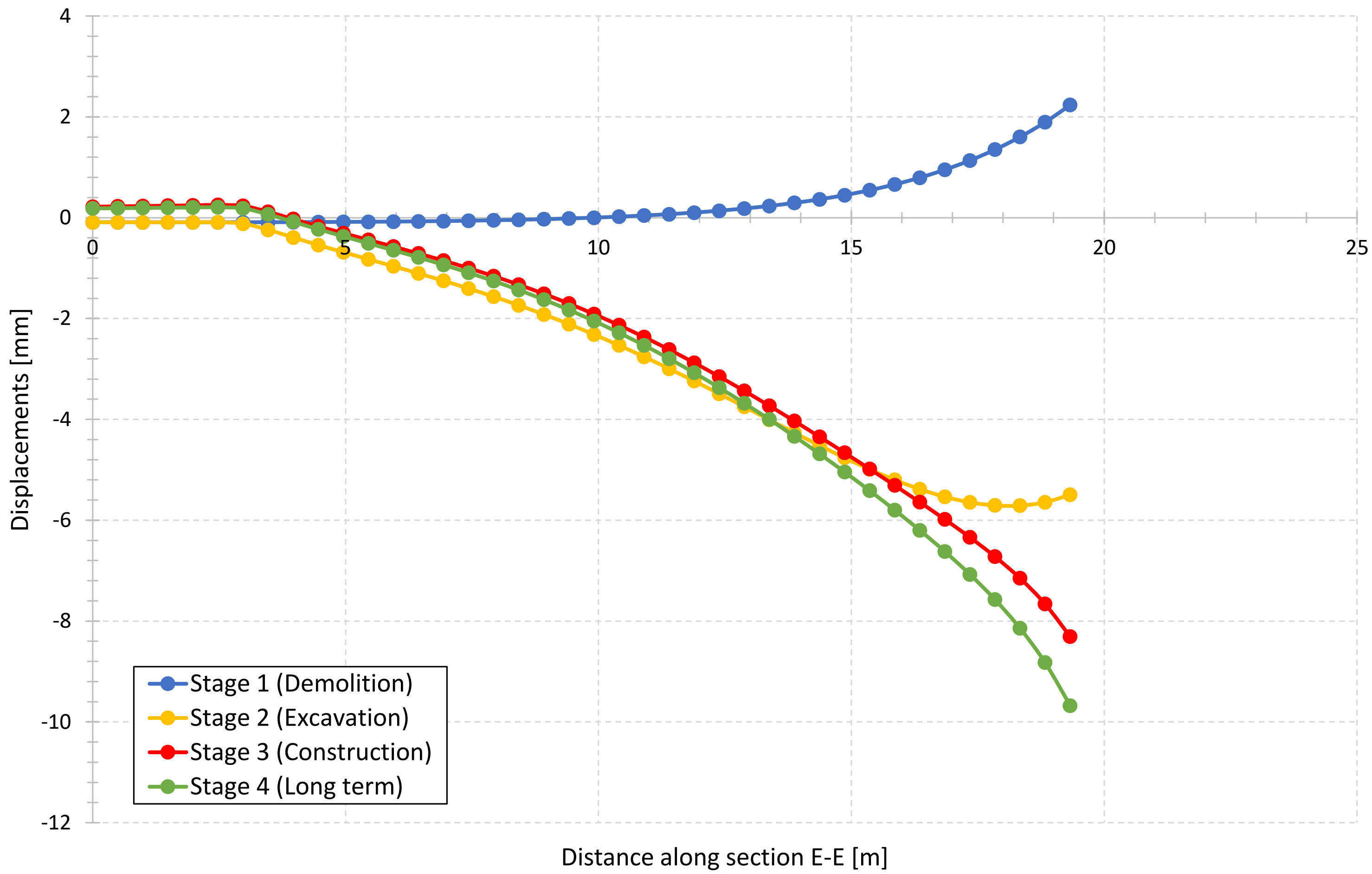
British Museum East Road Building redevelopment		Figure 17
Predicted vertical movements along Section B-B Positive sign means heave, negative sign means settlements		



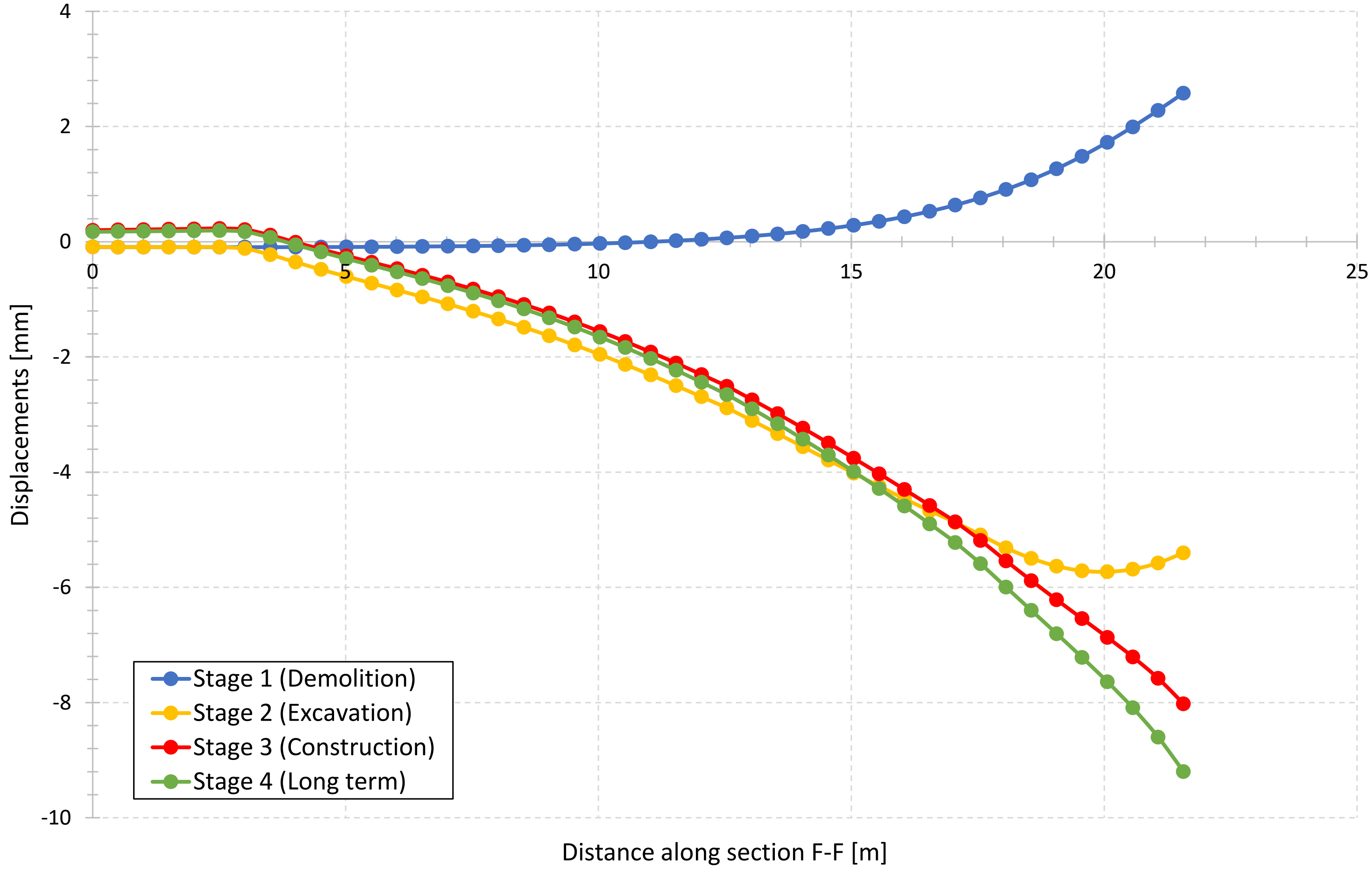
GCG	**British Museum** East Road Building redevelopment	**Figure 18**
	Predicted vertical movements along Section C-C Positive sign means heave, negative sign means settlements	



	British Museum East Road Building redevelopment	**Figure 19**
	Predicted vertical movements along Section D-D Positive sign means heave, negative sign means settlements	



	British Museum East Road Building redevelopment	**Figure 20**
	Predicted vertical movements along Section E-E Positive sign means heave, negative sign means settlements	



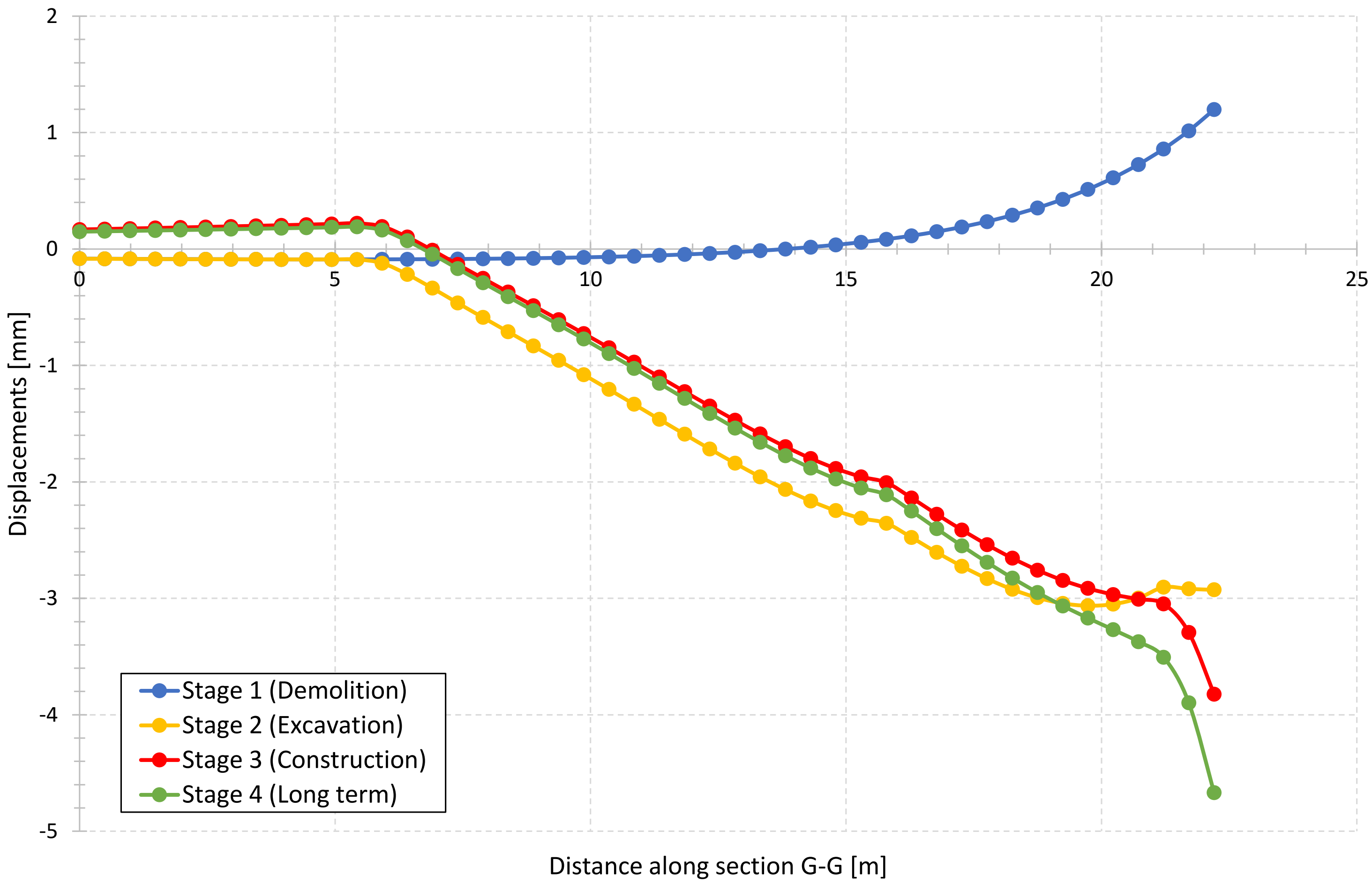
British Museum

East Road Building redevelopment

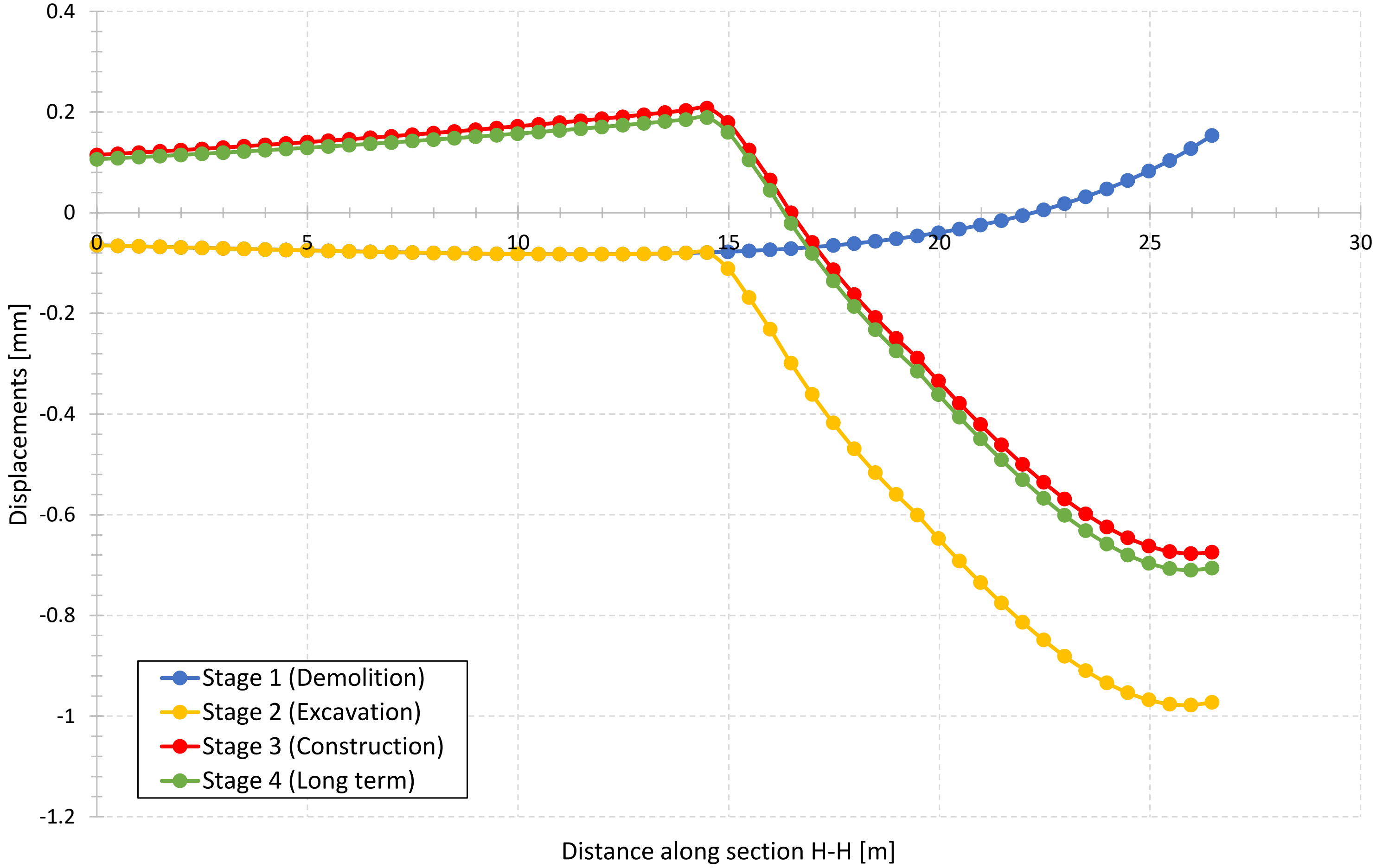
Predicted vertical movements along Section F-F

Positive sign means heave, negative sign means settlements

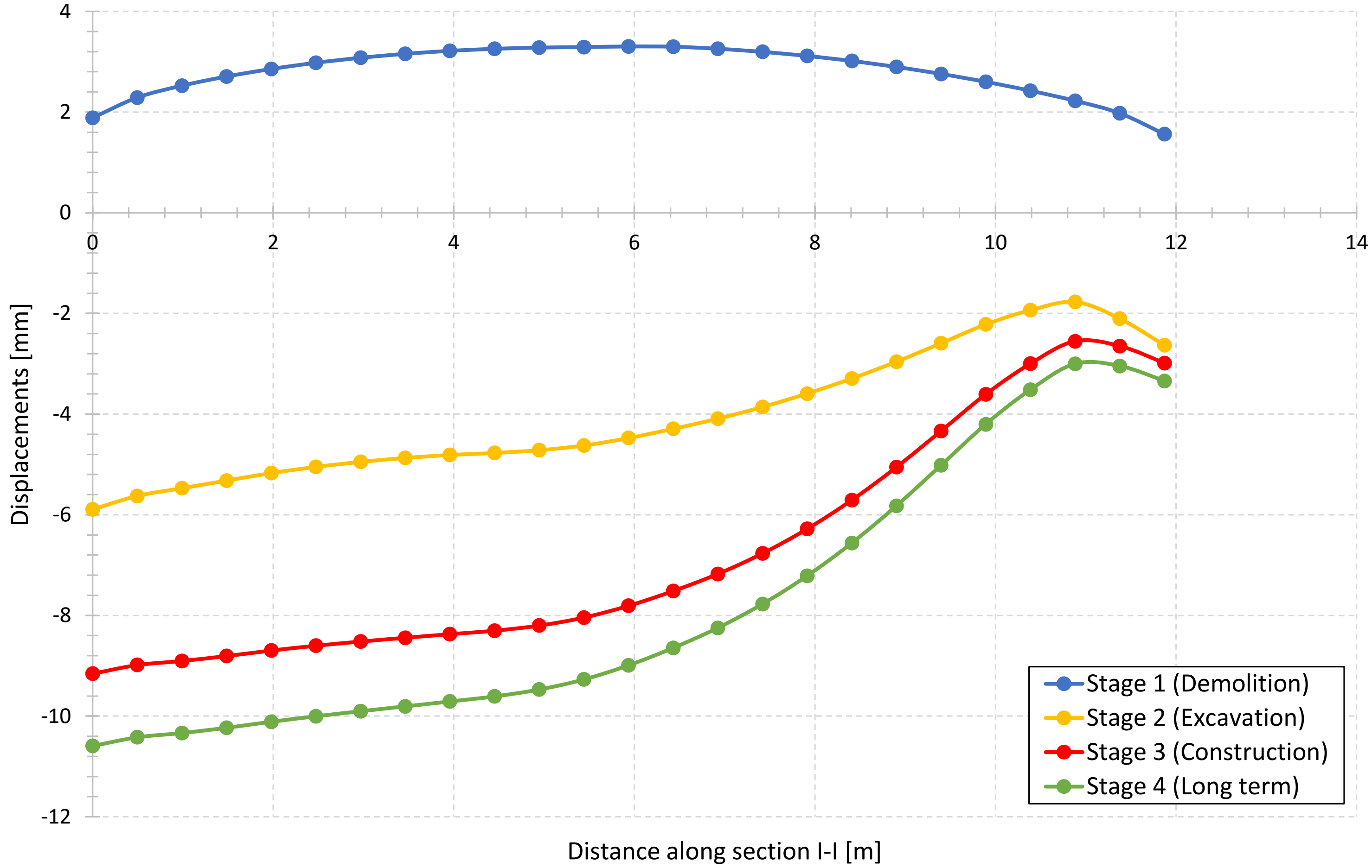
Figure 21



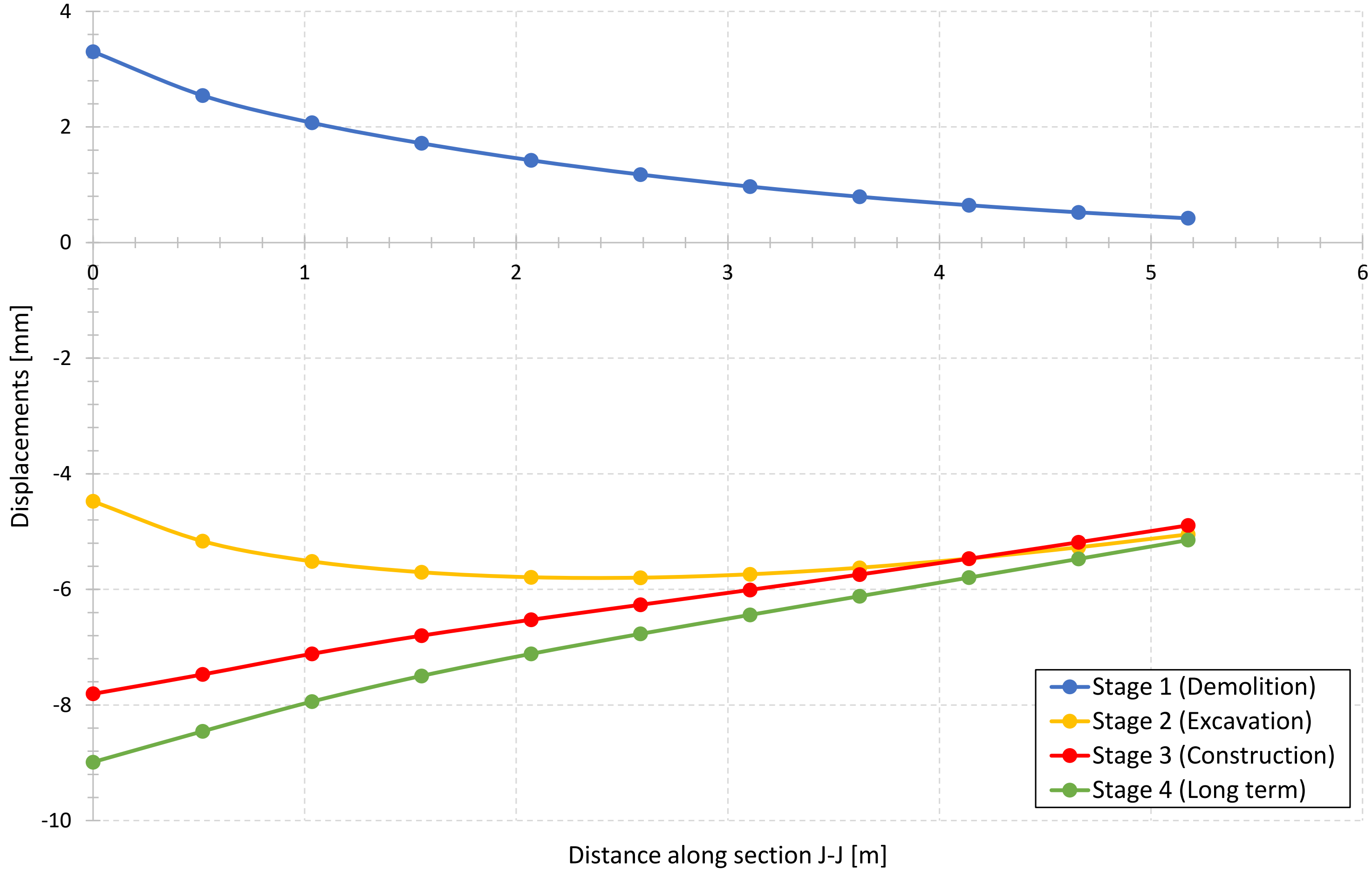
GCG	**British Museum** East Road Building redevelopment	**Figure 22**
	Predicted vertical movements along Section G-G Positive sign means heave, negative sign means settlements	



British Museum East Road Building redevelopment		**Figure 23**
Predicted vertical movements along Section H-H Positive sign means heave, negative sign means settlements		



GCG	**British Museum** East Road Building redevelopment	**Figure 24**
	Predicted vertical movements along Section I-I Positive sign means heave, negative sign means settlements	



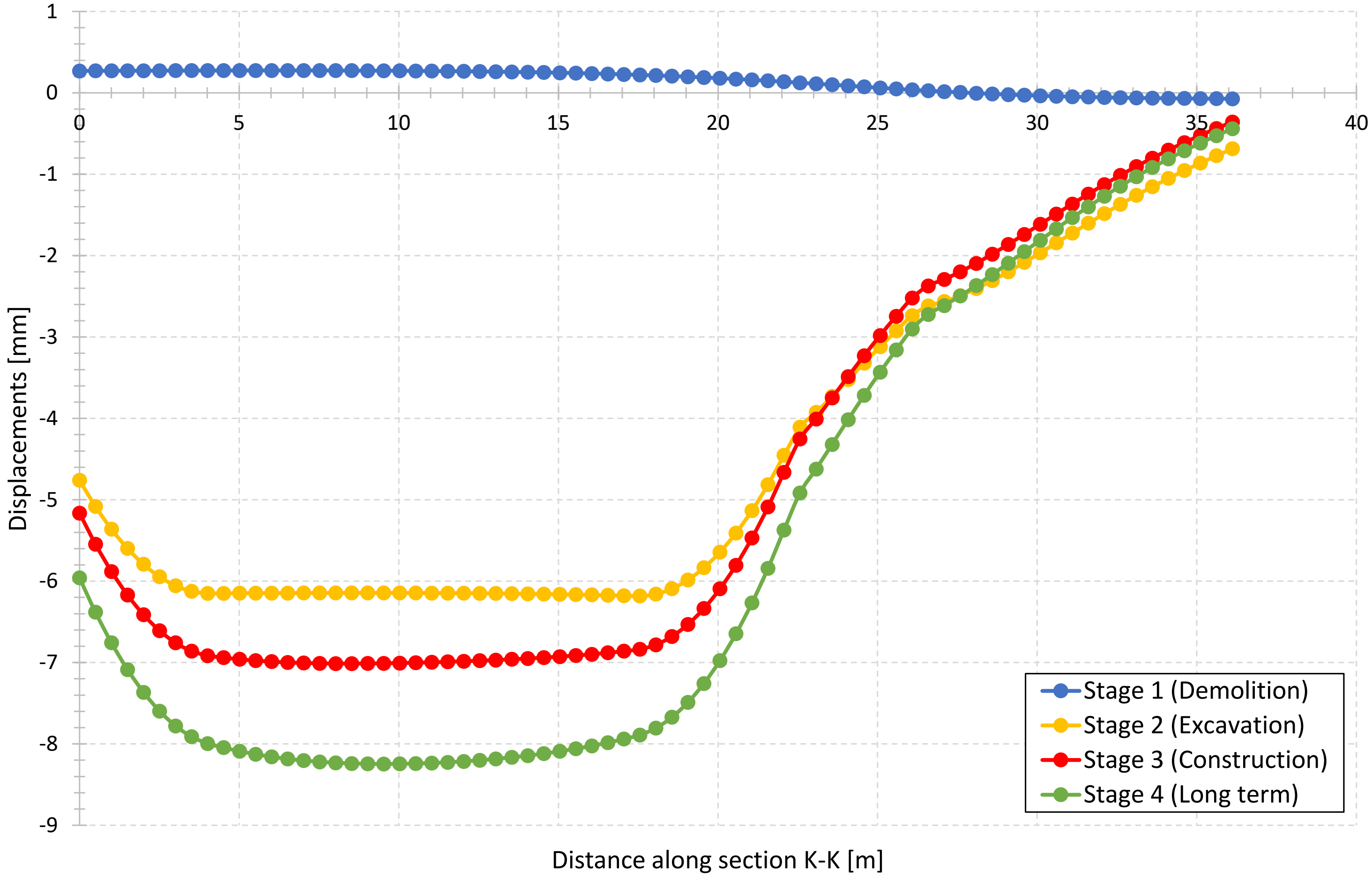
British Museum

East Road Building redevelopment

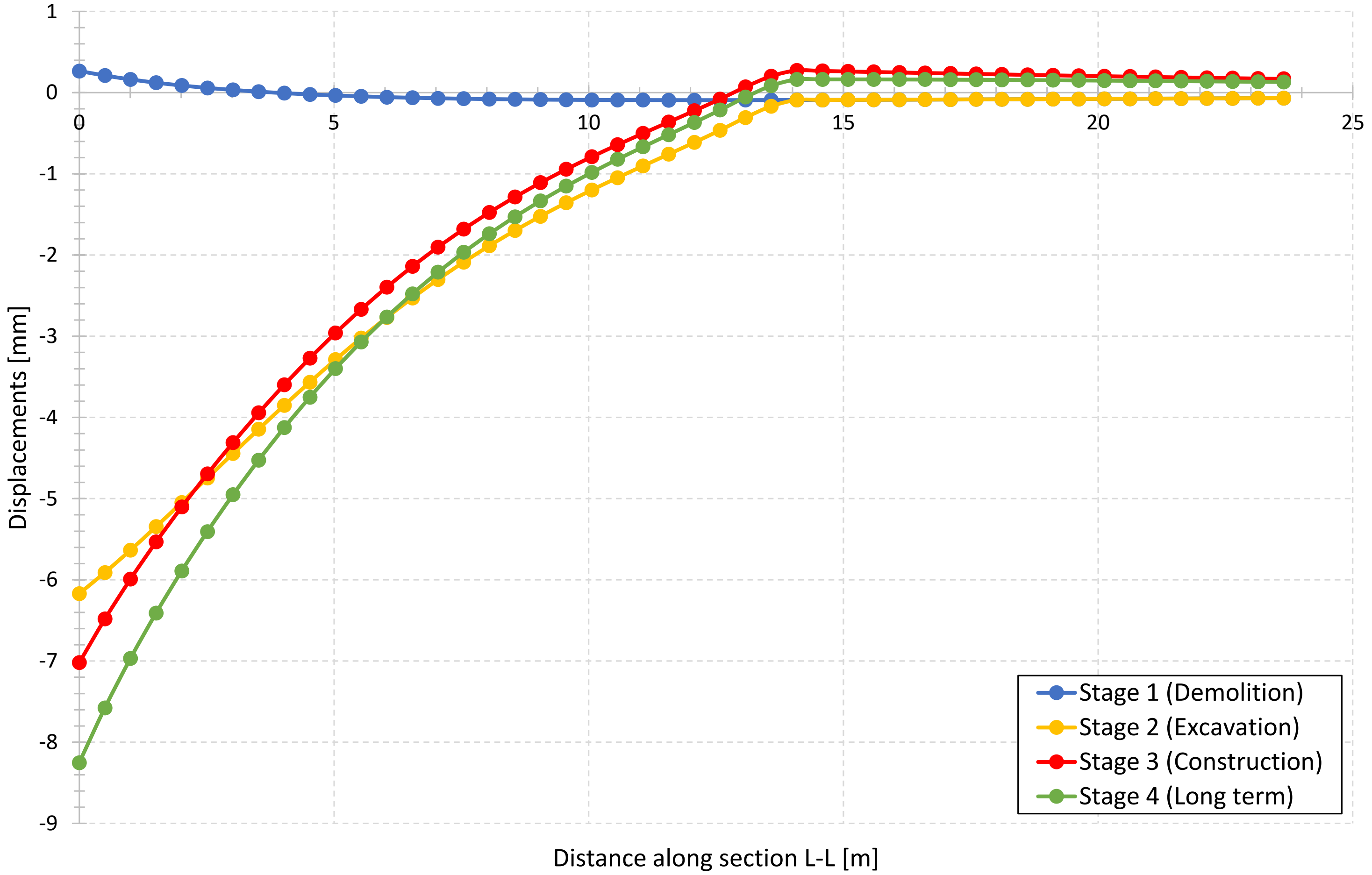
Predicted vertical movements along Section J-J

Positive sign means heave, negative sign means settlements

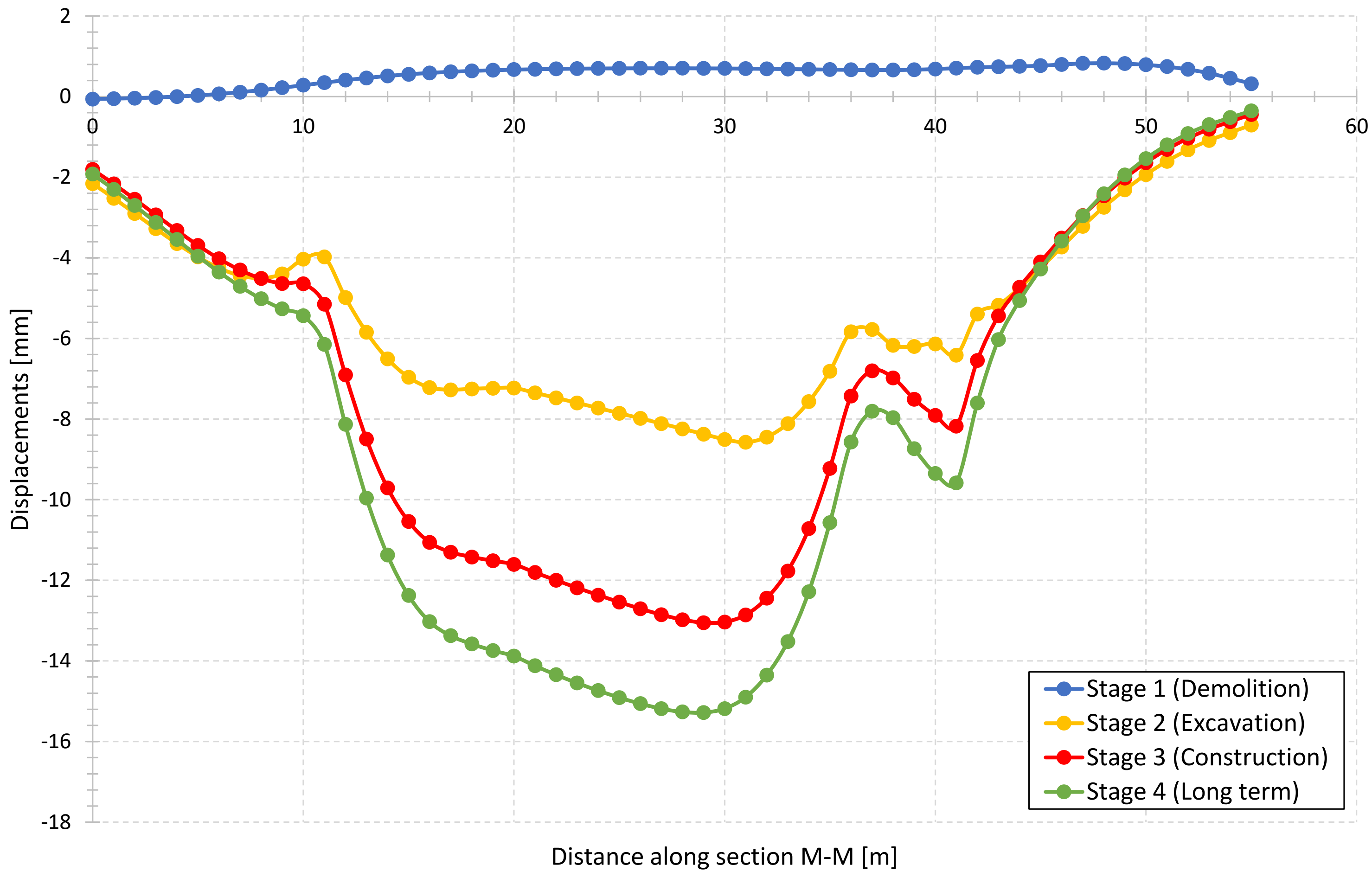
Figure 25



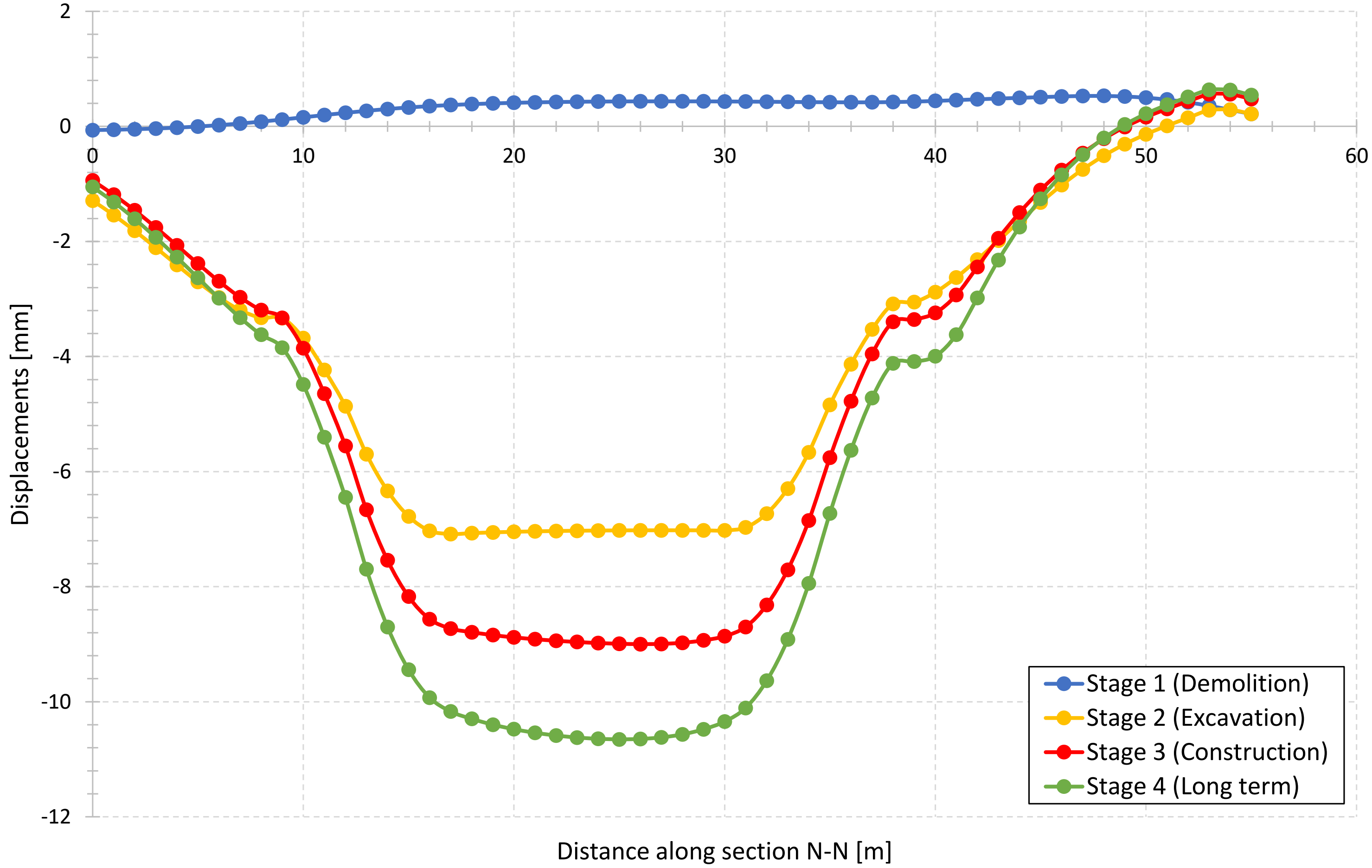
GCG	**British Museum** East Road Building redevelopment	**Figure 26**
	Predicted vertical movements along Section K-K Positive sign means heave, negative sign means settlements	



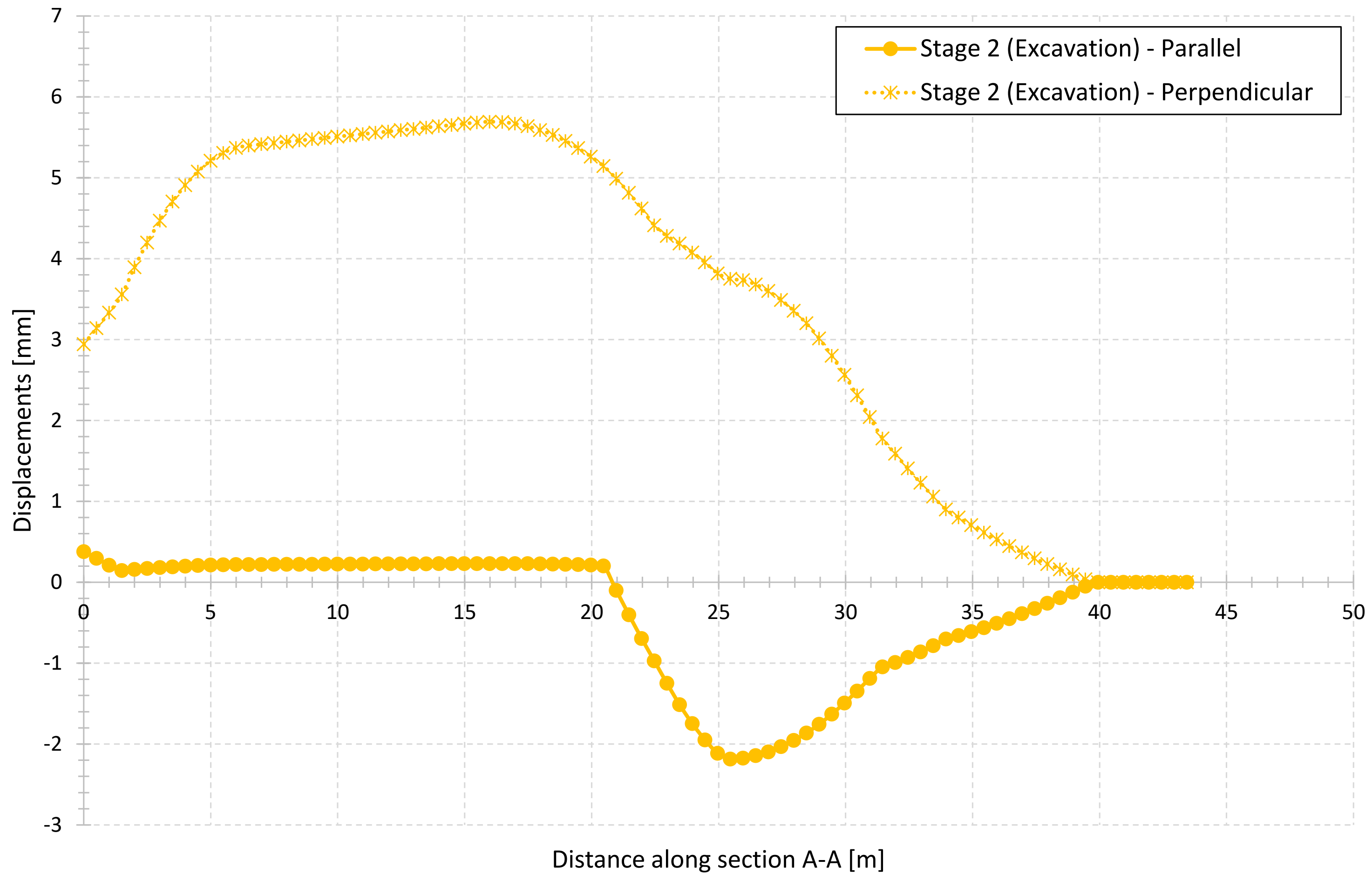
GCG	**British Museum** East Road Building redevelopment	**Figure 27**
	Predicted vertical movements along Section L-L Positive sign means heave, negative sign means settlements	



	British Museum East Road Building redevelopment	Figure 28
	Predicted vertical movements along Section M-M Positive sign means heave, negative sign means settlements	



GCG	**British Museum** East Road Building redevelopment	**Figure 29**
	Predicted vertical movements along Section N-N Positive sign means heave, negative sign means settlements	



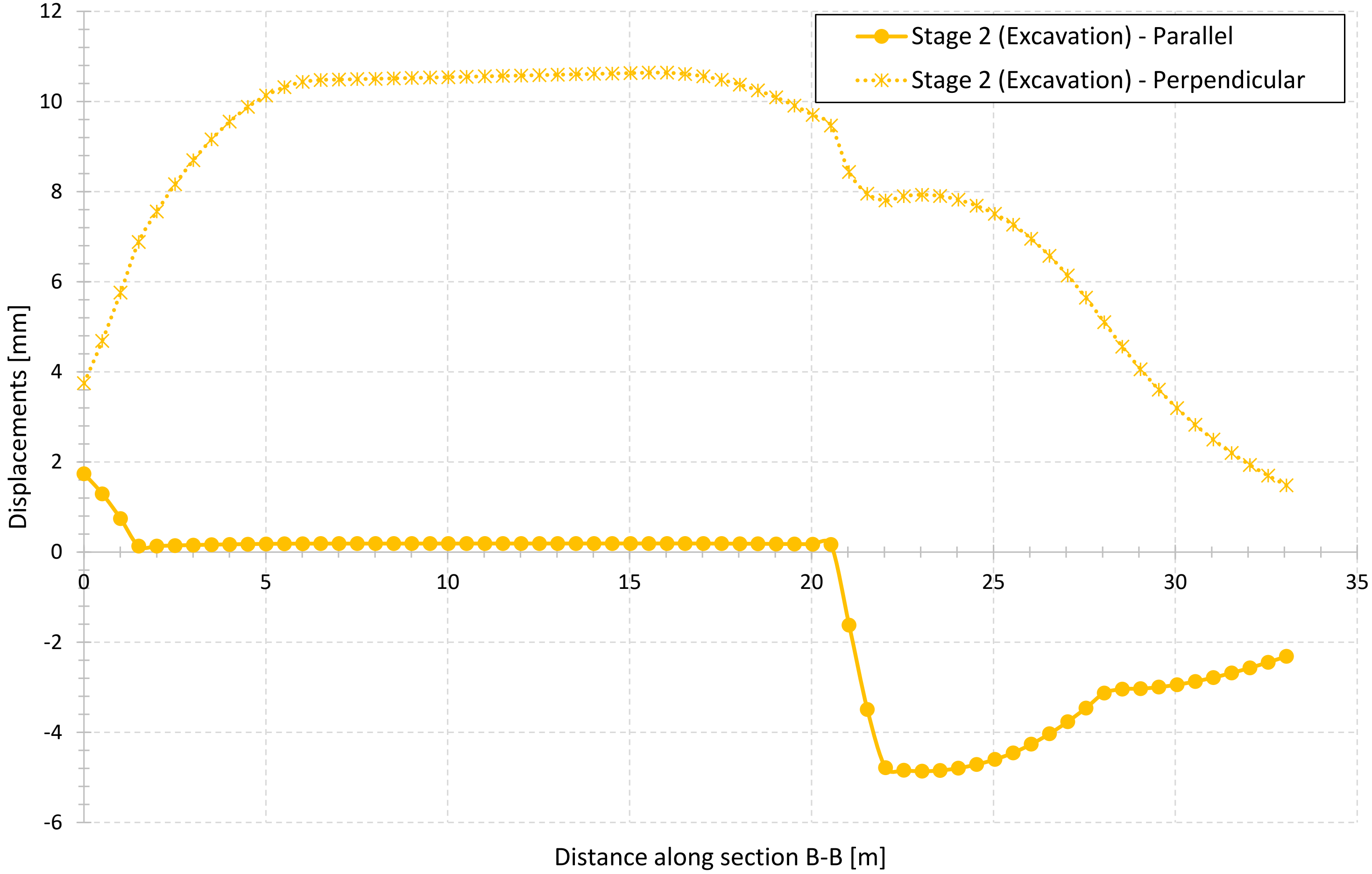
British Museum

East Road Building redevelopment

Predicted horizontal movements along Section A-A

Positive sign for parallel movements means that the orientation of movements is the same of the orientation of the assessed profile

Figure 30



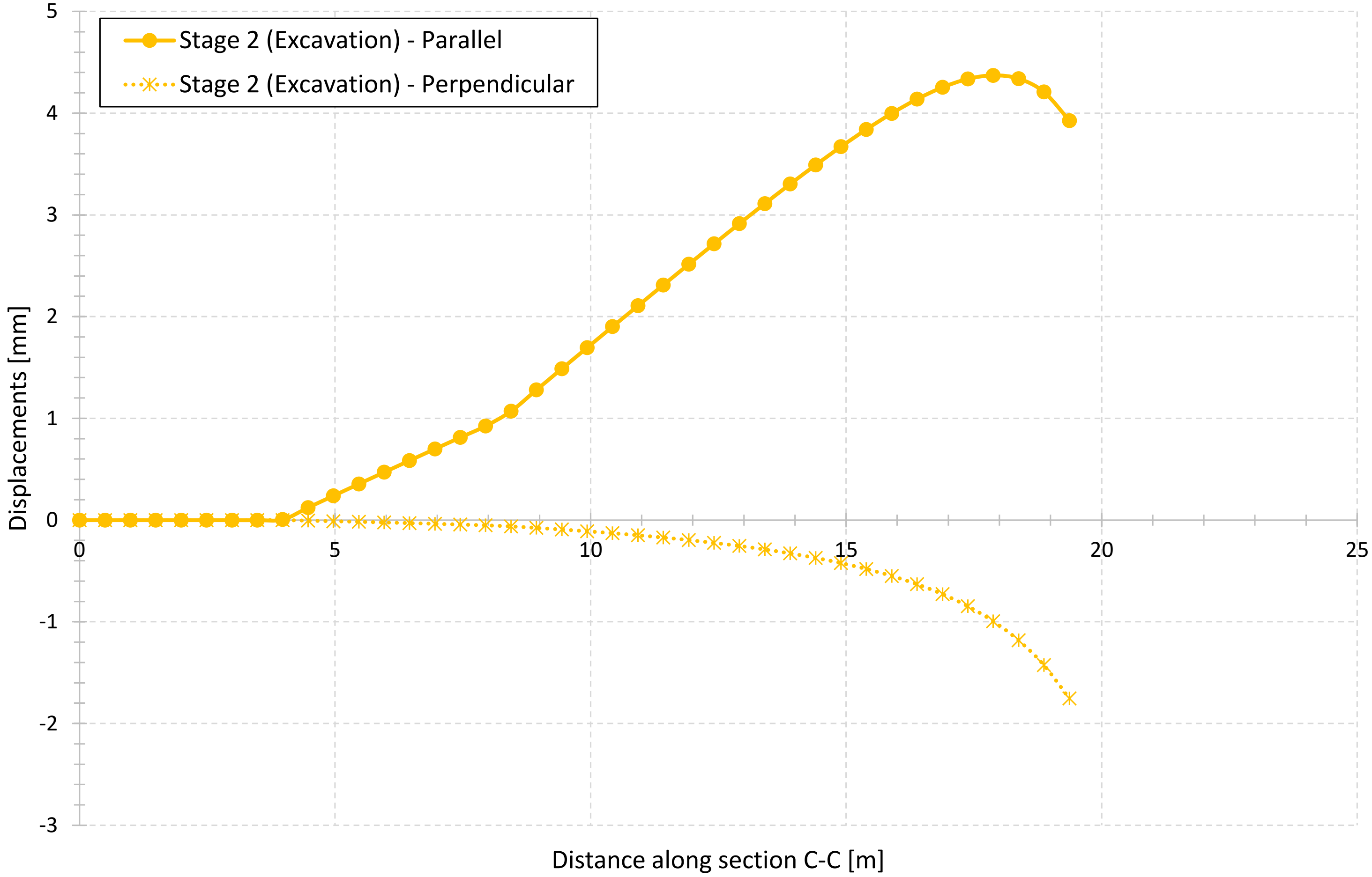
British Museum

East Road Building redevelopment

Predicted horizontal movements along Section B-B

Positive sign for parallel movements means that the orientation of movements is the same of the orientation of the assessed profile

Figure 31



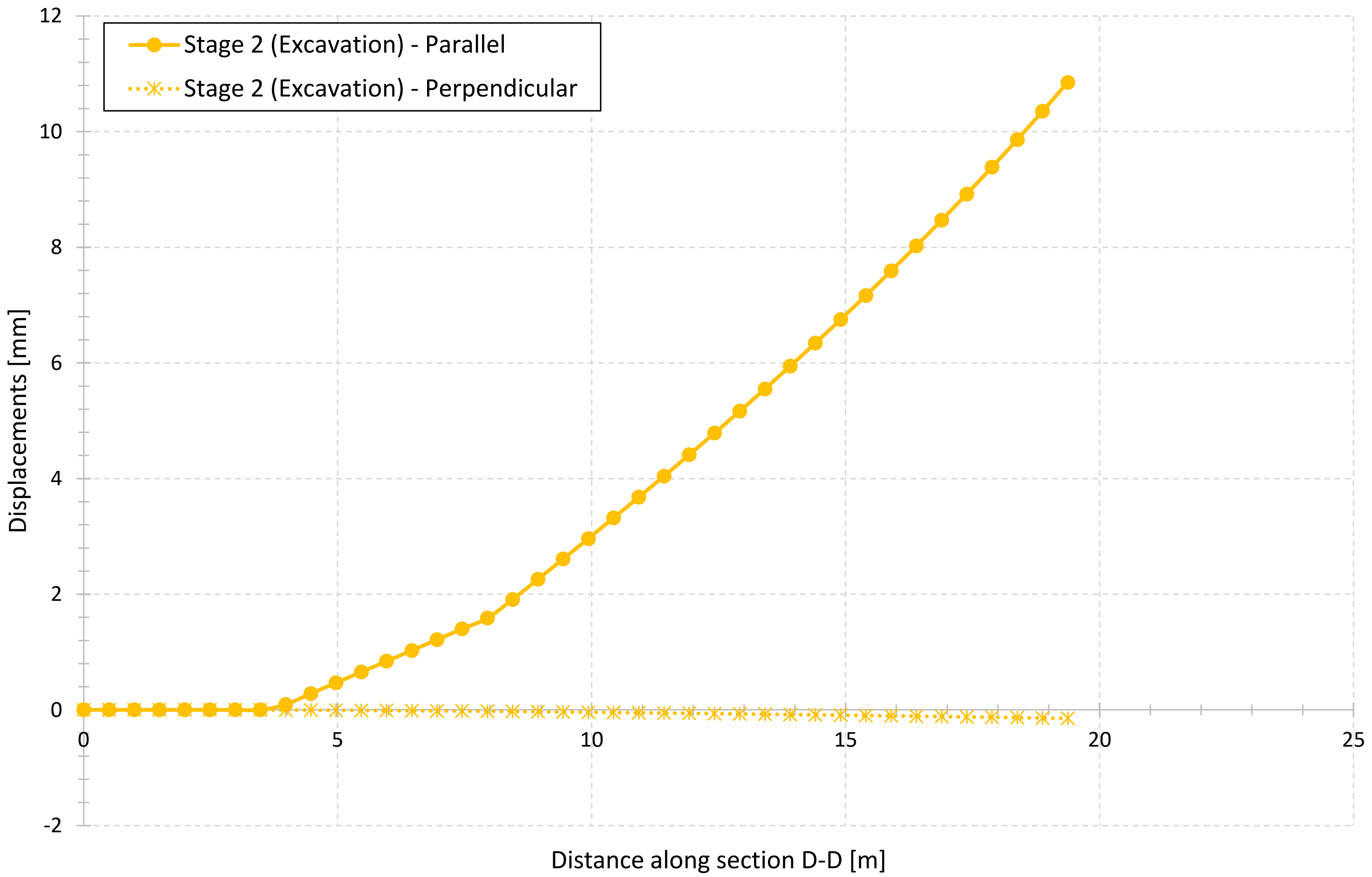
British Museum

East Road Building redevelopment

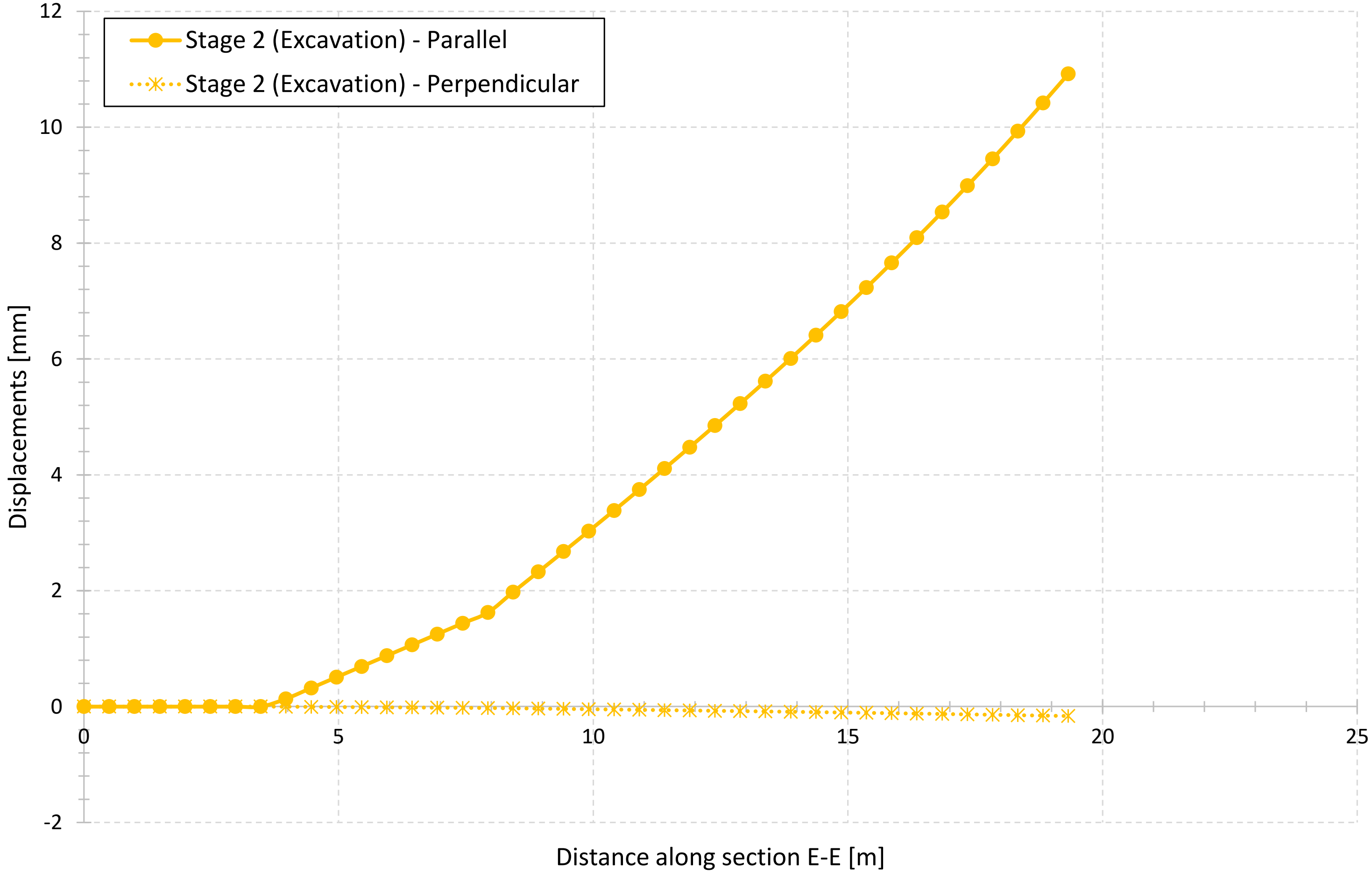
Predicted horizontal movements along Section C-C

Positive sign for parallel movements means that the orientation of movements is the same of the orientation of the assessed profile

Figure 32



	British Museum East Road Building redevelopment	**Figure 33**
	Predicted horizontal movements along Section D-D Positive sign for parallel movements means that the orientation of movements is the same of the orientation of the assessed profile	



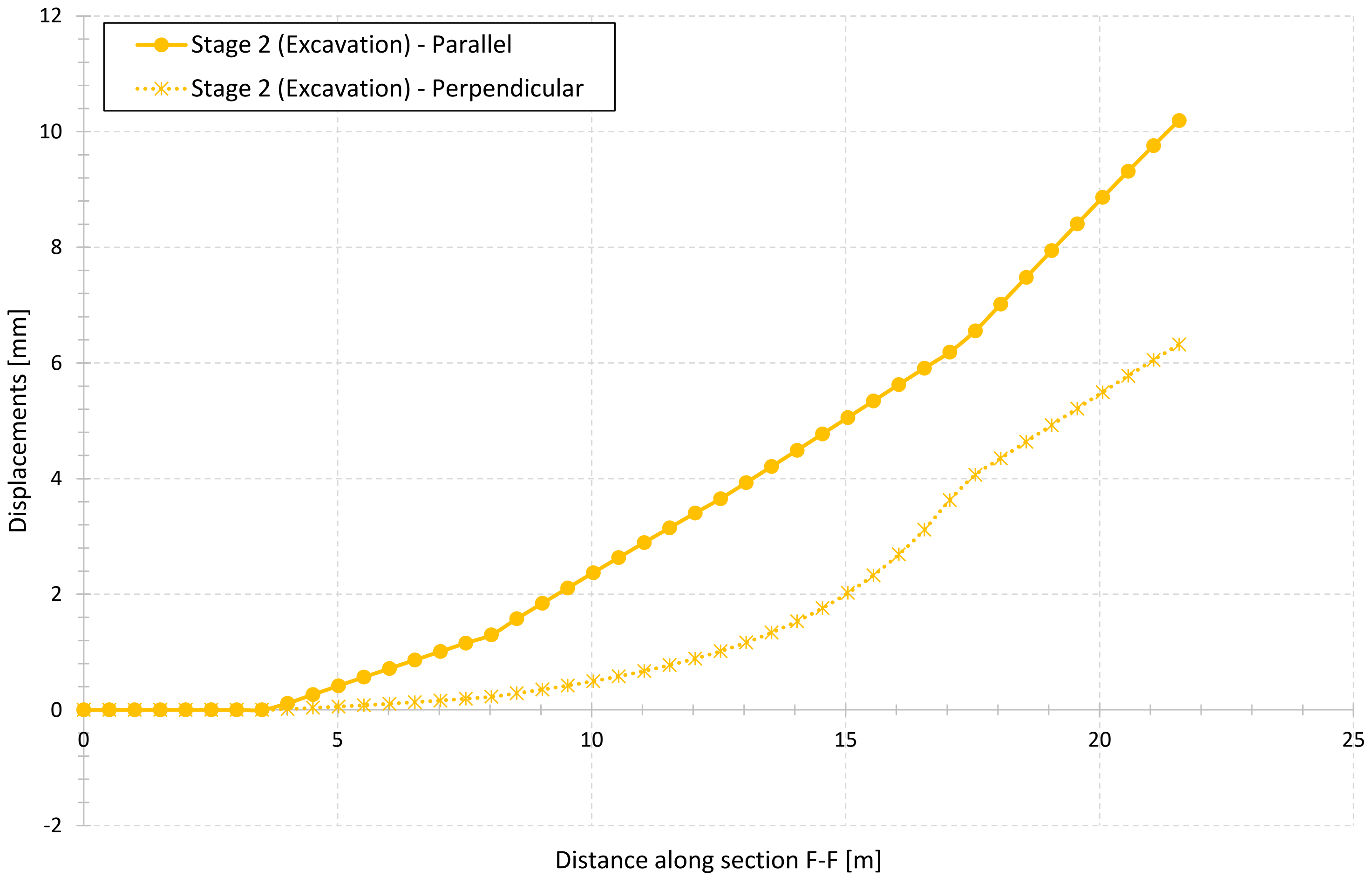
British Museum

East Road Building redevelopment

Predicted horizontal movements along Section E-E

Positive sign for parallel movements means that the orientation of movements is the same of the orientation of the assessed profile

Figure 34



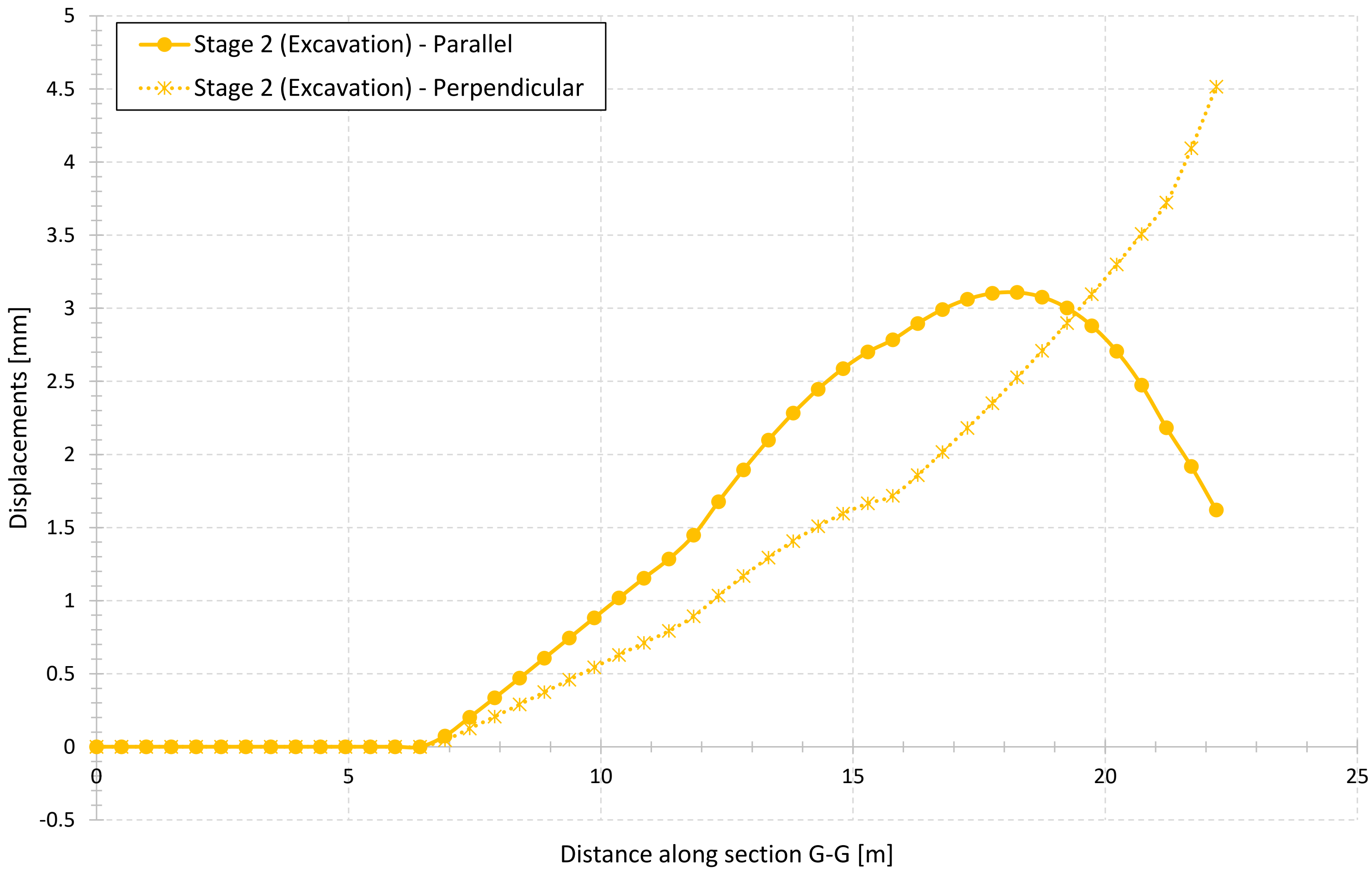
British Museum

East Road Building redevelopment

Predicted horizontal movements along Section F-F

Positive sign for parallel movements means that the orientation of movements is the same of the orientation of the assessed profile

Figure 35



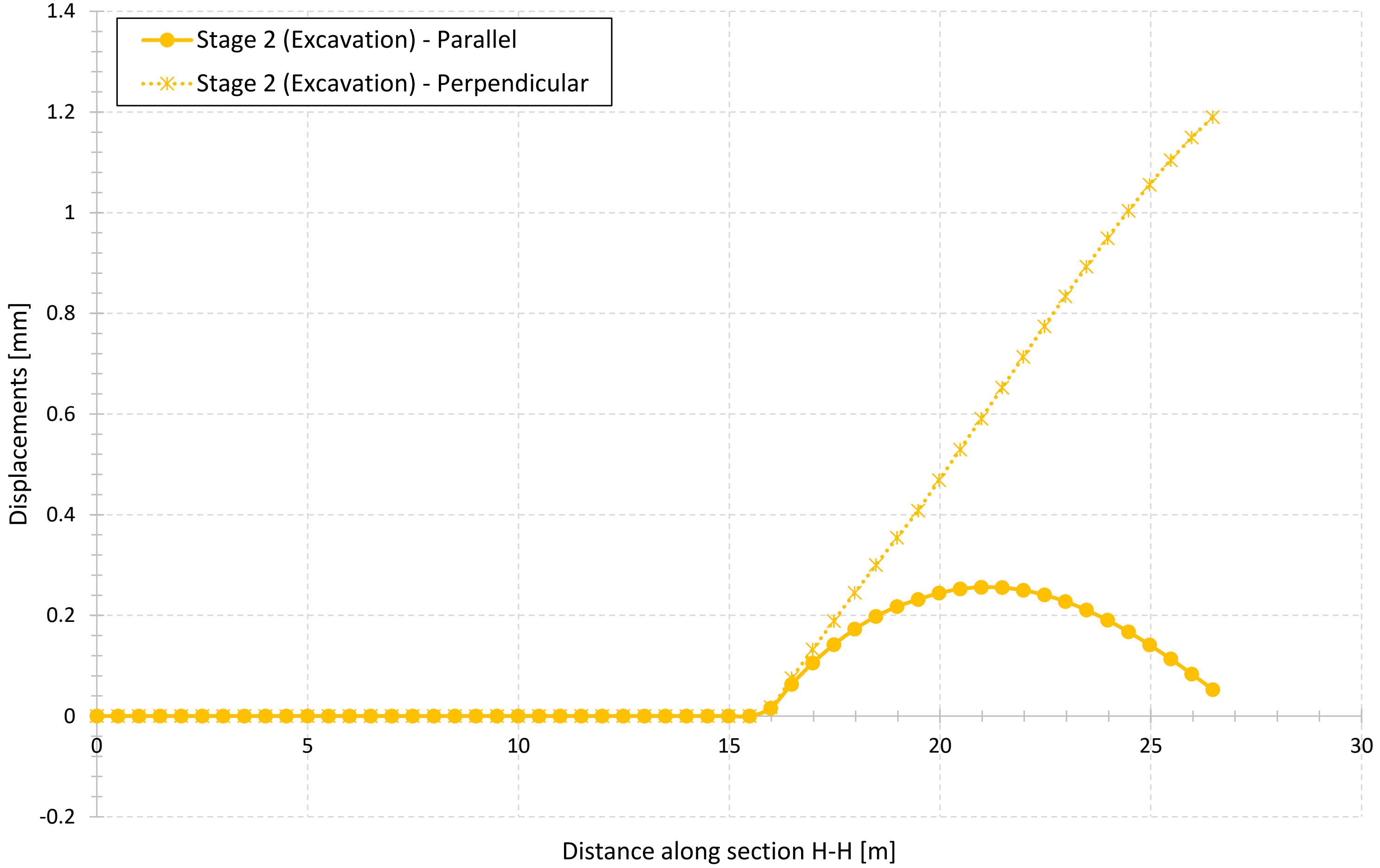
British Museum

East Road Building redevelopment

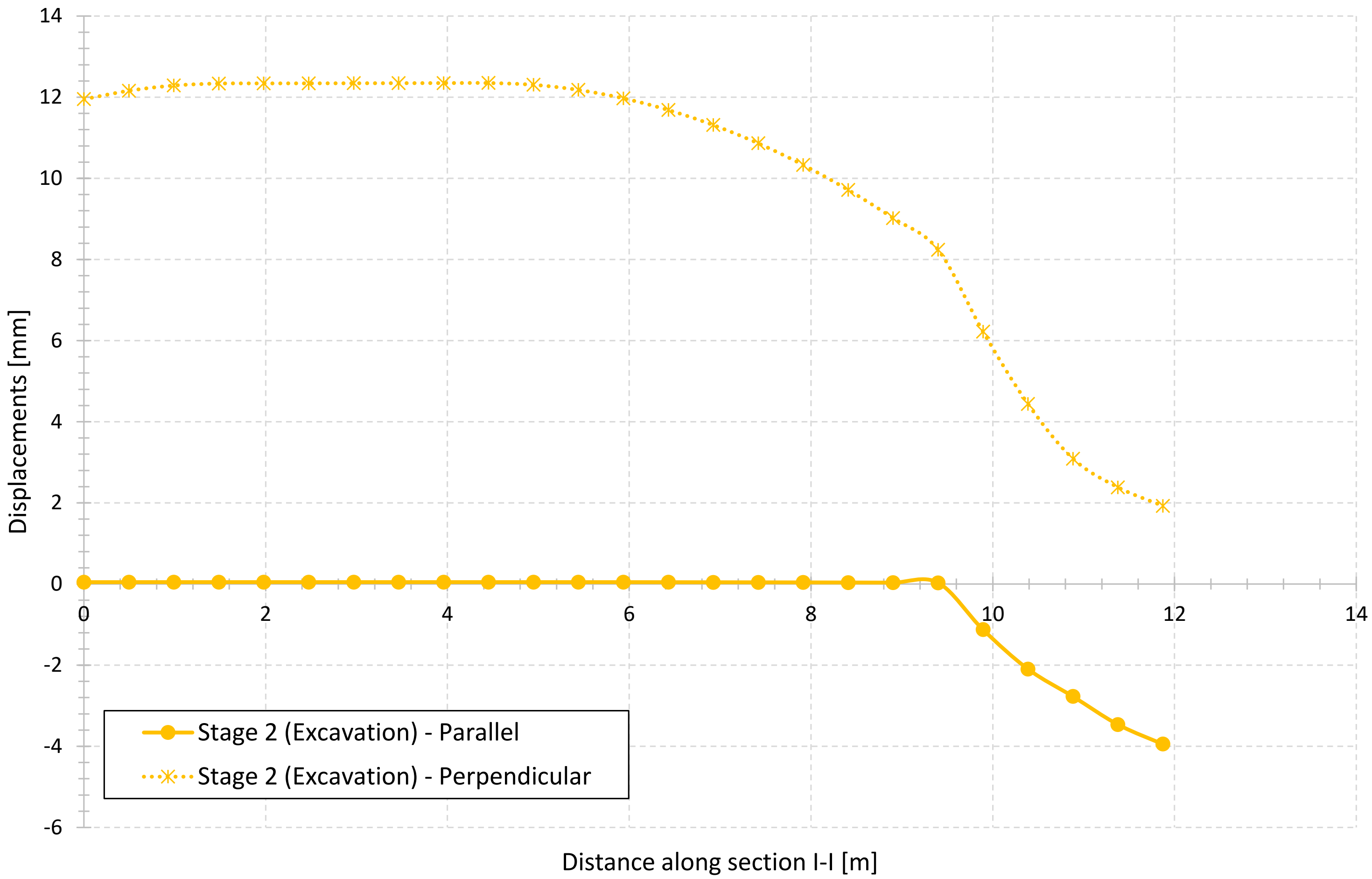
Predicted horizontal movements along Section G-G

Positive sign for parallel movements means that the orientation of movements is the same of the orientation of the assessed profile

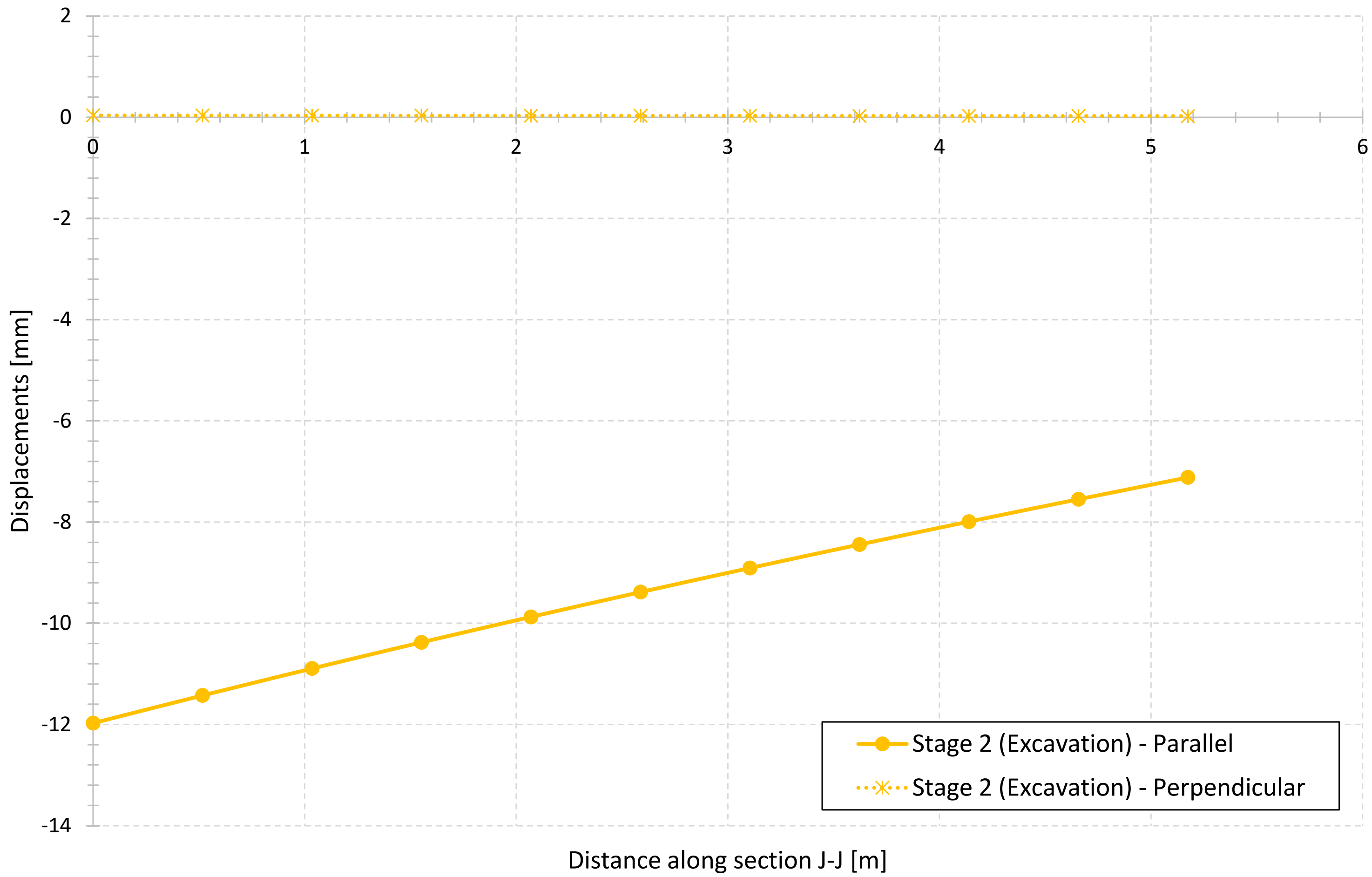
Figure 36



	British Museum East Road Building redevelopment	Figure 37
	Predicted horizontal movements along Section H-H Positive sign for parallel movements means that the orientation of movements is the same of the orientation of the assessed profile	



	British Museum East Road Building redevelopment	**Figure 38**
	Predicted horizontal movements along Section I-I Positive sign for parallel movements means that the orientation of movements is the same of the orientation of the assessed profile	



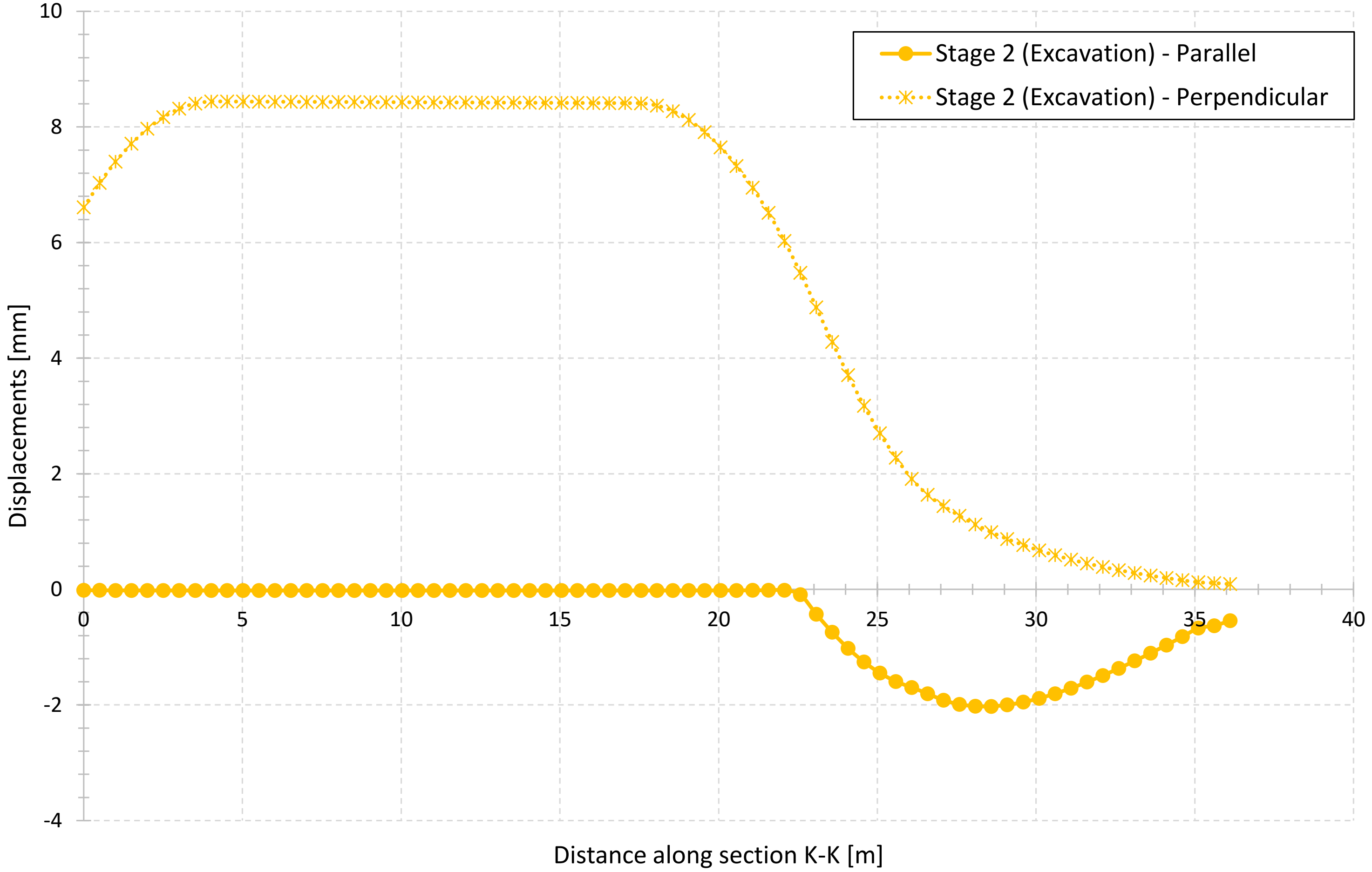
British Museum

East Road Building redevelopment

Predicted horizontal movements along Section J-J

Positive sign for parallel movements means that the orientation of movements is the same of the orientation of the assessed profile

Figure 39



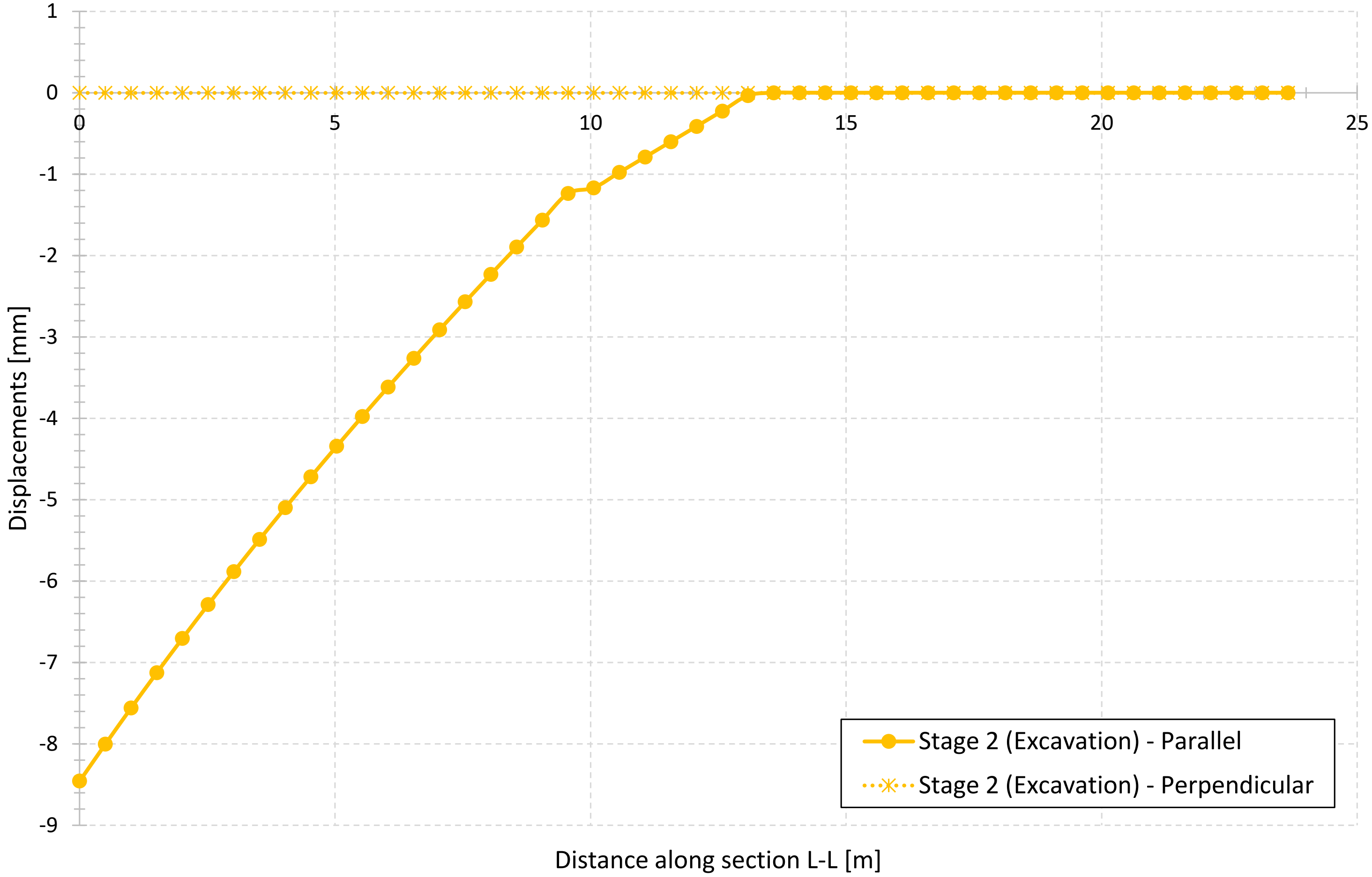
British Museum

East Road Building redevelopment

Predicted horizontal movements along Section K-K

Positive sign for parallel movements means that the orientation of movements is the same of the orientation of the assessed profile

Figure 40



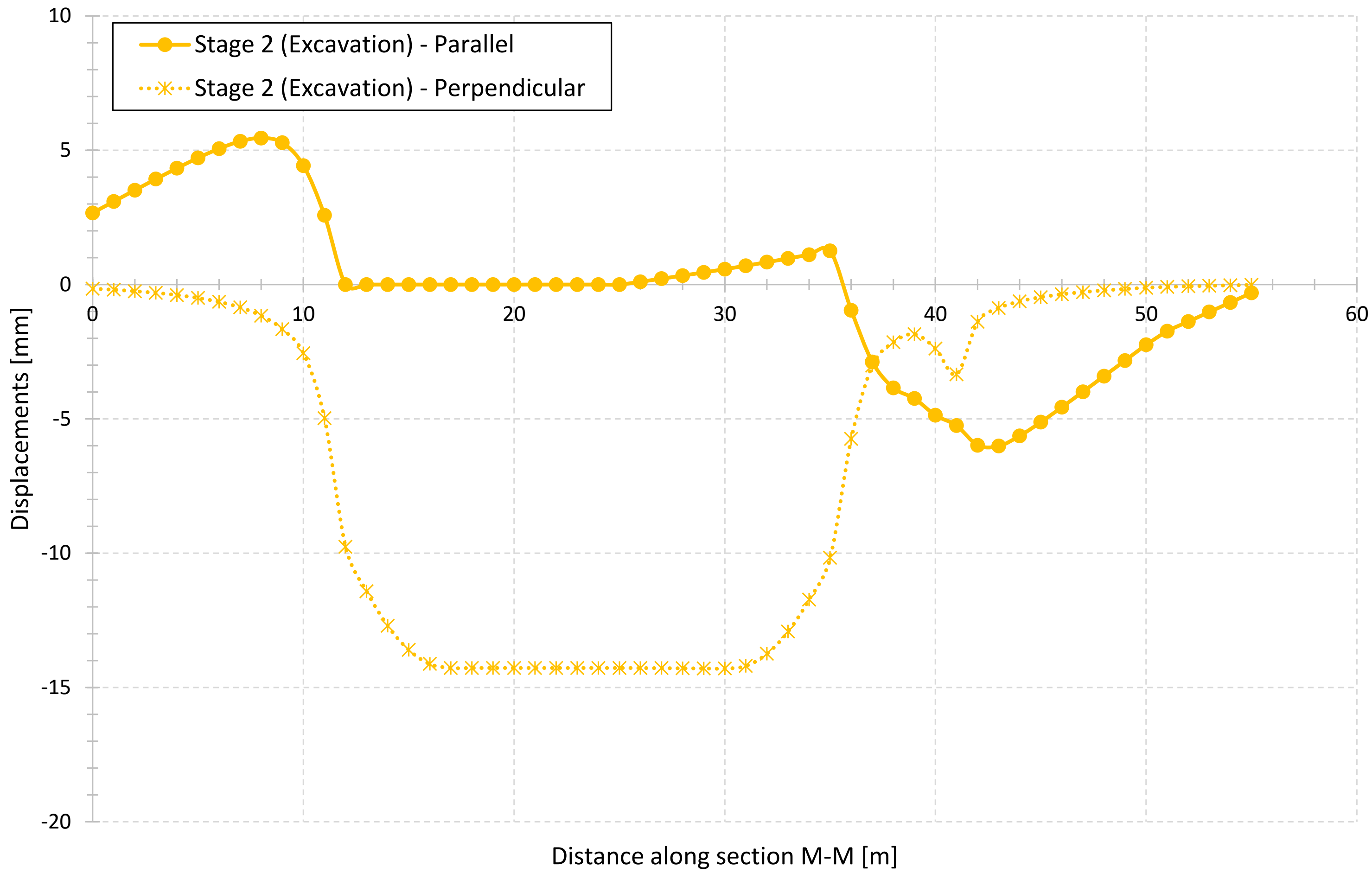
British Museum

East Road Building redevelopment

Predicted horizontal movements along Section L-L

Positive sign for parallel movements means that the orientation of movements is the same of the orientation of the assessed profile

Figure 41



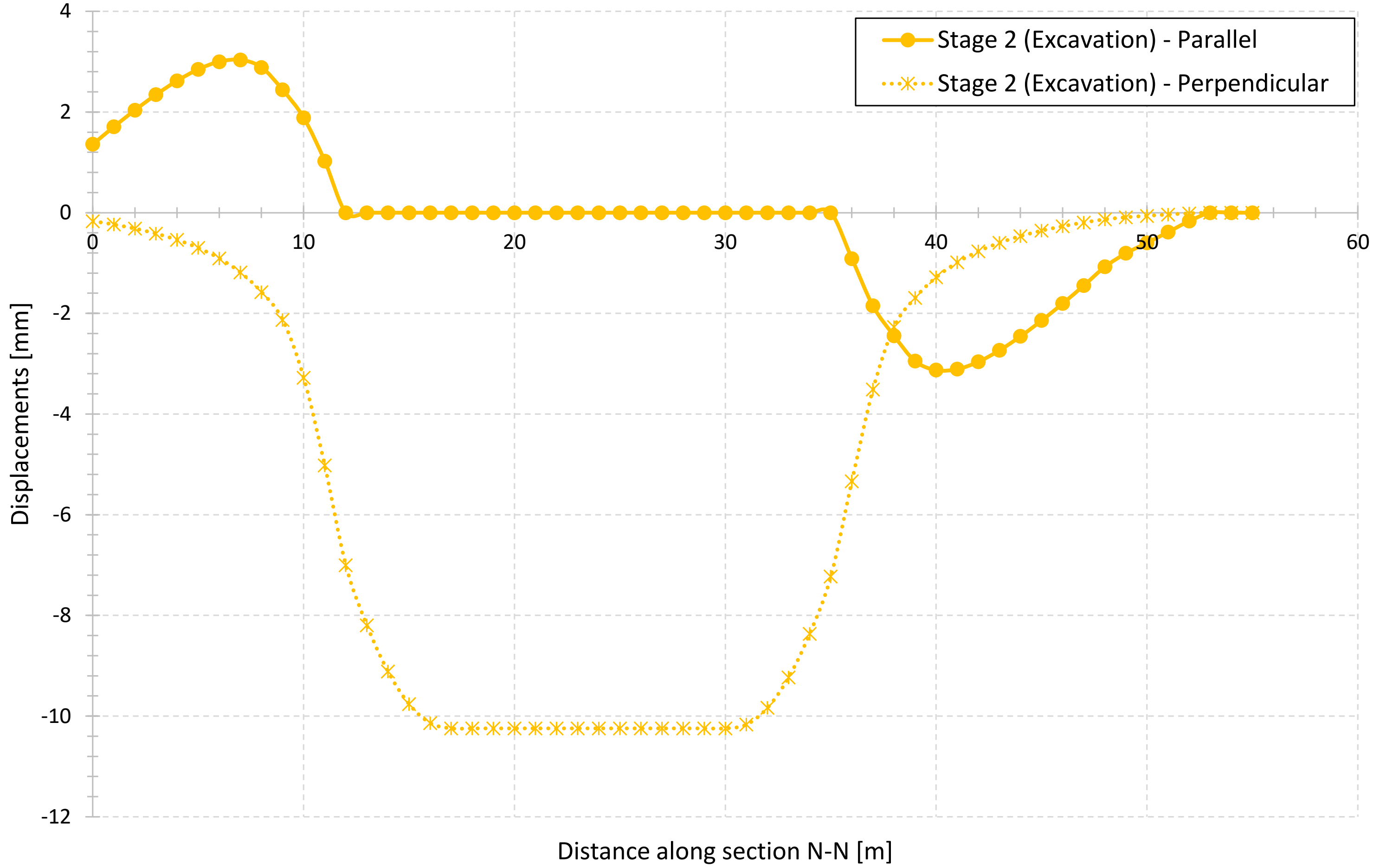
British Museum

East Road Building redevelopment

Predicted horizontal movements along Section M-M

Positive sign for parallel movements means that the orientation of movements is the same of the orientation of the assessed profile

Figure 42



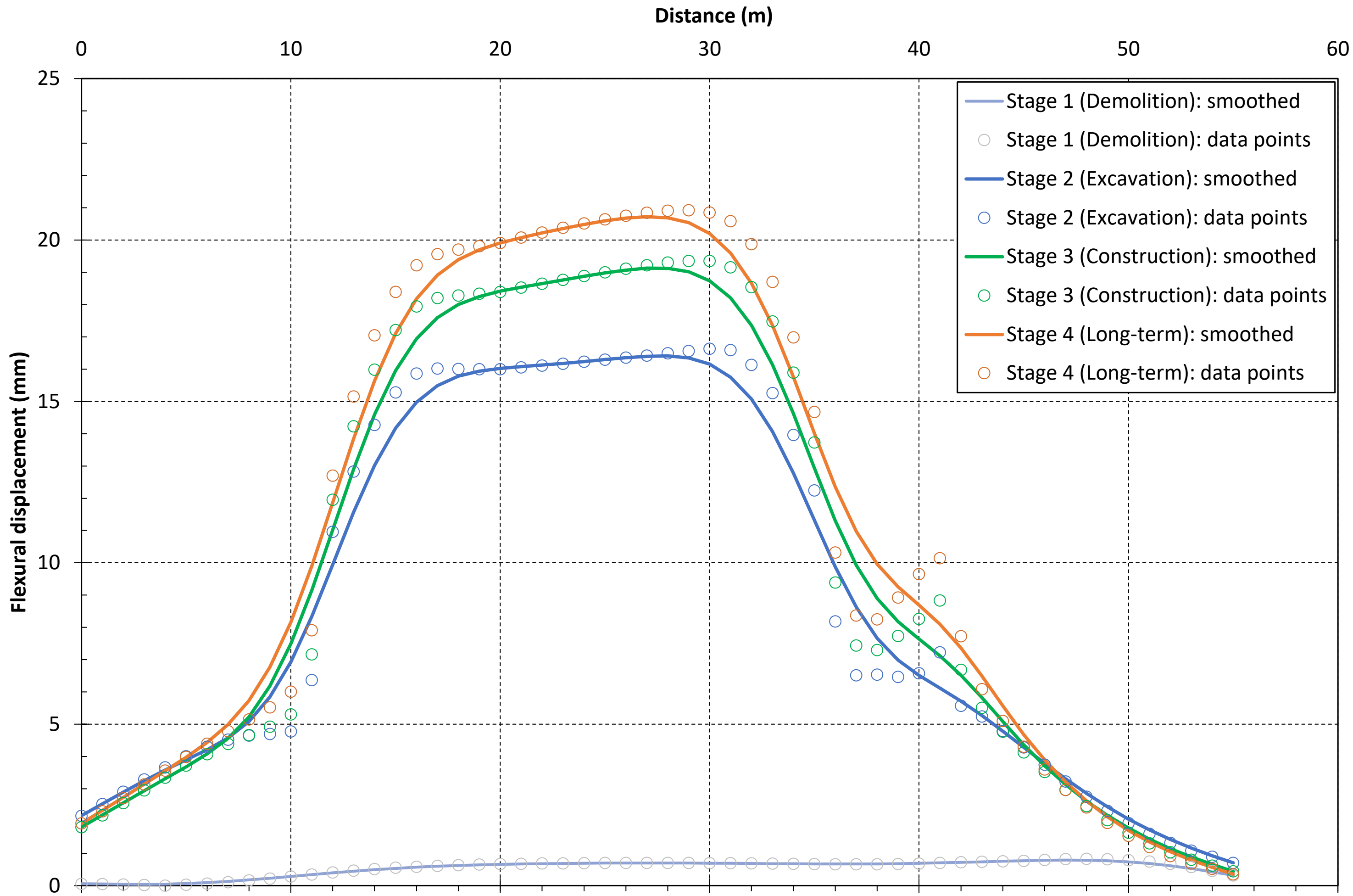
British Museum

East Road Building redevelopment

Predicted horizontal movements along Section N-N

Positive sign for parallel movements means that the orientation of movements is the same of the orientation of the assessed profile

Figure 43

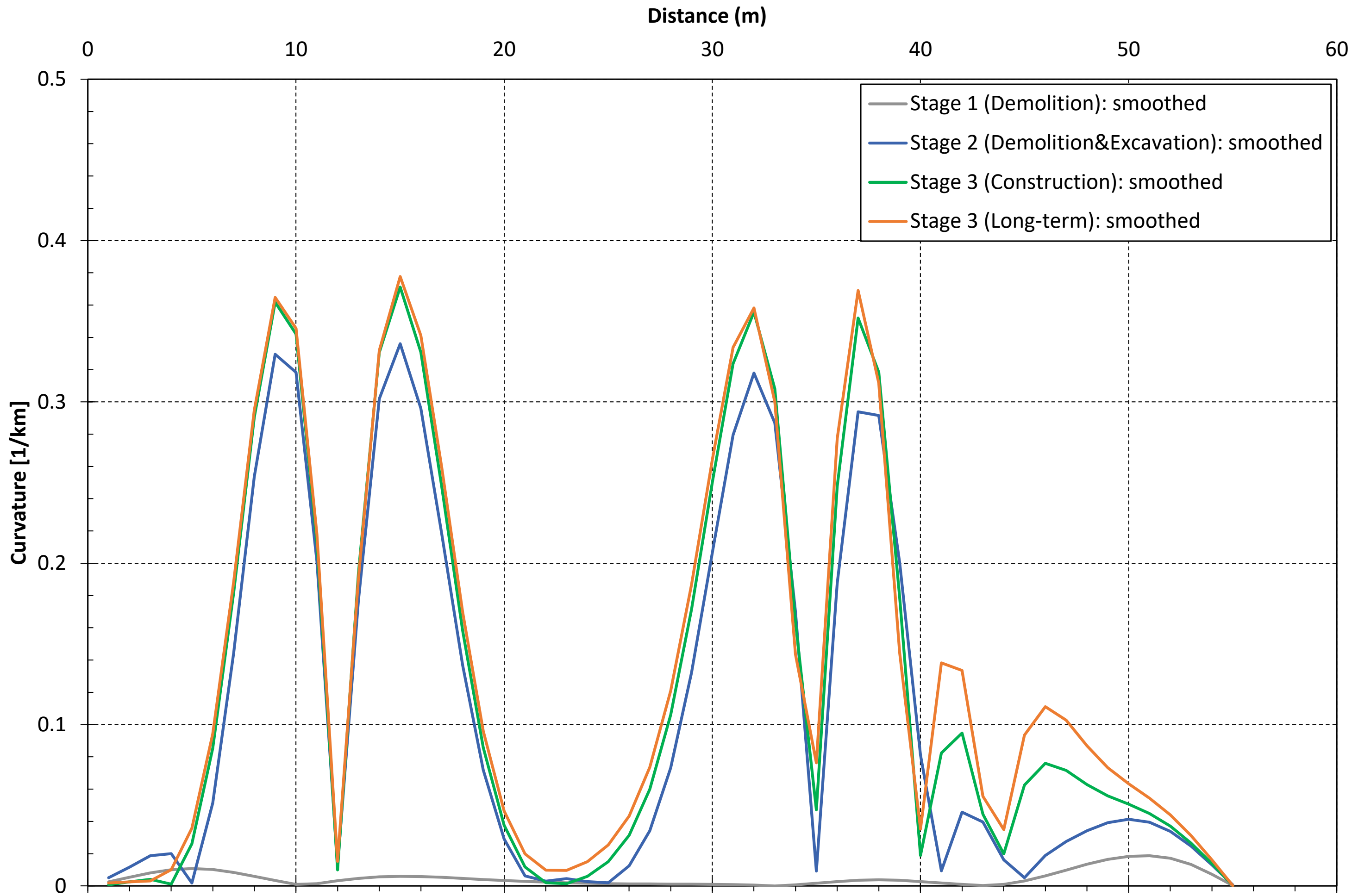


British Museum

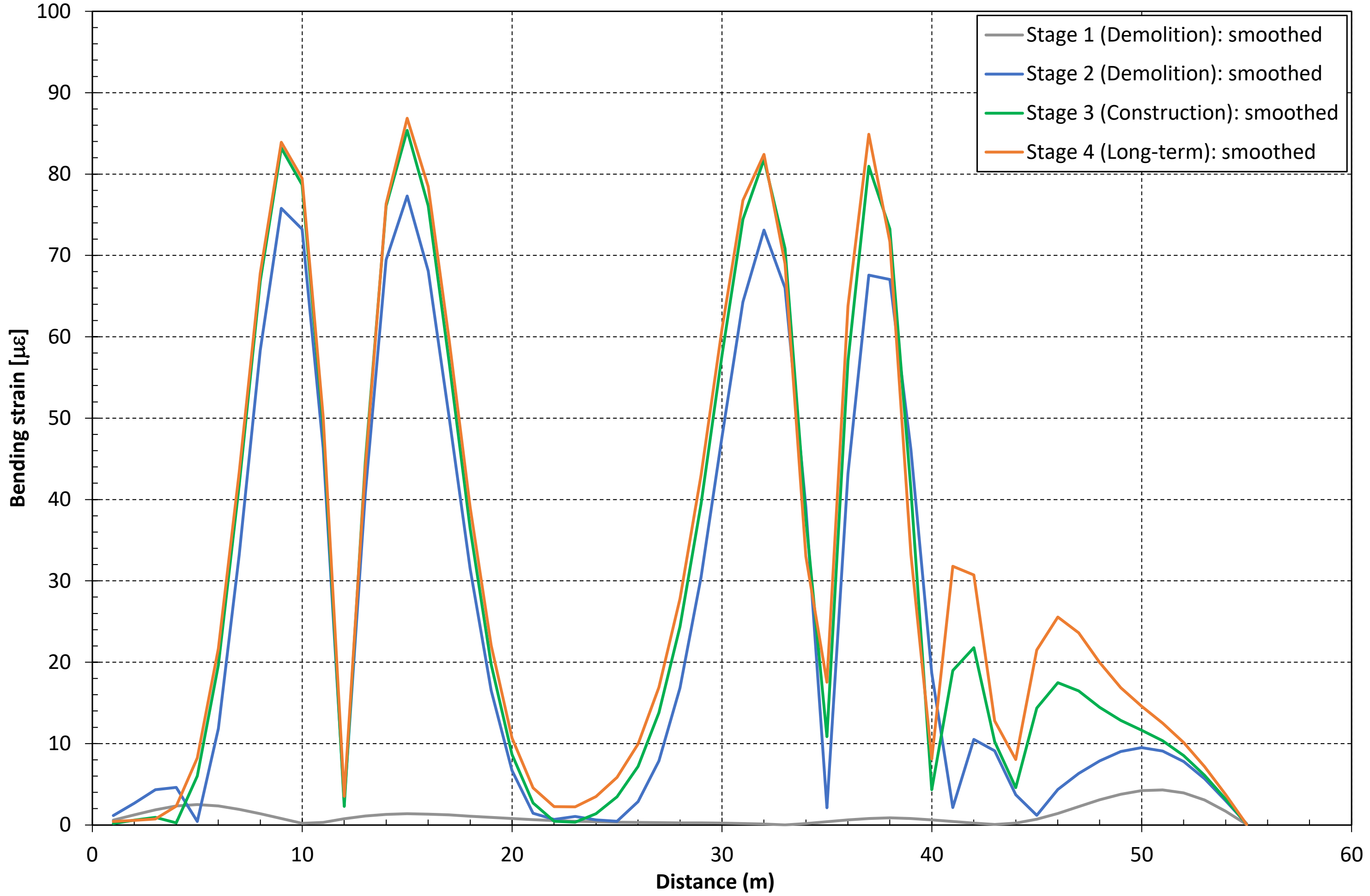
East Road Building redevelopment

Predicted flexural displacement along Section M-M

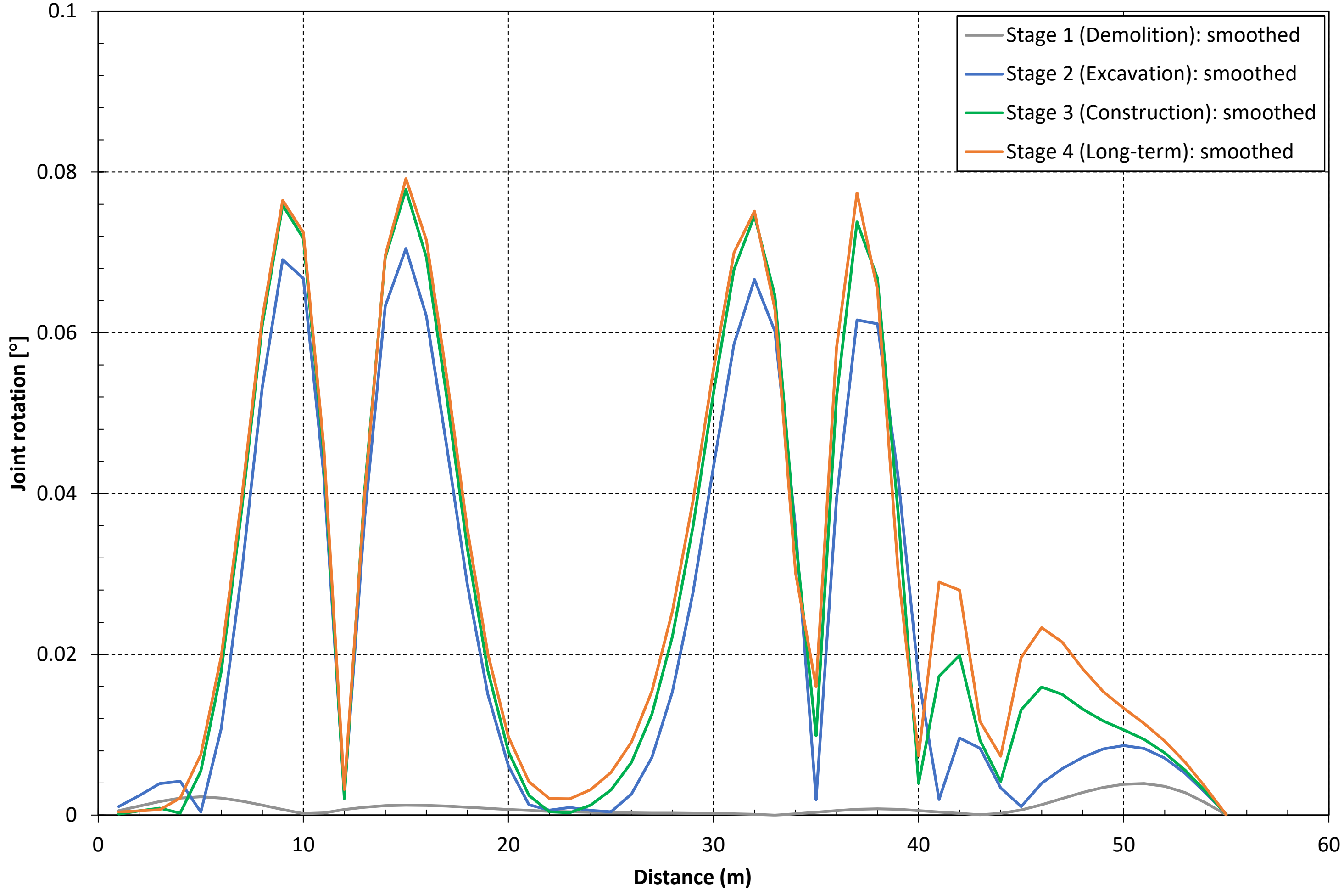
Figure 44



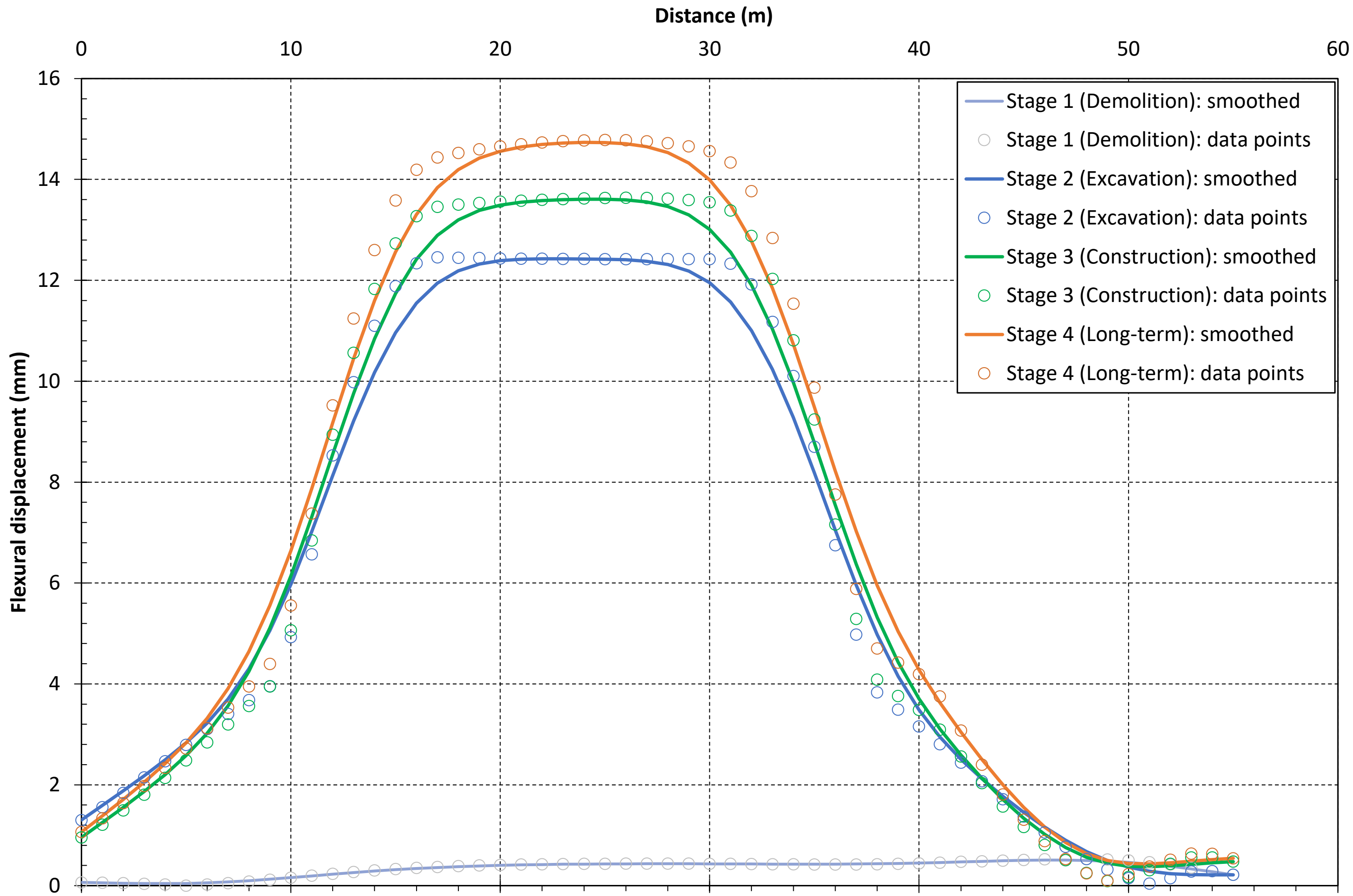
GCG	**British Museum** East Road Building redevelopment	**Figure 45**
	Predicted radius of curvature along Section M-M	



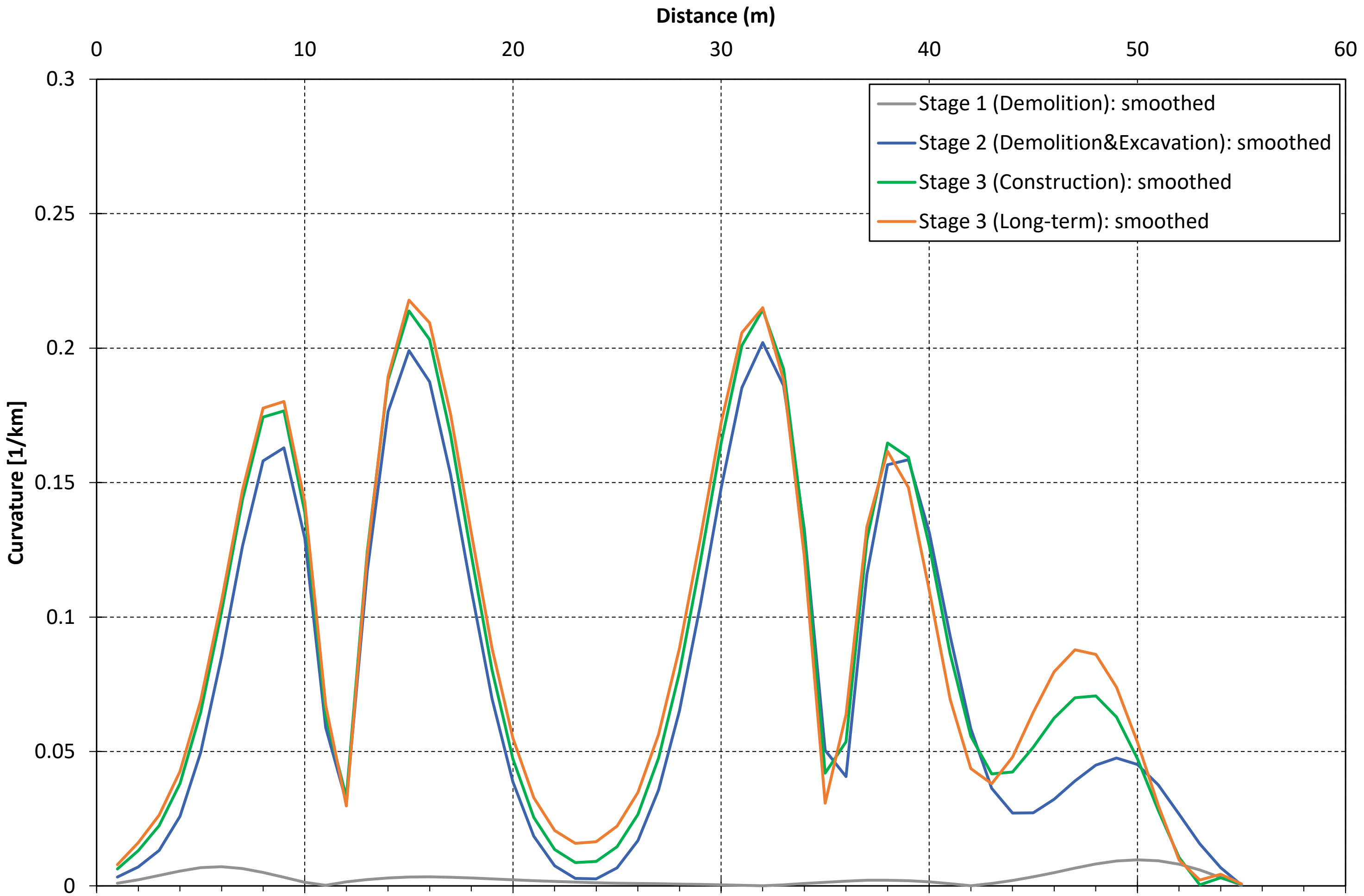
British Museum East Road Building redevelopment		**Figure 46**
Predicted bending strain along Section M-M		



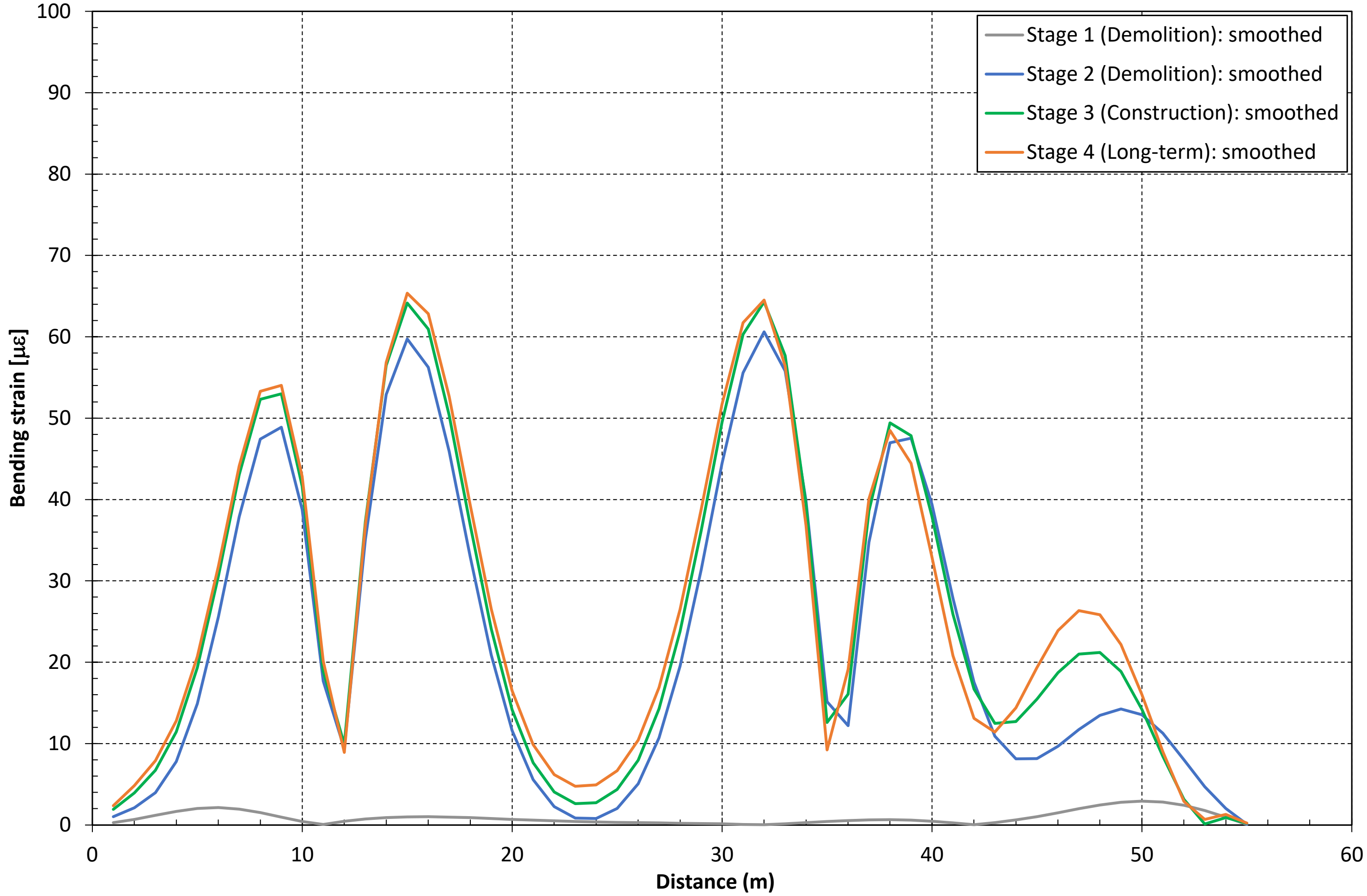
	British Museum East Road Building redevelopment	**Figure 47**
	Predicted joint rotation along Section M-M	



British Museum East Road Building redevelopment		**Figure 48**
Predicted flexural displacement along Section N-N		



British Museum East Road Building redevelopment	**Figure 49**	
Predicted radius of curvature along Section N-N		

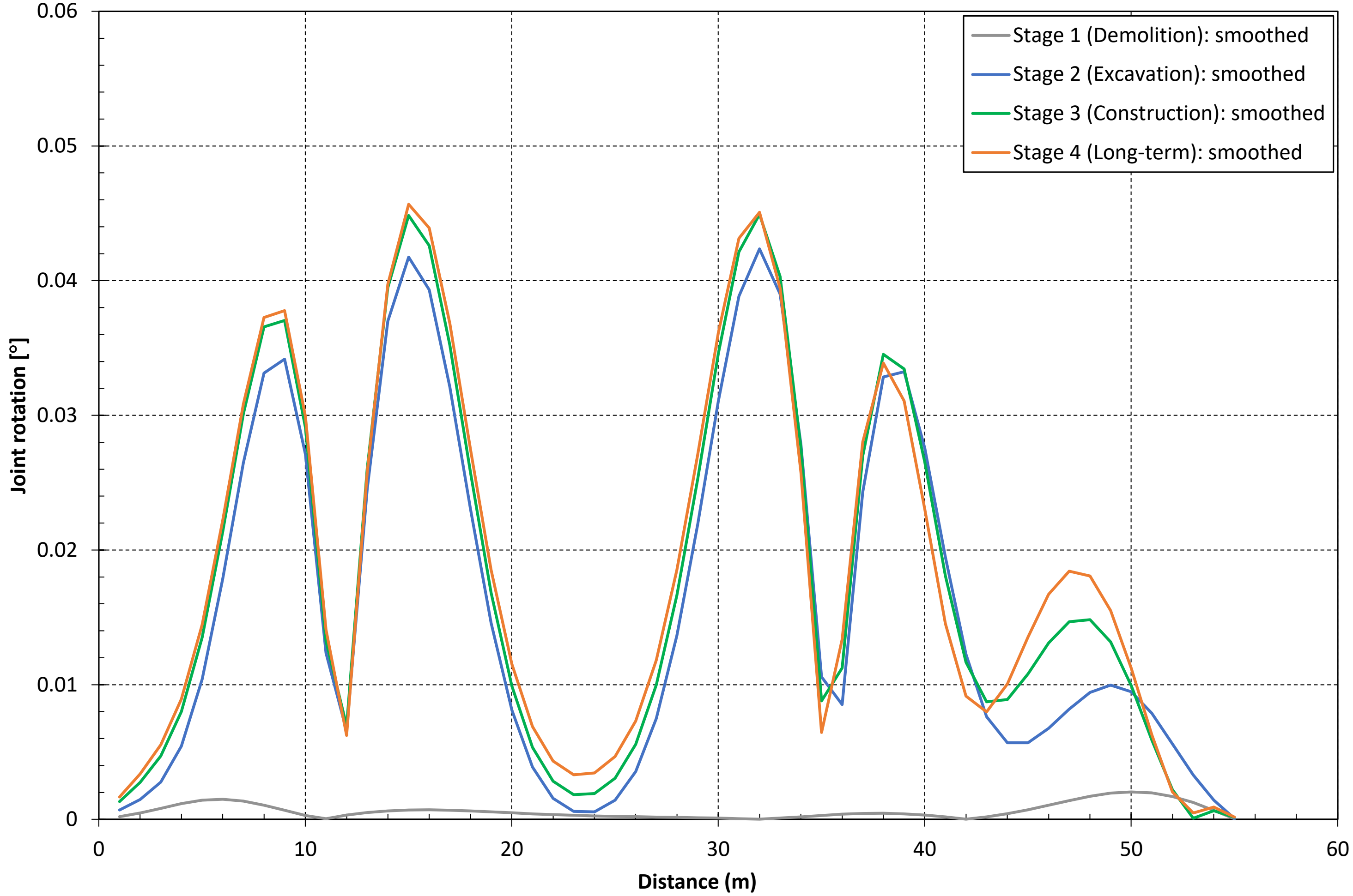


British Museum

East Road Building redevelopment

Predicted bending strain along Section N-N

Figure 50



British Museum

East Road Building redevelopment

Predicted joint rotation along Section N-N

Figure 51