A10.2 – Building Damage Assessment Reports

Building A4: 27 Poultry/5 Prince’s Street

Building A5: 1 Princes Street

Building A6: Mansion House

Building A7: 1-6 Lombard Street

Building A10: 13 Sherbourne Road, 19 St. Swithin’s Lane, 20 St. Swithin’s Lane and 21-23 St. Swithin’s Lane

Building A11: 1 King William Street

Building A12: 5 King William Street

Building A13: 15 Abchurch Lane

Building A14: St. Mary Abchurch

Building A16: 121 Cannon Street

Building A17: 123-127 Cannon Street

Building A18: 129 Cannon Street

Building A27: Guild Church of St. Mary Woolnoth

Building A34: 29 Martin Lane

Building A39: Adelaide House

Building B1: 3-4 Lothbury

Building B3: Bank of England

Building B5: 1 Queen Victoria, Magistrates Court

Building B18: Fishmongers’ Hall

Building B21: St. Clement’s Church

Building B22: 27 Clement’s Lane

Building B23: 6-8 Clement’s Lane

Building B24: 24 Lombard Street

Building B26: 1 Cornhill / 82 Lombard Street

Building B29: Duke of Wellington Statue

Building B31: 6 Lothbury

Building B33: 4 Moorgate

Building B34: 7-11 Moorgate

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Bank Station Capacity Upgrade

Building Damage Assessment Report

Building A4

27 Poultry/5 Princes Street

URS-8798-RPT-G-001168

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Document History

Revision	Date	Summary of changes
1.0	March 2014	Issue for Heritage
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1 Introduction

This report summarises the results of a Stage 2 damage assessment for 27 Poultry/5 Princes Street (Building ref. A4).

Stage 2 damage assessments are undertaken for all buildings within the Stage 1 Greenfield ground surface 1mm settlement contour induced by the construction of the Bank Station Capacity Upgrade (BSCU).

The purpose of the assessment is to determine the potential impact that the works will have on the building. This report describes the engineering and heritage assessments undertaken for the building and concludes whether mitigation is likely to be needed and if a further (Stage 3) assessment is recommended in order to verify this.

2 The Building

2.1 General Information

27 Poultry/5 Princes Street is located adjacent to the 1 Princes Street building. The building occupies a site that runs parallel with Princes Street and Poultry Street with access from both of these streets. The general building information used in the assessment has been acquired as part of the structural desktop appraisal. This information is presented in Table 1.

Category	Building Information
BSCU Reference	A4
Location	27 Poultry, 5 Princes Street
Address	27 Poultry, 5 Princes Street
Building Type	Steel framed and R.C. framed
Construction Age	1924-1939
No. of Storeys	7
Basements	3
Roof Level (mATD)	151.1
Foundation Type	Mixed Raft and Piled (NW façade).
Ground Level (mATD)	113.2
Listed Grade	Grade I
Note: Levels given refer to metres above Tunnel Datum, mATD. Tunnel Datum is 100m below Ordnance Survey Datum at Newlyn	

Table 1: General building information

A general view of the building exterior is shown in Plate 1. A location plan showing the building in relation to the proposed BSCU works is presented in Figure 2.

Plate 1: General view

2.2 Building Description

27 Poultry/5 Princes Street is a Grade I listed building with its main façade on Poultry. The original building and modern extensions occupy a large, irregular lot between Poultry and Princes Street and has historically been home to banking institutions. It was built during the years 1924-1939 by the architect Sir Edwin Lutyens in collaboration with Gotch & Saunders as the headquarters of the Midland Bank.

The building retains original Lutyens designed elements, including the original elevations, the banking hall with marble staircase, the safe deposit in the first basement and the entire fifth floor comprising a suite of accommodation for bank directors.

The building is in Classical style with a Portland stone clad façade including sculptural elements and single and double attics. There is a low central dome. The arcaded ground storey is clad with rusticated blocks, and there are pilasters and Doric columns to the recessed entrance. The mezzanine holds sculpted figures of boys designed by Lutyens and carved by Sir William Reid Dick. The tall arcade to above is treated with channelled stonework. The projecting attic with Corinthian pilasters and pediment frames a large, arched opening. To the internal courtyards, plain elevations are clad with white, glazed brick and stone cladding to the ground storey. On Princes Street the short elevation has a simplified classical façade.

The building is made of masonry with steel framed construction, concrete floors with some concrete walls in the basement. Stability is probably provided by a masonry façade, core and internal walls on concrete raft foundation. A major 1970s extension added a rectangular concrete-framed structure over four storeys plus two mansard storeys and two basements. The top two floors are steel portal mansard frames, where the lower floors and basement is reinforced concrete frame. The building is currently empty and stripped out of all but the historic finishes. There are proposals to refurbish the building and turn it into a hotel. Structural changes proposed are minimal and are limited to re-arranging the core to add 2 lifts. A piled wall, as temporary works, is proposed to facilitate the construction of the core. Additional storeys will be added to both the original building and 70's extension.

The older building has three level basements. Over the majority of the building it is assumed that a 1.3m thick raft is below the basement level of 102.6mATD. The foundation level is assumed to be at 101.3mATD. The original structure is a steel frame. The later extension is a RC frame with two levels of basement. There is record of 8 number piles being installed along its northern façade.

The toe level of the piles is unknown. Calculations indicate that they could extend to the proposed tunnel level. The alignment of the tunnel will possibly intersect some of these piles. The source drawing is presented as Figure 4.

3 Methodology

This building damage assessment is undertaken in accordance with LU Works Information WI2300[1] and LU Civil Engineering - Common Requirements S1050[2].

The analysis methodology applies to ground-bearing buildings which will be affected by ground movements resulting from the construction of the BSCU. The engineering assessment calculates the potential impact of ground movements and assigns a damage category to the building based on a numeric scale. Additionally, for listed buildings, a heritage assessment is carried out which considers the sensitivity of the structure and the sensitivity of its particular features; a heritage sensitivity score is assigned. The heritage sensitivity score is added to the damage category to obtain the total score. If the total score is 3 or more, a more detailed Stage 3 assessment is triggered.

Oasys Xdisp is used to analyse the Greenfield ground movement in terms of settlement and horizontal displacement. Subsurface tunnelling induced ground movement profiles are determined in accordance with the methodology described by Mair et al[3 & 4].

Movements resulting from the Whole Block Scheme (WBS) and shaft excavations have been calculated using LU Guidance Document G0058[5].

An assessment of the load capacity of the pile versus depth shows that it is only a possibility that they extend to the tunnel level. It is proposed that should the piles be encountered they are trimmed to above the tunnel lining and structurally isolated from it. The change in performance of a friction pile of this length which has some shaft removed is very small. The damage assessment does not address the piles specifically since they influence a very small part of the whole building. There is a two basement level high reinforced concrete wall over them spanning across the tunnel line. It is therefore considered that the stiffness of the building will redistribute the loads and effects arising from the potential additional settlement of the piles.

The building is modelled as a simple elastic beam which is conservatively assumed to follow the Greenfield ground displacements. The beam is divided into hogging and sagging segments. The tensile strains within each segment are calculated based on the distortion associated with differential settlement (which is characterised by deflection ratio) and the distortion associated with differential horizontal displacement (characterised by horizontal strain).

Xdisp provides a method for calculating the maximum tensile strain within the building superstructure associated with these movements, in accordance with the assessment methodology described by Mair et al[4]. This strain is used to determine the damage category for traditional masonry structures based on the classification system proposed by Burland[6] and in accordance with LU Civil Engineering - Common Requirements S1050[2]. The categories are presented in Table 2.

Damage category	Description of degree of damage	Description of typical damage and likely forms of repair for typical masonry buildings.	Approx. crack width (mm)	Max. tensile strain %
0	Negligible	Hairline cracks.		< 0.05
1	Very slight	Fine cracks easily treated during normal redecoration. Perhaps isolated slight fracture in building. Cracks in exterior visible upon close inspection.	0.1 to 1.0	0.05 to 0.075
2	Slight	Cracks easily filled. Redecoration probably required. Several slight fractures inside building. Exterior cracks visible; some repainting may be required for weather-tightness. Doors and windows may stick slightly.	1 to 5	0.075 to 0.15
3	Moderate	Cracks may require cutting out and patching. Recurrent cracks can be masked by suitable linings. Tuck pointing and possible replacement of a small amount of exterior brickwork may be required. Doors and windows sticking. Utility services may be interrupted. Weather tightness often impaired.	5 to 15 or a number of cracks > 3	0.15 to 0.3
4	Severe	Extensive repair required involving removal and replacement of walls especially over doors and windows. Window and door frames distorted. Floor slopes noticeably. Walls lean or bulge noticeably. Some loss of bearing in beams. Utility services disrupted.	15 to 25 but also depends on number of cracks	> 0.3
5	Very severe	Major repair required involving partial or complete reconstruction. Beams lose bearing, walls lean badly and require shoring. Windows broken by distortion. Danger of instability.	Usually > 25 but depends on number of cracks	
Note: Please refer LU Civil Engineering - Common Requirements S1050[2].				

Table 2: Building damage classification

4 Input Data

- The magnitude and distribution of ground movements and degree of building damage is calculated based on the following input data:
- The Xdisp model coordinates and levels are based on the 3D model (20130212DSPITT Scheme R09) and Central line temporary tunnel BSCU-DRA-DTT-N133_Z-M3-Y-8000;
- Four construction stages are considered in accordance with the proposed programme (November 2013) as illustrated in Figure 1;
- Trough width parameter constant, K=0.5 is used in accordance with WI2300[1].

The input data for the building, tunnels and shaft excavation are summarised in Table 3, Table 4 and Table 5 respectively.

Location	Foundation level (mATD)	Building Height above foundation level (m)	E/G
27 Poultry Street/5 Princes Street	101.3*	49.8	12.5
Note: Where E / G is the ratio of Young's modulus to shear modulus of the deep beam that is to represent the building. * Assumed level, 1.3m thick slab beneath floor level.			

Table 3: Building data

Tunnel Item	Level of axis (mATD)	External diameter (m)	Volume Loss (%)
Running tunnels	Inclined (82.7 to 85.8)	5.4	1.5
Temporary Access Tunnel North	82.3	5	1.5
Square works adits	75.8 to 95.3	4.1 to 7.8	2.5
Platform enlargement	85.6	7.4 to 11.2	1.5
Escalator barrels	Inclined	8.3 to 8.4	1.5
Central Line Connection	Inclined (87.6 to 89.2)	8.6	1.5

Table 4: Tunnel data

The running tunnel beneath Building A4 has a sump to one side with an invert level of 78.88mATD.

Excavation	Excavation Base Level (mATD)
Grout Shaft at King William Street	97
Whole Block Scheme Box excavation	73
Arthur Street Shaft	81

Table 5: Excavation data

The distance of building 27 Poultry/5 Princes Street (A4) relative to the excavation elements listed in Table 5 is sufficiently large that this building should not be affected by their construction.

The Xdisp model filenames used to undertake this assessment are:

- A4 – 14.4.14 Stage 1
- A4 - 14.4.14 Stage 2
- A4 - 14.4.14 Stage 3
- A4 - 14.4.14 Stage 4

5 Results

5.1 Engineering Assessment

The sections through the building which have been analysed are shown on plan in Figure 3.

Assessment has been undertaken at three intermediate construction stages and at the end of construction when all major elements of the works including shaft and tunnels have been completed. The damage category assigned to the building is based on the construction stage at which the potential impact on the building is most severe.

The maximum settlement and tensile strain calculated for each analysed section at the most onerous intermediate construction stage and at the end of construction are presented Table 6 and Table 7.

Section	Settlement (mm)	Maximum Tensile Strains (%)
A4 (line 1)	15	0.016
A4 (line 2)	15	0.012
A4 (line 3)	3	0.007
A4 (line 4)	21	0.018
A4 (line 5)	21	0.009

Table 6: Building response at most onerous intermediate stage - Construction Stage 2

Section	Settlement (mm)	Maximum Tensile Strains (%)
A4 (line 1)	15	0.016
A4 (line 2)	15	0.012
A4 (line 3)	3	0.007
A4 (line 4)	21	0.018
A4 (line 5)	21	0.010

Table 7: Building response at end of Construction Stage 4

At Stage 2 the running tunnel passes beneath the building and the Temporary Access Tunnel North is constructed. The results of the assessment show that construction Stage 2 is the critical stage for this building where A4 (line 4) experiences the most onerous combined tensile strain. The orientation is shown in Figure 3. The vertical and horizontal Greenfield ground movements along the section of the building are shown in Figure 5. The relative position of the building and tunnels along section A4 (line 2) is shown Figure 6. The calculated strains are summarised in Table 8.

Line No	Strains in section (Curvature)	Position from start (m)	Length (m)	Average* Horizontal Strain (%)	Maximum Tensile Strains (%)	Damage Category
4	Hogging	0	11.4	0.016	0.018	Negligible
4	Sagging	11.4	13.4	-0.030	0.011	Negligible
Note: * Tensile horizontal strains are +ve. Compressive horizontal strains are –ve.						

Table 8: Building response at end of construction stage

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0. This corresponds to Negligible damage in accordance with Table 2.

The settlement of the building at foundation level at the end of Stage 2 is approximately 21mm, which does not increase in the subsequent stages.

5.2 Heritage and Structural Assessment

Following site inspection, assessment has been made using the scoring methodology set out in Table 9.

Score	Structure (Sensitivity of the structure to ground movements and interaction with adjacent buildings)	Heritage features (Sensitivity to calculated movement of particular features within the building)	Condition (Factors which may affect the sensitivity of structural or heritage features)
0	Masonry buildings with lime mortar and regular openings, not abutted by other buildings, and therefore similar to the buildings on which the original Burland assessment was based.	No particular sensitive features	Good/Fair - not affecting the sensitivity of structural or heritage features
1	Buildings not complying with categories 0 or 2, but still with some sensitive structural features in the zone of settlement e.g.: cantilever stone staircases, long walls without joints or openings, existing cracks where further movements are likely to concentrate, mixed foundations	Brittle finishes, e.g. faience or tight-jointed stonework, which are susceptible to small structural movements and difficult to repair invisibly.	Poor - may change the behaviour of a building in cases of movement. Poor condition of heritage features and finishes. Evidence of previous movement.
2	Buildings which, by their structural form, will tend to concentrate all their movements in one location (e.g.: a long wall without joints and with a single opening).	Finishes which if damaged will have a significant effect on the heritage value of the building, e.g. Delicate frescos, ornate plasterwork ceilings.	Very poor – parlous condition of heritage features and finishes, severe existing damage to structure including evidence of ongoing movement. Essentially buildings where even very small movements could lead to significant damage.

Table 9: Heritage and structural scoring methodology

The results of the heritage assessment carried out for the building are summarised in Table 10.

SENSITIVITY OF THE STRUCTURE
The steel frame of the original building and the reinforced concrete frame of the later extension both have a reasonable degree of flexibility and robustness. As such both should be able to cope with the expected ground movements without significant damage to the primary structure or any reduction in load carrying capacity. There are retained sensitive elements of the building such as cantilevered stone staircases; however the amount of movement is not expected to have a significant impact on these elements. The main location of sensitivity is expected to be at the link between the original building and the eastern extension across the narrowest point of the building. This is where the settlement plane changes as the tunnel runs below the building. However the magnitude of the movement is still small and no damage to the structure is expected and negligible damage to the building fabric. The primary structural elements visible at the time of the site visit all appear to be in a good condition with little visible rusting or cracking.
Score: 1 - Steel and reinforced concrete frames are reasonably flexible and should be able to cope with the expected movements without significant damage to the primary structure. However, there are structural elements such as cantilevered stairs, which may be more sensitive to movement.
SENSITIVITY OF THE HERITAGE
This Grade I listed building is of exceptional importance in many respects. It is an exceptionally well preserved example of Lutyens' architecture, with precious interiors and fine decorations. The building's architectural, artistic, historical and social significance is largely intact and fully embodied by the building as it stands as a whole. So far Lutyens' exteriors and interiors have survived in very good condition and the building character is intact. Externally the sensitive fabric includes the original elevations with the fine jointed stonework, the sculptures and other carved decorative panels. The dome with its decorative apparatus and moulded parapets, architraves and sculptures is a sensitive element to rooftop. Internally the most sensitive fabric include the fully fitted marble corridor and safe to first basement below ground, the banking hall to ground floor with its marble and decorative plaster finishes, marble staircases, furniture and fittings which are all surviving in good conditions; the panelled rooms and circulation spaces retained to fourth and fifth floor. The original stairs to the east and west corners of the building are particularly well preserved and significant elements of the original design. The predicted movements are likely to have a negligible impact on the building fabric. Areas of brittle finishes, for instance marble and plaster within the banking hall and its stairs, are particularly sensitive to small movements. The predicted hairline cracking to marble may be difficult to repair and leave a lasting aesthetic impact. Timber finishes may tolerate small movements, though some splitting to the joints may occur. Other features, such as plaster and painted surfaces, may see hairline cracking but are repairable.
Score: 2 - The building retains original features, some of which are brittle. Small damage to marble surfaces or timber may have a permanent aesthetic impact on the heritage significance of the building.
SENSITIVITY OF THE CONDITION
The building exterior appears to be in good condition. Internally the building is largely stripped from first to third floor and generally seems in good condition with localized dampness to the upper floors and within the basement. The original features which have been retained are in relatively good condition, with no visible signs of cracks, damage or previous movement.
Score: 0 The exterior and interior of the building appear in generally good condition, with minor, localised dampness. The particularly sensitive heritage elements are all currently in good condition with no visible cracks or damage.

Table 10: Heritage and structural assessment

5.3 Total Score

The total score is the summation of the damage category, structural sensitivity, heritage sensitivity and condition sensitivity scores:

The damage category is 0

The structural sensitivity score is 1

The heritage sensitivity score is 2

The condition sensitivity score is 0

The total score for this building is 3

6 Conclusion

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0 for 27 Poultry/5 Princes Street. However, specific heritage and structural assessment taking into account the location and extent of settlement and tensile strains indicates that the building has a high level of heritage sensitivity to movement. This assessment has determined that the building has a total score of 3.

The structural frame of the Building at 27 Poultry/5 Princes Street is not inherently sensitive to ground movements. It is not expected that the predicted movements will significantly damage the primary structure or cause any reduction in load carrying capacity. However, the building contains exceptionally fine and sensitive heritage finishes, and further investigation as to the expected behaviour of marble finishes and elements (particularly stairs) may be required.

The BSCU Environmental Statement considers the mitigation that could be needed, however, it is recommended that Stage 3 assessment is undertaken to verify how heritage finishes and features may respond and whether such mitigation is required.

7 References

[1] LU Works Information WI 2300 Ground Movement version 3, 19-07-13.

[2] LU Category 1 Standard: S1050 Civil Engineering - Common Requirements, Issue No. A7, Nov. 2013.

[3] Mair R J, Taylor R N and Bracegirdle A (1993). Subsurface settlement profiles above tunnels in clays. Géotechnique 43, No. 2, pp. 315-320.

[4] Mair R J, Taylor R N and Burland J B (1996). Prediction of ground movements and assessment of risk of building damage due to bored tunnelling. (In: International Conference of Geotechnical Aspects of Underground Construction in Soft Ground, London, pp. 713–718.

[5] LU Guidance Document G0058 Civil Engineering Technical Advice Notes, Issue No. A17, Feb. 2013.

[6] Burland J B (1995). Assessment of risk of damage to buildings due to tunnelling and excavation. Proceedings: 1st International Conference of Earthquake Geotechnical Engineering, IS Tokyo, 1995.

[7] Mott MacDonald (2012). Bank Station building data sheets – A list buildings. N133-BCR-MMD-00-Z-DC-S-0003-S0-1.0.

[8] Selemetas.D et al (2005). The response of full scale piles to tunnelling. Geotechnical aspects of underground construction in soft ground (Bakker et al (eds)) pp.763-769.

[9] Sir Frederick Snow and Partners (1970). Foundations in area J-M/6-7, DRG no.3711.1st/1054. Architectural drawing shows 8 number piles along adjacent building wall..

[10] Elliot Wood Partnership (2013). Proposed Core Section A-A. Design drawing no.212507. Sk-25.

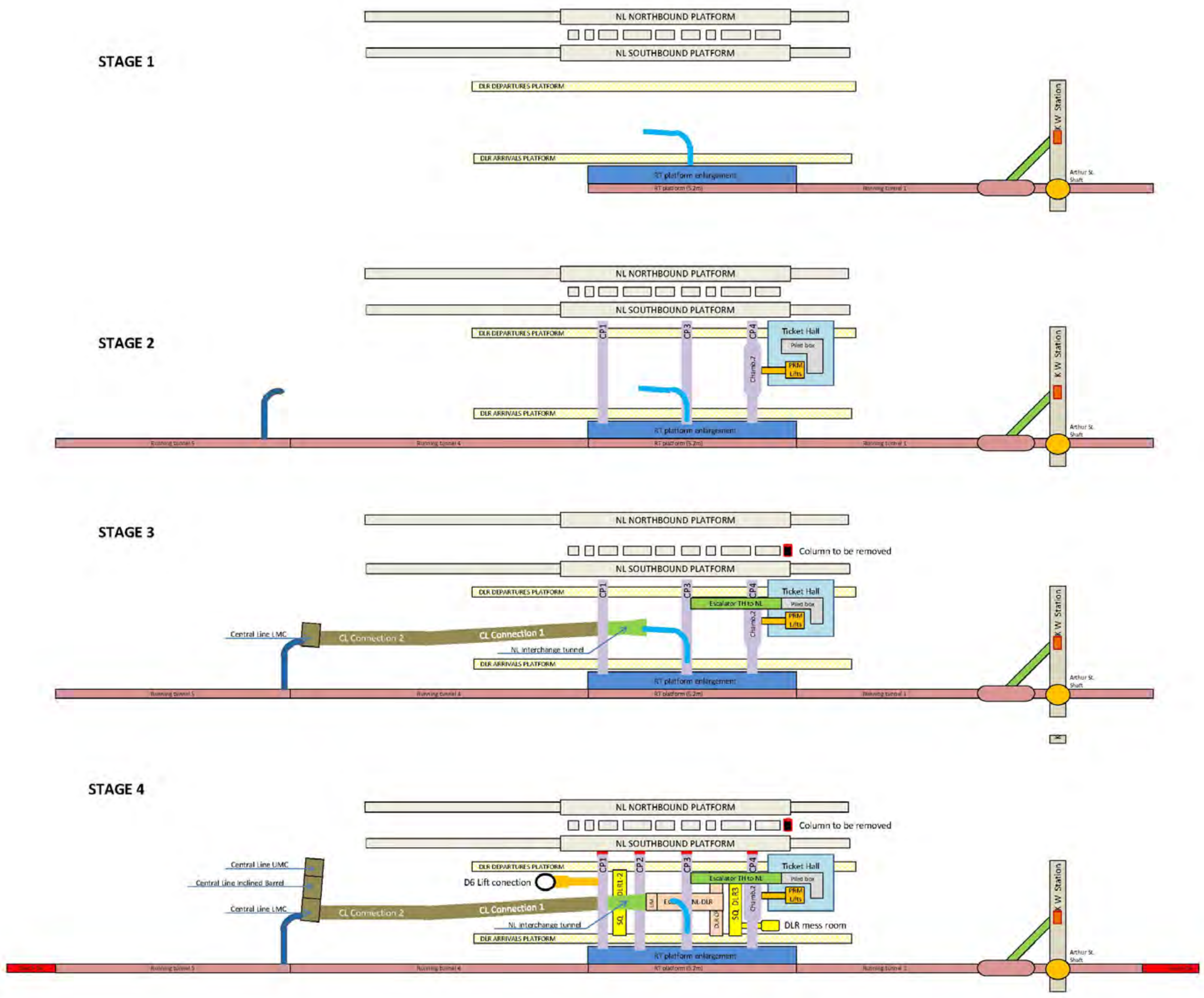

Figure 1: Construction Stage model

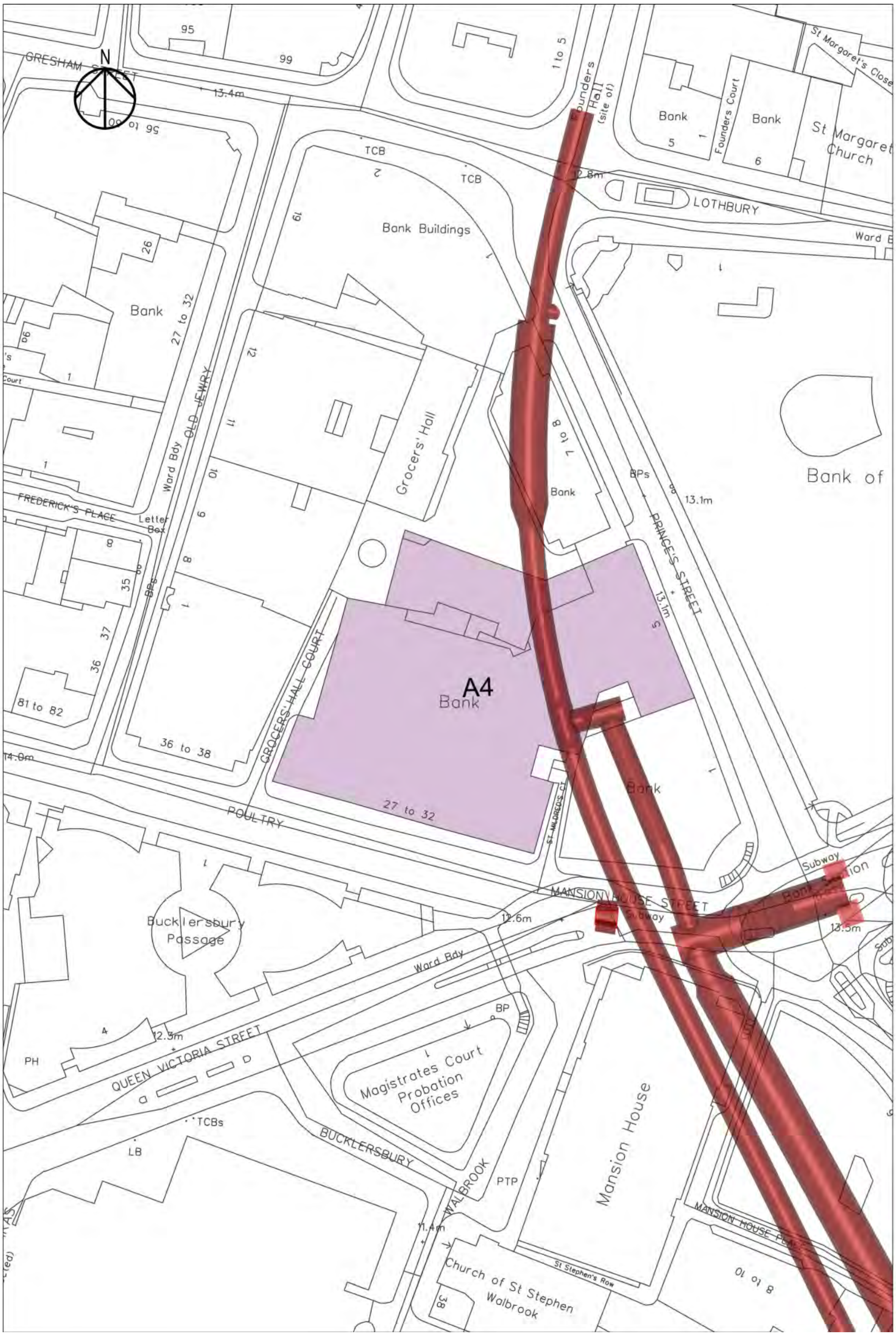

Figure 2: Location plan showing building location in relation to BSCU works

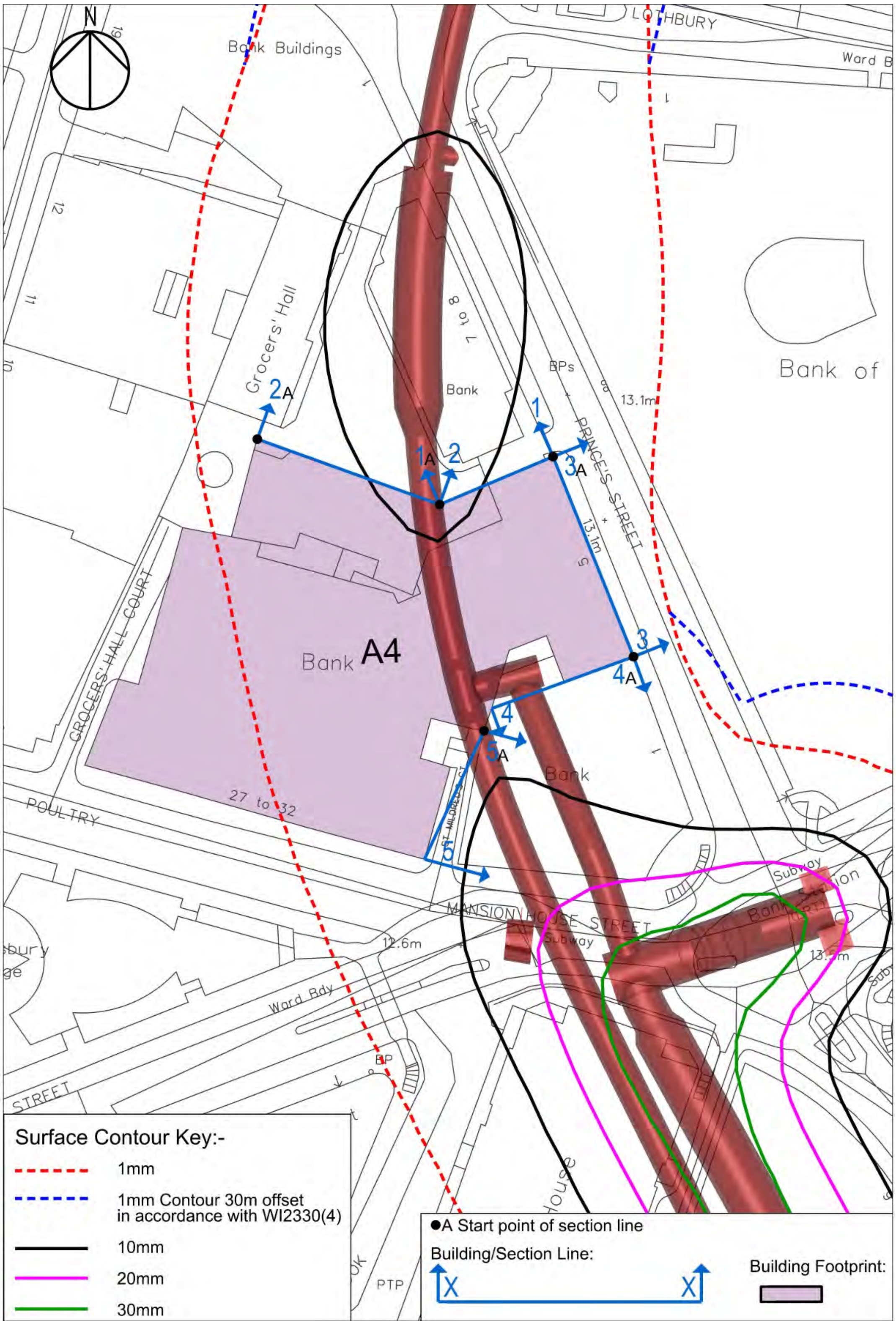

Figure 3: Building location, sections analysed and Settlement Contours at stage of worst case for tensile strains

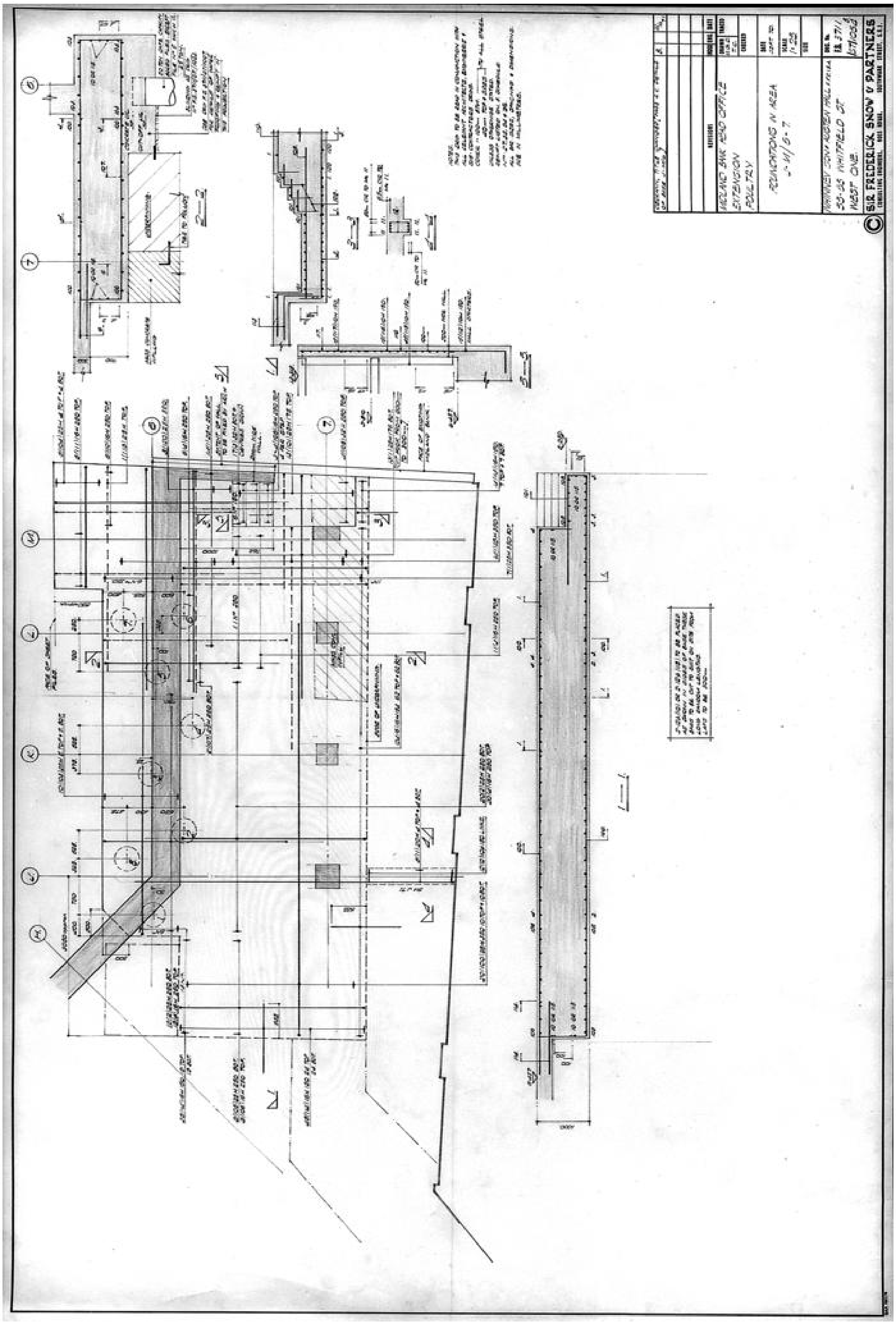

Figure 4: Plan of pile locations on northern boundary

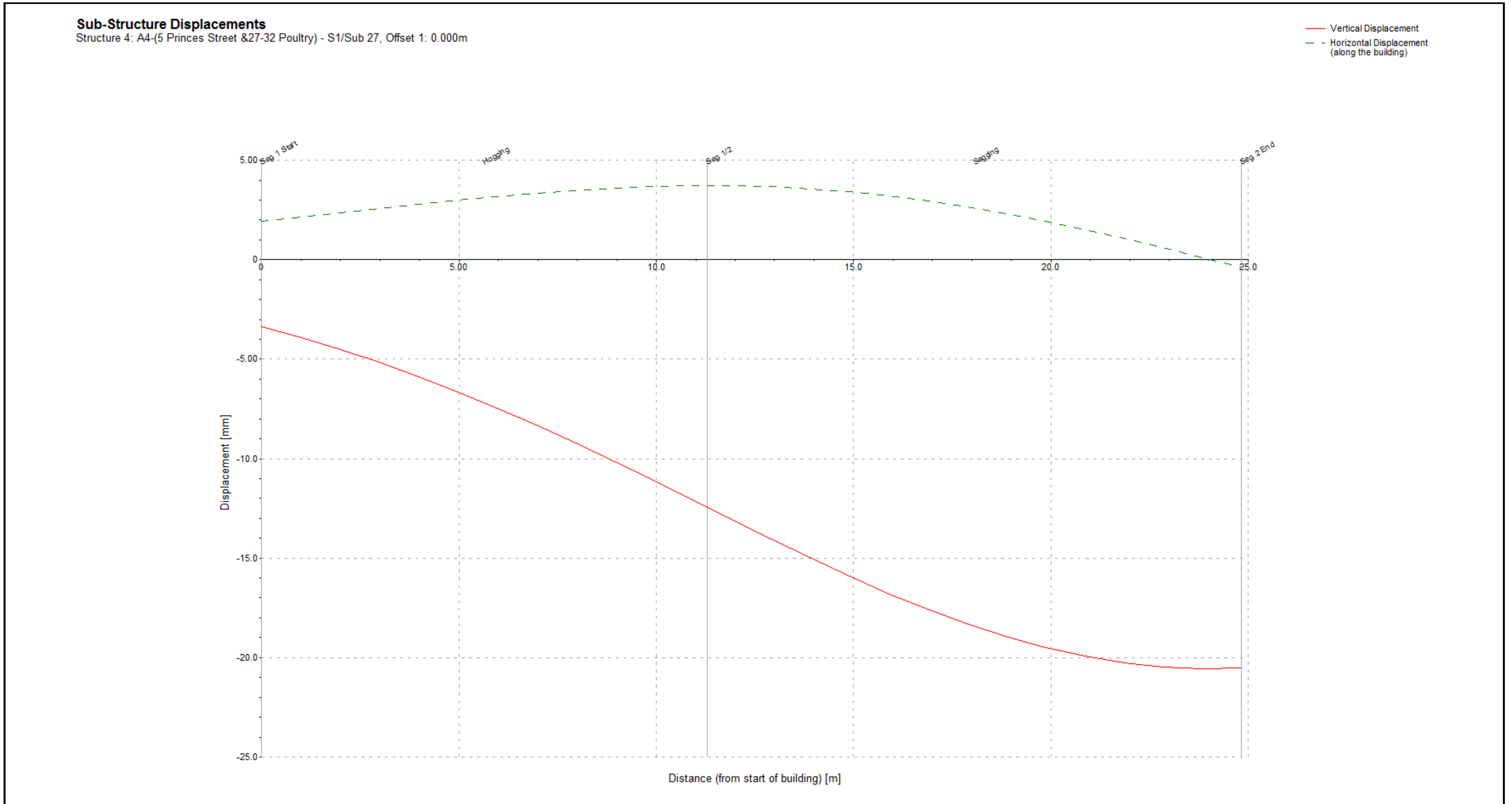

Figure 5: Building displacement at founding level at stage 4 (line 4) of worst case for tensile strains

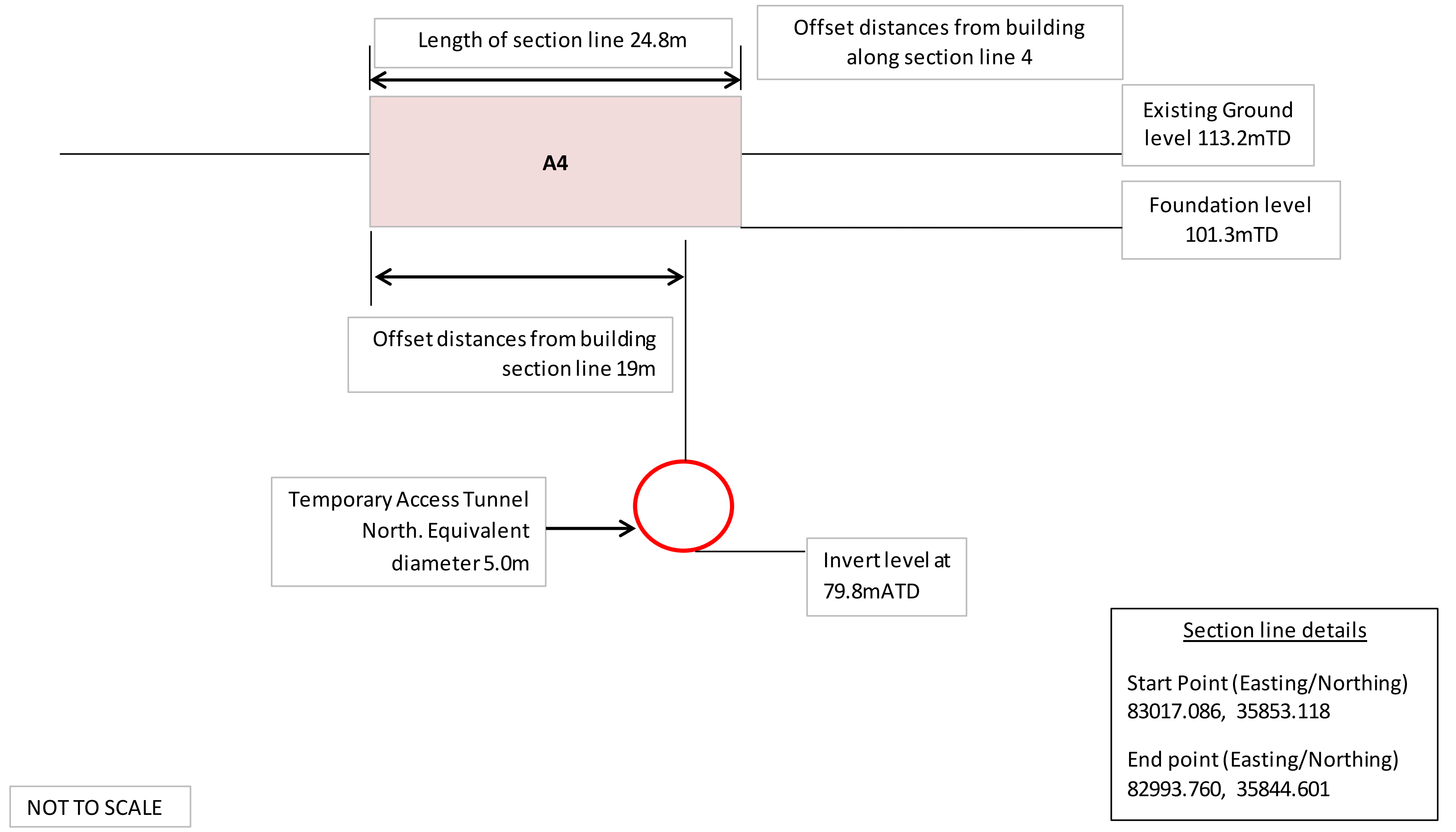

Figure 6: Diagrammatic cross-section of section (line 4) relative to tunnel position

Safely Together

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Bank Station Capacity Upgrade

Building Damage Assessment Report

Building A5

1 Princes Street

URS-8798-RPT-G-001169

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Consultation:

• Ela Palmer	URS Heritage
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• Keith Bowers/Neil Moss/Paul Dryden	London Underground
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Contents

FIGURES

TABLES

1 Introduction

This report summarises the results of a Stage 2 damage assessment for 1 Princes Street, Ref A5.

Stage 2 damage assessments are undertaken for all buildings within the Stage 1 Greenfield ground surface 1mm settlement contour induced by the construction of the Bank Station Capacity Upgrade (BSCU).

The purpose of the assessment is to determine the potential effect the works will have on the building. This report describes the engineering and heritage assessments undertaken for the building and concludes whether mitigation is likely to be needed and if a further (Stage 3) assessment is recommended in order to verify this.

2 The Building

2.1 General Information

No. 1 Princes Street is located at the junction between Princes street and Mansion House Street. General building information used in the assessment has been acquired as part of the structural desktop appraisal. This information is presented in Table 1.

Category	Building Information
BSCU Reference	A5
Location	Princes street
Address	1 Princes street
Building Type	Steel framed
Construction Age (Refurbished 1994-1997)	1929-32
No. of Storeys	8
Basements	3
Top Level (mATD)	142.3
Foundation Type	3 No. caissons / raft
Ground Level (mATD)	113.3
Listed Grade	II
Note: Levels given are in metres above Tunnel Datum, mATD. Tunnel Datum is 100m below Ordnance Survey Datum at Newlyn.	

Table 1: General building information

A general view of the building exterior is shown in Plate 1. A location plan showing the building in relation to the proposed BSCU works is presented in Figure 2

Plate 1: General view

2.2 Building Description

A paper by Richardson[9] mentions three caissons being sunk to 55 feet below the site level. For the purpose of this assessment, given that the site level is unknown, it is assumed at ground level (113.3mATD) which implies a founding level of 96.5mATD. This is deeper than would be indicated by three levels of basement and an allowance of 1.5m for a raft (102.8mATD). Due to the uncertainty as to the existence of the caissons and their effect on the settlement the assessment has been carried out at 96.5mATD to be conservative.

The building was partially demolished and rebuilt in 1997 and the facades and structure to ground level together with an internal dome and support structure were retained. "A new raft foundation of 1.2m thick reinforced concrete was provided below basement 3 to supplement the original. The raft is founded in the London Clay". No mention is made of the caissons and a brochure from structural engineers NYL does not show them in a diagrammatic cross section.

The building was designed by Sir Edwin Cooper and is classical in style, with a five storey Portland stone elevation that includes a Doric frieze and cornice above the ground floor and incorporates a group of statues. A plaque records that Mrs Elizabeth Fry (1780-1845), Prison Reformer, lived here 1800-1809. Internally, the building has been stripped of historic features, and shows predominantly modern finishes with dropped ceilings and partitions. To the centre of the building is a retained domed banking hall, which contains square marble columns and statuary, and plaster decorative elements. This historic section of the interior, together with the Portland stone façade, retains much heritage value.

3 Methodology

This building damage assessment is undertaken in accordance with LU Works Information WI2300[1] and LU Civil Engineering - Common Requirements S1050[2].

The analysis methodology applies to ground-bearing buildings which will be affected by ground movements resulting from the construction of the BSCU. The engineering assessment calculates the potential impact of ground movements and assigns a damage category to the building based on a numeric scale. Additionally, for listed buildings, a heritage assessment is carried out which considers the sensitivity of the structure and the sensitivity of its particular features and a heritage sensitivity score is assigned. The heritage sensitivity score is added to the damage category to obtain the total score. If the total score is 3 or more, a more detailed Stage 3 assessment is triggered.

Oasys Xdisp is used to analyse the Greenfield ground movement in terms of settlement and horizontal displacement. Subsurface tunnelling induced ground movement profiles are determined in accordance with the methodology described by Mair et al [3 & 4].

Movements resulting from the Whole Block Scheme (WBS) and shaft excavations have been calculated using LU Guidance Document G0058[5].

The building is modelled as a simple elastic beam which is conservatively assumed to follow the Greenfield ground displacements. The beam is divided into hogging and sagging segments. The tensile strains within each segment are calculated based on the distortion associated with differential settlement (which is characterised by deflection ratio) and the distortion associated with differential horizontal displacement (characterised by horizontal strain).

Xdisp provides a method for calculating the maximum tensile strain within the building superstructure associated with these movements, in accordance with the assessment methodology described by Mair et al[4]. This strain is used to determine the damage category for traditional masonry structures based on the classification system proposed by Burland[6] and in accordance with LU Civil Engineering - Common Requirements S1050[2]. The categories are presented in Table 2.

Damage Category	Description of Degree of Damage	Description of Typical Damage and likely forms of Repair for Typical Masonry Buildings.	Approx. Crack Width (mm)	Max. Tensile Strain %
0	Negligible	Hairline cracks.		< 0.05
1	Very slight	Fine cracks easily treated during normal redecoration. Perhaps isolated slight fracture in building. Cracks in exterior visible upon close inspection.	0.1 to 1.0	0.05 to 0.075
2	Slight	Cracks easily filled. Redecoration probably required. Several slight fractures inside building. Exterior cracks visible; some repainting may be required for weather-tightness. Doors and windows may stick slightly.	1 to 5	0.075 to 0.15
3	Moderate	Cracks may require cutting out and patching. Recurrent cracks can be masked by suitable linings. Tuck pointing and possible replacement of a small amount of exterior brickwork may be required. Doors and windows sticking. Utility services may be interrupted. Weather tightness often impaired.	5 to 15 or a number of cracks > 3	0.15 to 0.3
4	Severe	Extensive repair required involving removal and replacement of walls especially over doors and windows. Window and door frames distorted. Floor slopes noticeably. Walls lean or bulge noticeably. Some loss of bearing in beams. Utility services disrupted.	15 to 25 but also depends on number of cracks	> 0.3
5	Very severe	Major repair required involving partial or complete reconstruction. Beams lose bearing, walls lean badly and require shoring. Windows broken by distortion. Danger of instability.	Usually > 25 but depends on number of cracks	
Note: Please refer LU Civil Engineering - Common Requirements S1050[2].				

Table 2: Building damage classification

4 Input Data

The magnitude and distribution of ground movements and degree of building damage is calculated based on the following input data:

- The Xdisp model coordinates and levels are based on the 3D model (20130212DSPITT Scheme R09) and Central line temporary tunnel BSCU-DRA-DTT-N133_Z-M3-Y-8000;
- Four construction stages are considered in accordance with the proposed programme (November 2013) as illustrated in Figure 1;
- Trough width parameter constant, K=0.5 is used in accordance with WI2300[1].

The input data for the building, tunnels and shaft excavation are summarised in Table 3, Table 4 and Table 5 respectively.

Location	Foundation level (mATD)	Building Height above foundation level (m)	E/G
1 Princes Street	96.5*	45.8	12.5
Note: Where E / G is the ratio of Young's modulus to shear modulus of the deep beam representing the building. * Base level of caissons[9]			

Table 3: Building data

Tunnel Item	Level of axis (mATD)	External diameter (m)	Volume Loss (%)
Running tunnels	Varies	5.4	1.5
Temporary access tunnel	Inclined (82.3 to 89.2)	5.0	1.5
Square works adits	75.8 to 95.3	4.1 to 7.8	2.5
Platform enlargement	85.6	7.4 to 11.2	1.5
Escalator barrels	Inclined	8.3 to 8.4	1.5
Central Line Connection	Inclined (87.6 to 89.2)	8.6	1.5

Table 4: Tunnel data

Excavation	Excavation Base Level (mATD)
Grout Shaft at King William Street	97
Whole Block Scheme Box excavation	73
Arthur Street Shaft	81

Table 5: Excavation data

The distance of building 1 Princes Street (A5) relative to the excavation elements listed in Table 5 is sufficiently large that this building should not be affected by their construction.

The Xdisp model filenames used to undertake this assessment are:

- A5 – 14.4.14 Stage 4
- A5 – 14.4.14 Stage 3
- A5 – 14.4.14 Stage 2
- A5 – 14.4.14 Stage 1

5 Results

5.1 Engineering Assessment

The sections through the building which have been analysed are shown on plan in Figure 3.

Assessment has been undertaken at three intermediate construction stages and at the end of construction when all major elements of the works including shaft and tunnels have been completed. The damage category assigned to the building is based on the construction stage at which the potential impact on the building is most severe.

The maximum settlement and tensile strain calculated for each of the analysis sections at the most onerous intermediate construction stage and at the end of construction are presented in Table 6 and Table 7.

Section	Maximum Settlement (mm)	Max Tensile Strain (%)
A5 (line 1)	26	0.035
A5 (line 2)	24	0.009
A5 (line 3)	24	0.025
A5 (line 4)	2	0.001
A5 (line 5)	15	0.046

Table 6: Building response at most onerous intermediate stage - Construction Stage 3

Section	Maximum Settlement (mm)	Max Tensile Strain (%)
A5 (line 1)	26	0.026
A5 (line 2)	24	0.009
A5 (line 3)	24	0.026
A5 (line 4)	2	0.001
A5 (line 5)	19	0.057

Table 7: Building response at end of Construction

The results of the assessment show that construction stage 4 is the critical stage for this building, where line 5 experiences the most onerous combined tensile strain (0.057%) on the short southern end of the building. This façade is very short and the analysed strains are therefore not likely to be correct. Further comment is made below about the behaviour of the building. The vertical Greenfield ground movements along the section line 1 and line 5 are shown in Figure 4 and Figure 5 respectively. The relative position of the building and tunnels along section line 1 and section line 5 are shown in Figure 6 and Figure 7 respectively. The calculated strains are summarised in Table 8.

Strains in section (Curvature)	Position from start (m)	Length (m)	Average* Horizontal Strain (%)	Maximum Tensile Strains (%)	Damage Category
Sagging (Stage 3 line1)	0.0	24.5	-0.031	0.035	Negligible
Hogging (Stage 3 line1)	24.5	6.5	0.003	0.003	Negligible
Hogging (Stage 4 line 5)	0.0	12.8	0.041	0.057	Very Slight
Note: * Tensile horizontal strains are +ve. Compressive horizontal strains are –ve.					

Table 8: Section analysed, results for worst case tensile strain

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 1. This corresponds to Very Slight damage in accordance with Table 2.

5.2 Heritage and Structural Assessment

Following site inspection, assessment has been made using the following scoring methodology set out in Table 9.

Score	STRUCTURE Sensitivity of the structure to ground movements and interaction with adjacent buildings	HERITAGE FEATURES Sensitivity to calculated movement of particular features within the building	CONDITION Factors which may affect the sensitivity of structural or heritage features
0	Masonry buildings with lime mortar and regular openings, not abutted by other buildings, and therefore similar to the buildings on which the original Burland assessment was based.	No particular sensitive features	Good/Fair - not affecting the sensitivity of structural or heritage features
1	Buildings not complying with categories 0 or 2, but still with some sensitive structural features in the zone of settlement e.g.: cantilever stone staircases, long walls without joints or openings, existing cracks where further movements are likely to concentrate, mixed foundations	Brittle finishes, e.g. faience or tight-jointed stonework, which are susceptible to small structural movements and difficult to repair invisibly.	Poor - may change the behaviour of a building in cases of movement. Poor condition of heritage features and finishes. Evidence of previous movement.
2	Buildings which, by their structural form, will tend to concentrate all their movements in one location (e.g.: a long wall without joints and with a single opening).	Finishes which if damaged will have a significant effect on the heritage value of the building, e.g. Delicate frescos, ornate plasterwork ceilings.	Very poor – parlous condition of heritage features and finishes, severe existing damage to structure including evidence of ongoing movement. Essentially buildings where even very small movements could lead to significant damage.

Table 9: Heritage and structural scoring methodology

The results of the heritage assessment carried out for the building are summarised in Table 10.

SENSITIVITY OF THE STRUCTURE
There is some doubt over the exact details of the 1930's foundations and how the raft added in the 1997 refurbishment relates to the caissons described in historic documents. The description provided by the Engineers to the 1997 refurbishment (Campbell Reith Hill) makes no reference to the caissons described in historic documents, but does describe a new 1.2m raft provided below basement level 3. The refurbishment works resulted in the demolition and replacement of much of the building's structure. The basement retaining walls (2.4m thick), main columns up to underside of first floor, the plate transfer beams at second floor and much of the steel framed and stone clad facades were retained. The new steel frame and concrete floor decks take support from the original steel framed façade. This arrangement fixes the retained façade to the new internal structure, without a movement joint being provided. It is noted that the 1.2m raft and the original basement retaining walls are founded at approximately the same level, however if the raft interacts with the caissons then some differential movement may occur. The elevations to Princes Street and Mansion House Street include a large set back above second floor level extending to the underside of the cornice at sixth floor level. This set back will have the effect of concentrating all movement on these elevations to either end of the cornice, as indicated in the image below, where red lines indicate areas of stress concentration.  **Plate 2: Stress Concentration in Elevations**

Score: 2 - The inset elements of the façade will effectively act as large openings, leaving the narrow cornice to prop the two ends of the opening. This will lead to a stress concentration at each end of the set back, focusing all movement in these locations.
SENSITIVITY OF THE HERITAGE
Following a redevelopment during the 1990s, only the façade and the banking hall which is located to the centre of the building through the entrance from Princes Street, are of heritage interest. The octagonal banking hall has a large glazed central dome, which is now roofed over with a concrete structure. The hall is double height and has marble columns up to a balustraded balcony with statuary. There is decorative plasterwork to the balcony, walls, cornices and around the neck of the dome. Both the marble and plasterwork elements of the interior would be susceptible to damage from differential settlements, particularly the marble which would be difficult to repair when cracked. The Portland stone façade is fine jointed and would not be tolerant to large movements. The façade features heavy decorative detail including cornices and statuary, as well as fine jointed window surrounds and large openings where movement may be concentrated. Cracking through the Portland stone features may damage the heritage value of the building.
Score: 1 – the building incorporates brittle and tightly jointed surfaces which may be susceptible to damage in the event of differential settlement
SENSITIVITY OF THE CONDITION
The elevations appear to be in good structural condition and were extensively repaired and restored during the 1997 refurbishment.
Score: 0 – The condition of the building will not exacerbate the structural or heritage sensitivities.

Table 10: Heritage and structural assessment

5.3 Total Score

The total score is the summation of the damage category, structural sensitivity, heritage sensitivity and condition sensitivity scores:

The damage category is 1

The structural sensitivity score is 2

The heritage sensitivity score is 1

The condition sensitivity score is 0

The total score for this building is 4

6 Conclusion

1 Princes Street has sensitive structural elements to its façade, where movements may be concentrated in specific areas. There are also high value heritage features which are brittle and may be damaged by differential settlement.

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 1 for 1 Princes Street. However, specific heritage and structural assessment taking into account the location and extent of settlement and tensile strains, alongside uncertainty over the extent of caisson foundations, indicates that the building could have a high level of structural and heritage sensitivity to movement. This assessment has determined that the building has a total score of 4.

It is recommended that a Stage 3 assessment is undertaken to further consider the potential damage to the structural form.

In particular, the Stage 3 assessment should examine the implications of previous alterations to the building, including investigation of the foundations and further assessment of the brittle interior and façade finishes.

The BSCU Environmental Statement considers the mitigation that could be needed, however, it is recommended that Stage 3 assessment is undertaken to verify how heritage finishes and features may respond and whether such mitigation is required.

7 References

[1] LU Works Information WI 2300 Ground Movement version 3, 19-07-13.

[2] LU Category 1 Standard: S1050 Civil Engineering - Common Requirements, Issue No. A7, Nov. 2013.

[3] Mair R J, Taylor R N and Bracegirdle A (1993). Subsurface settlement profiles above tunnels in clays. Géotechnique 43, No. 2, pp. 315-320.

[4] Mair R J, Taylor R N and Burland J B (1996). Prediction of ground movements and assessment of risk of building damage due to bored tunnelling. (In: International Conference of Geotechnical Aspects of Underground Construction in Soft Ground, London, pp. 713–718.

[5] LU Guidance Document G0058 Civil Engineering Technical Advice Notes, Issue No. A17, Feb. 2013.

[6] Burland J B (1995). Assessment of risk of damage to buildings due to tunnelling and excavation. Proceedings: 1st International Conference of Earthquake Geotechnical Engineering, IS Tokyo, 1995.

[7] Mott MacDonald (2012). Bank Station building data sheets – A list buildings. N133-BCR-MMD-00-Z-DC-S-0003-S0-1.0.

[8] Mott MacDonald (2012). Bank Station building data sheets – A list buildings. N133-BCR-MMD-00-Z-DC-S-0003-S0-1.0.

[9] Richardson. A.E (1932). The National Provincial Bank, Princes Street and Mansion House Street, London. Architectural Review paper.

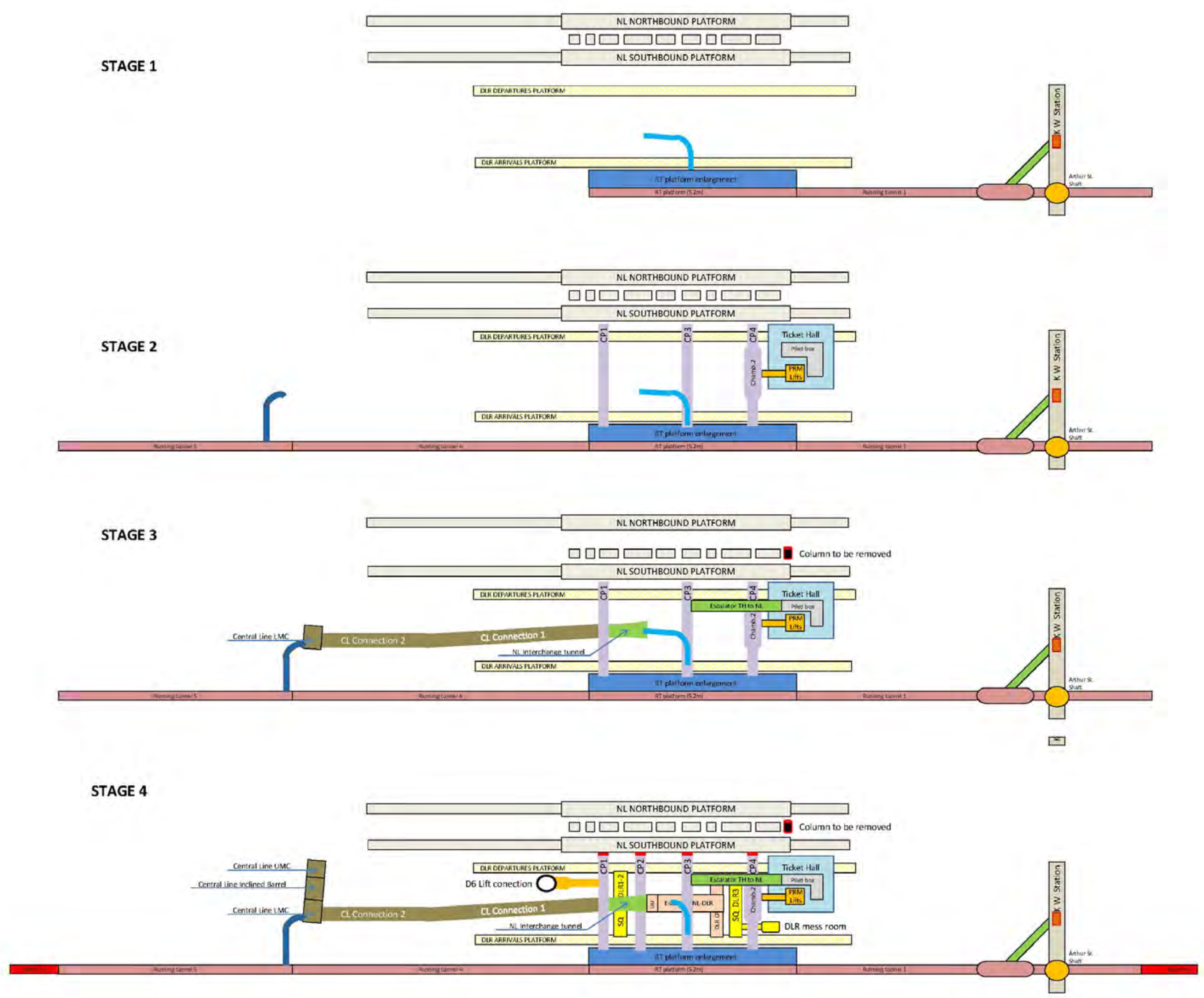

Figure 1: Construction Stage model

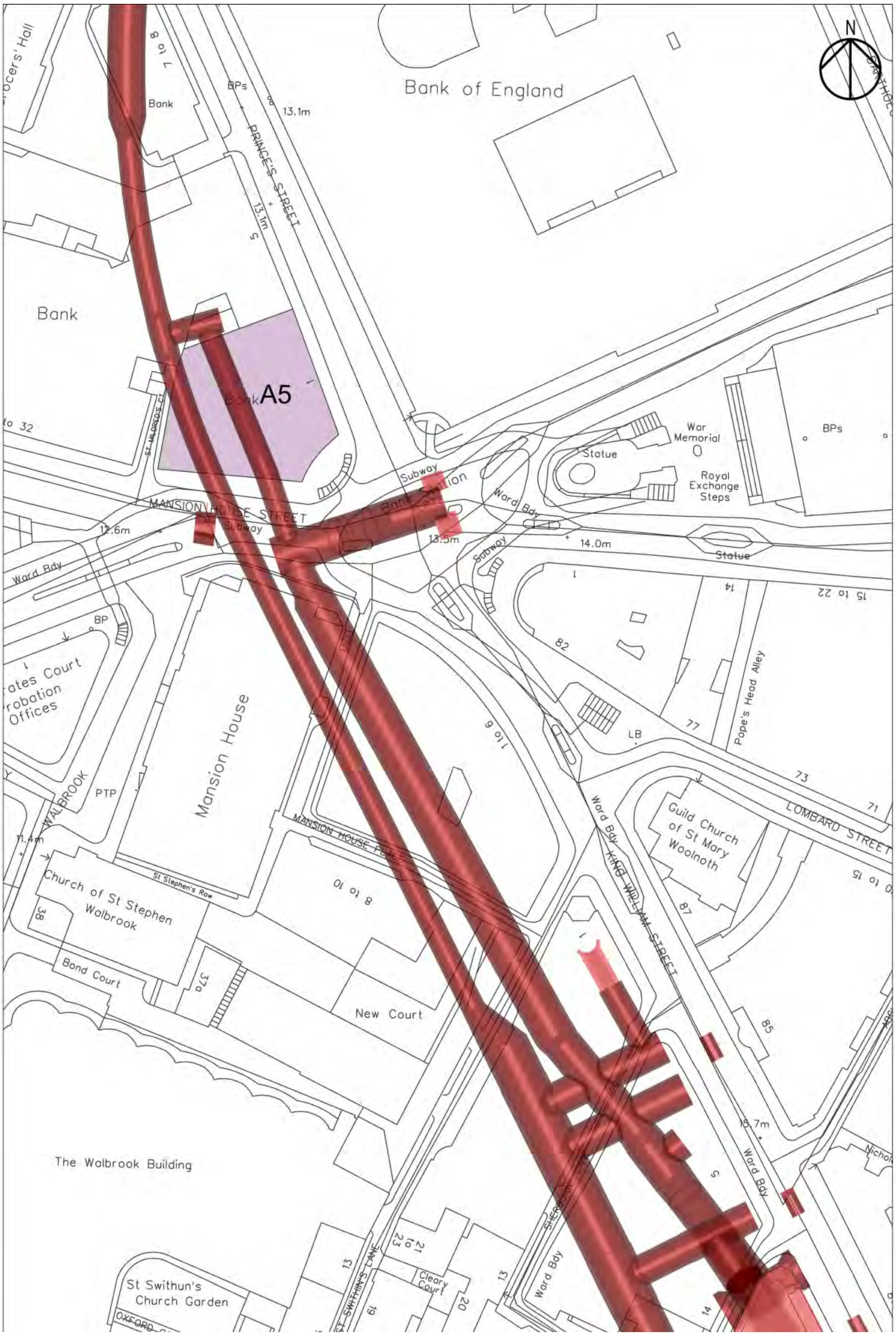

Figure 2: Location plan showing building location in relation to BSCU works

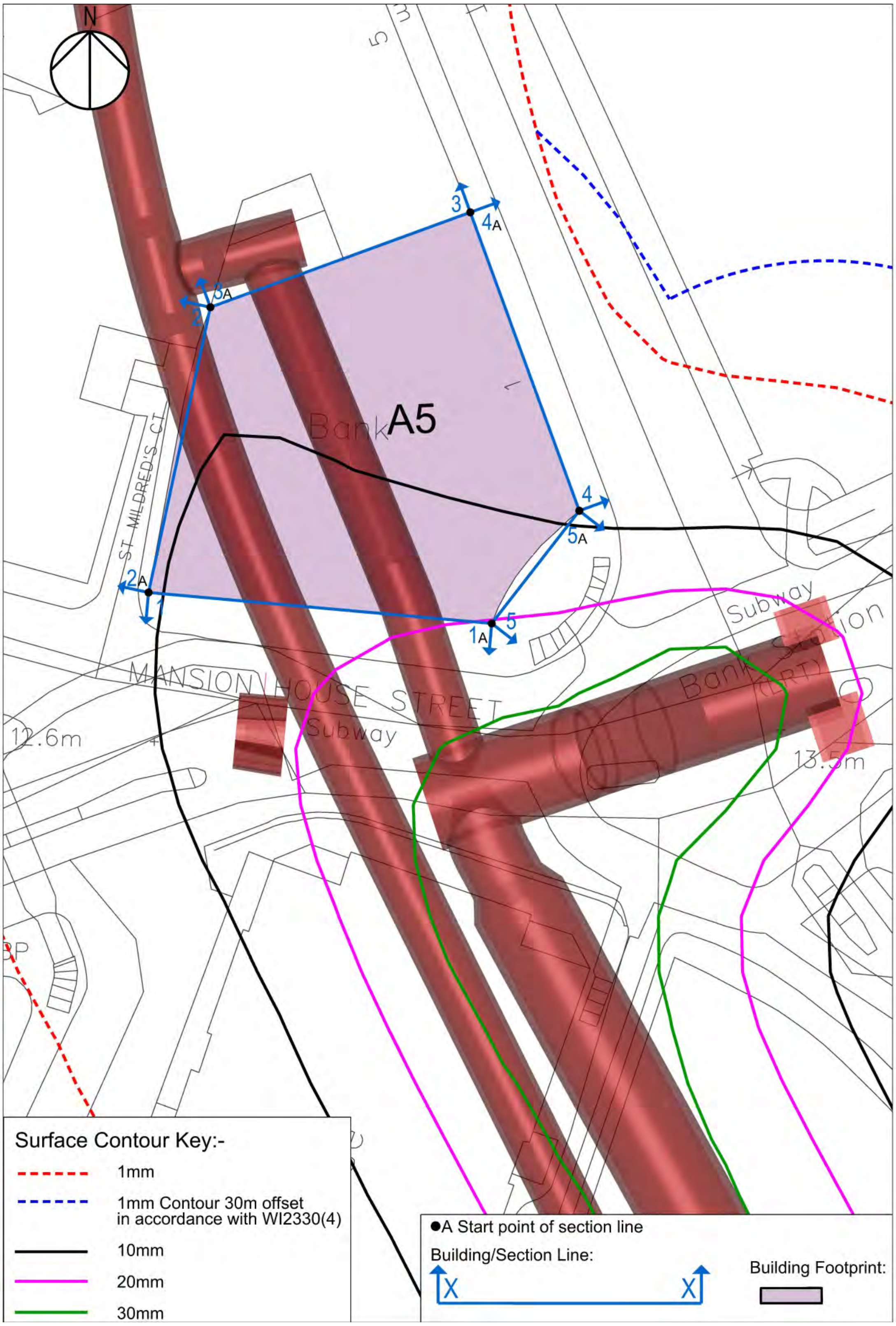

Figure 3: Building location, sections analysed and Settlement Contours at stage of worst case for tensile strains

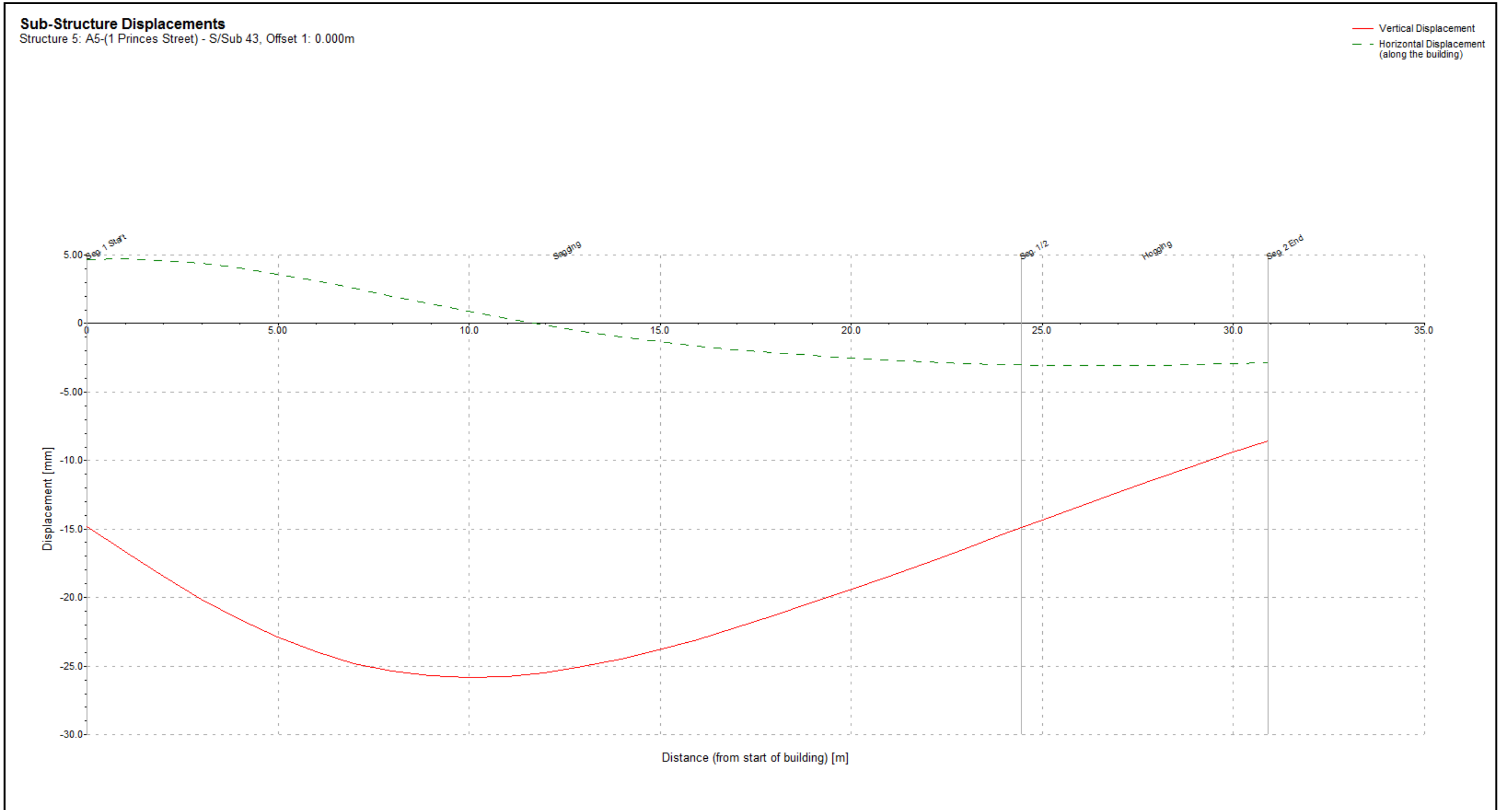

Figure 4: Building displacement at founding level at stage 3 A5 (line 1)

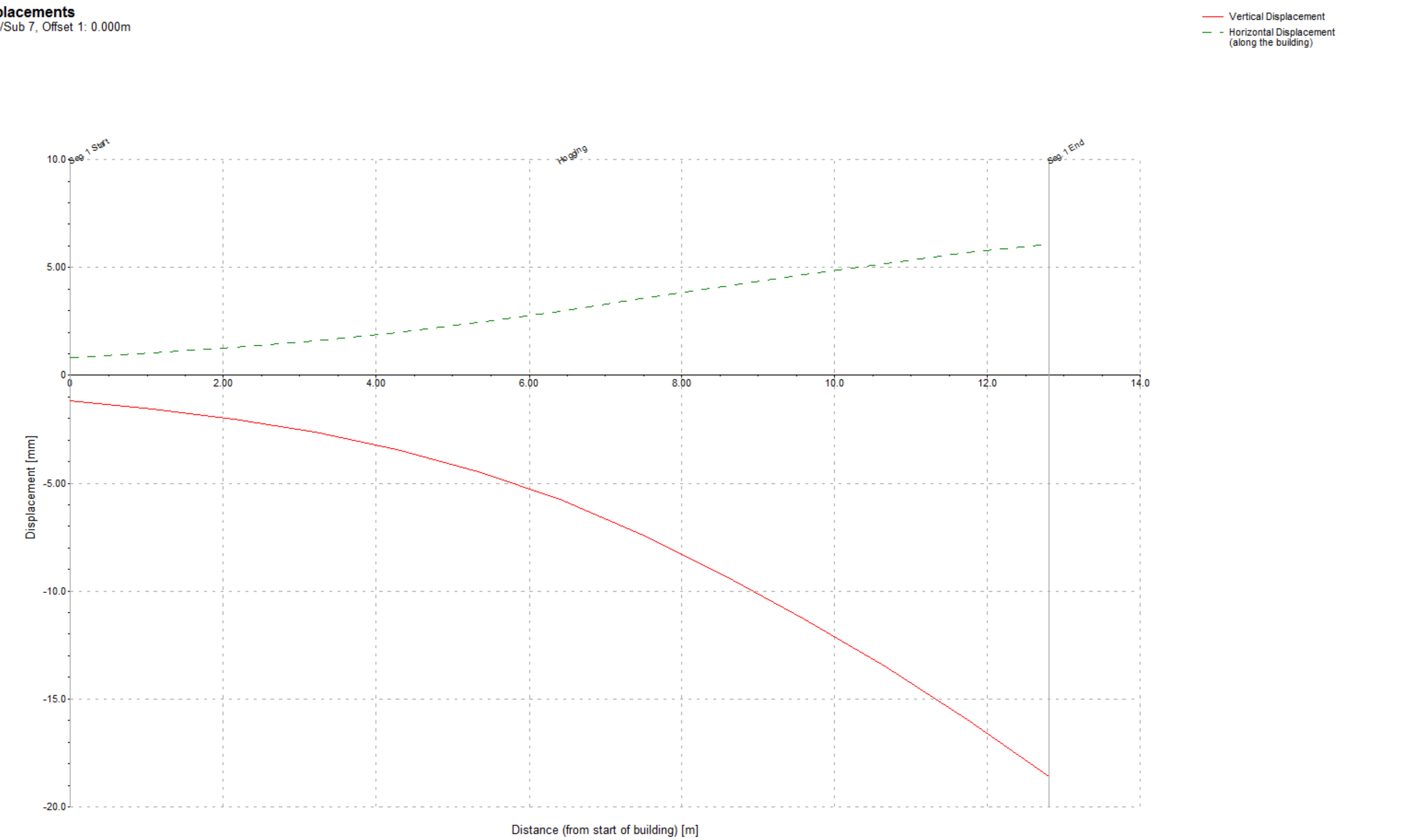

Figure 5: Building displacement at founding level at stage 4 (line 5) of worst case for tensile strains

LUL Bank Project Office
10 King William Street
London EC4 N7TW

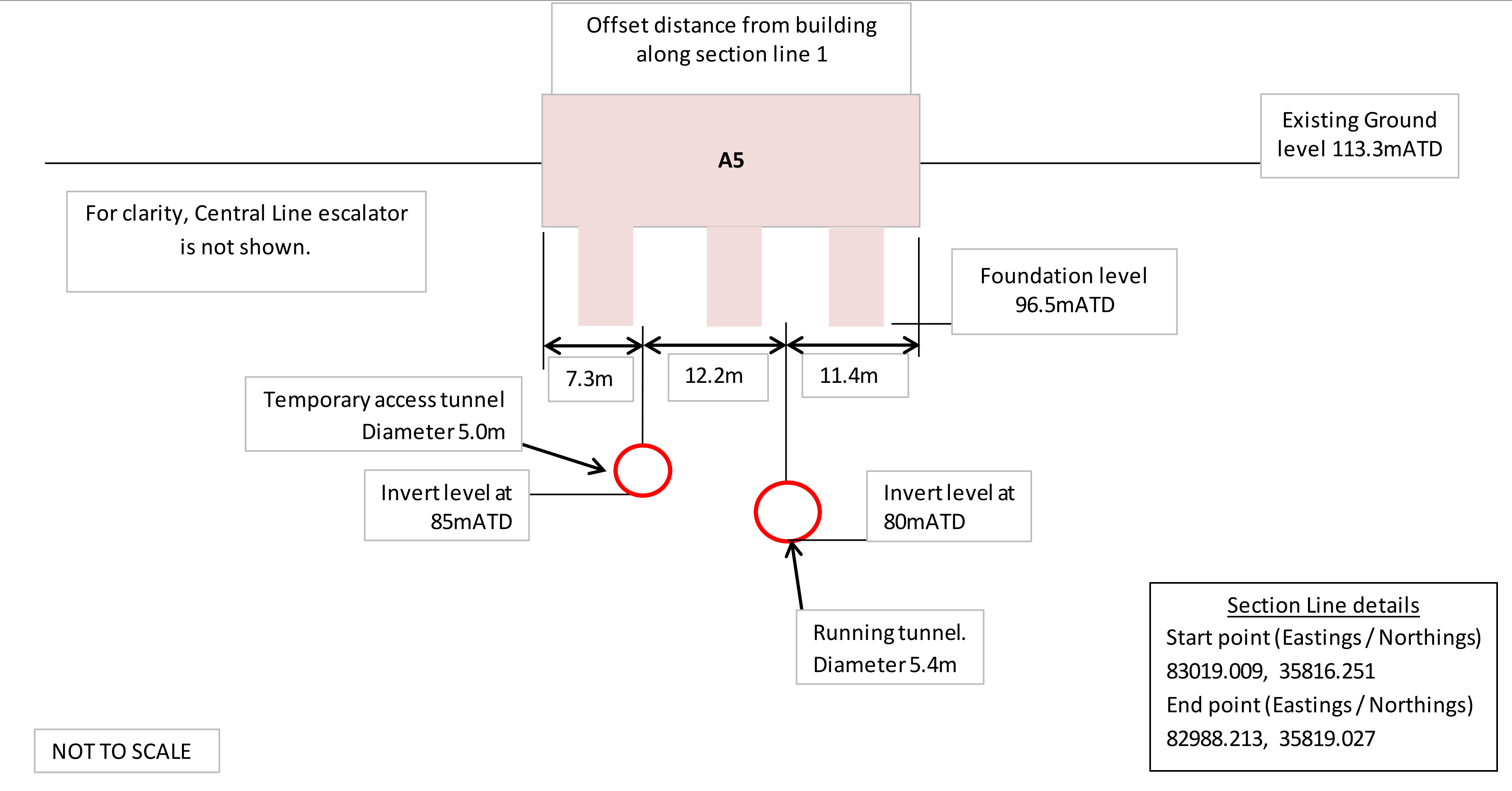

Figure 6: Diagrammatic cross-section of section (line 1) relative to tunnel position

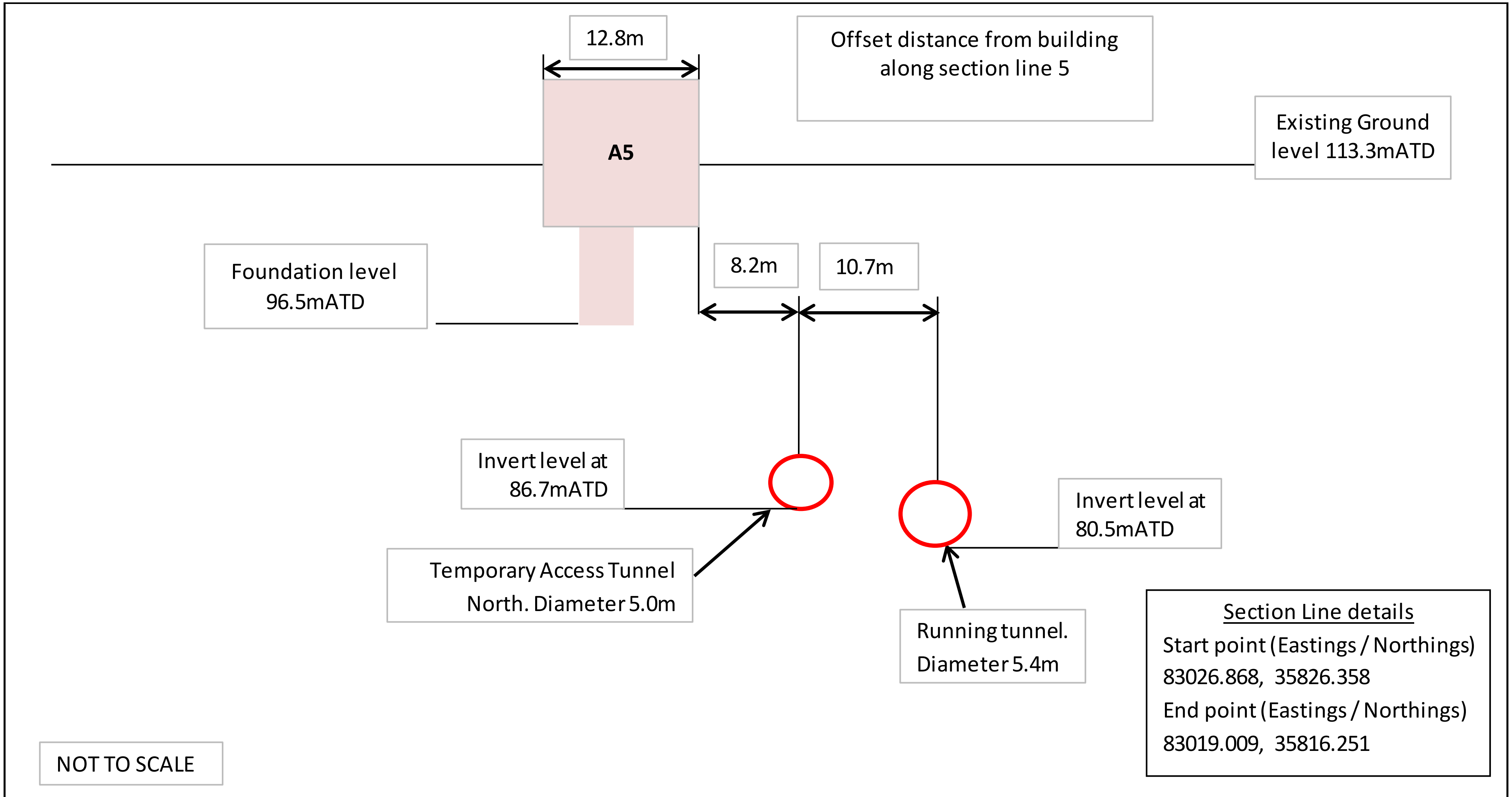

Figure 7: Diagrammatic cross-section of section (line 5) relative to tunnel position

Bank Station Capacity Upgrade

Building Damage Assessment Report

Building A6

Mansion House

URS-8798-RPT-G-001170

Prepared by: Lisa Perkins, Assistant Geotechnical Engineer — L. Perkins 21/07/14

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Document Owner	
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Role:	Designer

Document History

Revision	Date	Summary of changes
1.0	March 2014	Issue to Heritage
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3.0	July 2014	TWAO Issue

For the status of this document, please refer to the Building Damage Assessment Report Register (URS-8798-RGT-001229)

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- Keith Bowers/Neil Moss/Paul Dryden — London Underground
- Olly Newman — Dragados

Contents

FIGURES

TABLES

1 Introduction

This report summarises the results of a Stage 2 damage assessment for Mansion House.

Stage 2 damage assessments are undertaken for all buildings within the Stage 1 Greenfield ground surface 1mm settlement contour induced by the construction of the Bank Station Capacity Upgrade (BSCU).

The purpose of the assessment is to determine the potential impact that the Works will have on the building. This report describes the updated engineering and heritage assessments undertaken for the building and concludes whether mitigation is likely to be needed and if a further (Stage 3) assessment is recommended in order to verify this.

2 The Building

2.1 General Information

Mansion House is 5 storeys high with an attic and basement. It is a standalone building located at the junction between Queen Victoria Street and King William Street. It is a Grade I listed building and was designed by George Dance. Its construction began in 1739. In plan, the building is approximately 30m by 60m and it is approximately 17.5m tall (from GL to eaves). Throughout its life the building has undergone extensive alterations. These alterations took place in the 1790s, 1840s, 1860s and 1990s. The early alterations were mainly changes to the roof structure, with the removal of the transverse attic and grand staircase. In the 1990s, the alterations and strengthening works consisted of protective measures to protect/repair damage caused by the construction of the Dockland Light Railway (DLR). These works included the installation of internal tie rods and ties to prevent the main portico from becoming detached from the main building. This was followed in 1991-1993 by a major refurbishment which included the replacement of the courtyard roof. General refurbishment and repair work occurred in 1931, with further restoration required to repair damage sustained in WWII.

Originally it was understood that the building was founded on timber piles with planking support walls. Underpinning and strengthening works were subsequently carried out on several occasions including the reported reinforcement of the timber piles in 1868, as well as underpinning in 1901. However, trial pits were dug to investigate the building foundations as part of a condition survey in 1985 [7]; the investigations revealed no evidence of timber piles and planking. Therefore, it is assumed that the foundation level of Mansion House (BSCU reference A6) is at 106mATD[8].

General building information used in the assessment has been acquired as part of the structural desktop appraisal. This information is presented in Table 1.

Category	Building Information
BSCU Reference	A6
Location	Mansion House
Address	Mansion House
Building Type	Load bearing brickwork/stone cladding
Construction Age	1739-1758
No. of Storeys	5
Basements	1
Eaves Level (mATD)	131.0
Foundation Type	Strip
Ground Level (mATD)	113.5
Listed Grade	I
Note: Levels given are in metres above Tunnel Datum, mATD. Tunnel Datum is 100m below Ordnance Survey Datum at Newlyn.	

Table 1: General building information

A general view of the building exterior is shown in Plate 1. A location plan showing the building in relation to the proposed BSCU works is presented in Figure 2.

Plate 1: General view

2.2 Building Description

The Mansion House, by George Dance the Elder, was constructed between 1739 and 1758. The building reflects the classical style to its northern elevation with a rusticated ground storey and order of Corinthian columns and pilasters through two main storeys with an attic and entablature above. There are large round arched openings to the east and west elevations which also show paired pilasters under a heavy cornice, with an attic storey above. The southern elevation, of brick, is blank.

The form of the interior has been altered, predominantly in the later roofing of internal courtyards and historic changes to the roofline. Even so, the building retains much of its rich original decoration, formed of delicate and finely worked plaster, timber and marble, and also contains 19th century sculpture. Of great value are the ballroom to the north which contains a bracketed balcony, and Egyptian room to the south with its stained glass windows. There are timber stairs to each end of the building, the one to the north being carved and highly decorative

3 Methodology

This building damage assessment is undertaken in accordance with LU Works Information WI2300[1] and LU Civil Engineering – Common Requirements S1050[2].

The analysis methodology applies to ground-bearing buildings which will be affected by ground movements resulting from the construction of the BSCU. The engineering assessment calculates the potential impact of ground movements and assigns a damage category to the building based on a numeric scale. Additionally, for listed buildings, a heritage assessment is carried out which considers the sensitivity of the structure and the sensitivity of its particular features; a heritage sensitivity score is assigned. The heritage sensitivity score is added to the damage category to obtain the total score. If the total is 3 or more a more detailed Stage 3 assessment is triggered.

Oasys Xdisp is used to analyse the Greenfield ground movement in terms of settlement and horizontal displacement. Subsurface tunnelling induced ground movement profiles are determined in accordance with the methodology described by Mair et al[3 & 4].

Movements resulting from the Whole Block Scheme (WBS) and shaft excavations have been calculated using LU Guidance Document G0058[5].

The building is modelled as a simple elastic beam which is conservatively assumed to follow the Greenfield ground displacements. The beam is divided into hogging and sagging segments. The tensile strains within each segment are calculated based on the distortion associated with differential settlement (which is characterised by deflection ratio) and the distortion associated with differential horizontal displacement (characterised by horizontal strain).

Xdisp provides a method for calculating the maximum tensile strain within the building superstructure associated with these movements, in accordance with the assessment methodology described by Mair et al. This strain is used to determine the damage category based on the classification system proposed by Burland[6] and in accordance with S1050 Civil Engineering – Common Requirements[2]. The categories are presented in Table 2.

Damage Category	Description of Degree of Damage	Description of Typical Damage and likely forms of Repair for Typical Masonry Buildings.	Approx. Crack Width (mm)	Max. Tensile Strain %
0	Negligible	Hairline cracks.		< 0.05
1	Very slight	Fine cracks easily treated during normal redecoration. Perhaps isolated slight fracture in building. Cracks in exterior visible upon close inspection.	0.1 to 1.0	0.05 to 0.075
2	Slight	Cracks easily filled. Redecoration probably required. Several slight fractures inside building. Exterior cracks visible; some repainting may be required for weather-tightness. Doors and windows may stick slightly.	1 to 5	0.075 to 0.15
3	Moderate	Cracks may require cutting out and patching. Recurrent cracks can be masked by suitable linings. Tuck pointing and possible replacement of a small amount of exterior brickwork may be required. Doors and windows sticking. Utility services may be interrupted. Weather tightness often impaired.	5 to 15 or a number of cracks > 3	0.15 to 0.3
4	Severe	Extensive repair required involving removal and replacement of walls especially over doors and windows. Window and door frames distorted. Floor slopes noticeably. Walls lean or bulge noticeably. Some loss of bearing in beams. Utility services disrupted.	15 to 25 but also depends on number of cracks	> 0.3
5	Very severe	Major repair required involving partial or complete reconstruction. Beams lose bearing, walls lean badly and require shoring. Windows broken by distortion. Danger of instability.	Usually > 25 but depends on number of cracks	
Note: Please refer to LU S1050 Civil Engineering - Common Requirements[2]				

Table 2: Building damage classification

4 Input Data

The magnitude and distribution of ground movements and degree of building damage are calculated based on the following input data:

- The Xdisp model coordinates and levels are based on the 3D model (20130212DSPITT Scheme R09);
- Four construction stages are considered in accordance with the proposed programme (November 2013) as illustrated in Figure 1;
- Trough width parameter constant, K=0.5 is used in accordance with WI2300.

The input data for the building, tunnels and shaft excavations are summarised in Table 3, Table 4 and Table 5, respectively.

Location	Foundation level (mATD)	Building Height above foundation level (m)	E/G
Mansion House	106*	25	2.6
Note: Where E / G is the ratio of Young's modulus to shear modulus of the deep beam representing the building. * Known level [8].			

Table 3: Building data

Tunnel Item	Level of axis (mATD)	External diameter (m)	Volume Loss (%)
Running tunnels	84	5.4	1.5
Square works adits	75.8 to 95.3	4.1 to 7.8	2.5
Platform enlargement	85.6	7.4 to 11.2	1.5
Escalator barrels	Inclined	8.3 to 8.4	1.5
Central Line Connection	Inclined (87.6 to 89.2)	8.6	1.5

Table 4: Tunnel data

Construction of Central Line cross-passage CP1 will commence after the completion of Northern Line to Central Line escalator barrels, at construction stage 4.

Excavation	Excavation Base Level (mATD)
Grout Shaft at King William Street	97
Whole Block Scheme Box excavation	73
Arthur Street Shaft	81

Table 5: Excavation data

The distance of building Mansion House (A6) relative to the excavation elements listed in Tables 5 is sufficiently large that this building should not be affected by their construction. A new cross passage is also proposed between the platform tunnels of the central line, see Figure 3.

The Xdisp model filenames used to undertake this assessment are:

- A6 - Stage 4
- A6 - Stage 3
- A6 - Stage 2
- A6 - Stage 1

5 Results

5.1 Engineering Assessment

The sections through the building which have been analysed are shown on plan in Figure 3.

Assessment has been undertaken at three intermediate construction stages and at the end of construction when all major elements of the works including shaft and tunnels have been completed. The damage category assigned to the building is based on the construction stage at which the potential impact on the building is most severe.

The maximum settlement and tensile strain calculated for each analysed section at the most onerous intermediate construction stage and at the end of construction are presented in Table 6 and Table 7 respectively.

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
A6 (line 1)	44	0.039
A6 (line 2)	<1	0.001
A6 (line 3)	11	0.017
A6 (line 4)	42	0.023

Table 6: Building response at most onerous intermediate stage - Construction Stage 3

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
A6 (line 1)	45	0.039
A6 (line 2)	<1	0.001
A6 (line 3)	14	0.023
A6 (line 4)	46	0.030

Table 7: Building response at end of Construction Stage 4

The results of the assessment show that the end of construction Stage 4 is the critical stage for this building although this is similar to Stage 3. Section A6 line 1 experiences the most onerous combined tensile strain. The orientation is shown in Figure 3. The vertical and horizontal ground movements along line 1 are shown in Figure 4. The relative positions of the building and tunnels along section A6 line 1 is shown in Figure 5. The calculated strains are summarised in Table 8.

Strains in section (Curvature)	Position from start (m)	Length (m)	Average* Horizontal Strain (%)	Maximum Tensile Strains (%)	Damage Category
Sagging	0.0	18.4	-0.042	0.021	Negligible
Hogging	18.4	42.9	0.012	0.039	Negligible
Note: * Tensile horizontal strains are +ve. Compressive horizontal strains are –ve.					

Table 8: Section analysed, results for worst case tensile strain

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0. This corresponds to Negligible damage in accordance with Table 2.

The maximum settlement of the building at foundation level at the end of construction is 46mm.

Whilst the Stage 2 assessment includes all major works in the vicinity of Mansion House, it does not specifically include the construction of a 0.75m external diameter cable tunnel which will be constructed from the Moving Walkway tunnel in the vicinity of the North East corner of Mansion House approximately 21m in a Northerly direction to a shaft leading to the Central Line Ticket Hall area. This has been assessed and is confirmed to have no significant impact on tensile strain and settlement. The cable tunnel will be included in the Stage 3 assessment.

5.2 Heritage and Structural Assessment

Following site inspection, assessment has been made using the scoring methodology set out in Table 9.

Score	Structure (Sensitivity of the structure to ground movements and interaction with adjacent buildings)	Heritage features (Sensitivity to calculated movement of particular features within the building)	Condition (Factors which may affect the sensitivity of structural or heritage features)
0	Masonry buildings with lime mortar and regular openings, not abutted by other buildings, and therefore similar to the buildings on which the original Burland assessment was based.	No particular sensitive features	Good/Fair - not affecting the sensitivity of structural or heritage features
1	Buildings not complying with categories 0 or 2, but still with some sensitive structural features in the zone of settlement e.g.: cantilever stone staircases, long walls without joints or openings, existing cracks where further movements are likely to concentrate, mixed foundations	Brittle finishes, e.g. faience or tight-jointed stonework, which are susceptible to small structural movements and difficult to repair invisibly.	Poor - may change the behaviour of a building in cases of movement. Poor condition of heritage features and finishes. Evidence of previous movement.
2	Buildings which, by their structural form, will tend to concentrate all their movements in one location (e.g.: a long wall without joints and with a single opening).	Finishes which if damaged will have a significant effect on the heritage value of the building, e.g. Delicate frescos, ornate plasterwork ceilings.	Very poor – parlous condition of heritage features and finishes, severe existing damage to structure including evidence of ongoing movement. Essentially buildings where even very small movements could lead to significant damage.

Table 9: Heritage and structural scoring methodology

The results of the heritage assessment carried out for the building are summarised in Table 10.

Sensitivity of the structure
The Mansion House is an unframed rectangular masonry box. It is approximately 61m long. East and west elevations have major windows near each end, in the Ballroom and the Egyptian Room. The windows are discontinuities where movement will tend to concentrate. Hogging movement will produce tensile strains towards the top of the windows where there are vulnerable structural elements: the window arches, the stained glass, the internal balconies, and the bottle balustraded parapets. Window arches may spread and the voussoirs joggle vertically. Stained glass may stretch and tear its lead cames. The internal balconies which bridge the windows may be stretched and pulled away from their supports. The bottle balustrade parapets may be stretched and lose their stability. Elsewhere, other sensitive structural elements are timber staircases with hanging newels, and timber ceilings supporting heavy plaster enrichments.
Score: 2 – The predicted movements will tend to be concentrated in areas of weakness, particularly large openings to the west and east elevations.
Sensitivity of the heritage
The building contains rich decorative surfaces. To the northern portion, particularly sensitive heritage features include the plaster ceilings/walls to the first floor administrative spaces and former court. Also at this end of the building, the ballroom has delicate plaster finishes and a bracketed balcony which shows signs of sagging. This area is closest to the higher predicted settlements, and differential movements across this section of the building may concentrate damage within this area. Further south, there are areas of heavy plasterwork in deep relief throughout the central public and private apartments. To the west, the Egyptian Room contains statuary, plaster decoration, and a balcony, all of which may be sensitive to cracking. The stained glass windows are very sensitive and show signs of bulging and distortion. Externally, the facades of the building are of high heritage value, with sensitivities including the northern portico and tall windows to the long east and west elevations. Damage may occur to the window surrounds and voussoirs.
Score: 2 – The building contains a wealth of original finishes and surfaces, damage to which has the potential to significantly affect the heritage value of the building. The external Portland stone finishes are also highly sensitive and finely jointed.
Sensitivity of the condition
A continuous programme of renovation is undertaken throughout the building, and the surface condition of the building and its features is generally good, with some localised areas of crazing and cracking to plaster surfaces. However, there is evidence of previous movement which may have caused hidden weaknesses, and will be the focus of future movement. The building has been much altered since its construction in 1739, and strengthened on various occasions in response to decay of its piled foundations and subsidence due to successive tunnelling. Visible evidence of previous movement includes uneven floors, joggled arch voussoirs, sagging stairs and balconies, and a distorted portico on the west side. Hidden movement may include the opening of timber joints, reduced bearing length of beams, and loosening of timber carcassing which supports plasterwork. Successive bouts of movement are accumulative and fabric can only be stretched so far before local failures occur. Repairs and strengthening over the years will have dealt with much of the stretching, but some planes of weakness are likely to remain.
Score: 1 – though the internal condition of the building is generally good and undergoes repair and renovation on a regular basis, there is evidence of previous movement and specific areas of disrepair which may exacerbate the structural and heritage sensitivities of the building.

Table 10: Heritage and structural assessment

5.3 Total Score

The total score is the summation of the damage category, structural sensitivity, heritage sensitivity and condition sensitivity scores:

The damage category is 0

The structural sensitivity score is 2

The heritage sensitivity score is 2

The condition sensitivity score is 1

The total score for this building is 5

6 Conclusion

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0 for the Mansion House. However, specific heritage and structural assessment taking into account the location and extent of settlement and tensile strains indicates that the building has a high level of structural and heritage sensitivity to movement, particularly due to previous incidents of settlement which may have impacted the structural behaviour of the building. This assessment has determined that the building has a total score of 5.

It is recommended that a Stage 3 assessment is undertaken to further consider the potential damage to the structural form.

In particular, the Stage 3 assessment should examine the implications of previous mitigation, and further assess the behaviour of the rich and fragile finishes and structural elements.

The BSCU Environmental Statement considers the mitigation that could be needed, however, it is recommended that Stage 3 assessment is undertaken to verify how heritage finishes and features may respond and whether such mitigation is required.

7 References

[1] LU Works Information WI 2300 Ground Movement version 3, 19-07-13.

[2] LU Category 1 Standard: S1050 Civil Engineering - Common Requirements, Issue No. A7, Nov. 2013.

[3] Mair R J, Taylor R N and Bracegirdle A (1993). Subsurface settlement profiles above tunnels in clays. Géotechnique 43, No. 2, pp. 315-320.

[4] Mair R J, Taylor R N and Burland J B (1996). Prediction of ground movements and assessment of risk of building damage due to bored tunnelling. (In: International Conference of Geotechnical Aspects of Underground Construction in Soft Ground, London, pp. 713–718.

[5] LU Guidance Document G0058 Civil Engineering Technical Advice Notes, Issue No. A17, Feb. 2013.

[6] Burland J B (1995). Assessment of risk of damage to buildings due to tunnelling and excavation. Proceedings: 1st International Conference of Earthquake Geotechnical Engineering, IS Tokyo, 1995.

[7] RIBA D – Phase 3 Potential Damage Assessment of the Mansion House. Mott MacDonald. N133-BCR-MMD-00-DC-Z-0067-S0-1.0. (2012).

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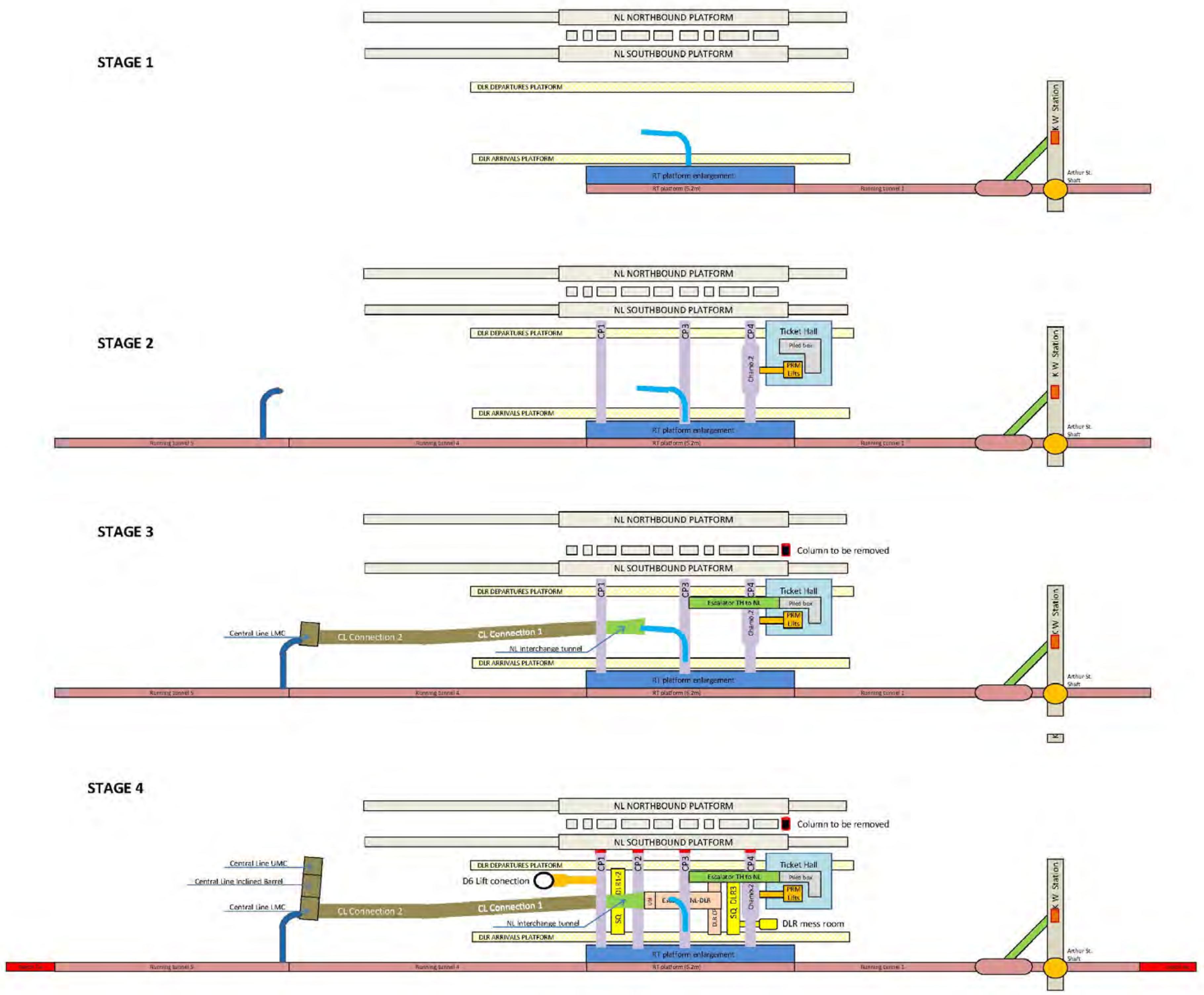

Figure 1: Construction Stage model

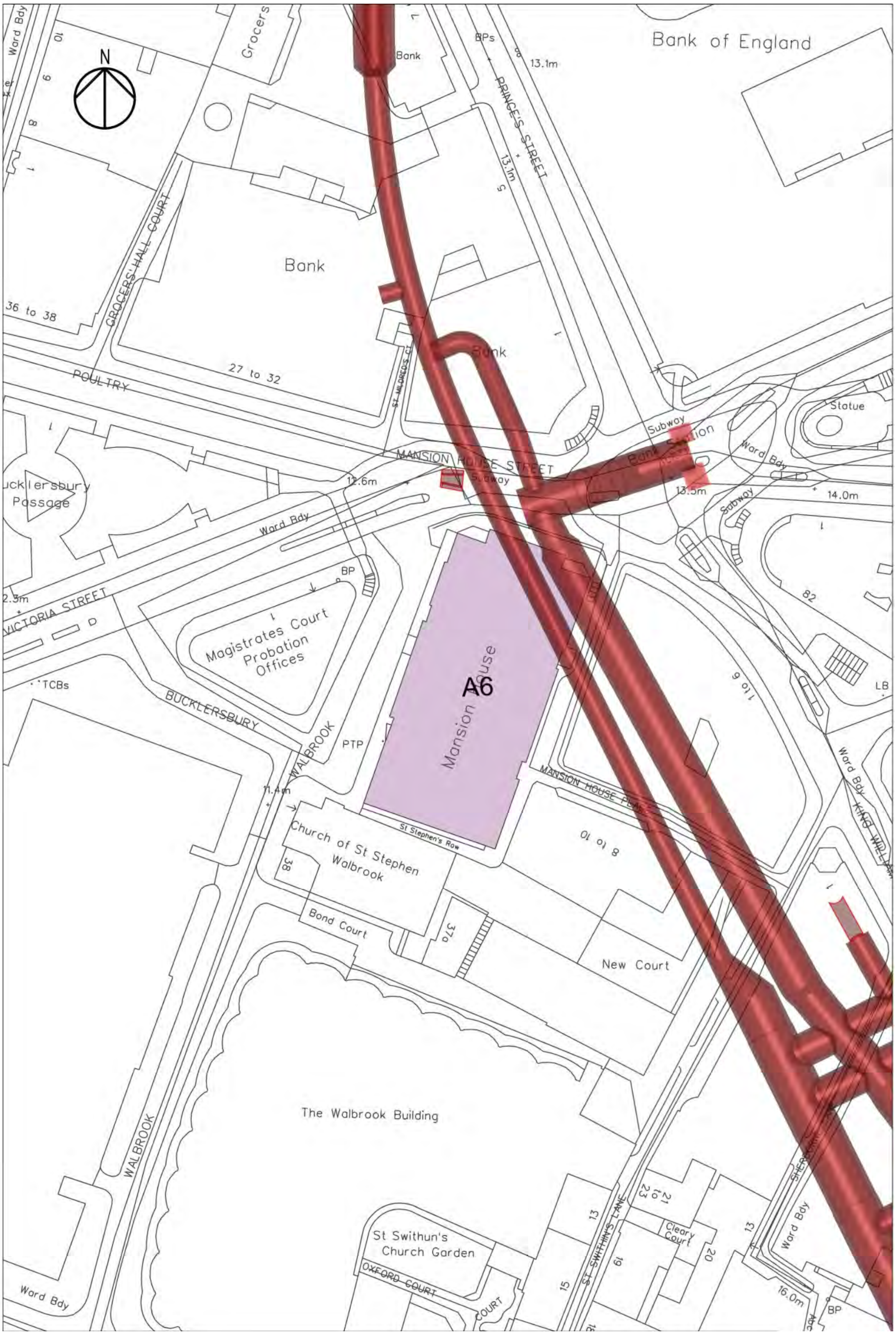

Figure 2: Location plan showing building location in relation to BSCU works

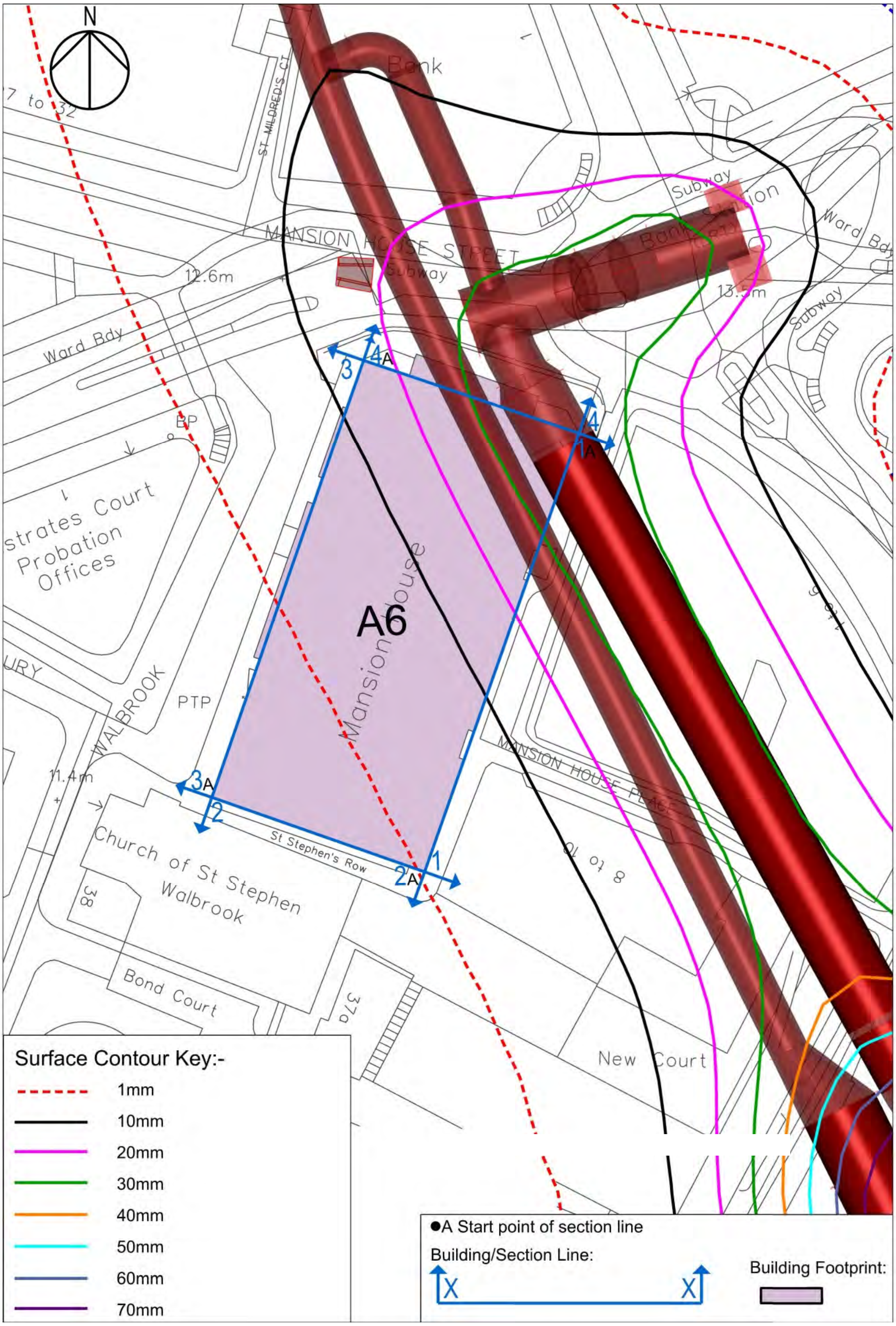

Figure 3: Building location, sections analysed and Settlement Contours at stage of worst case for tensile strains

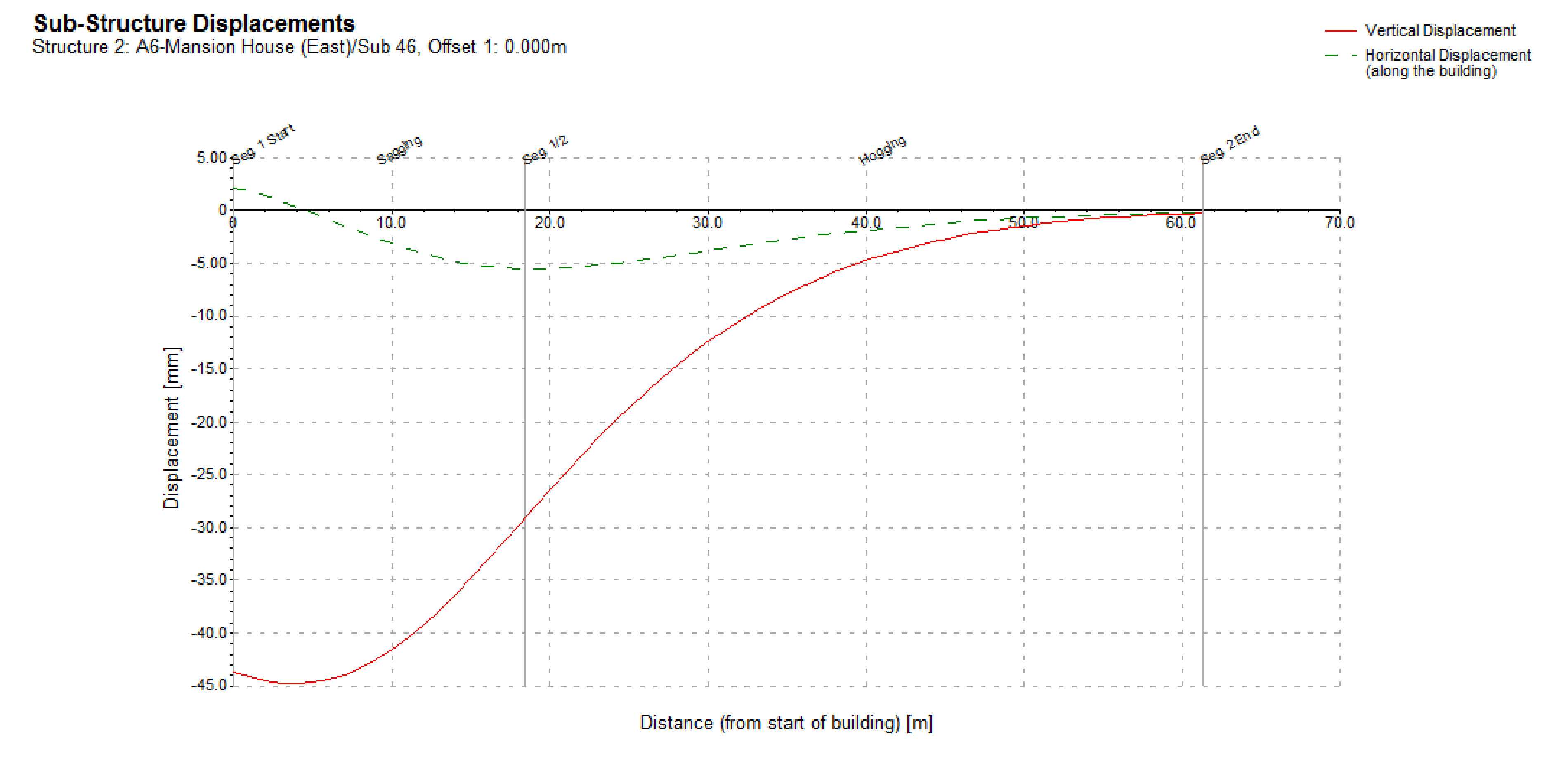

Figure 4: Building displacement at founding level at stage 4 (line 1) of worst case for tensile strains

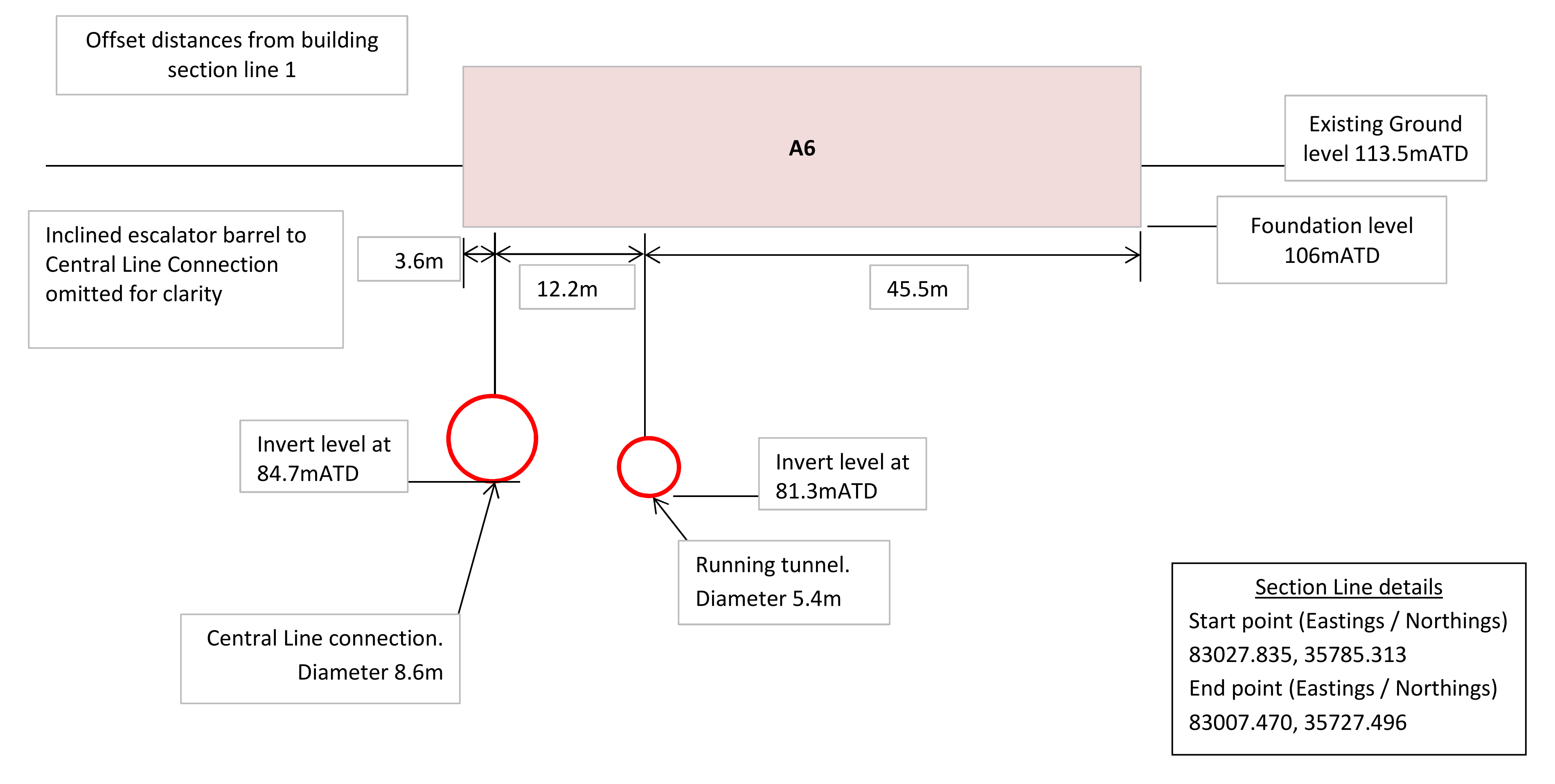

Figure 5: Diagrammatic cross-section of section (line 1) relative to tunnel locations

LUL Bank Project Office
10 King William Street
London EC4 N7TW

Bank Station Capacity Upgrade

Building Damage Assessment Report

Building A7

1 – 6 Lombard Street

URS-8798-RPT-G-001171

Prepared by:	Lisa Perkins Assistant Geotechnical Engineer	[signature]	21/07/14
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3.0	July 2014	TWAO Issue

For the status of this document, please refer to the Building Damage Assessment Report Register (URS-8798-RGT-001229)

Consultation:

• Ela Palmer	URS Heritage
• Brian Lyons	Dr.Sauer
• Keith Bowers/Neil Moss/Paul Dryden	London Underground
• Olly Newman	Dragados

Safely Together

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FIGURES

TABLES

1 Introduction

This report summarises the results of a Stage 2 damage assessment for 1-6 Lombard Street, Ref A7.

Stage 2 damage assessments are undertaken for all buildings within the Stage 1 predicted Greenfield ground surface 1mm settlement contour induced by the construction of the Bank Station Capacity Upgrade (BSCU.)

The purpose of the assessment is to determine the potential effect the works will have on the building. This report describes the engineering and heritage assessments undertaken for the building and concludes whether mitigation is likely to be needed and if a further (Stage 3) assessment is recommended in order to verify this..

2 The Building

2.1 General Information

Located next to Mansion House, 1-6 Lombard Street is at the junction between King William Street and Lombard Street. The building is 7 storeys high with the top two storeys consisting of a setback dormer on the roof. The original building was renovated in the mid-eighties in order to generate more office space with only the entrance hall and eastern end of the building being retained from the original office space. It has been assumed that the building sits on a raft foundation[7,8]. General building information used in the assessment has been acquired as part of the structural desktop appraisal. This information is presented in Table 1.

Category	Building Information
BSCU Reference	A7
Location	Lombard street
Address	1-6 Lombard street
Building Type	Steel framed / load bearing masonry
Construction Age	1905-1908, 1985(Refurbishment)
No. of Storeys	7
Basements	1
Eaves Level (mATD)	136.3
Foundation Type	Raft
Ground Level (mATD)	114.2
Listed Grade	II
Note: Levels given are in metres above Tunnel Datum, m ATD. Tunnel Datum is 100m below Ordnance Survey Datum at Newlyn	

Table 1: General building information

A general view of the building exterior is shown in Plate 1. A location plan showing the building in relation to the proposed BSCU works is presented in Figure 2.

Plate 1: General view

2.2 Building Description

1-6 Lombard Street dates from 1908 and 1915 and was designed by Dunn and Watson with W Curtis Green. The symmetrical stone façade is curved to follow the line of the street, and the building has five main storeys with two dormered roof storeys. It has 17 bays in all with slightly projecting end pavilions. The detail of the façade is classical, including giant Corinthian order columns which unite the second, third and fourth floors. The main entrance comprises a tall arched opening leading to a vaulted entrance turret flanked by further narrower openings matching those to the end pavilions.

Internally, the building has two distinct sections. That to the north-west contains a restaurant with a large central dome, and heavy plasterwork decoration. The rest of the building houses office accommodation, and is centred on a cantilevered staircase of stone and an iron balustrade, with a hexagonal timber skylight above. To each stair landing are stone columns with foliate capitals. There are additional, secondary stone cantilevered stairs to the southern range of the building. The south-eastern corner of the building contains a small panelled room with plaster cornice. The entrance foyer has a carved stone cornice around a central dome, the decorative detail of which echoes that of the columns to the stair landings. The basement contains a large Chubb safe, not presently in use.

3 Methodology

This building damage assessment is undertaken in accordance with LU Works Information WI2300[1] and LU Civil Engineering - Common Requirements S1050[2].

The analysis methodology applies to ground-bearing buildings which will be affected by ground movements resulting from the construction of the BSCU. The engineering assessment calculates the potential impact of ground movements and assigns a damage category to the building based on a numeric scale. Additionally, for listed buildings, a heritage assessment is carried out which considers the sensitivity of the structure and the sensitivity of its particular features; a heritage sensitivity score is assigned. The heritage sensitivity score is added to the damage category to obtain the total score. If the total score is 3 or more, a more detailed Stage 3 assessment is triggered.

Oasys Xdisp is used to analyse the Greenfield ground movement in terms of settlement and horizontal displacement. Subsurface tunnelling induced ground movement profiles are determined in accordance with the methodology described by Mair et al[3 & 4].

Movements resulting from the Whole Block Scheme (WBS) and shaft excavations have been calculated using LU Guidance Document G0058[5].

The building is modelled as a simple elastic beam which is conservatively assumed to follow the Greenfield ground displacements. The beam is divided into hogging and sagging segments. The tensile strains within each segment are calculated based on the distortion associated with differential settlement (which is characterised by deflection ratio) and the distortion associated with differential horizontal displacement (characterised by horizontal strain).

Xdisp provides a method for calculating the maximum tensile strain within the building superstructure associated with these movements, in accordance with the assessment methodology described by Mair et al[4]. This strain is used to determine the damage category based on the classification system proposed by Burland[6] and in accordance with LU Civil Engineering Common Requirements S1050[2]. The categories are presented in Table 2.

Damage Category	Description of Degree of Damage	Description of Typical Damage and likely forms of Repair for Typical Masonry Buildings.	Approx. Crack Width (mm)	Max. Tensile Strain %
0	Negligible	Hairline cracks.		< 0.05
1	Very slight	Fine cracks easily treated during normal redecoration. Perhaps isolated slight fracture in building. Cracks in exterior visible upon close inspection.	0.1 to 1.0	0.05 to 0.075
2	Slight	Cracks easily filled. Redecoration probably required. Several slight fractures inside building. Exterior cracks visible; some repainting may be required for weather-tightness. Doors and windows may stick slightly.	1 to 5	0.075 to 0.15
3	Moderate	Cracks may require cutting out and patching. Recurrent cracks can be masked by suitable linings. Tuck pointing and possible replacement of a small amount of exterior brickwork may be required. Doors and windows sticking. Utility services may be interrupted. Weather tightness often impaired.	5 to 15 or a number of cracks > 3	0.15 to 0.3
4	Severe	Extensive repair required involving removal and replacement of walls especially over doors and windows. Window and door frames distorted. Floor slopes noticeably. Walls lean or bulge noticeably. Some loss of bearing in beams. Utility services disrupted.	15 to 25 but also depends on number of cracks	> 0.3
5	Very severe	Major repair required involving partial or complete reconstruction. Beams lose bearing, walls lean badly and require shoring. Windows broken by distortion. Danger of instability.	Usually > 25 but depends on number of cracks	
Note: Please refer LU Civil Engineering - Common Requirements S1050[2].				

Table 2: Building damage classification

4 Input Data

The magnitude and distribution of ground movements and degree of building damage is calculated based on the following input data:

- The Xdisp model coordinates and levels are based on the 3D model (20130212DSPITT Scheme R09);
- Four construction stages are considered in accordance with the proposed programme (November 2013) as illustrated in Figure 1;
- Trough width parameter constant, K=0.5 is used in accordance with WI2300[1].

The input data for the building, tunnels and shaft excavation are summarised in Table 3, Table 4 and Table 5 respectively.

Location	Foundation level (mATD)	Building Height above foundation level (m)	E/G
1-6 Lombard Street	106.4[7]	29.9	2.6
Note: Where E / G is the ratio of Young's modulus to shear modulus of the deep beam that is to represent the building.			

Table 3: Building data

Tunnel Item	Level of axis (mATD)	External diameter (m)	Volume Loss (%)
Running tunnels	Inclined (82.8 to 85.8)	5.4	1.5
Square works adits	75.8 to 95.3	4.1 to 7.8	2.5
Platform enlargement	85.6	7.4 to 11.2	1.5
Escalator barrels	Inclined	8.3 to 8.4	1.5
Central Line Connection	Inclined (87.6 to 89.2)	8.6	1.5

Table 4: Tunnel data

Excavation	Excavation Base Level (mATD)
Grout Shaft at King William Street	97
Whole Block Scheme Box excavation	73
Arthur Street Shaft	81

Table 5: Excavation data

The distance of building 1-6 Lombard Street (A7) relative to the excavation elements listed in Table 5 is reasonably large so this building is unlikely to be affected by their construction.

The Xdisp model filenames used to undertake this assessment are:

- A7 - Stage 4
- A7 - Stage 3
- A7 - Stage 2
- A7 - Stage 1

5 Results

5.1 Engineering Assessment

The sections through the building which have been analysed are shown on plan in Figure 3.

Assessment has been undertaken at three intermediate construction stages and at the end of construction when all major elements of the works including shaft and tunnels have been completed. The damage category assigned to the building is based on the construction stage at which the potential impact on the building is most severe.

The maximum settlement and tensile strain calculated for each of the analysis sections at the most onerous intermediate construction stage and at the end of construction are presented in Table 6 and Table 7 respectively.

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
A7 (line 1)	43	0.036
A7 (line 2)	32	0.034
A7 (line 3)	40	0.022

Table 6: Building response at most onerous intermediate stage - Construction Stage 3

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
A7 (line 1)	43	0.032
A7 (line 2)	34	0.034
A7 (line 3)	41	0.021

Table 7: Building response at end of construction stage

The results of the assessment show that the intermediate construction Stage 3 is the critical stage for this building. At this stage, A7 line 1 experiences the most onerous combined tensile strain. The orientation is shown in Figure 3. The vertical and horizontal Greenfield ground movements along section line 1 are shown in Figure 4. The relative position of the building and tunnels along A7 line 1 is shown in Figure 5. The calculated strains are summarised in Table 8.

Line #	Strains in section (Curvature)	Position from start (m)	Length (m)	Average* Horizontal Strain (%)	Maximum Tensile Strains (%)	Damage Category
(Line 1)	Hogging	0.0	14.3	0.014	0.018	Negligible
	Sagging	14.3	28.7	-0.041	0.036	Negligible
Note: * Tensile horizontal strains are +ve. Compressive horizontal strains are –ve.						

Table 8: Section analysed, results for worst case tensile strain

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0. This corresponds to negligible damage in accordance with Table 2.

The maximum settlement of the building at foundation level at the end of construction is 43mm.

5.2 Heritage Assessment

Following site inspection, assessment has been made using the scoring methodology set out in Table 9.

Score	Structure (Sensitivity of the structure to ground movements and interaction with adjacent buildings)	Heritage features (Sensitivity to calculated movement of particular features within the building)	Condition (Factors which may affect the sensitivity of structural or heritage features)
0	Masonry buildings with lime mortar and regular openings, not abutted by other buildings, and therefore similar to the buildings on which the original Burland assessment was based.	No particular sensitive features	Good/Fair - not affecting the sensitivity of structural or heritage features
1	Buildings not complying with categories 0 or 2, but still with some sensitive structural features in the zone of settlement e.g.: cantilever stone staircases, long walls without joints or openings, existing cracks where further movements are likely to concentrate, mixed foundations	Brittle finishes, e.g. faience or tight-jointed stonework, which are susceptible to small structural movements and difficult to repair invisibly.	Poor - may change the behaviour of a building in cases of movement. Poor condition of heritage features and finishes. Evidence of previous movement.
2	Buildings which, by their structural form, will tend to concentrate all their movements in one location (e.g.: a long wall without joints and with a single opening).	Finishes which if damaged will have a significant effect on the heritage value of the building, e.g. Delicate frescos, ornate plasterwork ceilings.	Very poor – parlous condition of heritage features and finishes, severe existing damage to structure including evidence of ongoing movement. Essentially buildings where even very small movements could lead to significant damage.

Table 9: Heritage and structural scoring methodology

The results of the heritage assessment carried out for the building are summarised in Table 10.

Sensitivity of the structure
The Mansion House Place elevation is irregular, the central portion extending to only one storey in height, while the front and rear portions extend to the buildings full height. Based on the predicted settlements this arrangement will tend to focus strains to either end of the single storey portion, where cracks are likely to form in the fine jointed ashlar. In addition bottle baluster balustrades are present in this area, the stability of which is sensitive to movement which may crack the balustrade, leaving the balusters potentially unstable. The building contains two significant stone "cantilever" staircases. The main stair is curved on plan and extends from ground to sixth floor and is supported by a tightly jointed masonry wall. The rear escape stair extends from basement to sixth floor, is square on plan and is more utilitarian in nature. It is thought to have been altered during the various refurbishments. Both stairs rely on the treads being soundly locked into the supporting wall to resist torsion, while transmitting vertical load down from tread to tread onto the landings below. The closely jointed masonry supporting the main stair has numerous fine cracks running through both the joints and the stone units. The treads appear to be in good condition and no obvious signs of displacement or deflection are present. Some cracking was observed to the lover levels of the Lombard Street elevation at both the left and right hand ends. This may be the result of previous movement. The effects of new movement are likely to be concentrated at these locations. It is noted that modern interventions have included to the infilling of lightwells to provide additional office space. It is understood that these additions are supported on columns founded on the original raft foundation and as such will behave monolithically with the original building structure.
Score: 2 – The irregularity of the Mansion House Place façade may concentrate all movements, making this elevation structurally sensitive. In addition the fine jointed ashlar, bottle baluster balustrades and the two "cantilever" stairs are considered sensitive to the degree of movement predicted by the settlement analysis. Movement causing cracks within the masonry of the stair or balustrade could cause the integrity of the structure to be compromised. The existing cracks in the Lombard Street elevation are also vulnerable to the effects of the predicted movement.
Sensitivity of the heritage
There are two main areas of heritage sensitivity within the building. The first is concentrated on the decorative plaster ceilings and cornices of the restaurant area, which are also in poor condition. These surfaces are brittle, and may crack as a result of settlement, leading to loss of historic material and at worst failure of sections of surface plaster. The second is the stonework of the central stair and foyer, which currently show some fine cracks; the decorative elements of this stonework may be difficult to repair in the event of damage, and cracking as a result of the BSCU Works may lead to widening of existing cracks as well as within joints. The exterior cladding to the Mansion House Place façade is of high quality, but does not show the decorative detail of the Lombard Street elevation, which will experience smaller movements. Cracking of the stone masonry elements, whilst unlikely to cause loss of historic fabric and are repairable, risk a permanent impact on aesthetic value of the building.
Score: 1 – Damage to the areas of heritage sensitivity, which are comprised of brittle finishes, may cause a permanent aesthetic impact, and there may be loss of historic fabric to the plaster of the restaurant area.
Sensitivity of the condition
In general the building is in good condition, excepting the interior finishes to the restaurant which show fine cracking and flaking, and some fine stone cracking to the central stair and externally on the façade.
Score: 1 – the condition of the plasterwork within the restaurant exacerbates its fragility and sensitivity to the predicted movements

Table 10: Heritage and structural assessment

5.3 Total Score

The total score is the summation of the damage category, structural sensitivity, heritage sensitivity and condition sensitivity scores:

The damage category is 0

The structural sensitivity score is 2

The heritage sensitivity score is 1

The condition sensitivity score is 1

The total score for this building is 4

6 Conclusion

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0 for 1-6 Lombard Street. However, specific heritage and structural assessment taking into account the location and extent of settlement and tensile strains indicates that the building has a high level of structural and heritage sensitivity to movement in certain locations. This assessment has determined that the building has a total score of 4.

It is recommended that a Stage 3 assessment is undertaken to further consider the potential damage to the structural form.

There are areas of structural and heritage sensitivity which are brittle, and settlement generated by the BSCU Works is likely to be concentrated at these sensitive areas.

The BSCU Environmental Statement considers the mitigation that could be needed, however, it is recommended that Stage 3 assessment is undertaken to verify how heritage finishes and features may respond and whether such mitigation is required.

7 References

[1] LU Works Information WI 2300 Ground Movement version 3, 19-07-13.

[2] LU Category 1 Standard: S1050 Civil Engineering - Common Requirements, Issue No. A7, Nov. 2013.

[3] Mair R J, Taylor R N and Bracegirdle A (1993). Subsurface settlement profiles above tunnels in clays. Géotechnique 43, No. 2, pp. 315-320.

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[5] LU Guidance Document G0058 Civil Engineering Technical Advice Notes, Issue No. A17, Feb. 2013.

[6] Burland J B (1995). Assessment of risk of damage to buildings due to tunnelling and excavation. Proceedings: 1st International Conference of Earthquake Geotechnical Engineering, IS Tokyo, 1995.

[7] A.D de VINE & Associates drawing - A.D de VINE & Associates - 1985

[8] Mott MacDonald (2012). Bank Station building data sheets – A list buildings. N133-BCR-MMD-00-Z-DC-S-0003-S0-1.0.

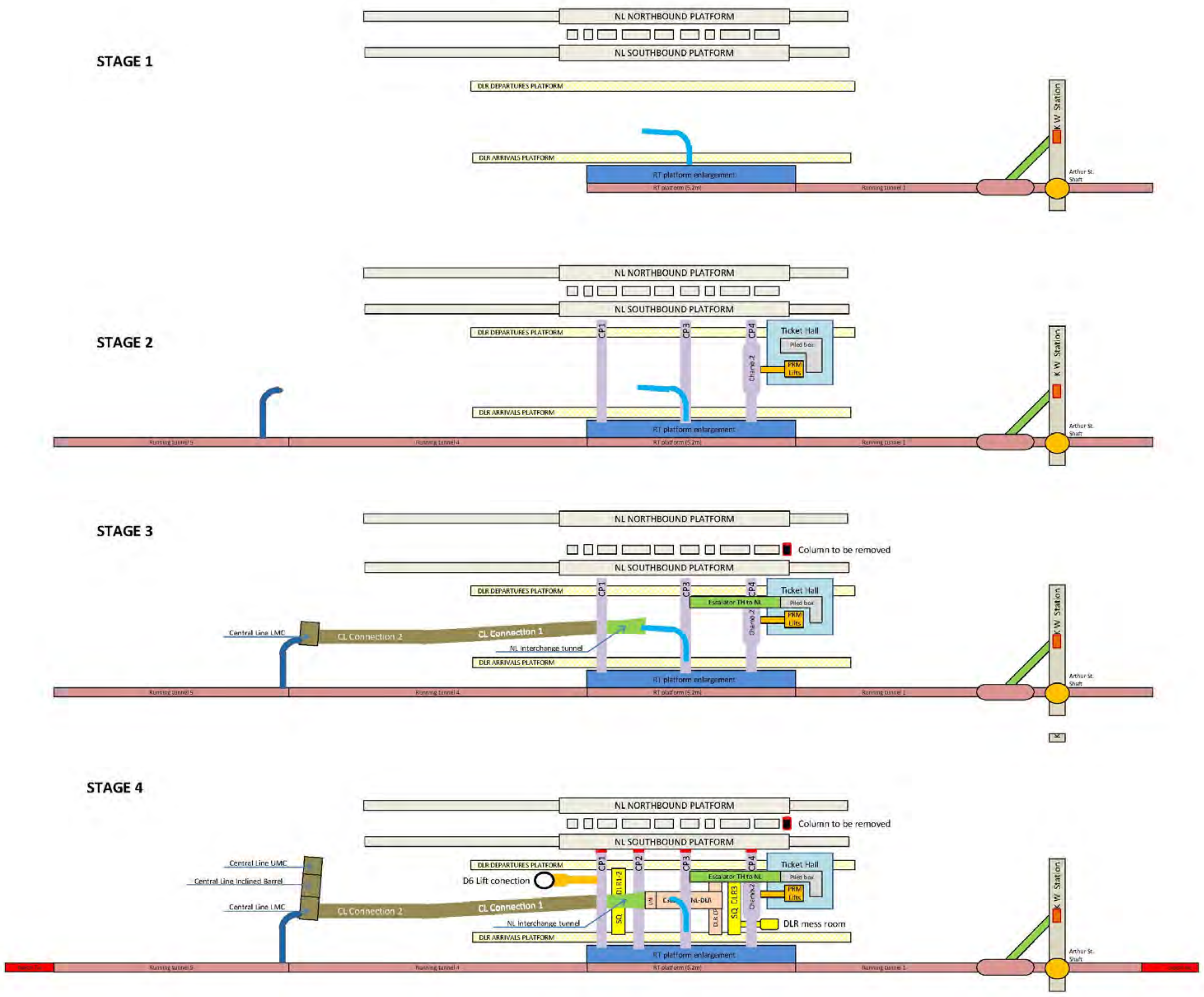

Figure 1: Construction Stage model

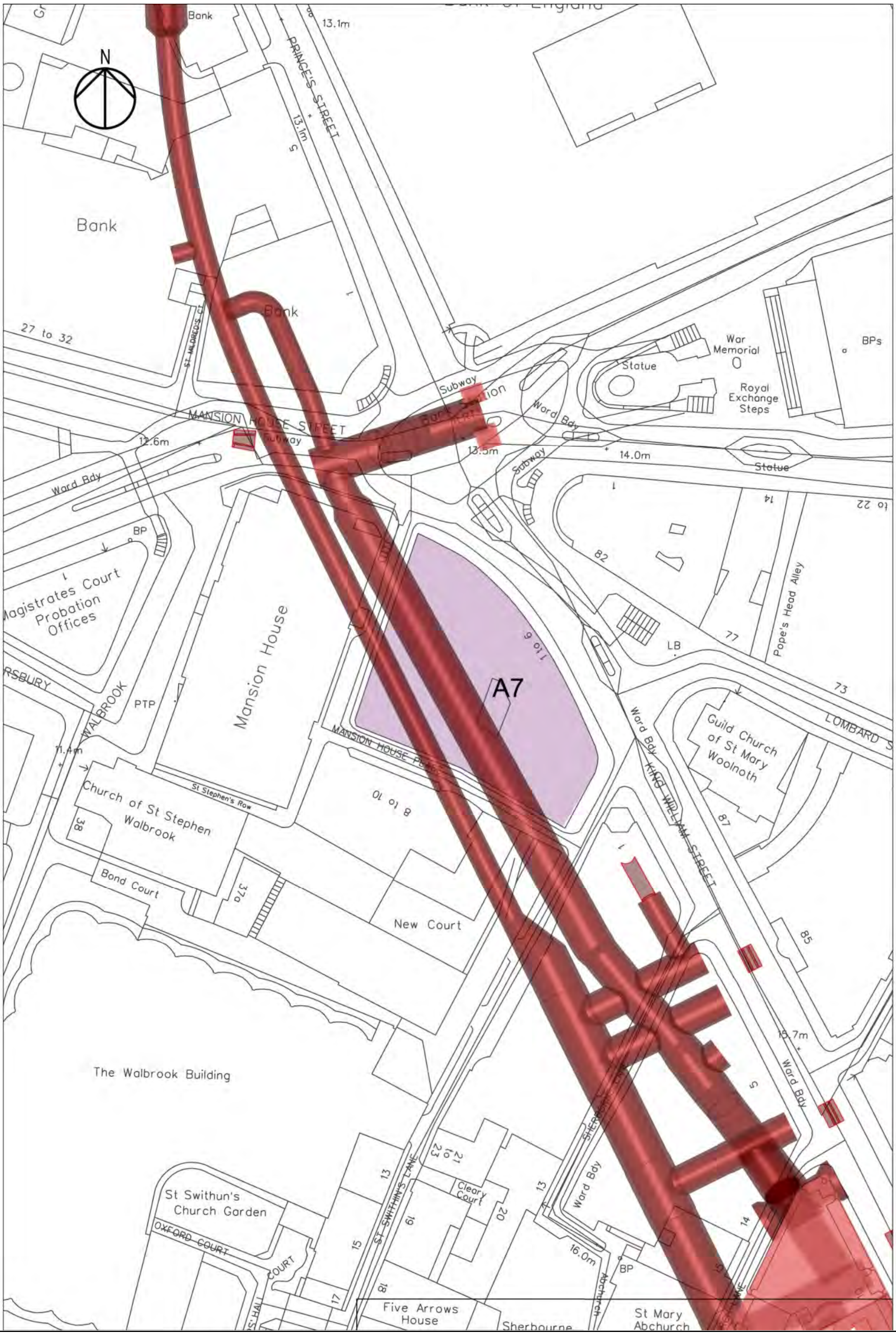

Figure 2: Location plan showing building location in relation to BSCU works

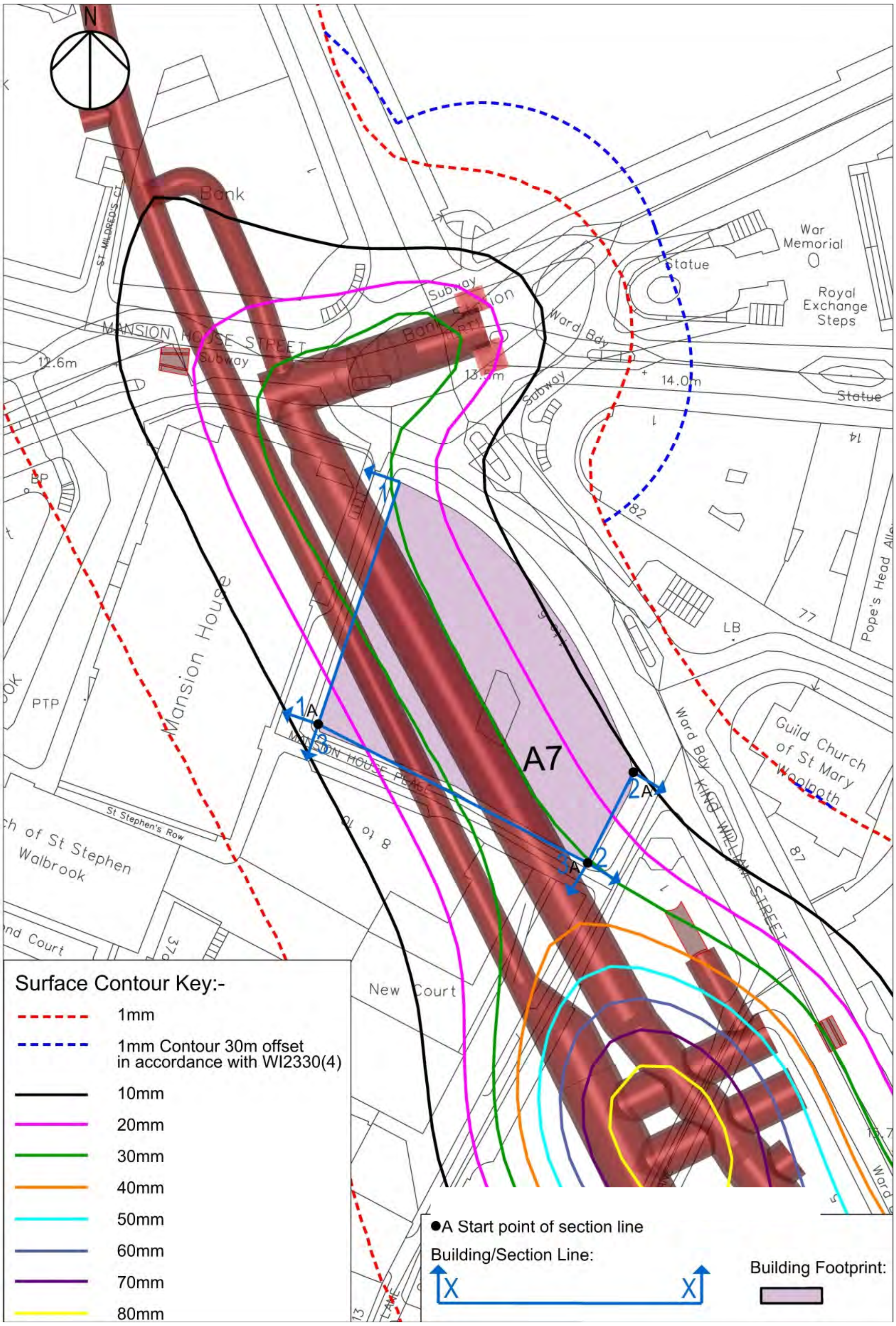

Figure 3: Building location, sections analysed and Settlement Contours at stage of worst case for tensile strains

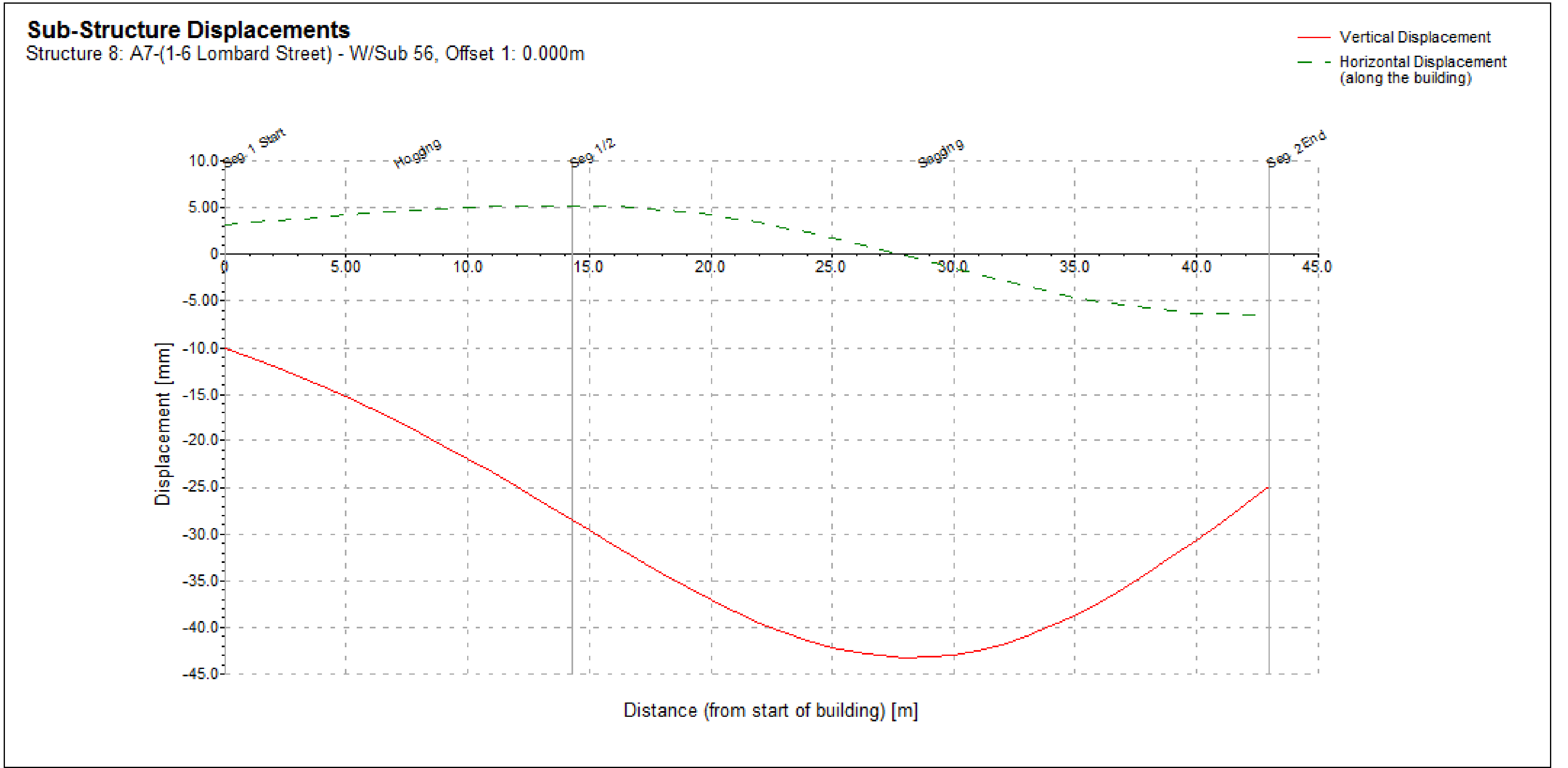

Figure 4: Building displacement at founding level at stage 3 (line 1) of worst case for tensile strains

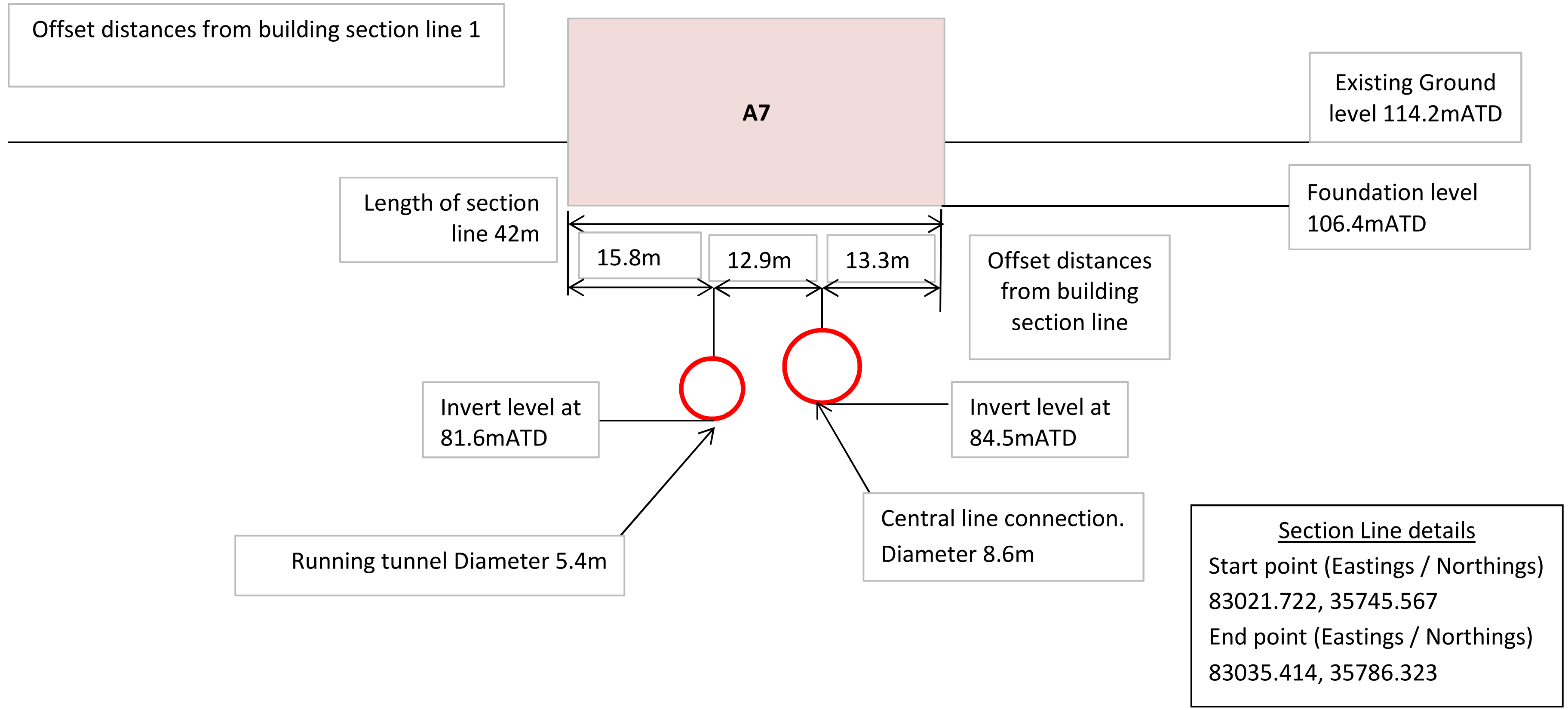

Figure 5: Diagrammatic cross-section of section (line 1) relative to tunnel position

Bank Station Capacity Upgrade

Building Damage Assessment Report

Building A10

13 Sherborne Road, 19 St Swithin's Lane, 20 St Swithin's Lane and 21-23 St Swithin's Lane

URS-8798-RPT-G-001174

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Revision	Date	Summary of changes
1.0	March 2014	Issue for Heritage
2.0	April 2014	For Approval
3.0	July 2014	TWAO Issue

Consultation:

• Ela Palmer	URS Heritage
• Brian Lyons	Dr.Sauer
• Keith Bowers/Neil Moss/Paul Dryden	London Underground
• Olly Newman	Dragados

Contents

FIGURES

TABLES

1 Introduction

This report summarises the results of a Stage 2 damage assessment for buildings 19, 20, 21-23 St Swithin's Lane and 13 Sherborne Road, A10.

Stage 2 damage assessments are undertaken for all buildings within the Stage 1 Greenfield ground surface 1mm settlement contour induced by the construction of the Bank Station Capacity Upgrade (BSCU).

The purpose of the assessment is to determine the potential effect the works will have on the building. This report describes the engineering assessments undertaken for the building and concludes whether mitigation is likely to be needed and if a further (Stage 3) assessment is recommended in order to verify this.

2 The Building

2.1 General Information

The Plot reference A10 consists of four buildings; 13 Sherborne Lane, 19 St Swithin's Lane, 20 St Swithin's Lane and 21-23 St Swithin's Lane. The buildings are arranged to form the Cleary court yard. No. 20 St Swithin's Lane's neighbouring buildings are 13 Sherborne to the north, Sherborne House to the east, Five Arrows House to the south and 19 St Swithin's Lane to the west.

General building information used in the assessment has been acquired as part of the structural desktop appraisal. This information is presented in Table 1.

Category	Building Information
BSCU Reference	A10
Location	St. Swithin's Lane
Address	13 Sherborne Lane, 19 St Swithin's Lane, 20 St Swithin's Lane, 21-23 St. Swithin's lane
Building Type	Load bearing masonry (assumed)
Construction Age	1880
No. of Storeys	4 (maximum)
Basements	Varied
Eaves Level (mATD)	125.4
Foundation Type	Assumed shallow foundations
Ground Level (mATD)	114.6
Listed Grade	Listed*

Note: Levels given are in metres above Tunnel Datum, mATD.
Tunnel Datum is 100m below Ordnance Survey Datum at Newlyn.

- 19 and 20 St Swithin's Lane are Grade II*. 21 to 23 St Swithin's Lane and 13 Sherborne Lane are not listed.

Table 1: General building information

A general view of the buildings exteriors from St Swithin's Lane is shown in Plate 1. A location plan showing the building in relation to the proposed BSCU works is presented in Figure 2.

Plate 1: General view

2.2 Building Description

This block contains a combination of listed and unlisted buildings. The description below relates to these buildings.

The buildings 19 and 20 St. Swithin's Lane dates from the early 19th century. They form a complex of interlinked buildings surrounding Cleary Court, from which the buildings are accessed. 19 St. Swithin's Lane also has a façade facing west onto St. Swithin's Lane whilst 20 St. Swithin's Lane also has a façade facing east onto Sherborne Lane. The form and structure of the two buildings has been created over time and as the result of several phases of development.

The combined buildings form a horseshoe shaped ensemble with a variety of stories, construction materials and roof finishes. Broadly speaking 19 St. Swithin's Lane is 4 stories high with two basements that extend to a depth of c.5.40m. The façade onto St. Swithin's Lane dates from when the building was converted into a hotel and is faced with non-load bearing granite at ground floor level and undressed Portland ashlar for the remaining three stories. The majority 19 St. Swithin's Lane above ground floor level has been rebuilt when the building was converted into a hotel, the exception being the portion bridging the entrance to Cleary Court. The windows are modern.

The majority of the ground floor of 19 St. Swithin's Lane and the two basements are utilised as a restaurant. The internal spaces have all been modernised with the removal of historic structure at ground floor level and the insertion of modern service, fixtures and furniture. The upper basement consists of a series of brick barrel vaults. To the rear of No. 19, underneath No. 20, the historic fabric survives whilst under No. 19 many of the spaces have been reorganised to accommodate kitchens and storage areas. In the lower basement, accessed via a new steel staircase, is a surviving medieval cellar or tunnel, thought to date from the 14th century, which runs parallel and broadly adjacent to St. Swithin's Lane. This is constructed with roughly coursed masonry to the walls with regular dressed stone springing courses and barrel vault.

No. 20 St. Swithin's Lane is an early 19th century brick building accessed from Cleary Court known as Sandeman House. Brick barrel vaults form the one basement level, extending to a depth of c.2.5m. Although it appears to be historic it has not been possible to examine the roof structure of 20 St. Swithin's.

Cleary Court itself retains a number of heritage features including granite setts paving and various 19th century embellishments.

The building fronting 13 Sherborne Lane has a single storey basement. The basement appears just a small section of a much larger basement that is occupied by its neighbouring tenants at 20 St Swithin's Lane. The current tenant of 13 Sherborne Lane is Travelodge who have combined (at first floor level) properties 19 and 21 to 23 St Swithin's Lane during refurbishment works in 2011.

Further inspection of the Travelodge suggests the structure has elements of reinforced concrete.

3 Methodology

This building damage assessment is undertaken in accordance with LU Works Information WI2300[1] and LU Civil Engineering - Common Requirements S1050[2].

The analysis methodology applies to ground-bearing buildings which will be affected by ground movements resulting from the construction of the BSCU. The engineering assessment calculates the potential impact of ground movements and assigns a damage category to the building based on a numeric scale. Additionally, for listed buildings, a heritage assessment is carried out which considers the sensitivity of the structure and the sensitivity of its particular features; a heritage sensitivity score is assigned. The heritage sensitivity score is added to the damage category to obtain the total score. If the total score is 3 or more, a more detailed Stage 3 assessment is triggered.

Due to the complicated arrangement between the buildings multiple section lines were investigated. These are set around the perimeter and along a simplification of the internal walls in Cleary Court. See Figure 3. Due to the lack of detailed information the following conservative assumptions have been made.

- Use the lowest individual foundation level for all buildings since this gives slightly higher strains and very similar vertical movements. This is taken at 109.7mATD.
- Assume load bearing masonry
- Assume an average building height

Oasys Xdisp is used to analyse the Greenfield ground movement in terms of settlement and horizontal displacement. Subsurface tunnelling induced ground movement profiles are determined in accordance with the methodology described by Mair et al[3 & 4].

Movements resulting from the Whole Block Scheme (WBS) and shaft excavations have been calculated using LU Guidance Document G0058[5].

Each building is modelled as a simple elastic beam which is conservatively assumed to follow the Greenfield ground displacements. The beam is divided into hogging and sagging segments. The tensile strains within each segment are calculated based on the distortion associated with differential settlement (which is characterised by deflection ratio) and the distortion associated with differential horizontal displacement (characterised by horizontal strain).

Xdisp provides a method for calculating the maximum tensile strain within the building superstructure associated with these movements, in accordance with the assessment methodology described by Mair et al [4]. This strain is used to determine the damage category based on the classification system proposed by Burland[6] and in accordance with LU Civil Engineering - Common Requirements S1050[2]. The categories are presented in Table 2.

Damage Category	Description of Degree of Damage	Description of Typical Damage and likely forms of Repair for Typical Masonry Buildings.	Approx. Crack Width (mm)	Max. Tensile Strain %
0	Negligible	Hairline cracks.		< 0.05
1	Very slight	Fine cracks easily treated during normal redecoration. Perhaps isolated slight fracture in building. Cracks in exterior visible upon close inspection.	0.1 to 1.0	0.05 to 0.075
2	Slight	Cracks easily filled. Redecoration probably required. Several slight fractures inside building. Exterior cracks visible; some repainting may be required for weather-tightness. Doors and windows may stick slightly.	1 to 5	0.075 to 0.15
3	Moderate	Cracks may require cutting out and patching. Recurrent cracks can be masked by suitable linings. Tuck pointing and possible replacement of a small amount of exterior brickwork may be required. Doors and windows sticking. Utility services may be interrupted. Weather tightness often impaired.	5 to 15 or a number of cracks > 3	0.15 to 0.3
4	Severe	Extensive repair required involving removal and replacement of walls especially over doors and windows. Window and door frames distorted. Floor slopes noticeably. Walls lean or bulge noticeably. Some loss of bearing in beams. Utility services disrupted.	15 to 25 but also depends on number of cracks	> 0.3
5	Very severe	Major repair required involving partial or complete reconstruction. Beams lose bearing, walls lean badly and require shoring. Windows broken by distortion. Danger of instability.	Usually > 25 but depends on number of cracks	
Note: Please refer LU Civil Engineering - Common Requirements S1050[2].				

Table 2: Building damage classification

4 Input Data

The magnitude and distribution of ground movements and degree of building damage is calculated based on the following input data:

- The Xdisp model coordinates and levels are based on the 3D model (20130212DSPITT Scheme R09);
- Four construction stages are considered in accordance with the proposed programme (November 2013) as illustrated in Figure 1;
- Trough width parameter constant, K=0.5 is used in accordance with WI2300[1].

The input data for the building, tunnels and shaft excavation are summarised in Table 3, Table 4 and Table 5 respectively.

Location	Foundation level (mATD)	Building Height above foundation level (m)	E/G
Building A10	109.7*	15.7	2.6
Note: Where E / G is the ratio of Young's modulus to shear modulus of the deep beam representing the building. * Assumed level, 1.5m thick slab beneath floor level.			

Table 3: Building data

Tunnel Item	Level of axis (mATD)	External diameter (m)	Volume Loss (%)
Running tunnels	83.5	5.4	1.5
Square works adits	75.8 to 95.3	4.1 to 7.8	2.5
Platform enlargement	85.5	9.6	1.5
Escalator barrels	Inclined	8.3 to 8.4	1.5
NL Interchange tunnel	84.8	9.75	1.5
D6 lift connection	86.2	5.9	1.5
Central Line Connection	Inclined (87.6 to 89.2)	8.6	1.5

Table 4: Tunnel data

Excavation	Excavation Base Level (mATD)
Grout Shaft at King William Street	97
Whole Block Scheme Box excavation	73
Arthur Street Shaft	81

Table 5: Excavation data

The distance of excavation elements at Arthur Street is sufficiently large that these buildings should not be affected by their construction.

The Xdisp model filenames used to undertake this assessment are:

- A10 - Stage 4
- A10 - Stage 3
- A10 - Stage 2
- A10 - Stage 1

5 Results

5.1 Engineering Assessment

The sections through the building which have been analysed are shown on plan in Figure 3.

Assessment has been undertaken at three intermediate construction stages and at the end of construction when all major elements of the works including shaft and tunnels have been completed. The damage category assigned to the building is based on the construction stage at which the potential impact on the building is most severe.

The maximum settlement and tensile strain calculated for each of the analysis sections at the most onerous intermediate construction stage and at the end of construction are presented in Table 6 and Table 7.

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
A10 (line 1)	17	0.040
A10 (line 2)	17	0.035
A10 (line 3)	<1	<0.001
A10 (line 4)	1	0.003
A10 (line 5)	7	0.021
A10 (line 6)	2	0.007
A10 (line 7)	17	0.030
A10 (line 8)	4	0.014

Table 6: Building response at most onerous intermediate stage - Construction Stage 2

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
A10 (line 1)	19	0.046
A10 (line 2)	19	0.041
A10 (line 3)	<1	0.001
A10 (line 4)	<1	0.003
A10 (line 5)	7	0.023
A10 (line 6)	2	0.008
A10 (line 7)	19	0.038
A10 (line 8)	4	0.015

Table 7: Building response at end of construction stage

The results of the assessment show that construction Stage 4 is the critical stage for these buildings. At this stage, Section A10 (line 1) experiences the most onerous combined tensile strain. The orientation is shown in Figure 3. The vertical and horizontal ground movements along the section of the building are shown in Figure 4. The relative position of the building and tunnels along section (line 1) is shown in Figure 5. The most onerous calculated strains are summarised in Table 8.

Line No	Strains in section (Curvature)	Position from start (m)	Length (m)	Average* Horizontal Strain (%)	Maximum Tensile Strains (%)	Damage Category
Line 1	(Line 1) Hogging	0.0	35	0.019	0.046	Negligible
Note: * Tensile horizontal strains are +ve. Compressive horizontal strains are –ve.						

Table 8: Section analysed, results for worst case tensile strain

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0 for the none listed buildings (21 to 23 St Swithin's Lane and 13 Sherborne Lane) and the Grade II* 19 St Swithin's Lane and 20 St Swithin's Lane. This corresponds to Negligible damage in accordance with Table 2.

It may be noted that the results presented above indicate that the tensile strain for line 1 is towards the top end of the range for Negligible classification, and within 10% of the Very Slight range. Given the lack of absolute certainty on the building characteristics and the potential for minor changes to BSCU works through the Detailed Design phase, it is necessary to take a conservative view on the building damage classification. As such the classification for line 1 is adjusted to Very Slight and damage category 1 in accordance with Table 2. This affects the damage category of the non-listed building 13 Sherbourne Lane and the Grade II* listed building 20 St Swithin's lane.

The maximum settlement of the building at foundation level at the end of construction is 19mm.

The building movements are less than those shown by the surface contours in Figure 3. This is correct and reflects the reduction in movement with depth which occurs adjacent to the box and shaft type excavations.

5.2 Heritage and Structural Assessment

Following site inspection, assessment has been made using the scoring methodology set out in Table 9.

Score	Structure	Heritage features	Condition
	(Sensitivity of the structure to ground movements and interaction with adjacent buildings)	(Sensitivity to calculated movement of particular features within the building)	(Factors which may affect the sensitivity of structural or heritage features)
0	Masonry buildings with lime mortar and regular openings, not abutted by other buildings, and therefore similar to the buildings on which the original Burland assessment was based.	No particular sensitive features	Good/Fair - not affecting the sensitivity of structural or heritage features
1	Buildings not complying with categories 0 or 2, but still with some sensitive structural features in the zone of settlement e.g.: cantilever stone staircases, long walls without joints or openings, existing cracks where further movements are likely to concentrate, mixed foundations	Brittle finishes, e.g. faience or tight-jointed stonework, which are susceptible to small structural movements and difficult to repair invisibly.	Poor - may change the behaviour of a building in cases of movement. Poor condition of heritage features and finishes. Evidence of previous movement.
2	Buildings which, by their structural form, will tend to concentrate all their movements in one location (e.g.: a long wall without joints and with a single opening).	Finishes which if damaged will have a significant effect on the heritage value of the building, e.g. Delicate frescos, ornate plasterwork ceilings.	Very poor – parlous condition of heritage features and finishes, severe existing damage to structure including evidence of ongoing movement. Essentially buildings where even very small movements could lead to significant damage.

Table 9: Heritage and structural scoring methodology

The results of the heritage assessment carried out for the building are summarised in Table 10.

Sensitivity of the structure
The long masonry vaulted basements, beneath number 20 and the courtyard, contain only one or two openings, which will act as stress concentrators to any movement. Existing fine cracks were also noted in the vault beneath the courtyard. It is however noted that the basements appeared dry and had not been lined and as such the presence or forming of small cracks are not thought to present a threat of water ingress. In cross section the vaults are not considered vulnerable to the anticipated degree of movement. The vaults have a relatively steep rise and appear to be constructed from bonded masonry of at least 1 brick thick (headers are present in the wall), this will allow small changes to be accommodated by maintaining the thrust line within the line of the arch. The older medieval vault, beneath number 19 is in less good condition, with little or no pointing between the stones. The anticipated degree of movement in this part of the building is however anticipated to be small. The vault is largely located beneath a modern basement and insitu concrete building, which appears to span over the vault and is assumed to be supported on piled foundations. Any movement of the piled building is anticipated to be independent of the vaulted structure. The relatively complex interface between number 20 and the adjoining building to the North (containing the hotel) is also considered sensitive. The timber staircase at ground to first floor level passes through arched openings in what is thought to be an older wall, before returning at higher level into number 20. It is however noted that the vertical and horizontal movements at this point are relatively small (around 5mm vertically).
Score: 1 - The relatively long walls in the basement with few if any openings and the complexity of the northern junction of number 20 with its neighbour are both considered to be structurally sensitive.
Sensitivity of the heritage
19 and 20 St. Swithin's Lane are both Grade II* Listed Buildings that stand on their original footprints and display a variety of historical layers, they are both rare survivals. Of greatest significance and sensitivity are the brick facades and timber staircase to no. 20, the post medieval and medieval cellars below no. 19 and the decorative crane house and machinery within Cleary Court. Of particular significance due to its extraordinary nature, is the surviving 14th century tunnel that exists underneath 19 St. Swithin's Lane. This tunnel is constructed of a combination of rough masonry and dressed stone. The joints between masonry blocks range from a few millimetres to 25mm, their susceptibility to damage resulting from structural movement will vary accordingly. There are no other internal heritage finishes that may be affected by the predicted settlement.

Score: 0 - The English Heritage listing description indicates that these buildings were designated due to the rare survival of their historic features from many periods that illustrate how this area of London has changed over the centuries. Damage to these historic layers, especially the subsurface levels, would denigrate the significance of the buildings. However, the predicted settlement due to tunnelling works is so slight as to render the risk of this negligible.
Sensitivity of the condition
The condition of the masonry walls within the medieval cellar below no. 19 is average – there are deep open joints between masonry elements, some large areas of salt efflorescence and a recently damaged masonry block that may be due to previous movement. However, as the medieval tunnel is located at the furthest distance from the BSCU tunnelling works and associated predicted settlement it is not thought this condition will be sensitive to the negligible movement caused by predicted settlement. In no.20 the condition of the timber staircases is apparently good and although being located adjacent to external signs of previous movement (above the main entrance to Sandeman House), the condition is considered similarly insensitive to movement caused by the predicted ground settlement.
Score: 0 – The exterior condition of the buildings is very good and there are no internal features whose existing condition is thought to be sensitive to the predicted settlement and subsequent structural movement.

Table 10: Heritage and structural assessment

5.3 Total Score

The total score is the summation of the damage category, structural sensitivity, heritage sensitivity and condition sensitivity scores:

The damage category is 1

The structural sensitivity score (for 19 and 20 St Swithin's Lane) is 1

The heritage sensitivity score (for 19 and 20 St Swithin's Lane) is 0

The condition sensitivity score (for 19 and 20 St Swithin's Lane) is 0

The total score for 21 to 23 St Swithin's Lane is 1 and for 19 and 20 St Swithin's Lane is 2

6 Conclusion

From site inspection and from the planning record it is predicted that the buildings will not suffer ground movement significant enough to damage the heritage finishes and features of the building. Furthermore, the most significant area of the buildings, the medieval tunnel below 19 St. Swithin's Lane, is considered relatively insensitive to the predicted movement and at the furthest point from the BSCU tunnelling works.

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 1 for 21 and 23 St Swithin's Lane and 13 Sherborne Lane. The Stage 2 engineering assessment has predicted that the maximum tensile strain for 19 St Swithin's Lane is negligible, damage category 0.

Specific heritage and structural assessment taking into account the location and extent of settlement and tensile strains highlights the buildings low level of structural and heritage sensitivity to movement. This assessment has determined that 19 and 20 St Swithin's Lane has a total score of 2.

It is recommended that these buildings do not require a Stage 3 assessment.

7 References

[1] LU Works Information WI 2300 Ground Movement version 3, 19-07-13.

[2] LU Category 1 Standard: S1050 Civil Engineering - Common Requirements, Issue No. A7, Nov. 2013.

[3] Mair R J, Taylor R N and Bracegirdle A (1993). Subsurface settlement profiles above tunnels in clays. Géotechnique 43, No. 2, pp. 315-320.

[4] Mair R J, Taylor R N and Burland J B (1996). Prediction of ground movements and assessment of risk of building damage due to bored tunnelling. (In: International Conference of Geotechnical Aspects of Underground Construction in Soft Ground, London, pp. 713–718.

[5] LU Guidance Document G0058 Civil Engineering Technical Advice Notes, Issue No. A17, Feb. 2013.

[6] Burland J B (1995). Assessment of risk of damage to buildings due to tunnelling and excavation. Proceedings: 1st International Conference of Earthquake Geotechnical Engineering, IS Tokyo, 1995.

[7] Mott MacDonald (2012). Bank Station building data sheets – A list buildings. N133-BCR-MMD-00-Z-DC-S-0003-S0-1.0.

[8] Selemetas.D et al (2005). The response of full scale piles to tunnelling. Geotechnical aspects of underground construction in soft ground (Bakker et al (eds)) pp.763-769.

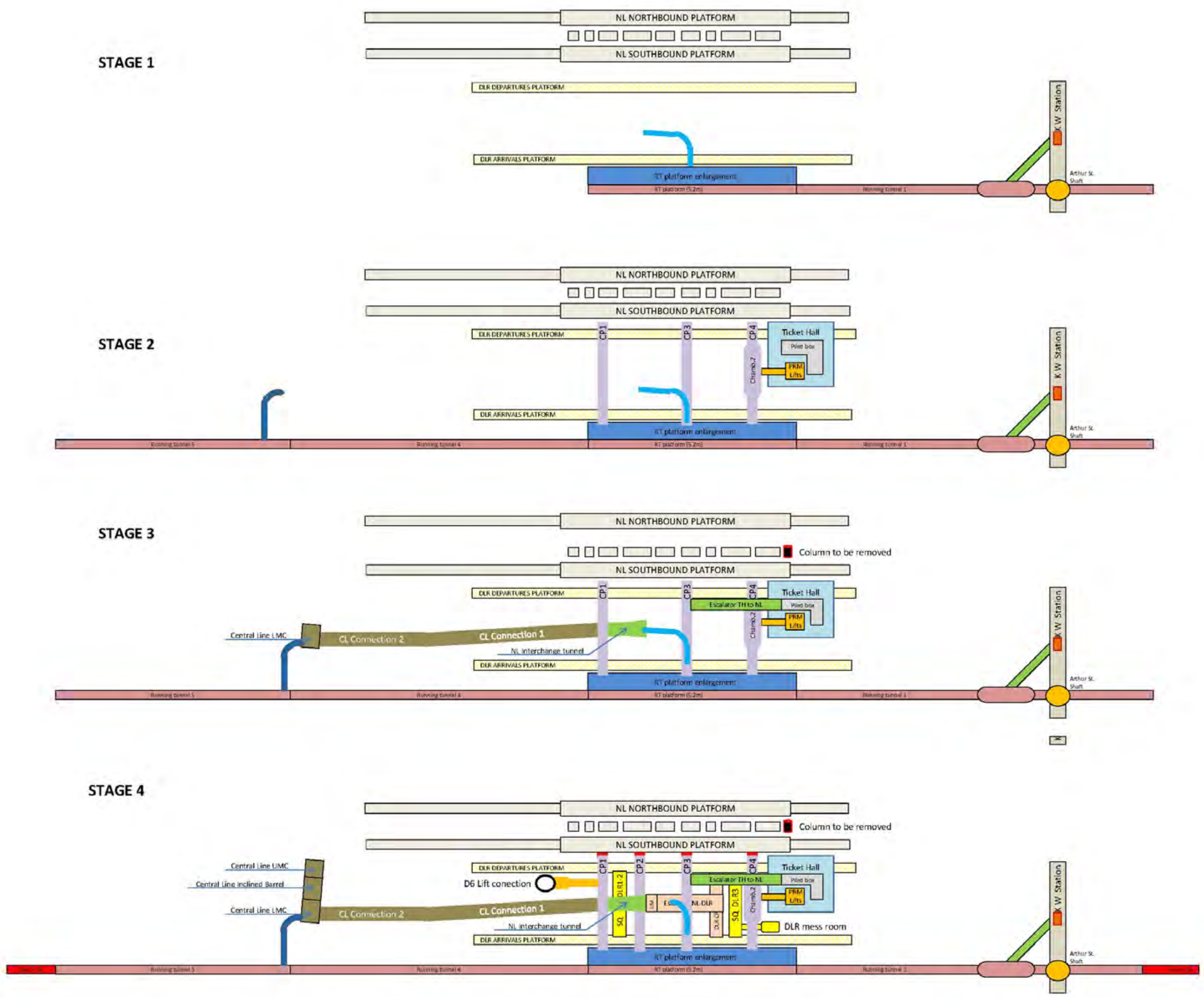

Figure 1: Construction Stage model

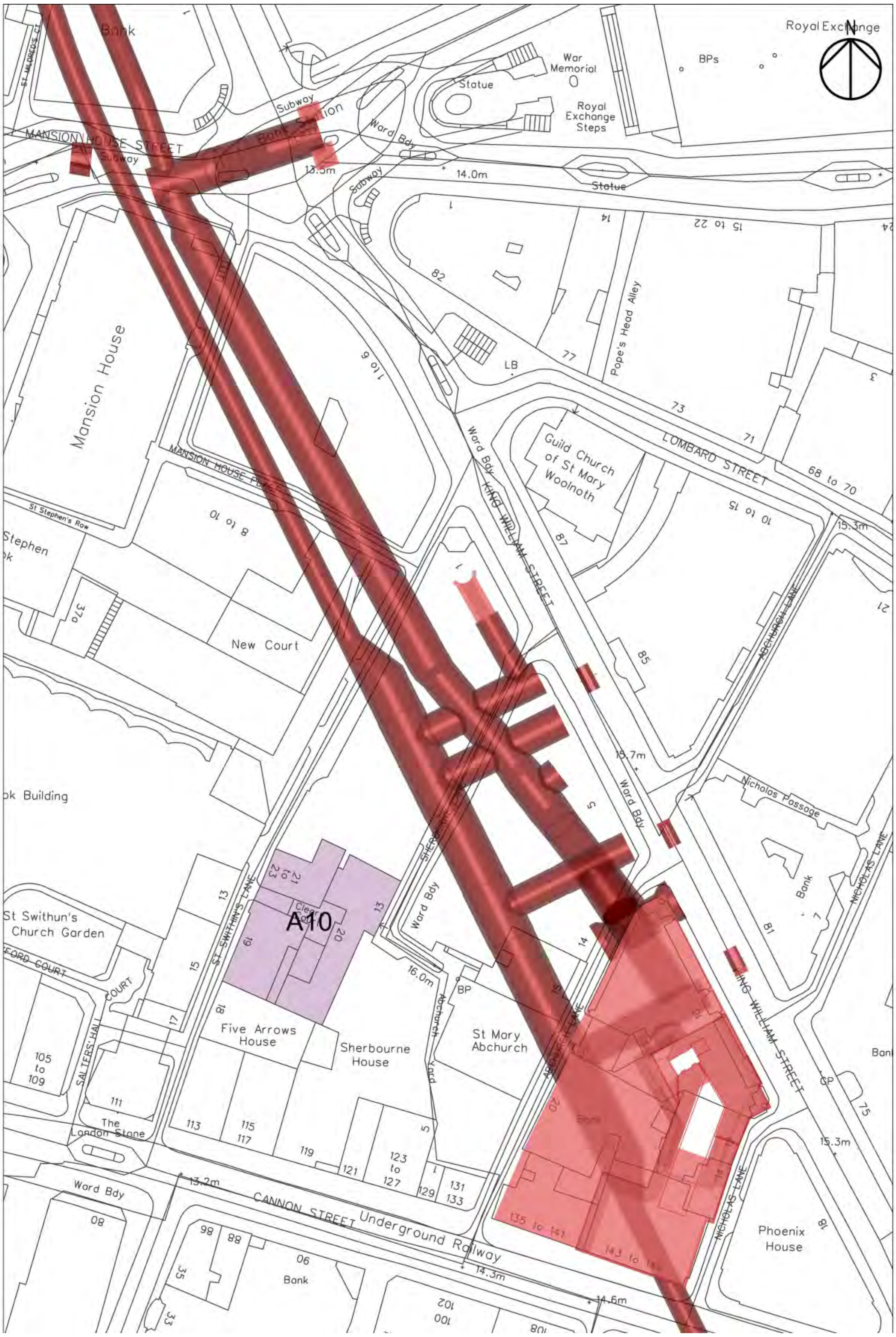

Figure 2: Location plan showing building location in relation to the BSCU works

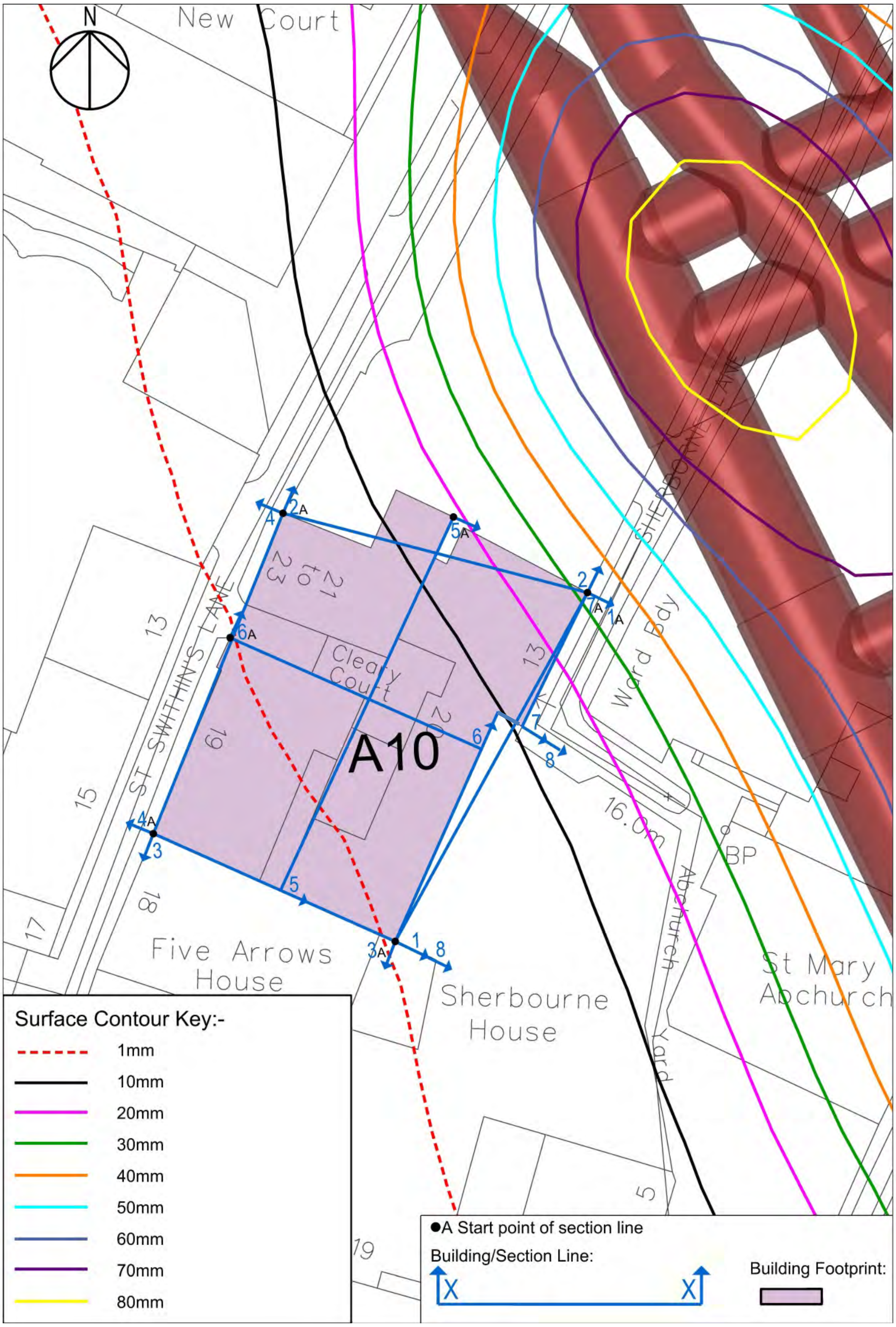

Figure 3: Building location, sections analysed and Settlement Contours at stage of worst case for tensile strains

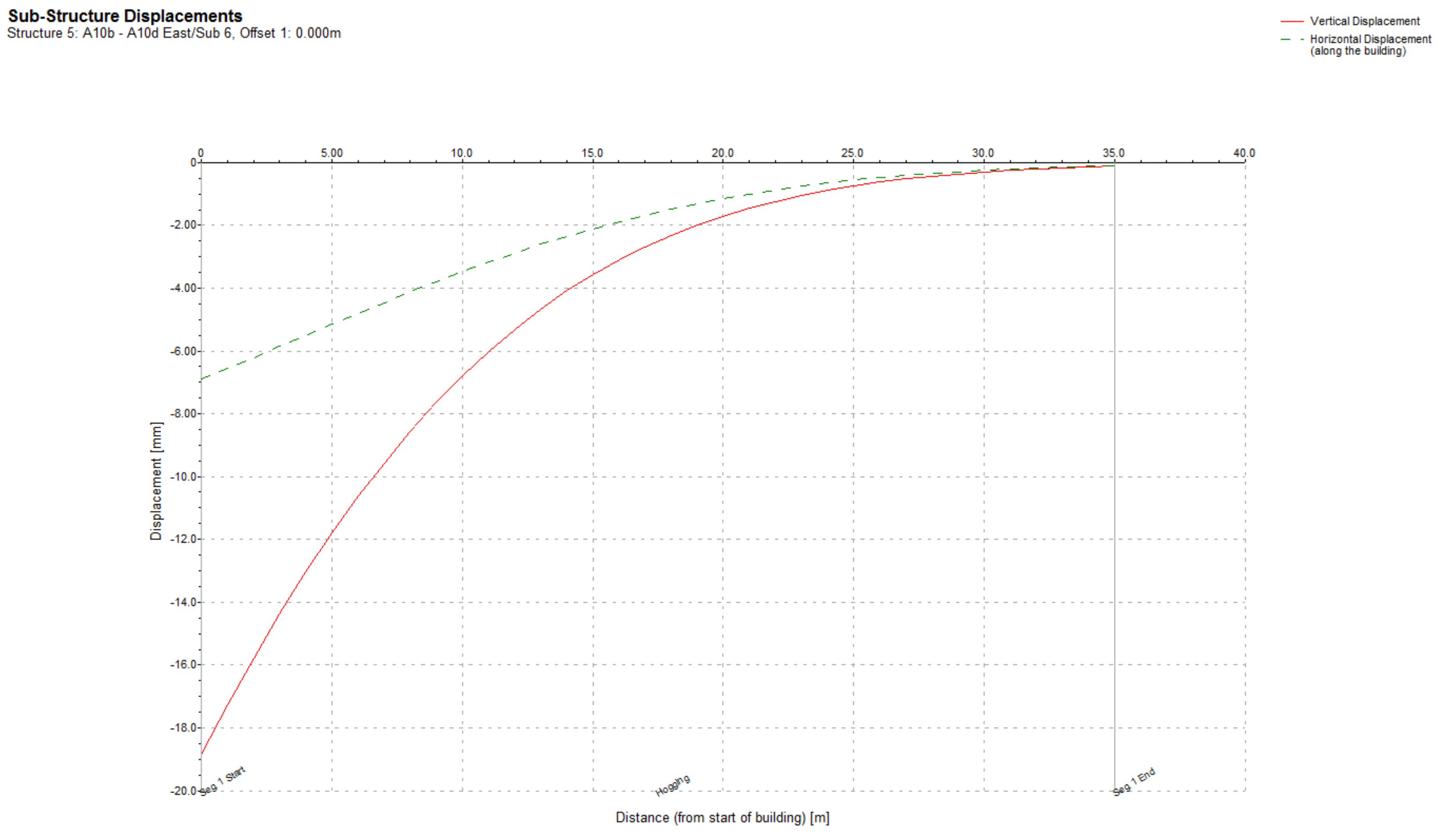

Figure 4: Building displacement at founding level at stage 4 of A10 (line 1) of worst case for tensile strains

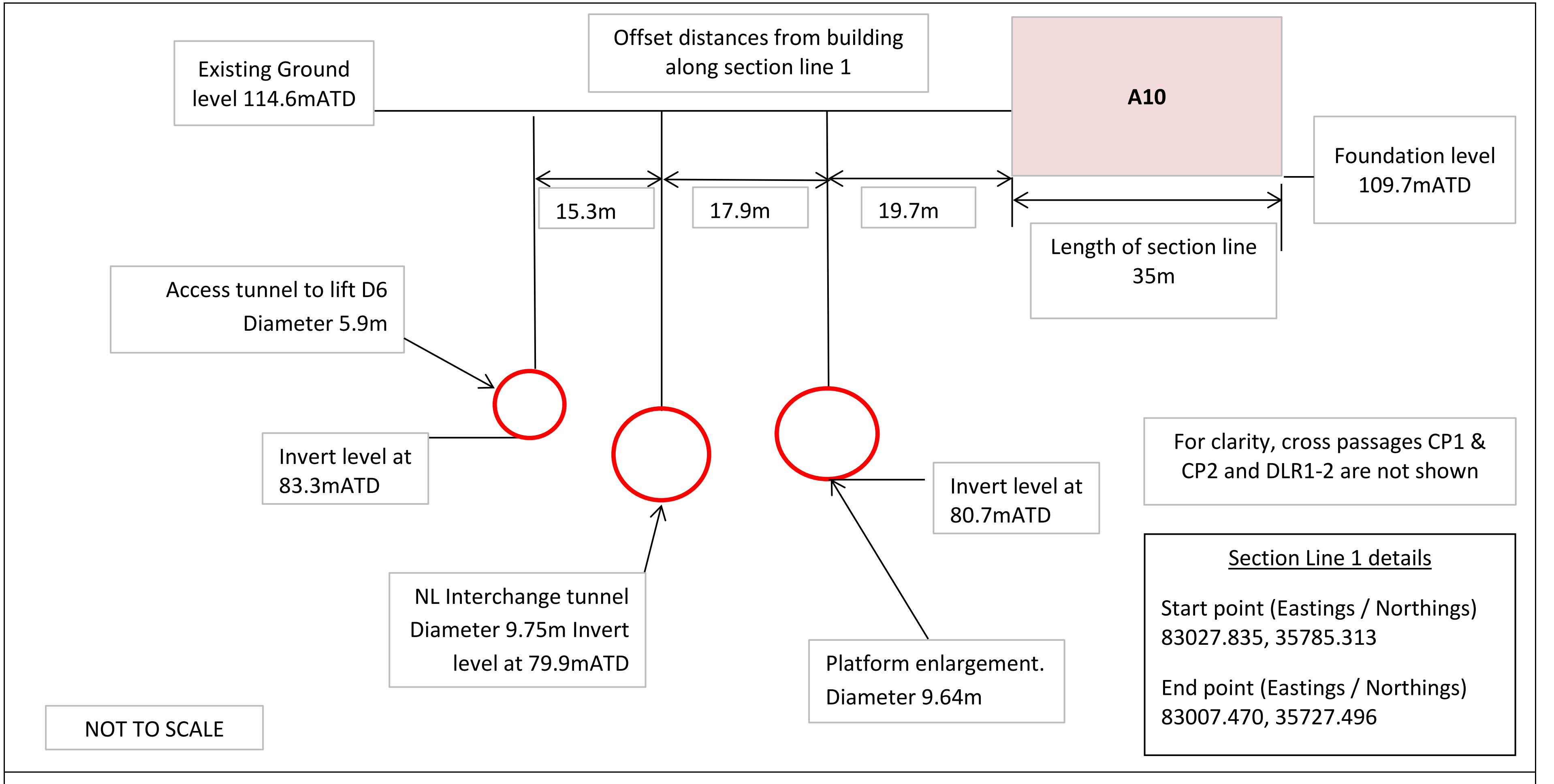

Figure 5: Diagrammatic cross-section of section (line 1) relative to tunnel position

LUL Bank Project Office
10 King William Street
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Bank Station Capacity Upgrade

Building Damage Assessment Report

Building A11

1 King William Street

URS-8798-RPT-G-001175

Prepared by:	Lisa Perkins Assistant Geotechnical Engineer	L. Perkins	18/07/14
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Role:	Designer

Document History

Revision	Date	Summary of changes
1.0	March 2014	Issue to Heritage
2.0	April 2014	For Approval
3.0	July 2014	TWAO Issue

For the status of this document, please refer to the Building Damage Assessment Report Register (URS-8798-RGT-001229)

Consultation:

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FIGURES

TABLES

Introduction

This report summarises the results of a Stage 2 damage assessment for 1 King William Street, Ref A11.

Stage 2 damage assessments are undertaken for all listed buildings within the Stage 1 Greenfield ground surface 1mm settlement contour induced by the construction of the Bank Station Capacity Upgrade (BSCU).

The purpose of the assessment is to determine the potential effect the works will have on the building. This report describes the updated engineering assessments undertaken for the building and concludes whether mitigation is likely to be needed and if a further (Stage 3) assessment is recommended in order to verify this..

1 The Building

1.1 General Information

No. 1 King William Street is at the junction of St Swithin's Lane and King William Street. The building was originally designed by Campbell Jones , Son and Smithers (1921-22) before undergoing redevelopment by architect GMW Partnership (1996). This extended the building South between St Swithins lane and Sherbourne Lane.

The building is a seven storey structure with three levels below ground. The building was redeveloped in the 1990s retaining the Portland stone façade and the internal steel framed column elements. The building is confirmed as steel framed with a raft foundation. General building information used in the assessment has been acquired as part of the structural desktop appraisal. This information is presented in Table 1.

Category	Building Information
BSCU Reference	A11
Location	King William Street
Address	1 King William Street
Building Type	Steel / concrete framed
Construction Age	1921-22 (Refurbished 1996-1998)
No. of Storeys	7
Basements	3
Eaves Level (mATD)	135.3
Foundation Type	Raft
Ground Level (mATD)	114.4
Listed Grade	II
Note: Levels given are in metres above Tunnel Datum, m ATD. Tunnel Datum is 100m below Ordnance Survey Datum at Newlyn	

Table 1: General building information

A general view of the building exterior is shown in Plate 1. A location plan showing the building in relation to the proposed BSCU works is presented in Figure 2.

Plate 1: General view

1.2 Building Description

1 King William Street is a bank and commercial building, built between 1921 and 1922 to designs by William Campbell-Jones and Alex Smithers for the London Assurance Company. Built of Portland stone which is channelled at ground floor and ashlar to the upper storeys, the main façade has five bays in a classical style, incorporating details such as giant pilasters to the first floor, and cornices to the fourth floor and the eaves. The main entrance is to the north, at the corner of the building. The historic façade returns for approximately six bays along Sherborne Lane and St Swithin's Lane, beyond which is a modern façade.

Internally, historic features are retained to the King William Street side of the building, comprising a ground floor foyer with marble columns and plaster detail to the ceilings, and a third floor room with fine timber panelling which has been supplemented with inferior panelling. This section of the building also has hollow clay tiles to its ceilings. Otherwise, the building had been subject to a façade retention scheme, and there are no further internal heritage features.

There are areas under the building with two and three levels of basement.

2 Methodology

This building damage assessment is undertaken in accordance with LU Works Information WI2300[1] and LU Civil Engineering – Common Requirements S1050[2].

The analysis methodology applies to ground-bearing buildings which will be affected by ground movements resulting from the construction of the BSCU. The engineering assessment calculates the potential impact of ground movements and assigns a damage category to the building based on a numeric scale. Additionally, for listed buildings, a heritage assessment is carried out which considers the sensitivity of the structure and the sensitivity of its particular features; a heritage sensitivity score is assigned. The heritage sensitivity score is added to the damage category to obtain the total score. If the total score is 3 or more, a more detailed Stage 3 assessment is triggered.

Oasys Xdisp is used to analyse the Greenfield ground movement in terms of settlement and horizontal displacement. Subsurface tunnelling induced ground movement profiles are determined in accordance with the methodology described by Mair et al[3 & 4]. The assessment has been conservatively carried out assuming the whole building is founded at the third basement level since this will indicate higher movements.

An additional displacement line (line 3) was drawn to assess movements between this building and the adjacent building A10, as shown in Figure 5.

The building is modelled as a simple elastic beam which is conservatively assumed to follow the Greenfield ground displacements. The beam is divided into hogging and sagging segments. The tensile strains within each segment are calculated based on the distortion associated with differential settlement (which is characterised by deflection ratio) and the distortion associated with differential horizontal displacement (characterised by horizontal strain).

Movements resulting from the Whole Block Scheme (WBS) and shaft excavations have been calculated using LU Guidance Document G0058[5].

Xdisp provides a method for calculating the maximum tensile strain within the building superstructure associated with these movements, in accordance with the assessment methodology described by Mair et al. This strain is used to determine the damage category based on the classification system proposed by Burland[6] and in accordance with S1050 Civil Engineering – Common Requirements[2]. The categories are presented in Table 2.

Damage category	Description of degree of damage	Description of typical damage and likely forms of repair for typical masonry buildings.	Approx. crack width (mm)	Max. tensile strain %
0	Negligible	Hairline cracks.		< 0.05
1	Very slight	Fine cracks easily treated during normal redecoration. Perhaps isolated slight fracture in building. Cracks in exterior visible upon close inspection.	0.1 to 1.0	0.05 to 0.075
2	Slight	Cracks easily filled. Redecoration probably required. Several slight fractures inside building. Exterior cracks visible; some repainting may be required for weather-tightness. Doors and windows may stick slightly.	1 to 5	0.075 to 0.15
3	Moderate	Cracks may require cutting out and patching. Recurrent cracks can be masked by suitable linings. Tuck pointing and possible replacement of a small amount of exterior brickwork may be required. Doors and windows sticking. Utility services may be interrupted. Weather tightness often impaired.	5 to 15 or a number of cracks > 3	0.15 to 0.3
4	Severe	Extensive repair required involving removal and replacement of walls especially over doors and windows. Window and door frames distorted. Floor slopes noticeably. Walls lean or bulge noticeably. Some loss of bearing in beams. Utility services disrupted.	15 to 25 but also depends on number of cracks	> 0.3
5	Very severe	Major repair required involving partial or complete reconstruction. Beams lose bearing, walls lean badly and require shoring. Windows broken by distortion. Danger of instability.	Usually > 25 but depends on number of cracks	
Note: Please refer LU Civil Engineering - Common Requirements S1050[2].				

Table 2: Building damage classification

3 Input Data

The magnitude and distribution of ground movements and degree of building damage is calculated based on the following input data:

- The Xdisp model coordinates and levels are based on the 3D model (20130212DSPITT Scheme R09);
- Four construction stages are considered in accordance with the proposed programme (November 2013) as illustrated in Figure 1;
- Trough width parameter, K=0.5 is used in accordance with LU Works Information WI2300[1]

The input data for the building, tunnels and shaft excavation are summarised in Table 3, Table 4 and Table 5 respectively.

Location	Foundation level (mATD)	Building Height above foundation level (m)	E/G
1 King William Street	101.27*	34	12.5
Note: Where E / G is the ratio of Young's modulus to shear modulus of the deep beam representing the building. * Assumed level, 1.5m thick slab beneath floor level.			

Table 3: Building data

Tunnel Item	Level of axis (mATD)	External diameter (m)	Volume Loss (%)
Running tunnels	83.5	5.4	1.5
Square works adits	75.8 to 95.3	4.1 to 7.8	2.5
Platform enlargement	85.5	9.64*	1.5
Escalator barrels	Inclined	8.3 to 8.4	1.5
Tunnel to D6 lift	86.2	5.9	1.5
NL Interchange tunnel	86.5	8.4	1.5
Central Line Connection	Inclined (87.6 to 89.2)	8.6	1.5
Note: * Cross section of the tunnel is oval in shape. Presented diameter is for equivalent circular area. Low Level Sewer 2 passes beneath the building. The sewer comprises a 3m diameter cast iron pipe with an invert level of ~94.7mATD.			

Table 4: Tunnel data

Excavation	Excavation Base Level (mATD)
Grout Shaft at King William Street	97
Whole Block Scheme Box excavation	73
Arthur Street Shaft	81

Table 5: Excavation data

The Arthur St shaft is remote and its construction will not contribute to ground movements at this building

The Xdisp model filenames used to undertake this assessment are:

- A11 - Stage 4
- A11 - Stage 3
- A11 - Stage 2
- A11 - Stage 1

4 Results

4.1 Engineering Assessment

The sections through the building which have been analysed are shown on plan in Figure 3.

Assessment has been undertaken at three intermediate construction stages and at the end of construction when all major elements of the works including shaft and tunnels have been completed. The damage category assigned to the building is based on the construction stage at which the potential impact on the building is most severe.

The maximum settlement and tensile strain calculated for each of the analysis sections at the most onerous intermediate construction stage and at the end of construction are presented in Table 6 and Table 7.

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
A11 (line 1)	61	0.054
A11 (line 2)	50	0.053
A11 (line 3)	63	0.057*
Note	* This is strain from an extended line which is not applicable to the building	

Table 6: Building response at most onerous intermediate stage - Construction Stage 3

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
A11 (line 1)	79	0.069
A11 (line 2)	51	0.053
A11 (line 3)	79	0.070*
Note	* This is strain from an extended line which is not applicable to the building	

Table 7: Building response at end of construction stage

The results of the assessment show that the construction Stage 4 is the critical stage for this building. At this stage, section A11 line 1 experiences the most onerous combined tensile strain (0.069%). The orientation is shown in Figure 3. The vertical and horizontal Greenfield ground movements along section line 1 are shown in Figure 4.

Figure 5 and Table 8 show the strains between the two adjacent buildings are in hogging mode. This could induce cracking at the junction between the two buildings. The maximum tensile strains in this area (line 3) (0.070%) result in a very slight damage category.

The relative position of the building and tunnels along section line 1 is shown in Figure 6. The calculated strains are summarised in Table 8.

Line #	Strains in section (Curvature)	Position from start (m)	Length (m)	Average* Horizontal Strain (%)	Maximum Tensile Strains (%)	Damage Category
(Line 1)	Hogging	0.0	10.6	0.026	0.030	Negligible
	Sagging	10.6	36.8	-0.049	0.069	Very Slight
	Hogging	47.5	13	0.025	0.029	Negligible
(Line 3)	Hogging	0.0	10.5	0.026	0.030	Negligible
	Sagging	10.5	36.0	-0.051	0.070	Very Slight
	Hogging	46.6	48.9	0.019	0.051**	Very Slight
Note: * Tensile horizontal strains are +ve. Compressive horizontal strains are –ve. ** This is strain from an extended line which is not applicable to the building						

Table 8: Section analysed, results for worst case tensile strain

It may be noted that the results presented above indicate that the tensile strain is towards the top end of the range for Very Slight classification, and within 10% of the Slight range. Given the lack of absolute certainty on the building characteristics and the potential for minor changes to BSCU works through the Detailed Design phase, it is necessary to take a conservative view on the building damage classification. As such the classification for this building is adjusted to Slight and damage category 2 in accordance with Table 2.

The maximum settlement of the building at foundation level (line 1) occurs at the end of construction and is 79mm.

4.2 Heritage and Structural Assessment

Following site inspection, assessment has been made using the scoring methodology set out in Table 9.

Score	Structure (Sensitivity of the structure to ground movements and interaction with adjacent buildings)	Heritage features (Sensitivity to calculated movement of particular features within the building)	Condition (Factors which may affect the sensitivity of structural or heritage features)
0	Masonry buildings with lime mortar and regular openings, not abutted by other buildings, and therefore similar to the buildings on which the original Burland assessment was based.	No particular sensitive features	Good/Fair - not affecting the sensitivity of structural or heritage features
1	Buildings not complying with categories 0 or 2, but still with some sensitive structural features in the zone of settlement e.g.: cantilever stone staircases, long walls without joints or openings, existing cracks where further movements are likely to concentrate, mixed foundations	Brittle finishes, e.g. faience or tight-jointed stonework, which are susceptible to small structural movements and difficult to repair invisibly.	Poor - may change the behaviour of a building in cases of movement. Poor condition of heritage features and finishes. Evidence of previous movement.
2	Buildings which, by their structural form, will tend to concentrate all their movements in one location (e.g.: a long wall without joints and with a single opening).	Finishes which if damaged will have a significant effect on the heritage value of the building, e.g. Delicate frescos, ornate plasterwork ceilings.	Very poor – parlous condition of heritage features and finishes, severe existing damage to structure including evidence of ongoing movement. Essentially buildings where even very small movements could lead to significant damage.

Table 9: Heritage and structural scoring methodology

The results of the heritage assessment carried out for the building are summarised in Table 10.

Sensitivity of the structure
The original northern part of the building on King William Street, built in the 1920's, consists of a steel frame with hollow-pots slabs. The façade is original and consists of steel columns built into the solid brick external walls. There is stone cladding fixed to the outside. During the 1990's development some of the internal structure to this part of the building was replaced with new steel beams/columns and holorib slabs. It also appears that some internal masonry walls have been replaced with steel cross bracing. The southern part of the building (1990's) is a reinforced concrete frame with holorib slabs and a steel mansard roof. The steel and reinforced concrete frames have an inherent degree of flexibility and should be able to cope with the expected movement without significant damage to the primary structure or any reduction in load carrying capacity. Due to the high magnitude of the predicted settlements it is likely that some cracking will occur to the masonry façade. The stone cladding fixings should be investigated to ensure they remain secure throughout the works. Also the foundations are unknown at this time and should be investigated to determine the foundation type and depth.
Score: 0 - The frame itself is not considered particularly sensitive but the magnitude of movement may cause cracking in ashlar of the façade, concentrated on openings and joints.
Sensitivity of the heritage
Due to the loss of most of the heritage features of this building, heritage sensitivities are concentrated on the stonework of the façade, particularly decorative elements, and the plasterwork of the ground floor foyer. The plasterwork of the foyer, as one of the few remaining heritage features of the building, is sensitive to the predicted crack widths as they may cause loss of historic fabric. The Portland stone façade is finely jointed, with low tolerance of the level of settlement predicted on the Sherborne Lane elevation. Cracking is likely to be concentrated at joints, but where these cannot accommodate the movements, cracks across stone panels, or in areas of decoration, may have a permanent aesthetic impact once repaired. In extreme cases, cracking may cause failure of elements of the stonework or its fixings to the internal structure.
Score: 1 – The brittle and finely jointed finishes of the building may be susceptible to damage due to the predicted settlements, and at worst case some loss of historic fabric may occur.
Sensitivity of the condition
It is expected that following the current refurbishment scheme taking place within the building, all elements will be in good condition at the time of the BSCU Works.
Score: 0 – the condition of the building will not exacerbate potential structural or heritage sensitivities

Table 10: Heritage and structural assessment

4.3 Total Score

The total score is the summation of the damage category, structural sensitivity, heritage sensitivity and condition sensitivity scores:

The damage category is 2

The structural sensitivity score is 0

The heritage sensitivity score is 1

The condition sensitivity score is 0

The total score for this building is 3

5 Conclusion

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 2 for 1 King William Street. Specific heritage and structural assessment taking into account the location and extent of settlement and tensile strains indicates that the building may be sensitive to the predicted movements. This assessment has determined that the building has a total score of 3.

It is recommended that a Stage 3 assessment is undertaken to further consider the potential damage to the form of the building.

The predicted settlement is high along the Sherborne Lane elevation, with steep differential movements. It is likely that cracks will be concentrated at joints, junctions and openings, and the damage may cause a permanent impact to the historic fabric. The internal plasterwork to the foyer is also sensitive to small movements.

The BSCU Environmental Statement considers the mitigation that could be needed, however, it is recommended that Stage 3 assessment is undertaken to verify how heritage finishes and the historic fabric may respond and whether such mitigation is required.

6 References

[1] LU Works Information WI 2300 Ground Movement version 3, 19-07-13.

[2] LU Category 1 Standard: S1050 Civil Engineering - Common Requirements, Issue No. A7, Nov. 2013.

[3] Mair R J, Taylor R N and Bracegirdle A (1993). Subsurface settlement profiles above tunnels in clays. Géotechnique 43, No. 2, pp. 315-320.

[4] Mair R J, Taylor R N and Burland J B (1996). Prediction of ground movements and assessment of risk of building damage due to bored tunnelling. (In: International Conference of Geotechnical Aspects of Underground Construction in Soft Ground, London, pp. 713–718.

[5] LU Guidance Document G0058 Civil Engineering Technical Advice Notes, Issue No. A17, Feb. 2013.

[6] Burland J B (1995). Assessment of risk of damage to buildings due to tunnelling and excavation. Proceedings: 1st International Conference of Earthquake Geotechnical Engineering, IS Tokyo, 1995.

[7] Selemetas.D et al (2005). The response of full scale piles to tunnelling. Geotechnical aspects of underground construction in soft ground (Bakker et al (eds)) pp.763-769.

[8] New B M and Bowers K H (1994). Ground movement model validation at the Heathrow Express trial tunnel. Proc. Tunnelling 1994. IMM, London, pp 301-327

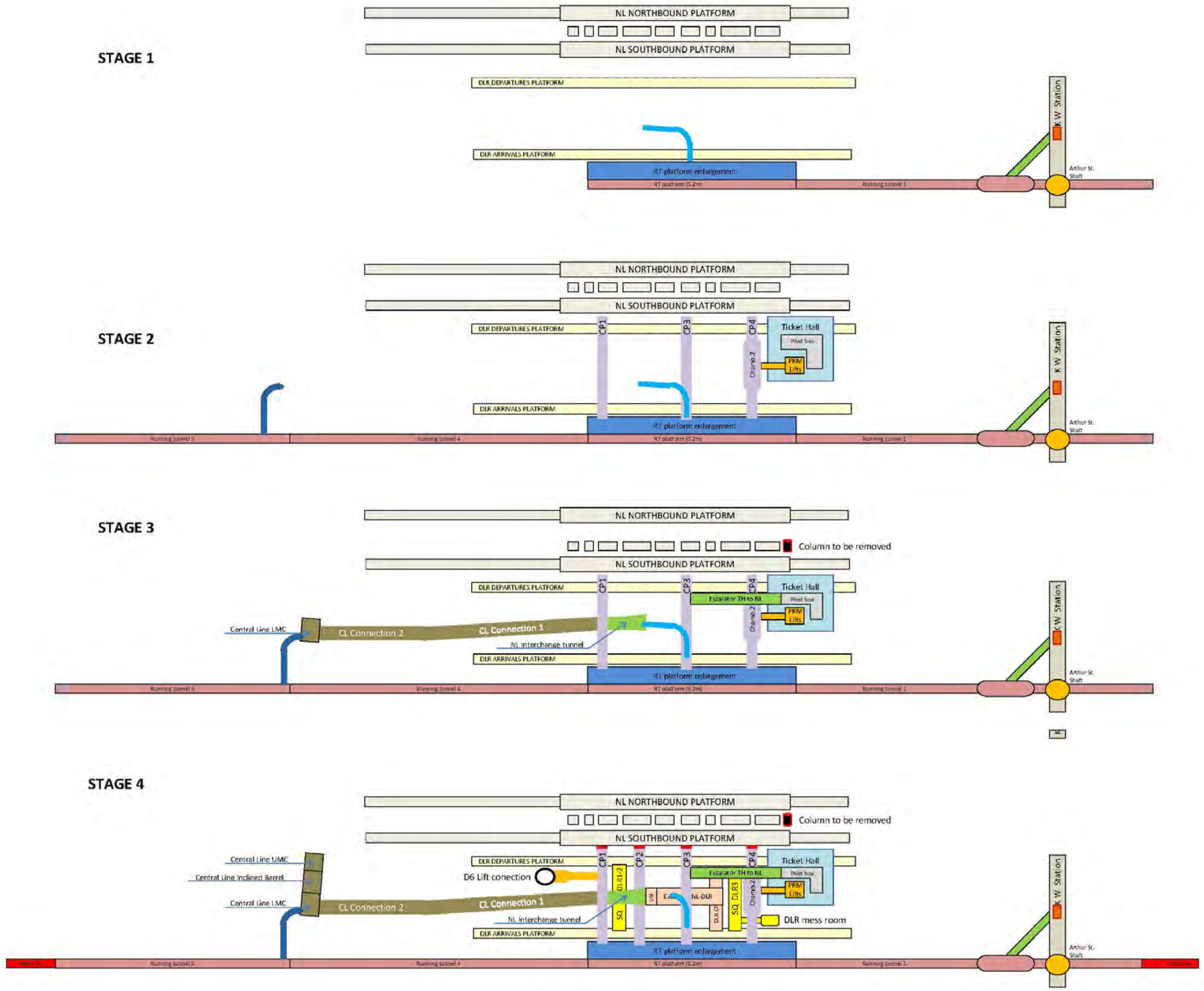

Figure 1: Construction Stage model

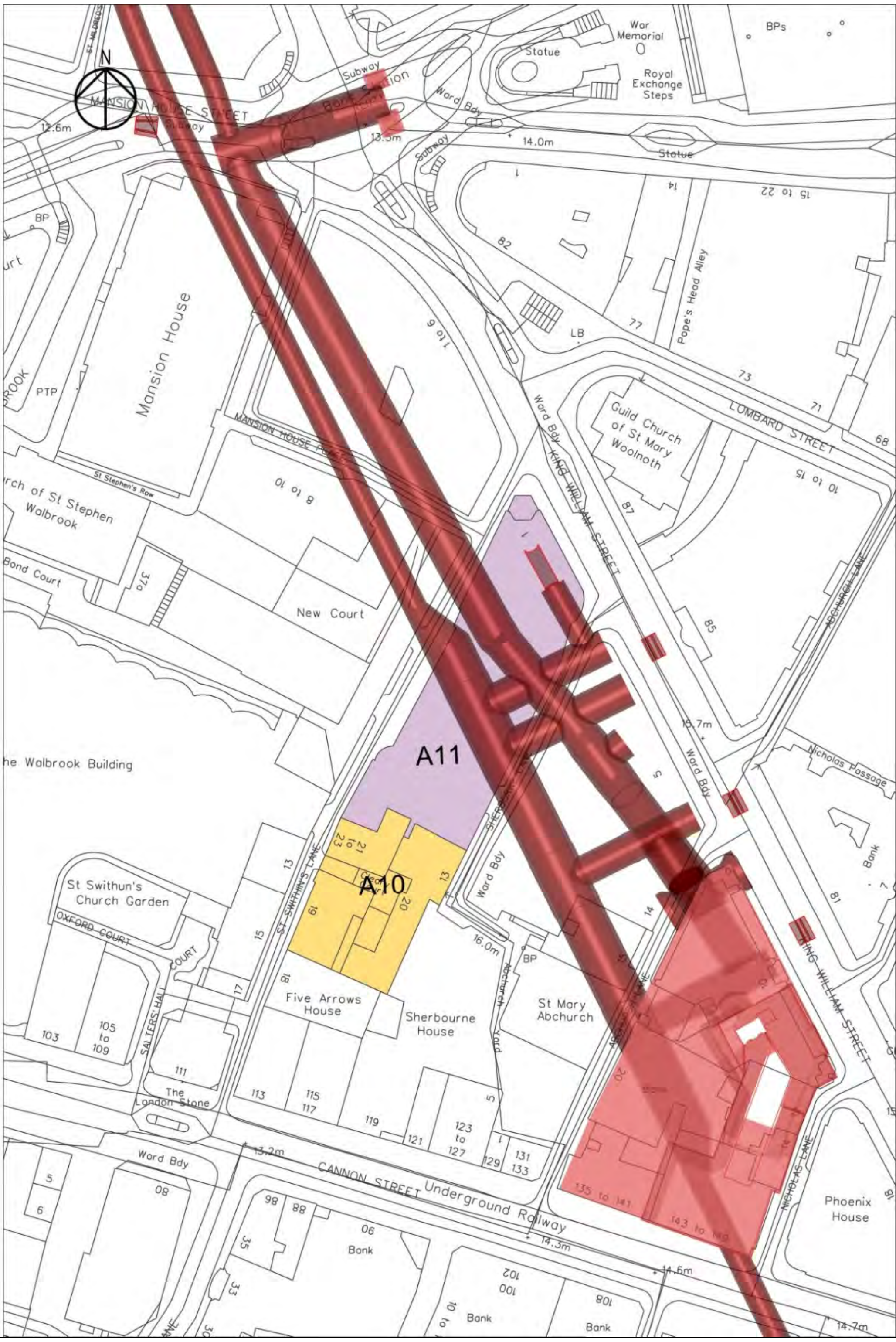

Figure 2: Location plan showing building location in relation to BSCU works

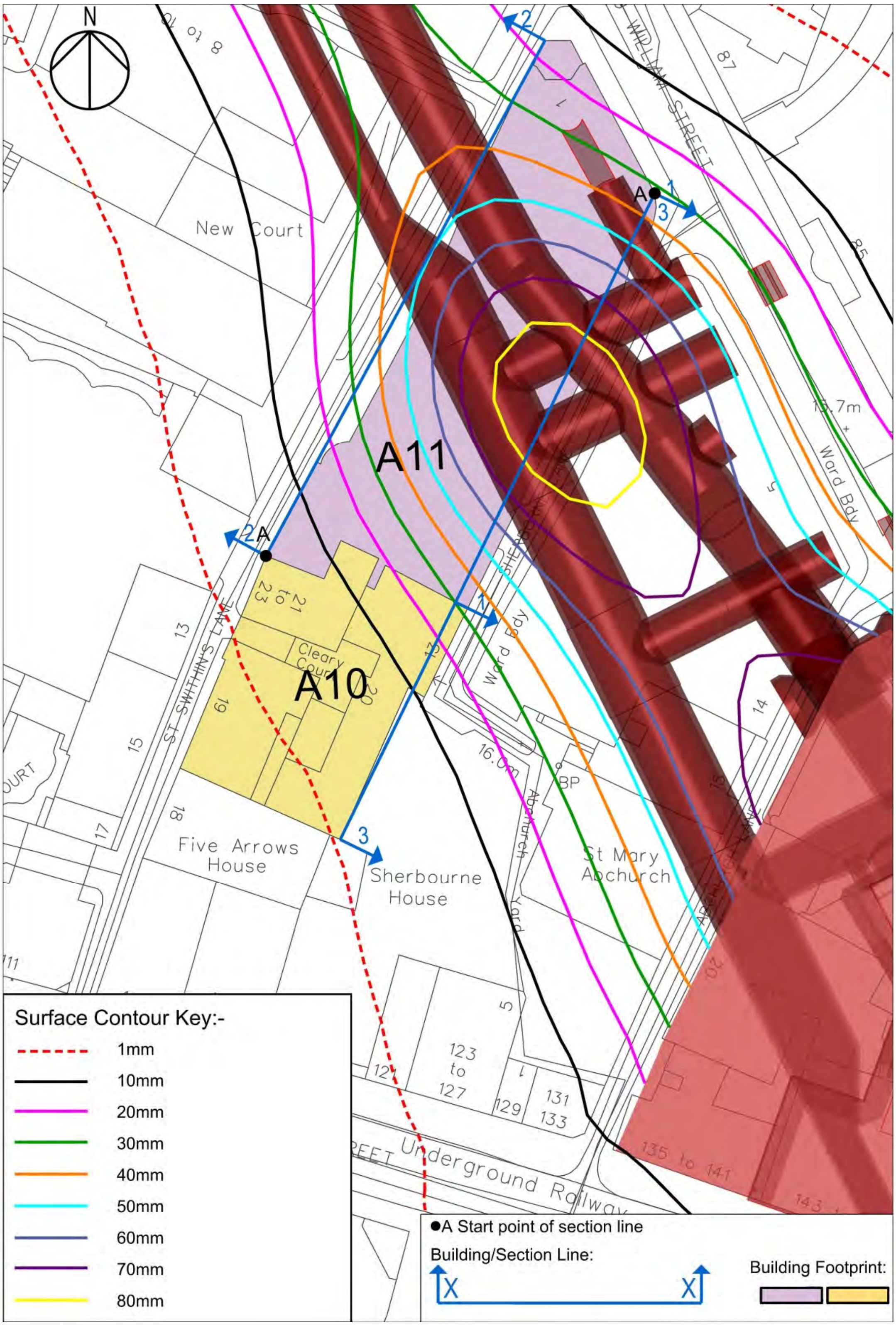

Figure 3: Building location, sections analysed and Settlement Contours at stage of worst case for tensile strains

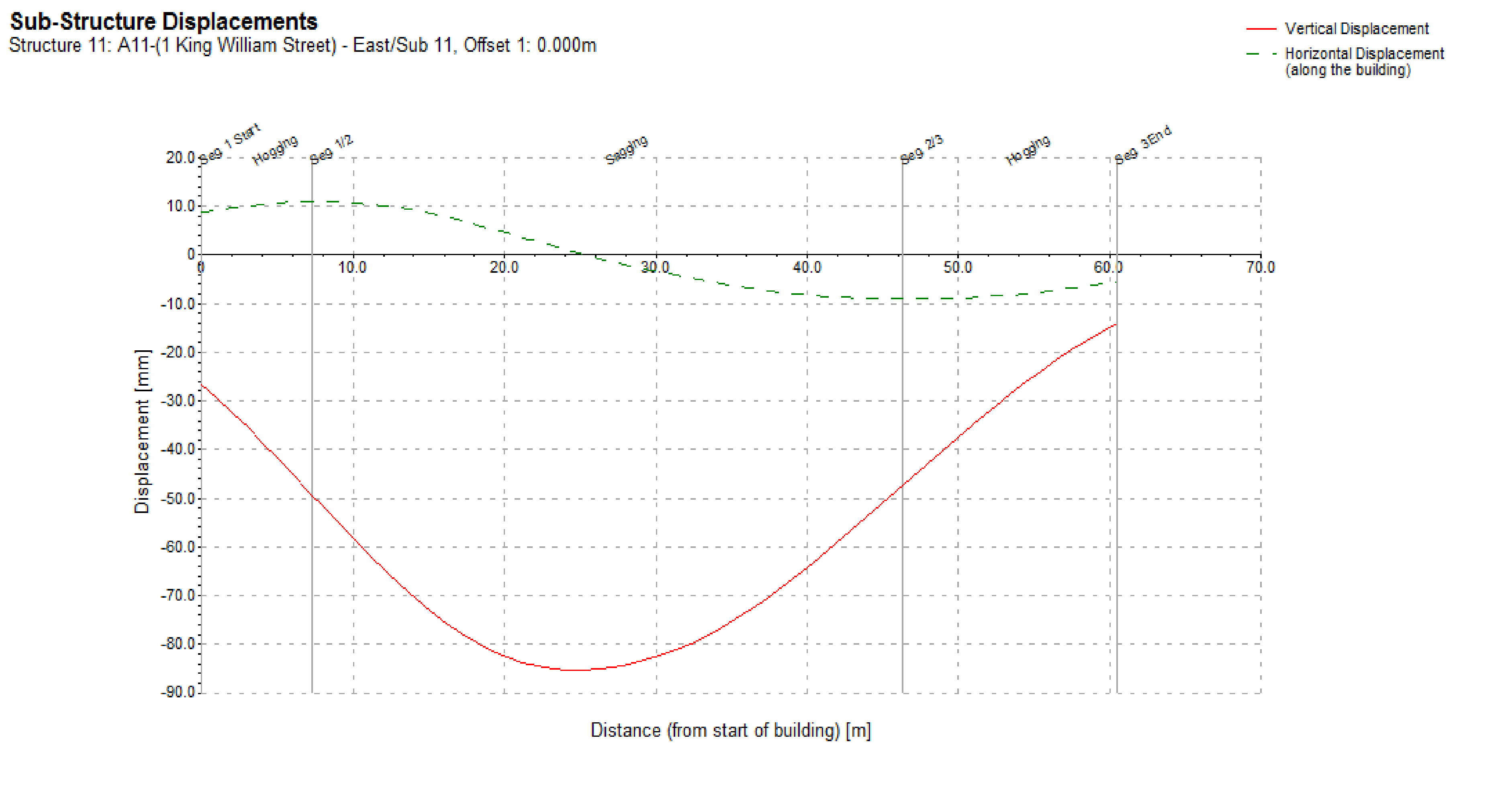

Figure 4: Building displacement at founding level of (line 1) at stage 4 of worst case for tensile strains

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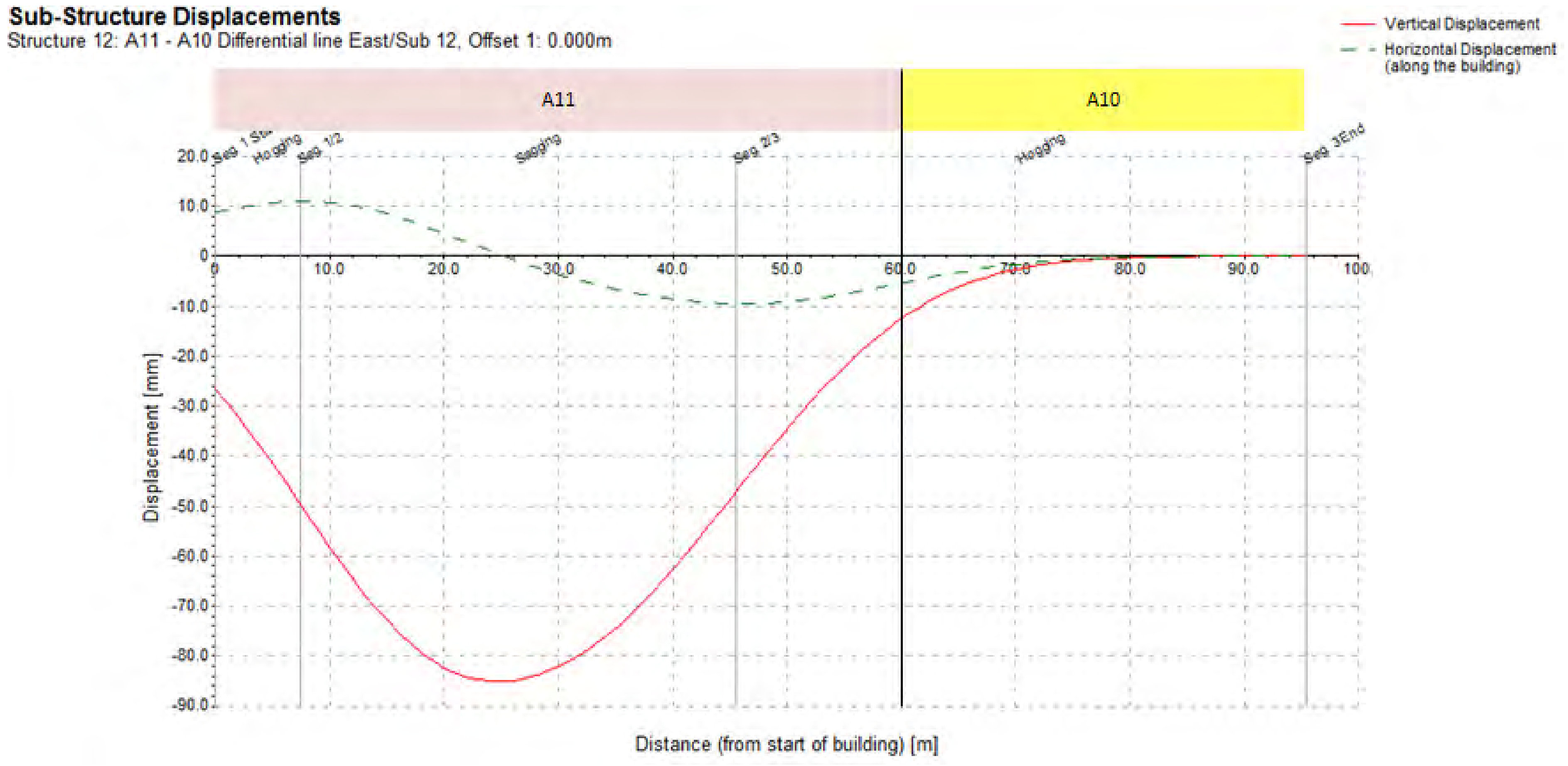

Figure 5: Building displacement at founding level of (line 3) at stage 4 of worst case for tensile strains

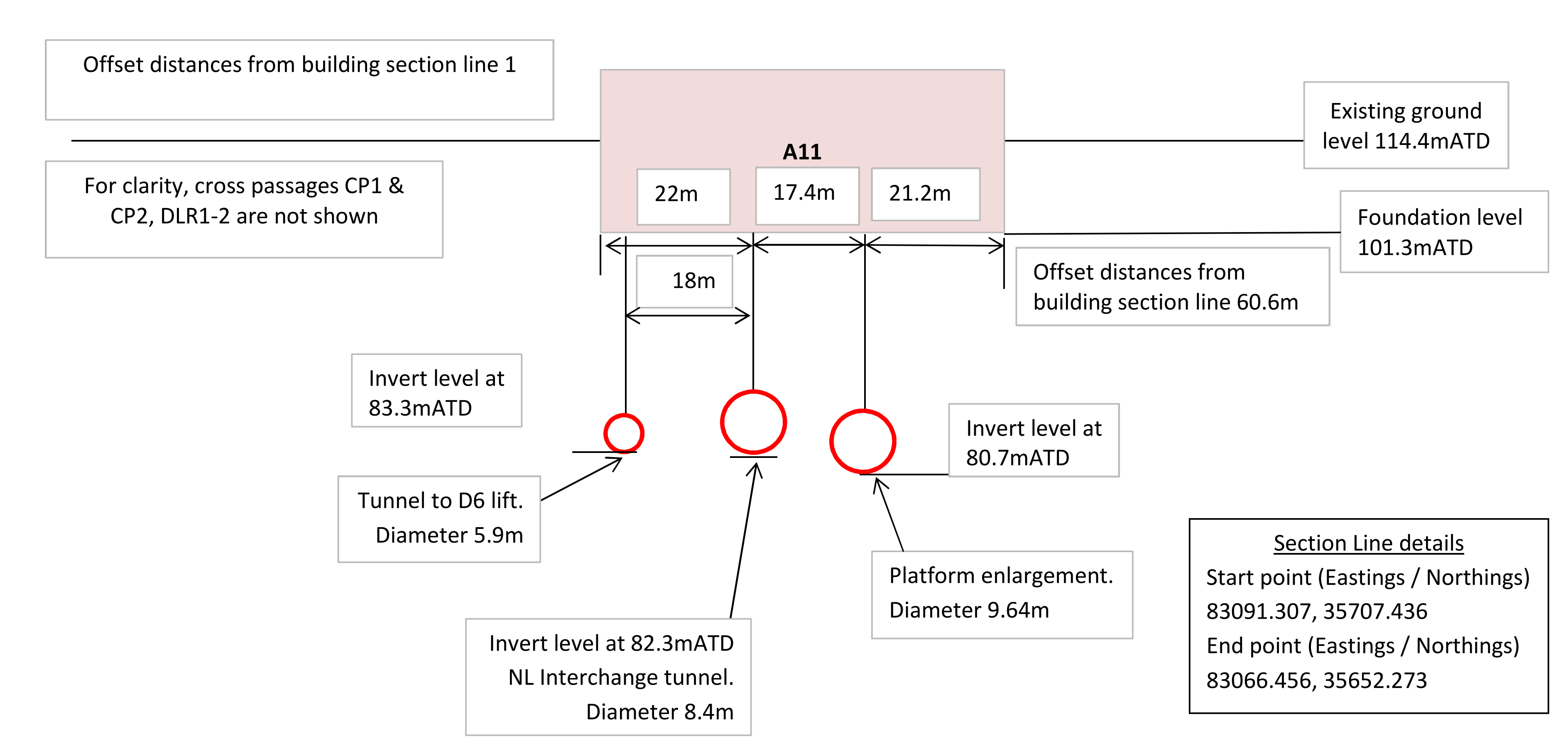

Figure 6: Diagrammatic cross-section of section (line 1) relative to tunnel position

LUL Bank Project Office
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Safely Together

Bank Station Capacity Upgrade

Building Damage Assessment Report

Building A12

5 King William Street

URS-8798-RPT-G-001176

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Revision	Date	Summary of changes
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For the status of this document, please refer to the Building Damage Assessment Report Register (URS-8798-RGT-001229)

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• Olly Newman	Dragados

Contents

FIGURES

TABLES

1 Introduction

This report summarises the results of a Stage 2 damage assessment for 5 King William Street Ref A12.

Stage 2 damage assessments are undertaken for all buildings within the Stage 1 predicted Greenfield ground surface 1mm settlement contour induced by the construction of the Bank Station Capacity Upgrade (BSCU).

The purpose of the assessment is to determine the potential effect the works will have on the building. This report describes the updated engineering and heritage assessments undertaken for the building and concludes whether mitigation is likely to be needed and if a further (Stage 3) assessment is recommended in order to verify this.

2 The Building

2.1 General Information

No. 5 King William Street is bounded by St Swithin’s Lane, Abchurch Lane and King William Street. Originally built to designs by J.Macvicar Anderson and H.L Anderson (1915) the building has undergone two further developments. The first development by Campbell-Jones and Sons (1931-32) extended the building south along Abchurch Lane before Fitzroy Robinson Partnership (1983-87) reconstructed the 1930s façade with an extension to the south along Sherborne Lane, including the addition of a new dormer storey. The building is confirmed as a steel framed structure with solid raft foundations. General building information used in the assessment has been acquired as part of the structural desktop appraisal. This information is presented in Table 1.

Category	Building Information
BSCU Reference	A12
Location	King William Street
Address	5 King William Street
Building Type	Steel framed
Construction Age	1915
No. of Storeys	5
Basements	3
Eaves Level (mATD)	137.8
Foundation Type	Raft
Ground Level (mATD)	115.3
Listed Grade	II
Note: Levels given are in metres above Tunnel Datum, mATD. Tunnel Datum is 100m below Ordnance Survey Datum at Newlyn.	

Table 1: General building informationA general view of the building exterior is shown in Plate 1. A location plan showing the building in relation to the proposed BSCU works is presented in Figure 2.

Plate 1: General view

2.2 Building Description

The Grade II listed building located at 5 King William Street is currently occupied by the financial company Daiwa Capital Markets and extends on a plot framed by King William Street to the north, Abchurch Lane to the east and Sherborne lane to the west.

The building is arranged over five storeys plus up to three levels of basement. The façade is arranged around a modern steel framed building re-built on a raft or pad foundations. The elevations to King William Street and Abchurch Lane are clad in Portland stone in a Classical Renaissance style.

The original building frontage was built in 1915. Part of the building was replaced to Abchurch Lane and Sherborne Lane in 1932. Between 1983-7 the building structure was rebuilt, retaining the façade and the entrance hall area. Major refurbishment and the vertical extension were completed in 1987.

Internally the building functions as a financial institution and the entire building has been renovated to offer a series of large open plan office spaces and smaller meeting rooms. The ground floor entrance hall and the northern range rooms to first floor are apparently original, the upper storeys seem to have been completely modernized and altered during the 1980s works. The ground floor entrance hall to King William Street comprises an octagon of tall marble columns and pilasters supporting an arcaded gallery surmounted by a steel framed glass dome. This space, including its marble floor and dado panelling are believed to be original.

The structure above ground is constructed of a steel frame and brick masonry with independent Portland stone and brick masonry facades. The steel frame is believed to extend below ground level, together with reinforced concrete and brick masonry construction.

According to historical reports the retaining wall structure to the basements and street frontages are of reinforced concrete. The original foundations are believed to have been comprised of steel grillages encased in concrete under the primary steel frame. However Alan Baxter Associate's Gazeteer (2012) suggests that "steel columns to original structure likely to be supported on grillage beams and concrete pad foundations or a raft foundation with thickenings under the columns. The recent structure may be on raft or piled foundations". Drawings (Andrews Kent & Stone) subsequently obtained indicate that the foundation is a raft. Three lifts exist in the north-east modernised wing and a separate goods lift. The basement hosts car parking provision with a car lift.

3 Methodology

This building damage assessment is undertaken in accordance with LU Works Information WI2300[1] and LU Civil Engineering - Common Requirements S1050[2].

The analysis methodology applies to ground-bearing buildings which will be affected by ground movements resulting from the construction of the BSCU. The engineering assessment calculates the potential impact of ground movements and assigns a damage category to the building based on a numeric scale. Additionally, for listed buildings, a heritage assessment is carried out which considers the sensitivity of the structure and the sensitivity of its particular features; a heritage sensitivity score is assigned. The heritage sensitivity score is added to the damage category to obtain the total score. If the total score is 3 or more, a more detailed Stage 3 assessment is triggered.

Oasys Xdisp is used to analyse the Greenfield ground movements in terms of settlement and horizontal displacement. Subsurface tunnelling induced ground movement profiles are determined in accordance with the methodology described by Mair et al[3 & 4].

Movements resulting from the Whole Block Scheme (WBS) and shaft excavations have been calculated using LU Guidance Document G0058[5].

An additional displacement line A12 line 2 was drawn to assess movements between this building and the adjacent building A13 (Capital Club), as shown in Figure 3.

The building is modelled as a simple elastic beam which is conservatively assumed to follow the Greenfield ground displacements. The beam is divided into hogging and sagging segments. The tensile strains within each segment are calculated based on the distortion associated with differential settlement (which is characterised by deflection ratio) and the distortion associated with differential horizontal displacement (characterised by horizontal strain).

Xdisp provides a method for calculating the maximum tensile strain within the building superstructure associated with these movements, in accordance with the assessment methodology described by Mair et al[4]. This strain is used to determine the damage category for traditional masonry structures based on the classification system proposed by Burland[6] and in accordance with S1050 Civil Engineering – Common Requirements[2]. The categories are presented in Table 2.

Damage Category	Description of Degree of Damage	Description of Typical Damage and likely forms of Repair for Typical Masonry Buildings.	Approx. Crack Width (mm)	Max. Tensile Strain %
0	Negligible	Hairline cracks.		< 0.05
1	Very slight	Fine cracks easily treated during normal redecoration. Perhaps isolated slight fracture in building. Cracks in exterior visible upon close inspection.	0.1 to 1.0	0.05 to 0.075
2	Slight	Cracks easily filled. Redecoration probably required. Several slight fractures inside building. Exterior cracks visible; some repainting may be required for weather-tightness. Doors and windows may stick slightly.	1 to 5	0.075 to 0.15
3	Moderate	Cracks may require cutting out and patching. Recurrent cracks can be masked by suitable linings. Tuck pointing and possible replacement of a small amount of exterior brickwork may be required. Doors and windows sticking. Utility services may be interrupted. Weather tightness often impaired.	5 to 15 or a number of cracks > 3	0.15 to 0.3
4	Severe	Extensive repair required involving removal and replacement of walls especially over doors and windows. Window and door frames distorted. Floor slopes noticeably. Walls lean or bulge noticeably. Some loss of bearing in beams. Utility services disrupted.	15 to 25 but also depends on number of cracks	> 0.3
5	Very severe	Major repair required involving partial or complete reconstruction. Beams lose bearing, walls lean badly and require shoring. Windows broken by distortion. Danger of instability.	Usually > 25 but depends on number of cracks	
Note: Please refer LU Civil Engineering - Common Requirements S1050[2].				

Table 2: Building damage classification

4 Input Data

The magnitude and distribution of ground movements and degree of building damage is calculated based on the following input data:

- The Xdisp model coordinates and levels are based on the 3D model (20130212DSPITT Scheme R09);
- Four construction stages are considered in accordance with the proposed programme (November 2013) as illustrated in Figure 1;
- Trough width parameter, K=0.5 is used in accordance with WI2300[1].

The input data for the building, tunnels and shaft excavation are summarised in Table 3, Table 4 and Table 5 respectively.

Location	Foundation level (mATD)	Building Height above foundation level (m)	E/G
5 King William	103.4*	34.4	12.5
Note: Where E / G is the ratio of Young's modulus to shear modulus of the deep beam representing the building. * Assumed level, 1.5m thick slab beneath floor level.			

Table 3: Building data

Tunnel Item	Level of axis (mATD)	External diameter (m)	Volume Loss (%)
Running tunnels	83.5	5.4	1.5
Square works adits	75.8 to 95.3	4.1 to 7.8	2.5
Platform enlargement	85.6	9.64*	1.5
Escalator barrels	Inclined	8.3 to 8.4	1.5
NL Interchange tunnel	86.4	8.4	1.5
Central Line Connection	Inclined (87.6 to 89.2)	8.6	1.5
Note: * Cross section of the tunnel is oval in shape. Presented diameter is for equivalent circular area. Low Level Sewer 2 passes beneath the building. The sewer comprises a 3m diameter cast iron pipe with an invert level of ~94.7mATD.			

Table 4: Tunnel data

Excavation	Excavation Base Level (mATD)
Grout Shaft at King William Street	97
Whole Block Scheme Box excavation	73
Arthur Street Shaft	81

Table 5: Excavation data

The Xdisp model filenames used to undertake this assessment are:

- A12 - Stage 4
- A12 - Stage 3
- A12 - Stage 2
- A12 - Stage 1

5 Results

5.1 Engineering Assessment

The sections through the building which have been analysed are shown on plan in Figure 3.

Assessment has been undertaken at three intermediate construction stages and at the end of construction when all major elements of the works including shaft and tunnels have been completed. The damage category assigned to the building is based on the construction stage at which the potential impact on the building is most severe.

The maximum settlement and tensile strain calculated for each of the analysis sections at the most onerous construction stage are presented in Table 6 and Table 7.

Section	Maximum Settlement (mm)		Maximum Tensile Strain (%)
A12 (line 1)	Stage 1	43	0.045
A12 (line 2)	Stage 1	40	0.019
	Stage 2	49	0.043
A12 (line 3)	Stage 1	7	0.004
A12 (line 4)	Stage 1	45	0.050
Note: (Line 2) represents two buildings. The strains are not therefore applicable to building A12			

Table 6: Building response at most onerous intermediate stage (Stage 1 and 2)

Section	Maximum Settlement (mm)	Max Tensile Strain (%)
A12 (line 1)	77	0.063
A12 (line 2)	(Stage 4) 62	0.022
	(Stage 2) 49	0.043
A12 (line 3)	48	0.015
A12 (line 4)	59	0.040
Note: (Line 2) represents two buildings. The strains are not therefore applicable to building A12		

Table 7: Building response at end of construction (stage 4)

The results of the assessment show that construction Stage 4 is critical for this building when A12 line 1 experiences the most onerous combined tensile strain (0.063%). The orientation is shown in Figure 3. The vertical and horizontal Greenfield ground movements along the section line 1 are shown in Figure 4.

The displacement line 2 also shows the relative movements with the adjacent building A13 along Abchurch Lane. Unlike displacement line 1, the displacement line 2 undergoes its most onerous tensile strain (0.043% in hogging) at Stage 2. Figure 5 and Table 8 show that the strain between the two adjacent buildings is in hogging mode. These movements would tend to open a crack between the two buildings at high level. The maximum tensile strains in this area result in a very slight damage category.

The relative position of the building and tunnels along section line 1 is shown in Figure 6. The calculated strains are summarised in Table 8.

Line No (stage)	Strains in section (Curvature)	Position from start (m)	Length (m)	Average* Horizontal Strain (%)	Maximum Tensile Strains (%)	Damage Category
(Line 1) (Stage 4)	Hogging	0.0	16.7	0.028	0.036	Negligible
	Sagging	16.7	42	-0.044	0.063	Very Slight
	Hogging	58.6	2.1	0.008	0.008	Negligible
(Line 2) (Stage 2)	Sagging	0.0	7.6	-0.013	0.004	Negligible
	Hogging	7.6	19.9	0.029	0.043**	Negligible
	Sagging	27.5	11.8	-0.053	0.018	Negligible
Note: * Tensile horizontal strains are +ve. Compressive horizontal strains are –ve. ** This is strain from an extended line which is not applicable to the building						

Table 8: Section analysed, results for worst case tensile strain

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 1. This corresponds to Very Slight damage in accordance with Table 2.

The maximum settlement of the building at foundation level at the end of construction is 77mm.

5.2 Heritage and Structural Assessment

Following site inspection, assessment has been made using the scoring methodology set out in Table 9.

Score	Structure (Sensitivity of the structure to ground movements and interaction with adjacent buildings)	Heritage features (Sensitivity to calculated movement of particular features within the building)	Condition (Factors which may affect the sensitivity of structural or heritage features)
0	Masonry buildings with lime mortar and regular openings, not abutted by other buildings, and therefore similar to the buildings on which the original Burland assessment was based.	No particular sensitive features	Good/Fair - not affecting the sensitivity of structural or heritage features
1	Buildings not complying with categories 0 or 2, but still with some sensitive structural features in the zone of settlement e.g.: cantilever stone staircases, long walls without joints or openings, existing cracks where further movements are likely to concentrate, mixed foundations	Brittle finishes, e.g. faience or tight-jointed stonework, which are susceptible to small structural movements and difficult to repair invisibly.	Poor - may change the behaviour of a building in cases of movement. Poor condition of heritage features and finishes. Evidence of previous movement.
2	Buildings which, by their structural form, will tend to concentrate all their movements in one location (e.g.: a long wall without joints and with a single opening).	Finishes which if damaged will have a significant effect on the heritage value of the building, e.g. Delicate frescos, ornate plasterwork ceilings.	Very poor – parlous condition of heritage features and finishes, severe existing damage to structure including evidence of ongoing movement. Essentially buildings where even very small movements could lead to significant damage.

Table 9: Heritage and structural scoring methodology

The results of the heritage assessment carried out for the building are summarised in Table 10.

Sensitivity of the structure

Much of the structure of the building is of new steel framed construction with modern concrete floors laid on profiled metal decking. The successive extensions to the building on Abchurch Lane and Sherborne Lane are also steel framed buildings which are believed to be constructed on modern foundations. It is not known whether allowances have been made for differential movement between these interfaces.

The recent structure is shown to be supported on a raft foundation. In some cases raft foundations can accommodate localised settlements without causing distortions to the structure and some decorative features. However this is largely dependent on the magnitude of the settlement. Likewise localised distortions are more likely if pad foundations are present. The floor level to the deepest basement (ground floor -3) is approximately 11m (36 ft). The construction of the lower basements is with reinforced concrete; however the extent of this construction is unknown.

The original façade on King William Street that returns onto Abchurch Lane and Sherborne Lane is retained from the earlier phases of construction. The available 1930 archive drawings suggest that the existing foundations were comprised of concrete pad foundations. Access to record drawings of the later refurbishments has not been possible, which could provide useful information on the re-modelled substructure (as implied in Alan Baxter Associate's Gazeteer). The relationship between the retained façade and the new structure behind is unknown. However it is believed that the existing façade rests on its original mass concrete footings, which also support the retaining wall set-back from the building perimeter – all as shown on the 1930's drawings.

The domed glass roof skylight sited above the decorative ground floor entrance is supported onto the eight double height internal circular pillars. The support to the pillars in currently unknown, and they should thus be considered sensitive structural features. This is due to the risk of differential settlement between the independent pillars and their support to the glass dome which is a brittle element.
There is a possibility distortion of the straight flight, entrance staircases between ground floor level and mezzanine level.

Score: 1 The impact of the various phases of the tunnelling works on the building and their connectivity may result in the concentration of strain at certain locations and interfaces.
Sensitivity of the heritage
Despite various alterations, extensions and refurbishments, the character of this building is preserved through its original elevations, surviving internal features such as the richly decorated entrance hall to ground floor, original stair, the dome above the entrance hall and the surviving panelled offices to directors' rooms to first floor. The most sensitive heritage elements are to the exterior, the original elevation with fine jointed stonework, stone balustrades to top floors and to the interior, the marble finishes, cornices and mouldings, ornate plasterwork, marble fireplaces and original windows to both ground floor entrance hall and meeting rooms to first floor. These heritage elements would be highly susceptible to high structural movements of the building, which are predicted to arise in close proximity of the internal features and along the external façade to Sherborne Lane. Damage through Portland stonework and interior marble could be difficult to repair, thus having a permanent aesthetic impact on the building.
Score: 1 The heritage sensitivity is determined by brittle historic finishes located in the proximity of high differential settlement
Sensitivity of the condition
The building is generally in good condition and features contemporary office finishing with carpeted floor, suspended ceilings, and dry lined and painted walls. The surviving original features are in excellent conditions. During the site inspection it was not possible to identify any defects that might be exacerbated by settlement.
Score: 0 The combined structural and heritage condition of the building as visible at time of inspection range from good to excellent. The condition of the building will not contribute to the overall sensitivity of the building to the predicted ground movements.

Table 10: Heritage and structural assessment

5.3 Total Score

The total score is the summation of the damage category, structural sensitivity, heritage sensitivity and condition sensitivity scores:

The damage category is 1

The structural sensitivity score is 1

The heritage sensitivity score is 1

The condition sensitivity score is 0

The total score for this building is 3

6 Conclusion

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 1. This corresponds to Very Slight damage in accordance with Table 2.

However, specific heritage and structural assessment taking into account the location and extent of settlement and tensile strains indicates that the building has a high level of structural and heritage sensitivity to movement. This assessment has determined that the building has a total score of 3.

It is recommended that a Stage 3 assessment is undertaken to further consider the potential damage to the structural formand to ascertain the presence of varied foundations.

The BSCU Environmental Statement considers the mitigation that could be needed, however, it is recommended that Stage 3 assessment is undertaken to verify how heritage finishes and features may respond and whether such mitigation is required.

7 References

[1] LU Works Information WI 2300 Ground Movement version 3, 19-07-13.

[2] LU Category 1 Standard: S1050 Civil Engineering - Common Requirements, Issue No. A7, Nov. 2013.

[3] Mair R J, Taylor R N and Bracegirdle A (1993). Subsurface settlement profiles above tunnels in clays. Géotechnique 43, No. 2, pp. 315-320.

[4] Mair R J, Taylor R N and Burland J B (1996). Prediction of ground movements and assessment of risk of building damage due to bored tunnelling. (In: International Conference of Geotechnical Aspects of Underground Construction in Soft Ground, London, pp. 713–718.

[5] LU Guidance Document G0058 Civil Engineering Technical Advice Notes, Issue No. A17, Feb. 2013.

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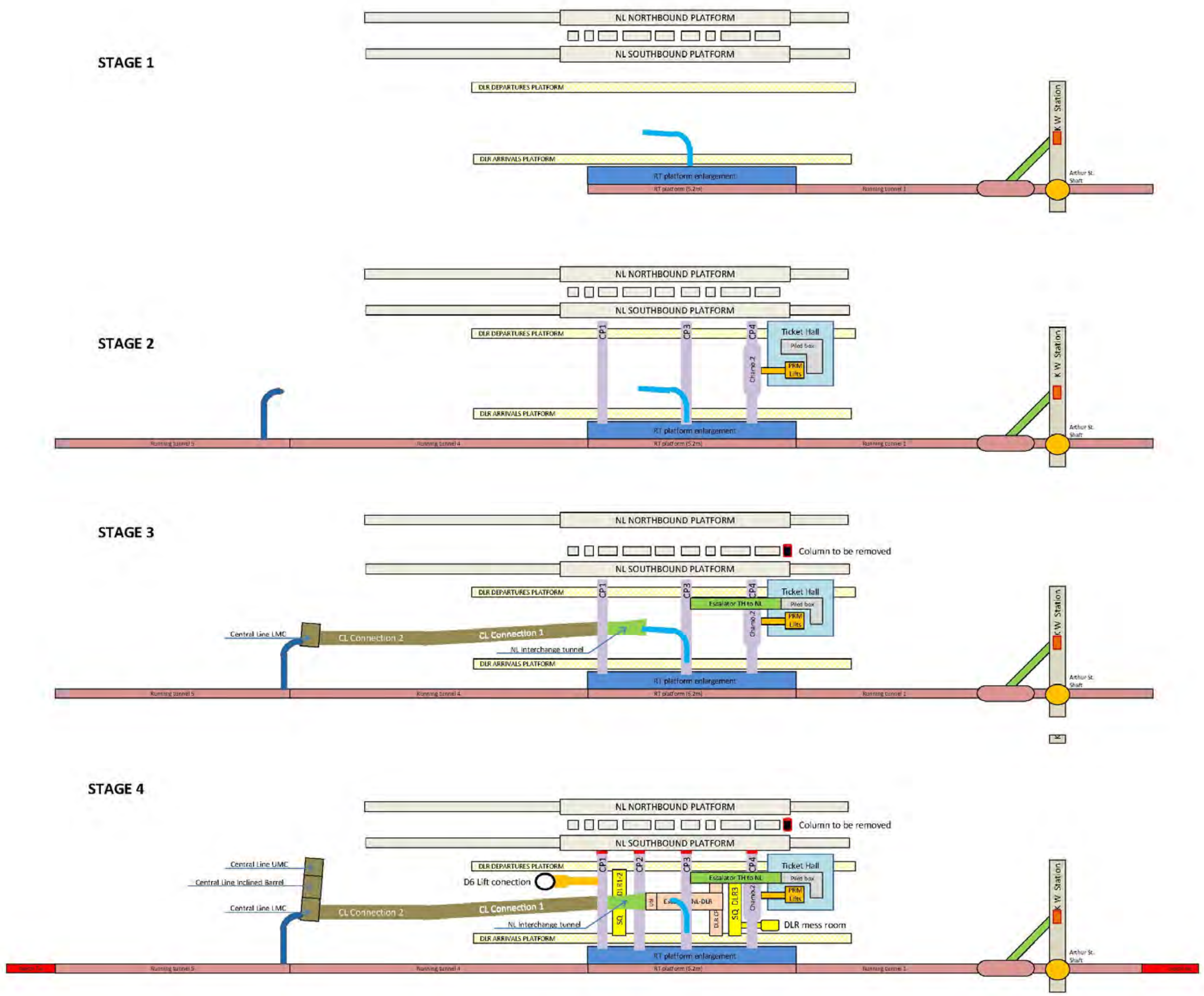

Figure 1: Construction Stage model

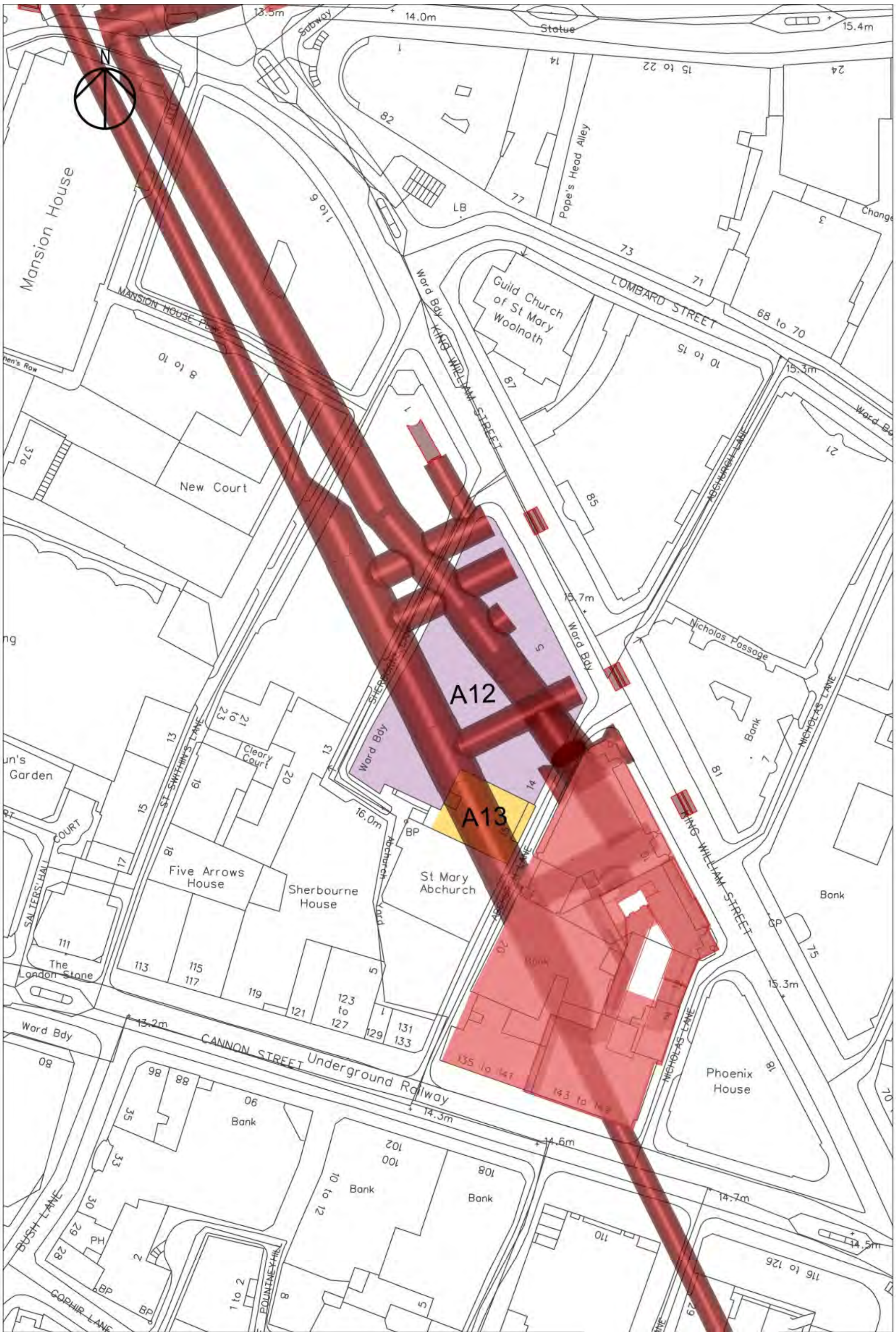

Figure 2: Location plan showing building location in relation to BSCU works

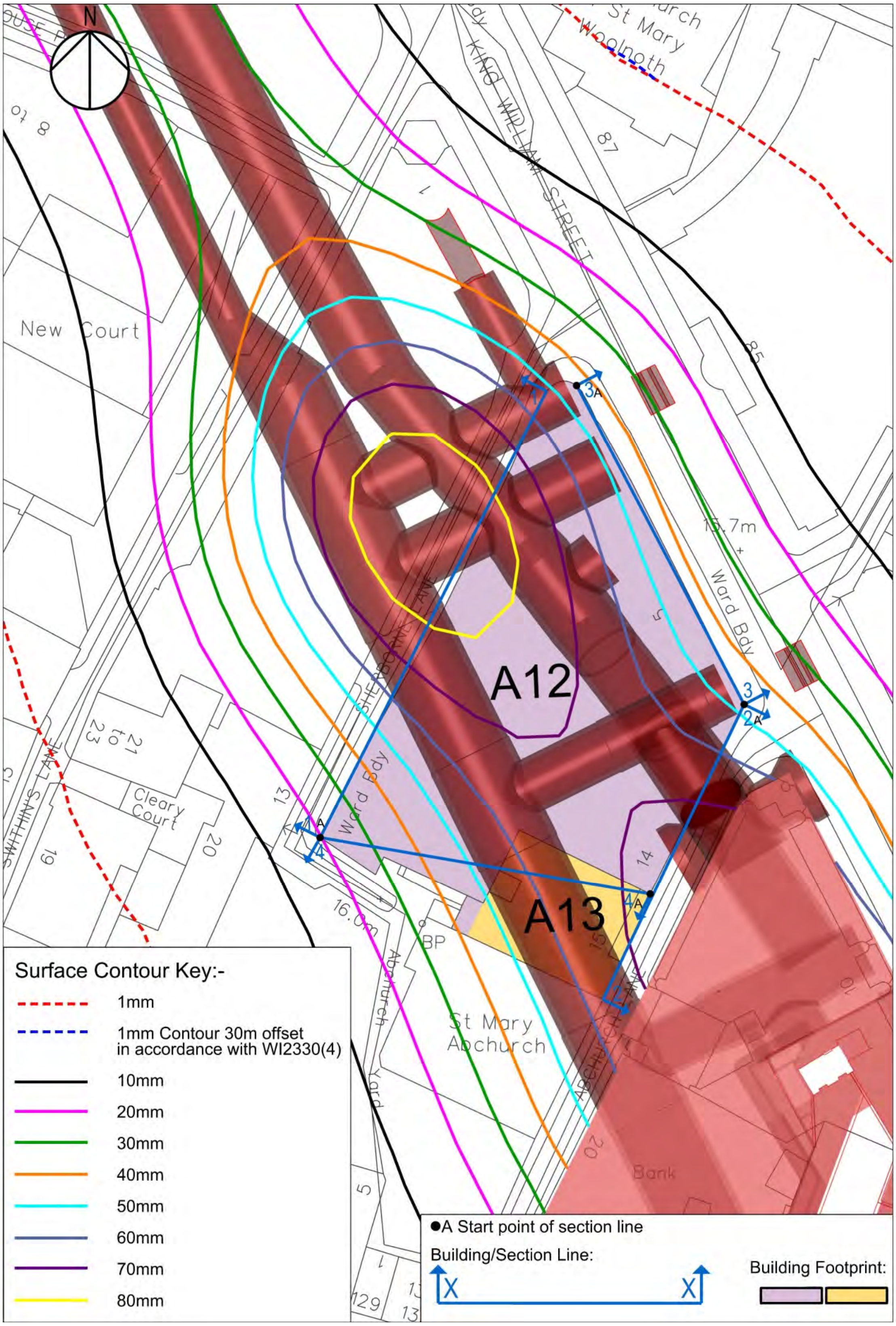

Figure 3: Building location, sections analysed and Settlement Contours at stage of worst case for tensile strains

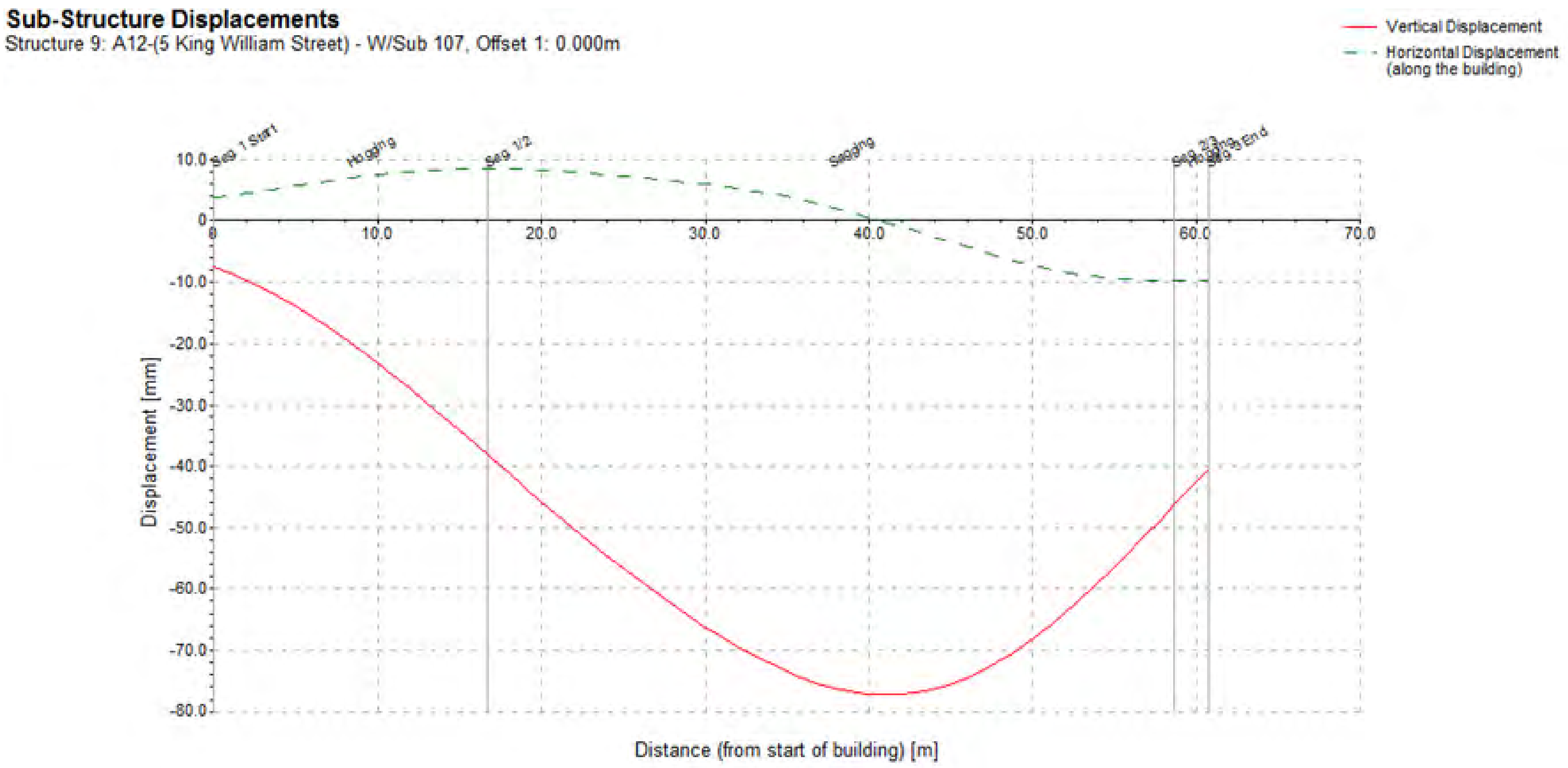

Figure 4: Building displacement at founding level of (line 1) at stage 4 of worst case for tensile strain

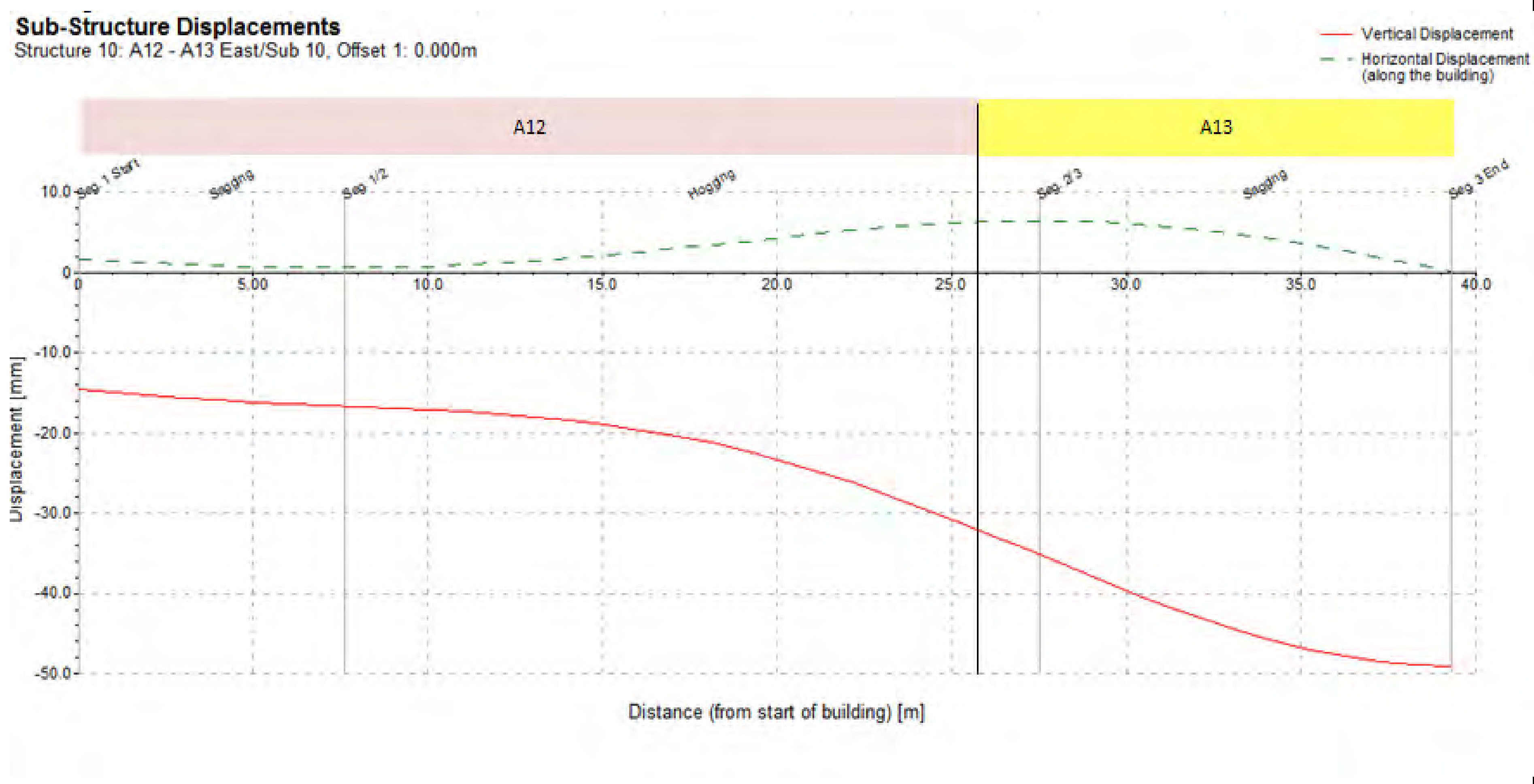

Figure 5: Building displacement at founding level of (line 2) at stage 2 of worst case for tensile strain

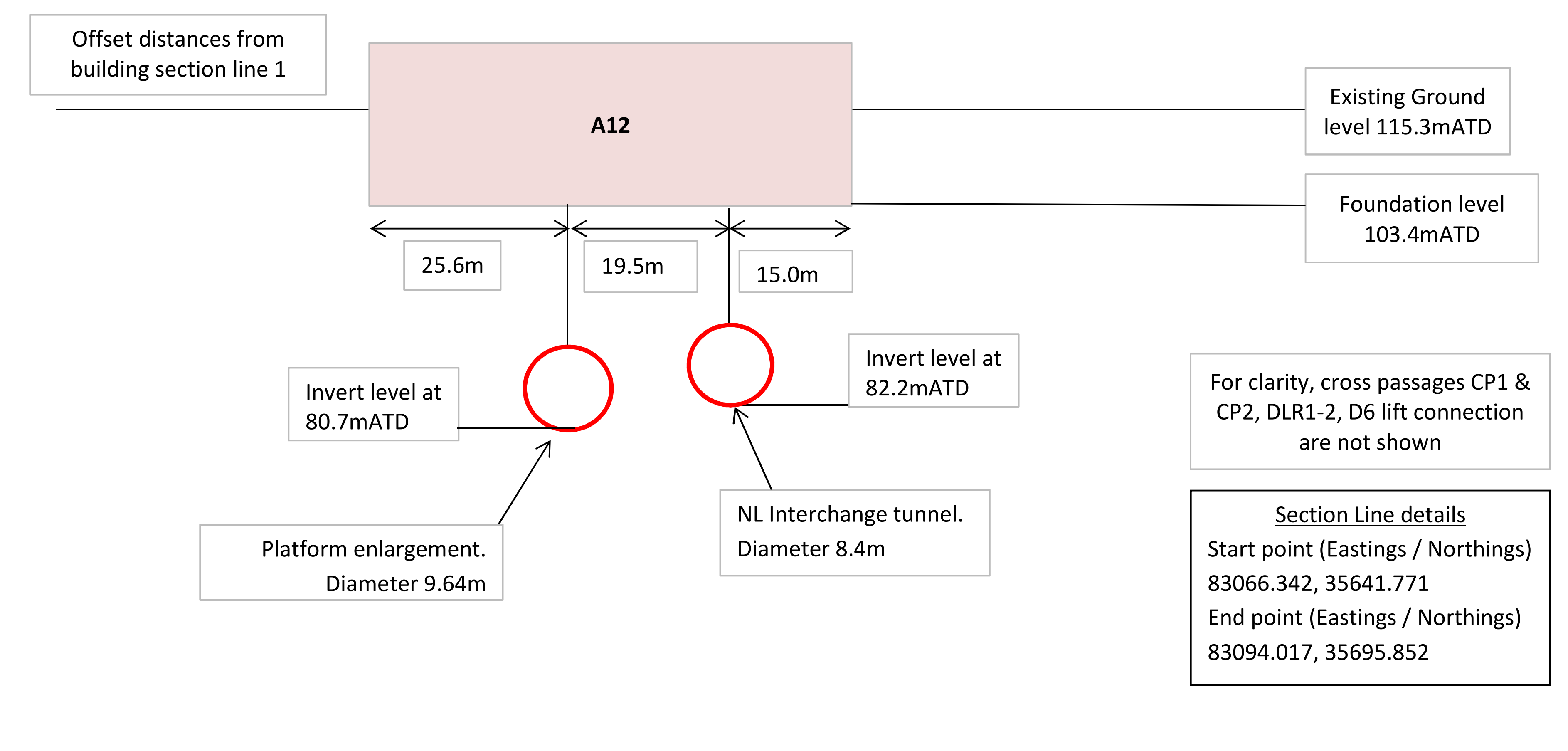

Figure 6: Diagrammatic cross-section of section (line 1) relative to tunnel position

LUL Bank Project Office
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Bank Station Capacity Upgrade

Building Damage Assessment Report

Building A13

15 Abchurch Lane

URS-8798-RPT-G-001177

Prepared by:	Lisa Perkins Assistant Geotechnical Engineer	[signature]	18/07/14
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Document History

Revision	Date	Summary of changes
1.0	March 2014	Issue to Heritage
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3.0	July 2014	TWAO Issue

For the status of this document, please refer to the Building Damage Assessment Report Register (URS-8798-RGT-001229)

Consultation:

• Ela Palmer	URS Heritage
• Brian Lyons	Dr.Sauer
• Keith Bowers/Neil Moss/Paul Dryden	London Underground
• Olly Newman	Dragados

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1 Introduction

This report summarises the results of a Stage 2 damage assessment for 15 Abchurch Lane.

Stage 2 damage assessments are undertaken for all buildings within the Stage 1 Greenfield ground surface 1mm settlement contour induced by the construction of the Bank Station Capacity Upgrade (BSCU).

The purpose of the assessment is to determine the potential effect the works will have on the building. This report describes the engineering and heritage assessments undertaken for the building and concludes whether mitigation is likely to be needed and if a further (Stage 3) assessment is recommended in order to verify this.

2 The Building

2.1 General Information

No. 15 Abchurch Lane is within close proximity to the new station box of the BSCU works. Situated adjacent to St Mary Abchurch the building is accessed from Abchurch Lane between Cannon Street and King William Street. The building is a five storey structure with two basement levels. The structure is cited by Alan Baxter's as likely to be steel framed [7]. The foundation has been assumed as a shallow raft. General building information for A13 used in the assessment has been acquired as part of the structural desktop appraisal. This information is presented in Table 1.

Category	Building Information
BSCU Reference	A13
Location	Abchurch Lane
Address	15 Abchurch Lane
Building Type	Steel framed with concrete external basement walls
Construction Age	1914
No. of Storeys	5
Basements	2
Eaves Level (mATD)	133.6
Foundation Type	Assumed Raft
Ground Level (mATD)	115.4
Listed Grade	II
Note: Levels given are in metres above Tunnel Datum, mATD. Tunnel Datum is 100m below Ordnance Survey Datum at Newlyn.	

Table 1: General building information

A general view of the building exterior is shown in Plate 1. A location plan showing the building in relation to the proposed BSCU works is presented in Figure 2.

Plate 1: General view

2.2 Building Description

Designed by William Campbell Jones and constructed in 1914/1515, 15 Abchurch Lane is a private members club accessed from Abchurch Lane.

The building, which is generally rectangular in plan, consists of 5 stories above ground level and 2 basement levels and is constructed of a combination of brick and structural steel frame which supports a Portland masonry façade fronting Abchurch Lane. The structure below street level is constructed of a combination of massed concrete, aerated concrete blocks and glazed brickwork. It is assumed to be founded on a structural steel grillage and concrete raft. The mortar used is cementitious. St. Mary Abchurch adjoins the building to the south and 13 Abchurch Lane adjoins the building to the north.

Internally the building has functioned as a private members club since it was constructed. It has been designed with an asymmetrical plan, with stairs, client lift, service lift and stairs and kitchens to the south and west of the building (adjoining St. Mary Abchurch and to the rear) and function and meeting rooms to the north and east of the building. In general the ceilings are coved with moulded plaster detailing. Other internal details of note include extensive timber joinery, original stone and terrazzo flooring on the stair landings and in the toilets, a reinforced concrete torsion staircase with stone tread finish and terrazzo landings for patrons' use, and a number of high quality chimney surrounds.

3 Methodology

This building damage assessment is undertaken in accordance with LU Works Information WI2300[1] and LU Civil Engineering - Common Requirements S1050[2].

The analysis methodology applies to ground-bearing buildings which will be affected by ground movements resulting from the construction of the BSCU. The engineering assessment calculates the potential impact of ground movements and assigns a damage category to the building based on a numeric scale. Additionally, for listed buildings, a heritage assessment is carried out which considers the sensitivity of the structure and the sensitivity of its particular features; a heritage sensitivity score is assigned. The heritage sensitivity score is added to the damage category to obtain the total score. If the total score is 3 or more, a more detailed Stage 3 assessment is triggered.

Oasys Xdisp is used to analyse the Greenfield ground movement in terms of settlement and horizontal displacement. Subsurface tunnelling induced ground movement profiles are determined in accordance with the methodology described by Mair et al[3 & 4].

In order to investigate the relative movements between this building and the neighbour to the south, St Mary Abchurch (A14), a displacement line (line 3) was drawn to represent the rear of the two buildings as shown in Figure 3. It was analysed at A13's founding level. This is not a strictly accurate model since building A14 is founded approximately 3.4m higher than A13 but will give an understanding of the behaviour in this area.

This building is understood to adjoin to its neighbour St Mary Abchurch (A14). The behaviour along this line was investigated as displacement (line 2). The results are shown in Table 6 and Table 8.

Movements resulting from the Whole Block Scheme (WBS) and shaft excavations have been calculated using LU Guidance Document G0058[5].

The building is modelled as a simple elastic beam which is conservatively assumed to follow the Greenfield ground displacements. The beam is divided into hogging and sagging segments. The tensile strains within each segment are calculated based on the distortion associated with differential settlement (which is characterised by deflection ratio) and the distortion associated with differential horizontal displacement (characterised by horizontal strain).

Xdisp provides a method for calculating the maximum tensile strain within the building superstructure associated with these movements, in accordance with the assessment methodology described by Mair et al [4]. This strain is used to determine the damage category based on the classification system proposed by Burland[6] and in accordance with LU Civil Engineering - Common Requirements S1050[2]. The categories are presented in Table 2.

Damage category	Description of degree of damage	Description of typical damage and likely forms of repair for typical masonry buildings.	Approx. crack width (mm)	Max. tensile strain %
0	Negligible	Hairline cracks.		< 0.05
1	Very slight	Fine cracks easily treated during normal redecoration. Perhaps isolated slight fracture in building. Cracks in exterior visible upon close inspection.	0.1 to 1.0	0.05 to 0.075
2	Slight	Cracks easily filled. Redecoration probably required. Several slight fractures inside building. Exterior cracks visible; some repainting may be required for weather-tightness. Doors and windows may stick slightly.	1 to 5	0.075 to 0.15
3	Moderate	Cracks may require cutting out and patching. Recurrent cracks can be masked by suitable linings. Tuck pointing and possible replacement of a small amount of exterior brickwork may be required. Doors and windows sticking. Utility services may be interrupted. Weather tightness often impaired.	5 to 15 or a number of cracks ≥ 3	0.15 to 0.3
4	Severe	Extensive repair required involving removal and replacement of walls especially over doors and windows. Window and door frames distorted. Floor slopes noticeably. Walls lean or bulge noticeably. Some loss of bearing in beams. Utility services disrupted.	15 to 25 but also depends on number of cracks	> 0.3
5	Very severe	Major repair required involving partial or complete reconstruction. Beams lose bearing, walls lean badly and require shoring. Windows broken by distortion. Danger of instability.	Usually > 25 but depends on number of cracks	
Note: Please refer LU Civil Engineering - Common Requirements S1050[2].				

Table 2: Building damage classification

4 Input Data

The magnitude and distribution of ground movements and degree of building damage is calculated based on the following input data:

- The Xdisp model coordinates and levels are based on the 3D model (20130212DSPITT Scheme R09);
- Four construction stages are considered in accordance with the proposed programme (November 2013) as illustrated in Figure 1;
- Trough width parameter constant, K=0.5 is used in accordance with WI2300[1]

The input data for the building, tunnels and shaft excavation are summarised in Table 3, Table 4 and Table 5 respectively.

Location	Foundation level (mATD)	Building Height above foundation level (m)	E/G
15 Abchurch Lane	107.4*	26.2	12.5
Note: Where E / G is the ratio of Young's modulus to shear modulus of the deep beam that is to represent the building. * Assumed level, 1.5m thick slab beneath floor level.			

Table 3: Building data

Tunnel Item	Level of axis (mATD)	External diameter (m)	Volume Loss (%)
Running tunnels	83.5	5.4	1.5
Square works adits	75.8 to 95.3	4.1 to 7.8	2.5
Platform enlargement	85.6	9.64	1.5
Escalator barrels	Inclined	8.3 to 8.4	1.5
Central Line Connection	Inclined (87.6 to 89.2)	8.6	1.5

Table 4: Tunnel data

Excavation	Excavation Base Level (mATD)
Grout Shaft at King William Street	97
Whole Block Scheme Box excavation	73
Arthur Street Shaft	81

Table 5: Excavation data

The eastern side of the building on Abchurch Lane is located close to the ticket hall lift shaft excavation (~15m).

Sewer 05BS is located below Abchurch lane, which is a brick structure with an invert level of ~99.9mATD and will be close to the WBS excavation and well above the crown level of the new tunnel.

The Xdisp models used to undertake this assessment are:

- A13- Stage 4
- A13- Stage 3
- A13- Stage 2
- A13- Stage 1

5 Results

5.1 Engineering Assessment

The sections through the building which have been analysed are shown on plan in Figure 3.

Assessment has been undertaken at three intermediate construction stages and at the end of construction when all major elements of the works including shaft and tunnels have been completed. The damage category assigned to the building is based on the construction stage at which the potential impact on the building is most severe.

The maximum settlement and maximum strain calculated for each of the analysis sections at the most onerous intermediate construction stage and at the end of construction are presented in Table 6 and Table 7.

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
A13 (line 1)	45	0.015
A13 (line 2)	45	0.004
A13 (line 3)	42	0.037
Note: Line 3 represents two buildings. The strains are not therefore applicable to building A13		

Table 6: Building response at most onerous intermediate stage - Construction Stage 2

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
A13 (line 1)	60	0.004
A13 (line 2)	52	0.005
A13 (line 3)	55	0.048
Note: Line 3 represents two buildings. The strains are not therefore applicable to building A13		

Table 7: Building response at end of construction stage

The results of the assessment show that the intermediate construction Stage 2 is the critical stage for this building where line 1 experiences the most onerous combined tensile strain. The orientation is shown in Figure 3. The vertical and horizontal Greenfield ground movements along the section of the building are shown in Figure 4. The relative position of the building and tunnels along section (line 1) is shown in

Figure 5. The junction with the adjoining building (A14) is in sagging mode but the curvature is small. Separation between the two buildings is not anticipated. The calculated strains are summarised in Table 8.

Line #	Strains in section (Curvature)	Position from start (m)	Length (m)	Average* Horizontal Strain (%)	Maximum Tensile Strains (%)	Damage Category
(line 1) (Stage 2)	Sagging	0.0	13.8	-0.042	0.015	Negligible
(line 2) (Stage 4)	Sagging	0.0	17.6	-0.13	0.005	Negligible
	Sagging	17.9	2.5	0.002	0.002	Negligible
(line 3) (Stage 4)	Sagging	0.0	11.7	-0.021	0.006	Negligible
	Hogging	11.8	20.2	0.030	0.048	Negligible
Note: * Tensile horizontal strains are +ve. Compressive horizontal strains are –ve.						

Table 8: Section analysed, results for worst case tensile strain

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0 for 15 Abchurch Lane (A13). This corresponds to Negligible damage in accordance with Table 2.

A13 (line 2) shows the movements for the adjoining wall between 15 Abchurch Lane (A13) and St Mary Abchurch (A14), see Figure 5. The displacement line between the bell tower and A13-A14 is in a sagging mode. The tensile strains are very small (Negligible) as shown in Table 8.

A13 (line 3) examines the differential movements between 15 Abchurch Lane (A13) and St Mary Abchurch (A14). It is a simplified line that represents both building's rear façades. The results along (line 3) can be seen in Figure 6 and show that the area between A13 and the bell tower is in a hogging mode. These movements, given the unknown foundation level of the bell tower and the existing condition of the building, could induce cracking at high level. The maximum tensile strains in this area result in a very slight damage category. Similarly, it is likely cracks could occur on the joints between the bell tower and the adjacent building A14. The settlement trough at the critical construction stage is shown diagrammatically in Figure 6.

The maximum settlement of the building at foundation level occurs at the end of construction and is 57mm.

5.2 Heritage and Structural Assessment

Following site inspection, assessment has been made using the following scoring methodology set out in Table 9.

Score	STRUCTURE Sensitivity of the structure to ground movements and interaction with adjacent buildings	HERITAGE FEATURES Sensitivity to calculated movement of particular features within the building	CONDITION Factors which may affect the sensitivity of structural or heritage features
0	Masonry buildings with lime mortar and regular openings, not abutted by other buildings, and therefore similar to the buildings on which the original Burland assessment was based.	No particular sensitive features	Good/Fair - not affecting the sensitivity of structural or heritage features
1	Buildings not complying with categories 0 or 2, but still with some sensitive structural features in the zone of settlement e.g.: cantilever stone staircases, long walls without joints or openings, existing cracks where further movements are likely to concentrate, mixed foundations	Brittle finishes, e.g. faience or tight-jointed stonework, which are susceptible to small structural movements and difficult to repair invisibly.	Poor - may change the behaviour of a building in cases of movement. Poor condition of heritage features and finishes. Evidence of previous movement.
2	Buildings which, by their structural form, will tend to concentrate all their movements in one location (e.g.: a long wall without joints and with a single opening).	Finishes which if damaged will have a significant effect on the heritage value of the building, e.g. Delicate frescos, ornate plasterwork ceilings.	Very poor – parlous condition of heritage features and finishes, severe existing damage to structure including evidence of ongoing movement. Essentially buildings where even very small movements could lead to significant damage.

Table 9: Heritage and structural scoring methodology

The results of the heritage assessment carried out for the building are summarised in Table 10.

SENSITIVITY OF THE STRUCTURE

The structure appears to be generally steel framed with some masonry load-bearing elements, in particular to the rear where the mansard elements set back as the building rises. Perimeter retaining walls enclose the two basement levels and are most likely to be mass concrete. Construction of the floors is unknown but the staircases appear to be reinforced concrete therefore it is likely that the floors are similarly constructed in concrete, possibly filler joist. While the rear elevation is red brick and Portland stone for the lower storey, the upper levels are white glazed brickwork, similar the all of the light wells, with the front elevation on Abchurch Lane faced with Portland stone. Foundations construction is unknown, but it is most likely to be formed from a structural steel grillage and concrete raft.

It would appear that there is no party wall between the building and St Mary Abchurch to the south, but separate walls, which can be seen from both the rear at street level and from the church roof, where the building abuts the church bell tower. A clear gap can be seen between the buildings in both of these locations, although it is probable that they both share a common foundation resulting from the formation of the later basement construction for 15 Abchurch Lane. Variable settlement across the two buildings is likely to cause differential movement between the two, effecting opening up of the junctions, water ingress, and general damage to structures.

A similar situation could be possible at the juncture with 5 King William Street to the north, with similar damage occurring, in particular to the facing stonework of both buildings.

Score: 1 - While the building should tend to move as a whole if on a grillage raft foundation, therefore not setting up internal strains frim differential elemental movements, the main concern should be damage caused by differential movements between 15 Abchurch Lane and its adjoining properties.

SENSITIVITY OF THE HERITAGE

Externally the Abchurch Lane façade is a successful combination of classical and modern detailing. A series of large segmented arched windows are similar to those found on the neighbouring St. Mary Abchurch with glazing designed in an early modern style. Masonry corbels, keystones and aprons are decorated with baroque style relief carving, also reflecting the design of the historically significant Grinling Gibbons reredos in St. Mary Abchurch. The design quality of Abchurch Lane façade which compliments the architecture of St. Mary Abchurch is an important element of the aesthetic and architectural significance of the building. The Joints between masonry blocks are between 3mm and 5mm and therefore susceptible to damage resulting from structural movement.

Internally there is extensive use of hard-wood wainscoting in all function rooms and communal areas, as well as high quality unpainted and moulded joinery utilised in window frames, doors and door surrounds. This use of hard-wood and its design is typical of the early 20th century, contributing to the aesthetic significance of interior and functional significance of the building as a members club. All of the ceilings are formed of coved and moulded plaster, including a segmental arched ceiling in the 4th floor boardroom. A reinforced concrete staircase rises from ground to 4th floor.

Score: 1 - The English Heritage listing description indicates that the building was designated due the quality of its external fabric and the contribution this makes to the character of Abchurch Lane and setting of other buildings. Damage to the exterior form and decoration therefore will undermine the heritage significance of the building. Damage to the internal features of the building, many of which are original and still in use as the building designed, will also adversely impact the significance of the building, but to a lesser degree. The north-east corner of the building, in which is located the club's member and function rooms, is predicted to be subject to the greatest amount of settlement which may result in damage to high quality internal finishes.
SENSITIVITY OF THE CONDITION
Generally the building is in good condition, being regularly maintained and redecorated. Examination of the exterior identified minor cracking to window cills and more significantly, vertical cracking running the full height of the Abchurch Lane façade at the northern external corner of the projecting entrance porch. At high level an area of masonry in this area appears to have moved outwards indicating some previous rotational force. This could be caused by rust-jacking of iron cramps. Internally the stone mosaic and terrazzo decorated landings are cracked indicating minor movement but is not cause for concern. The condition of timber joinery and chimney pieces is very good with no signs of previous damage due to movement. Plaster ceilings have been over painted many times and therefore the detailing is heavily clogged but no obvious areas of deformation were observed.
Score: 1 - The building is generally in good condition. However the condition of some areas of the Abchurch Lane façade is poor due to the cracking and movement already apparent. This may exacerbate the heritage sensitivities of the façade, and the high predicted settlement could cause further damage.

Table 10: Heritage and structural assessment

5.3 Total Score

The total score is the summation of the damage category, structural sensitivity, heritage sensitivity and condition sensitivity scores:

The damage category is 0

The structural sensitivity score is 1

The heritage sensitivity score is 1

The condition sensitivity score is 1

The total score for this building is 3

6 Conclusion

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0 for 15 Abchurch Lane. However, specific heritage and structural assessment taking into account the location and extent of settlement and tensile strains highlights that the building has particular sensitivities related to its façade and connections with St Mary Abchurch (A14). In addition, potential sensitivities due to poor condition have been identified. This assessment has determined that the building has a total score of 3 including a score of 1 for condition.

According to the methodology presented within LU Standard S1050, which does not take in to account condition scoring, a Stage 3 assessment is not required. However, considering the structural relationship of the building with St.Mary Abchurch, a Stage 3 assessment is recommended.

The BSCU Environmental Statement considers the mitigation that could be needed.

7 References

[1] LU Works Information WI 2300 Ground Movement version 3, 19-07-13.

[2] LU Category 1 Standard: S1050 Civil Engineering - Common Requirements, Issue No. A7, Nov. 2013.

[3] Mair R J, Taylor R N and Bracegirdle A (1993). Subsurface settlement profiles above tunnels in clays. Géotechnique 43, No. 2, pp. 315-320.

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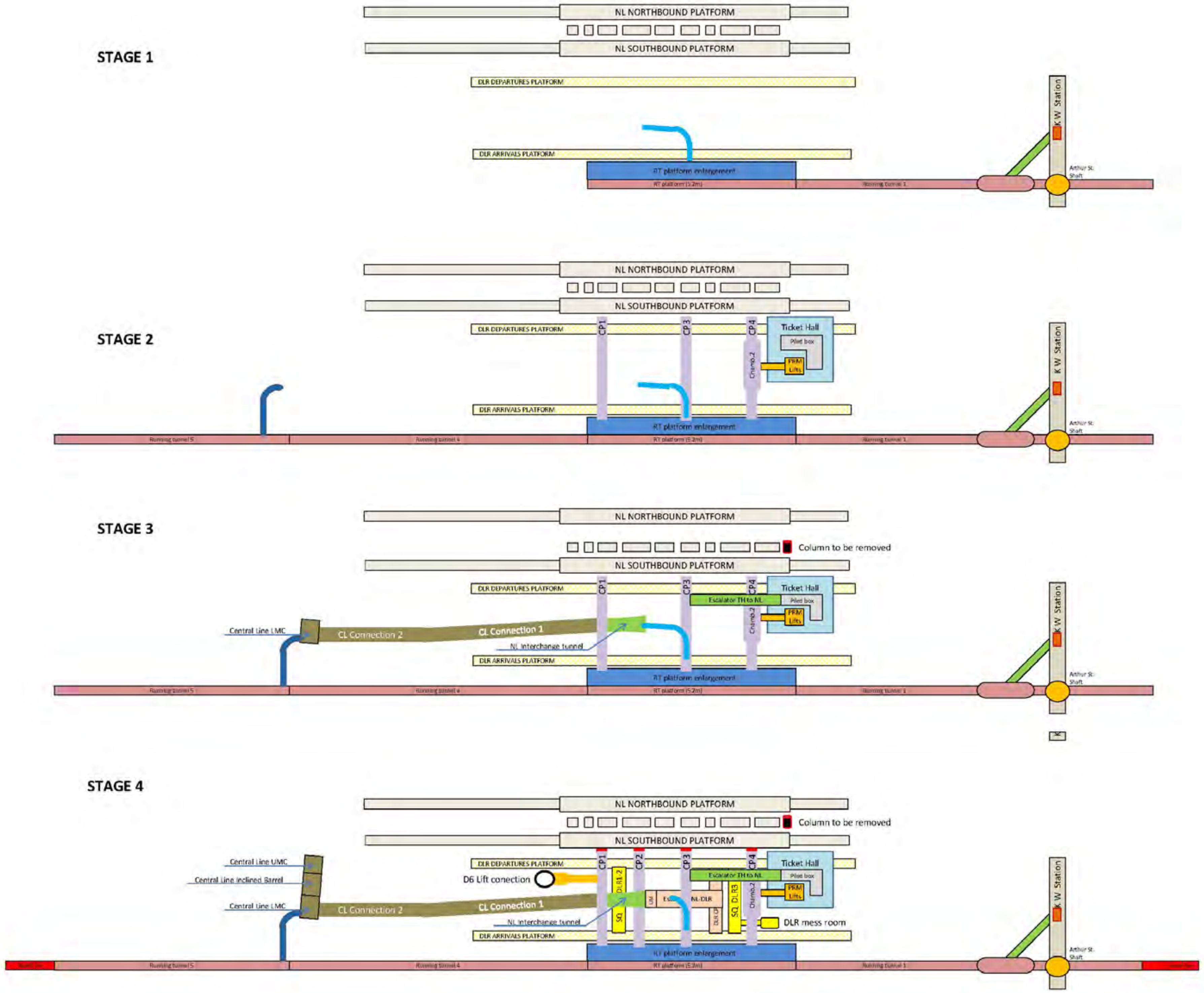
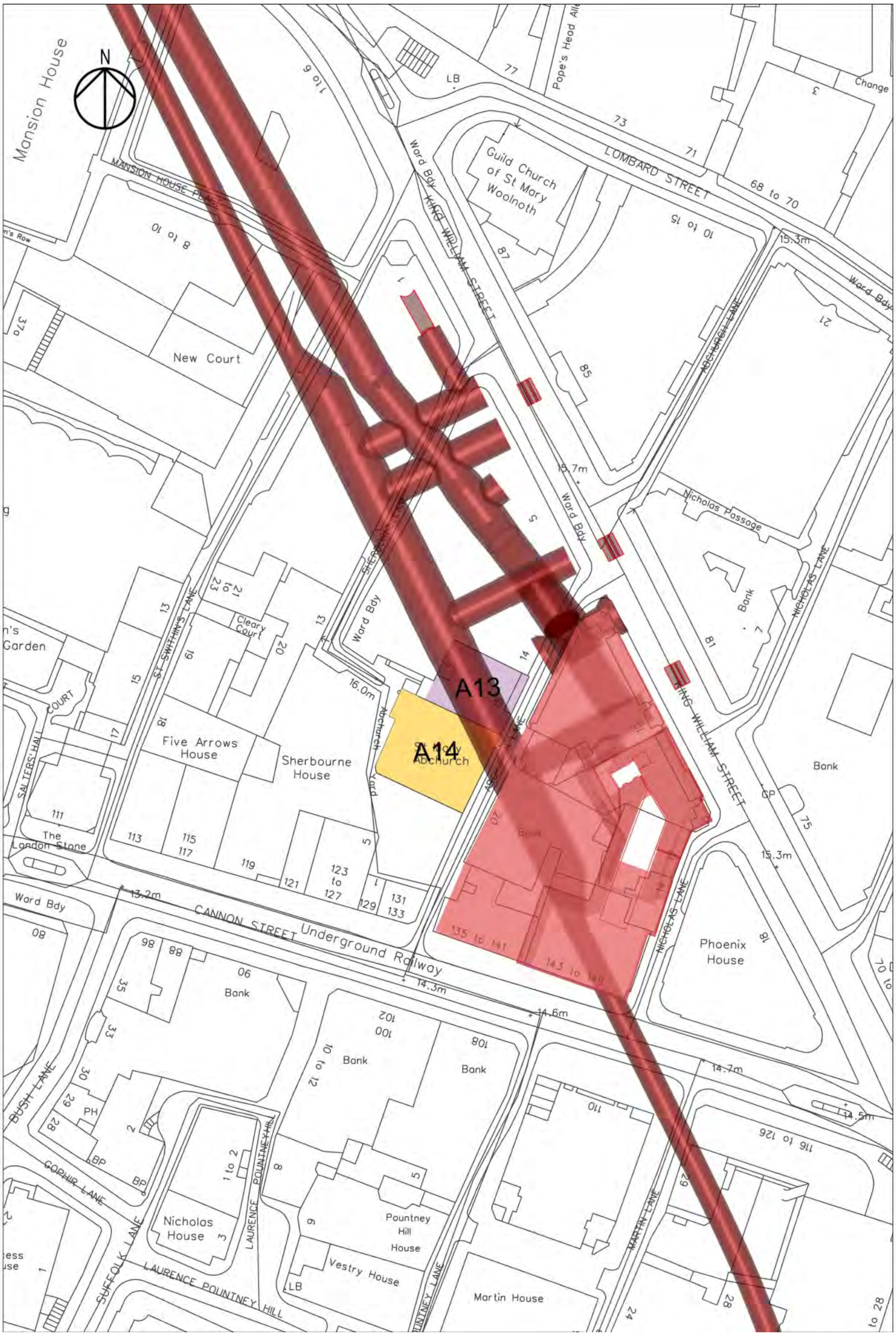


Figure 1: Construction Stage model



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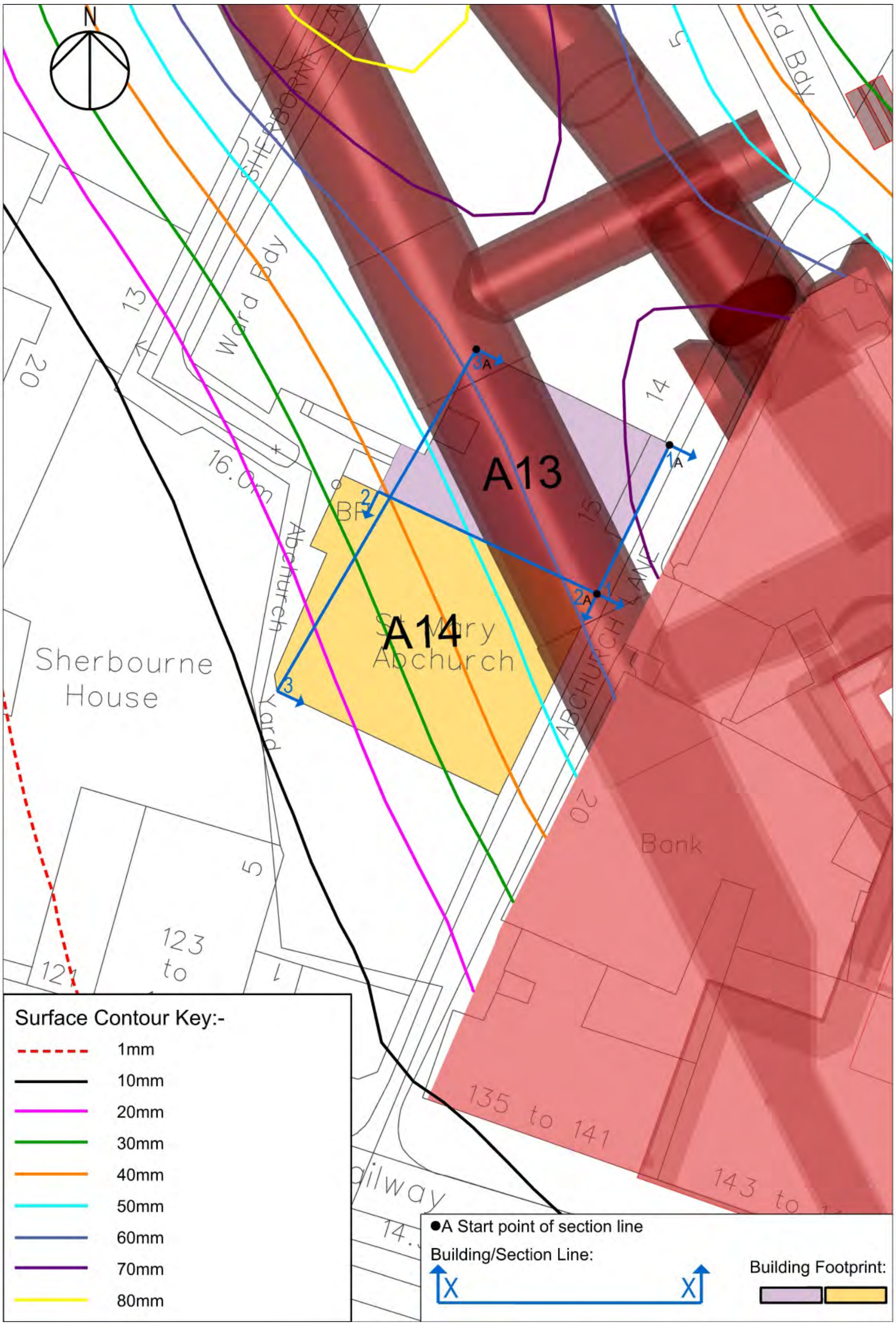

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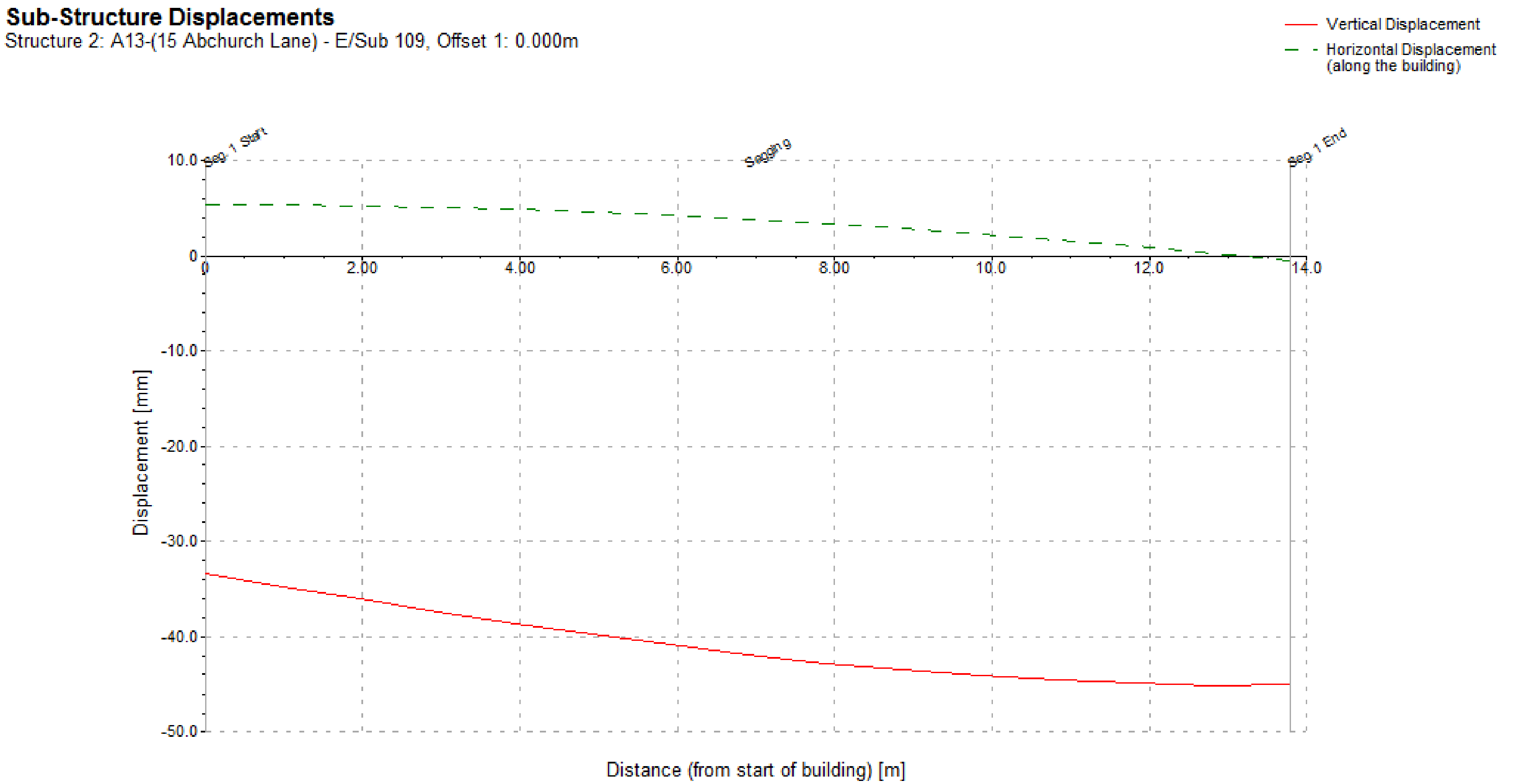
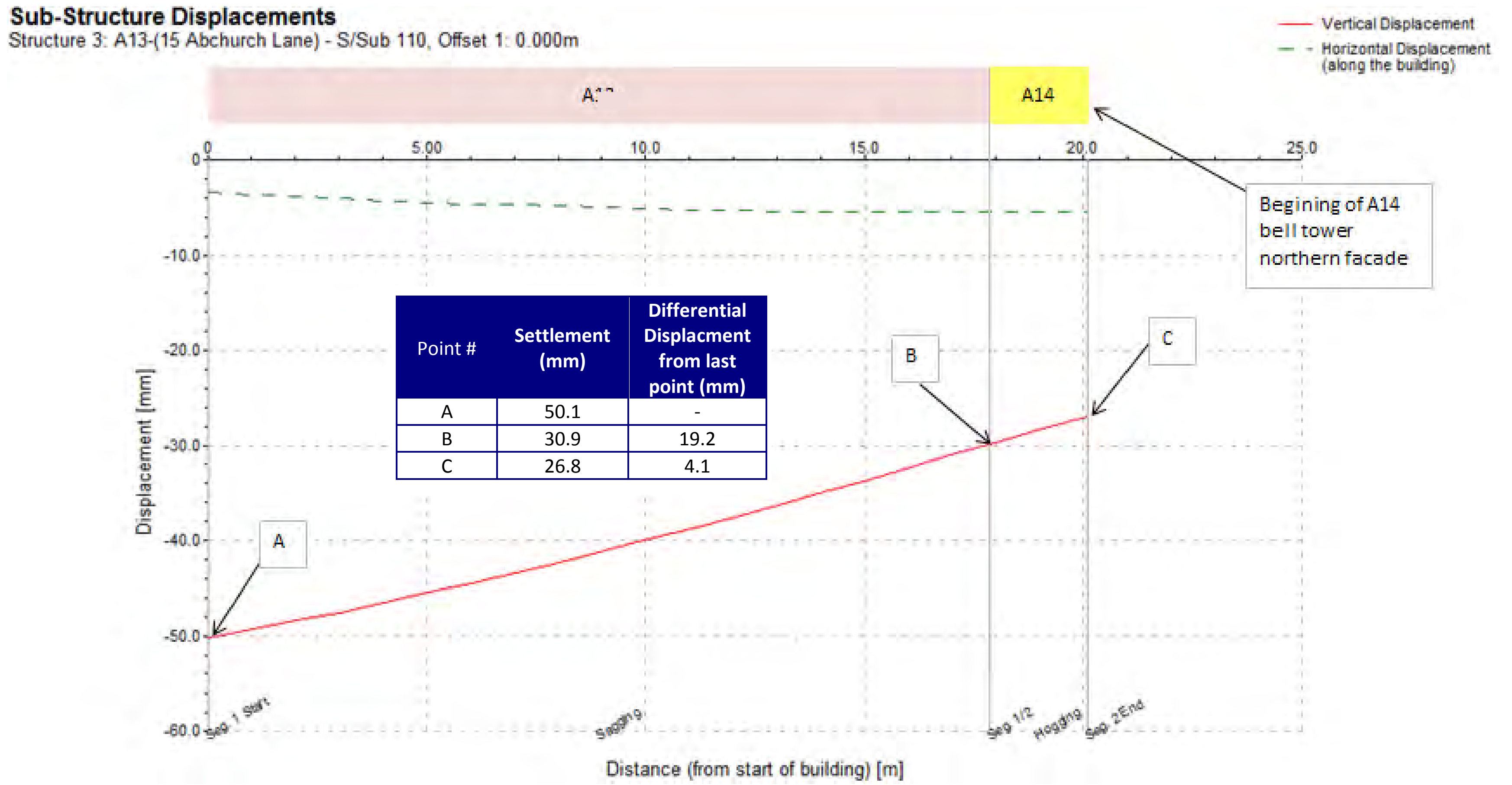
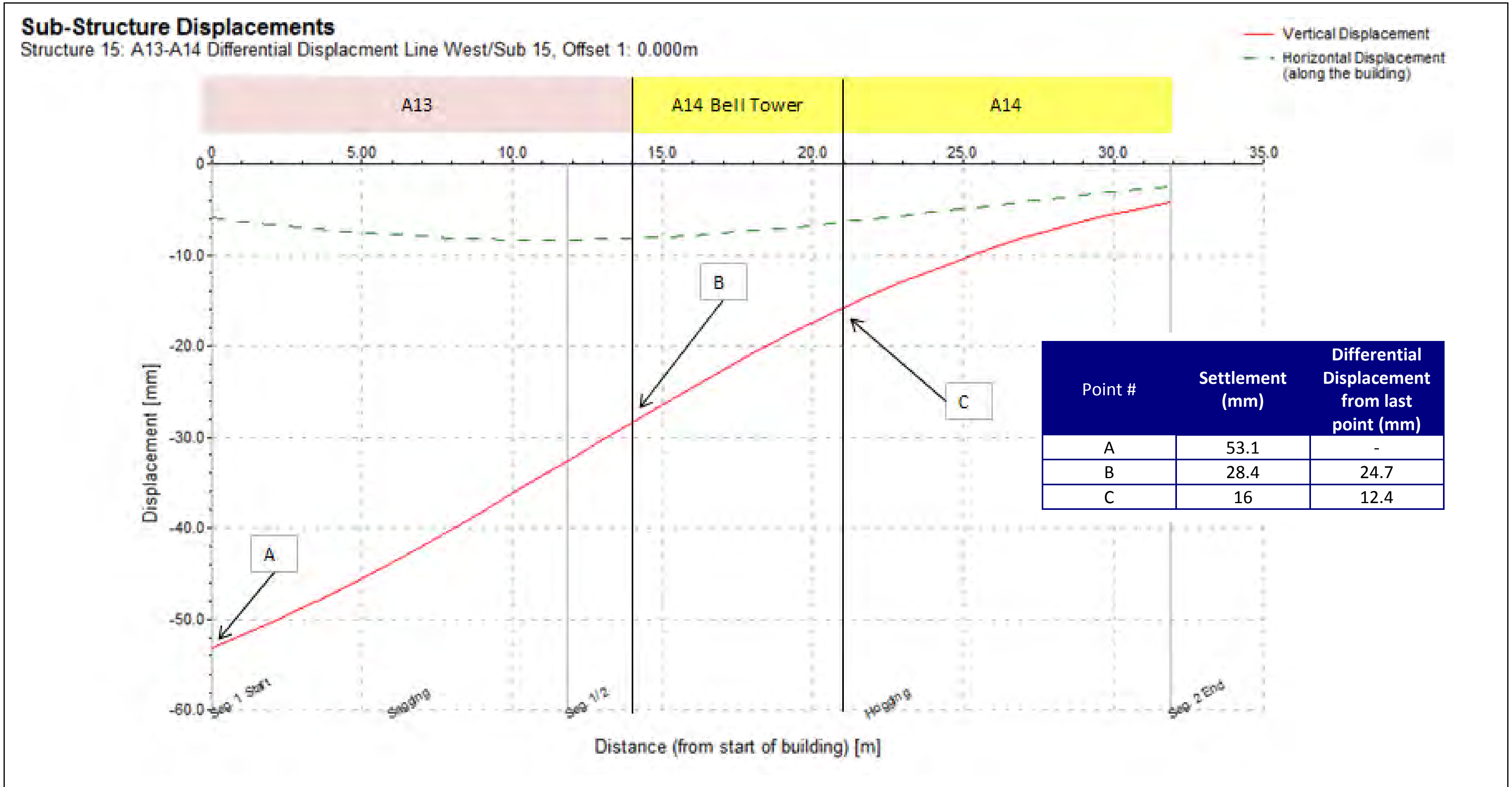


Figure 4: Building displacement at founding level of (line 1) at stage 2 of worst case for tensile strains



Point #	Settlement (mm)	Differential Displacment from last point (mm)
A	50.1	-
B	30.9	19.2
C	26.8	4.1

Figure 5: Building displacement at founding level of (line 2) at stage (4)of worst case for tensile strains



Point #	Settlement (mm)	Differential Displacement from last point (mm)
A	53.1	-
B	28.4	24.7
C	16	12.4

Figure 6: Building displacement at founding level of (line 3) at stage 4 of worst case for tensile strains

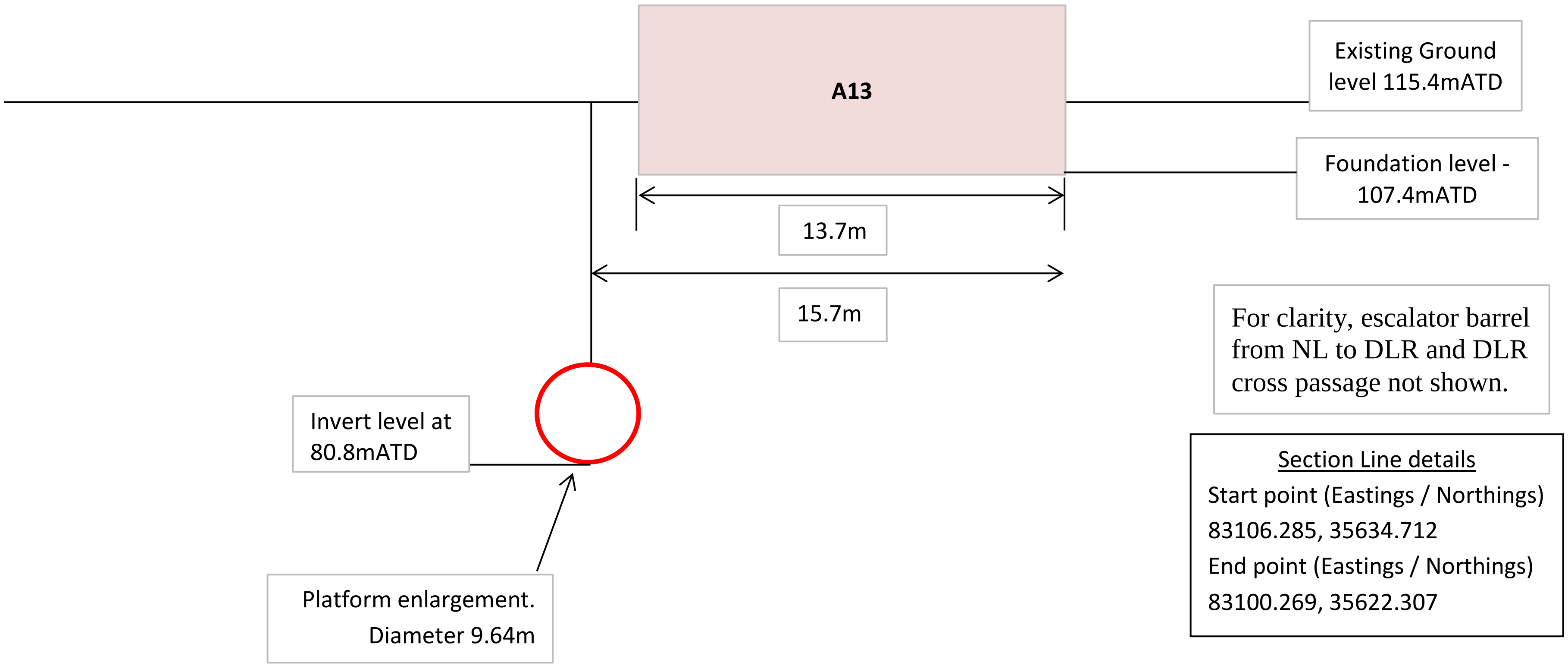


Figure 7: Diagrammatic cross-section of section (line 1) relative to tunnel position

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Bank Station Capacity Upgrade

Building Damage Assessment Report

Building A14

St. Mary Abchurch

URS-8798-RPT-G-001178

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Company:	URS
Role:	Designer

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The purpose of the assessment is to determine the potential effect the works will have on the building. This report describes the updated engineering assessments undertaken for the building and concludes whether mitigation is likely to be needed and if a further (Stage 3) assessment is recommended in order to verify this.

2 The Building

2.1 General Information

St Mary Abchurch (Grade I listed) is a red brick building with stone quoins and dressings[7-8]. It has a tower, with 4 levels, in its north western corner. The Nave of the church is approximately 23m by 18m and of a maximum height of 13m (from floor of Nave to point of domed roof). The bell tower is approximately 6.5m square in plan and a maximum height of approximately 32.4m (from ground level to eaves level of tower); the bell has been removed. There is some continuity between the nave and the bell tower[8]. The present church was constructed between1681-1686 on the site of the previous medieval church which was destroyed in the Great Fire of London 1666. The present church suffered significant damage during a bombing raid in WWII. As a result the church underwent comprehensive refurbishments in the 1960's[8].

The ground level at the church has been taken as 115.6mATD based upon SES Ltd survey drawing[9]. Foundation level is assumed as 110.8mATD, this is considered representative of the varying footing levels revealed around the building. The highest is at approximately 114.2mATD, the lowest at 108mATD [11]. [0].

General building information for A14 used in the assessment has been acquired as part of the structural desktop appraisal. This information is presented in Table 1.

Category	Building Information
BSCU Reference	A14
Location	St. Mary Abchurch
Address	St. Mary Abchurch, Abchurch Lane
Building Type	Load bearing masonry
Construction Age	1681 – 1686
No. of Storeys	N/A
Basements	1
Level (mATD)	Nave 125.9, Spire 148.0
Foundation Type	Vaults and strip footings (assumed)
Ground Level (mATD)	115.6
Listed Grade	I
Note: Levels given refer to metres above Tunnel Datum, mATD. Tunnel Datum is 100m below Ordnance Survey Datum at Newlyn	

Table 1: General building information

A general view of the building exterior is shown in Plate 1. A location plan showing the building in relation to the proposed BSCU works is presented in Figure 2.

Plate 1: General view from Abchurch Yard

2.2 Building Description

Following partial destruction in the Great Fire, St Mary Abchurch was rebuilt in between 1681 and 1686 to the design of Sir Christopher Wren.

The church is constructed from simple loadbearing brick and rubble filled walls with stone quoins and reveals to the window and door openings, as embellishment to the overall appearance. The general structural form is a tall single storey rectangular building with a scissor trussed timber roof and slated finishes housing the internal decorative dome, and a timber flat roof over the organ loft. To the north-west corner is a tall square bell tower with domed lead roof and spire, integrated into the main plan area of the church. There is a small parish room and external doorway adjoining the north elevation of the bell tower, although it is actually sited within a section of the rear of an adjoining property in 15 Abchurch Lane. Beneath the ground floor of the main church are two small vaulted cellars/crypts, constructed from a mix of brick and stone, having restricted access. One of these crypts extends beneath the courtyard to the immediate south of the building.

The south and east facades are three bays wide with two semi-circular headed windows with circular lights above, flanking a central tall segmental headed window.

The church is accessed via a doorway in the western end of the south elevation. The west façade faces onto Sherbourne Lane and includes an entrance to the Parish Room, also accessed from within the church but which is structurally part of the neighbouring 15 Abchurch Lane. There is no north façade as the building is adjoins15 Abchurch Lane although the nature of the connection between the two buildings is unclear.

Internally the church consists of a square nave with chancel and altar raised on a dias. A small Parish Room, of later date to the main church, is accessed via a doorway in the north-west corner. Also in the north-west corner is access to the tower, rising above a domed antechamber. A small gallery and organ loft are in the south west corner, accessed by a separate staircase. A vestry room is located at the west end of the church, underneath the organ. The roof structure is a complex design utilising a combination of primary timbers supported on the external walls itself supporting a secondary timber frame which forms the support for the painted plaster dome. Windows are filled with clear glazing (with the exception of one or two coloured panels). It is thought that all the original glazing was lost during WWII when the church was seriously damaged by bombing, if not before.

3 Methodology

This assessment is undertaken in accordance with LU Works Information WI2300[1] and LU Category 1 Standard S1050 Civil Engineering - Common Requirements [2].

The analysis methodology applies to ground-bearing buildings which will be affected by ground movements resulting from the construction of the BSCU. The engineering assessment calculates the potential impact of ground movements and assigns a damage category to the building based on a numeric scale. Additionally, for listed buildings, a heritage assessment is carried out which considers the sensitivity of the structure and the sensitivity of its particular features; a heritage sensitivity score is assigned. The heritage sensitivity score is added to the damage category to obtain the total score. If the total is 3 or more a more detailed Stage 3 assessment is triggered.

In order to investigate the relative movements between this building and the neighbour to the east, The Capital Club (A13), a displacement line (line 2) was drawn along the shared facades as shown in Figure 3, which was analysed at A14's founding level. This not strictly accurate since building A13 is founded approximately 3.4m below A14.

The behaviour along the adjoining building line was investigated along displacement line 3. The results are shown in Table 6 and Table 7.

The response of the bell tower to the anticipated excavation induced ground movements was considered in line 4. A survey review[9,10] of its foundation suggested that the structure is separate from the nave of the church. However, due to the lack of information on the foundations of the bell tower, it has been assumed that the founding level is the same as that of the nave (110.8mATD). The results of the analysis carried out on the bell tower are shown in Table 6 and Table 7.

Oasys Xdisp is used to analyse the Greenfield ground movements in terms of settlement and horizontal displacement. Subsurface tunnelling induced ground movement profiles are determined in accordance with the methodology described by Mair et al[3 & 4].

Historical information[8] suggests an excavation for the basement beneath Sherbourne House occurred in the early 1980s and that consequently the bell tower appears to tilt towards Sherbourne House. The ground movements analysis does not incorporate this in the assessment and/or the impact from this historical damage.

The building is within close proximity to the Whole Block Scheme (WBS) excavation. The excavation induced movements have been considered and calculated using LUL Guidance Document G0058[5].

The building is modelled as a simple elastic beam which is conservatively assumed to follow the Greenfield ground displacements. The beam is divided into hogging and sagging segments. The tensile strains within each segment are calculated based on the distortion associated with differential settlement (which is characterised by deflection ratio) and the distortion associated with differential horizontal displacement (characterised by horizontal strain).

Xdisp provides a method for calculating the maximum tensile strain within the building superstructure associated with these movements, in accordance with the assessment methodology described by Mair et al[4]. This strain is used to determine the damage category for traditional masonry structures based on the classification system proposed by Burland[1] and in accordance with S1050 Civil Engineering Standards. The categories are presented in Table 2.

Damage category	Description of degree of damage	Description of typical damage and likely forms of repair for typical masonry buildings.	Approx. crack width (mm)	Max. tensile strain %
0	Negligible	Hairline cracks.		< 0.05
1	Very slight	Fine cracks easily treated during normal redecoration. Perhaps isolated slight fracture in building. Cracks in exterior visible upon close inspection.	0.1 to 1.0	0.05 to 0.075
2	Slight	Cracks easily filled. Redecoration probably required. Several slight fractures inside building. Exterior cracks visible; some repainting may be required for weather-tightness. Doors and windows may stick slightly.	1 to 5	0.075 to 0.15
3	Moderate	Cracks may require cutting out and patching. Recurrent cracks can be masked by suitable linings. Tuck pointing and possible replacement of a small amount of exterior brickwork may be required. Doors and windows sticking. Utility services may be interrupted. Weather tightness often impaired.	5 to 15 or a number of cracks > 3	0.15 to 0.3
4	Severe	Extensive repair required involving removal and replacement of walls especially over doors and windows. Window and door frames distorted. Floor slopes noticeably. Walls lean or bulge noticeably. Some loss of bearing in beams. Utility services disrupted.	15 to 25 but also depends on number of cracks	> 0.3
5	Very severe	Major repair required involving partial or complete reconstruction. Beams lose bearing, walls lean badly and require shoring. Windows broken by distortion. Danger of instability.	Usually > 25 but depends on number of cracks	
Note: Please refer to LU S1050 Civil Engineering - Common Requirements[2]				

Table 2: Building damage classification

4 Input Data

The magnitude and distribution of ground movements and degree of building damage is calculated based on the following input data:

- The Xdisp model coordinates and levels are based on the 3D model (20130212DSPITT Scheme R09);
- Four construction stages are considered in accordance with the proposed programme (November 2013) as illustrated in Figure 1;
- Trough width parameter, K=0.5 is used in accordance with WI2300.

The input data for the building, tunnels and shaft excavations are summarised in Table 3, Table 4 and Table 5 respectively.

Location	Foundation level (mATD)	Building Height above foundation level (m)	E / G
St Mary Abchurch	110.8*	15.0	2.6
Bell Tower	110.8*	37.2	2.6
Note: Where E / G is the ratio of Young's modulus to shear modulus of the deep beam that is to represent the building.			

Table 3: Building data

Tunnel Item	Level of axis (mATD)	External diameter (m)	Volume Loss (%)
Running tunnels	83.5	5.4	1.5
Square works adits	75.8 to 95.3	4.1 to 7.8	2.5
Platform enlargement	85.6	7.4 to 11.2	1.5
Escalator barrels	Inclined	8.3 to 8.4	1.5
Central Line Connection	Inclined (87.6 to 89.2)	8.6	1.5

Table 4: Tunnel data

Excavation	Excavation Base Level (mATD)
Grout Shaft at King William Street	97
Whole Block Scheme Box excavation	73
Arthur Street Shaft	81

Table 5: Excavation data

The distance of building St. Mary Abchurch (A14) relative to the construction of Arthur Street shaft listed in Table 5 is sufficiently large that this building should not be affected by its construction.

The Xdisp models used to undertake this assessment are:

- A14- Stage 4
- A14- Stage 3
- A14- Stage 2
- A14- Stage 1

5 Results

5.1 Engineering Assessment

The sections through the building which have been analysed are shown on plan in Figure 3.

Assessment has been undertaken at three intermediate construction stages and at the end of construction when all major elements of the works including shaft and tunnels have been completed. The damage category assigned to the building is based on the construction stage at which the potential impact on the building is most severe.

The maximum settlement, and maximum tensile strain calculated for each of the analysis sections at the most onerous intermediate construction stage and at the end of construction are presented in Table 6 and Table 7. However it should be noted that the Stage 2 results are very close to those of Stage 3.

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
A14 (Line 1)	15	0.026
Extended A14 (Line 2)	43	0.031
A14 (Line 3)	44	0.003
Bell Tower (Line 4)	21	0.017
A14 (Line 5)	44	0.008

Table 6: Building response at most onerous intermediate stage - Construction Stage 3

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
A14 (line 1)	16	0.032
A14 (line 2)	51	0.040
A14 (line 3)	48	0.004
Bell Tower (line 4)	23	0.025
A14 (line 5)	48	0.011

Table 7: Building response at end of construction - Construction Stage 4

The results of the assessment show construction Stage 4 is the critical one for this building where A14 line 1 experiences the most onerous combined tensile strain. The orientation of the displacement line is shown in Figure 3. The vertical and horizontal ground movements along this section of the building are shown in Figure 4. The calculated strains are summarised in Table 8.

A14 line 2 examines the differential displacements between St Mary Abchurch (A14) and 15 Abchurch Lane (A13). It is a simplified line that represents both building's rear façades. The results along line 2 can be seen in Figure 5 and show that the area between A14 and the bell tower is in a hogging mode. These movements, given the unknown foundation level of the bell tower and the existing condition of the building, could induce cracking at high level. Similarly, it is likely cracks could occur on the joints between the bell tower and the adjacent building A13. Since this is close to the point of contraflexure the crack widths would be less.

A14 line 3 shows the movements for the wall between St Mary Abchurch (A14) and 15 Abchurch Lane (A13), see Figure 6. The displacement line between the bell tower and A14-A13 is in a sagging mode. The tensile strains are very small (Negligible) as shown in Table 8.

A14 line 4 shows the movements for the north-west façade of the bell tower, Figure 7. Tensile strains are in the Negligible damage category.

A14 (line 3 and 5) shows the façade that undergoes maximum vertical settlement of 48mm at end of construction, Figure 8. This is located directed above the tunnel at the junction between St Mary Abchurch and the Capital Club. The local tensile strains are within the Negligible damage category.

The relative position of the building and tunnels along section line 1 is shown in Figure 9.

Line #	Strains in section (Curvature)	Position from start (m)	Length (m)	Average* Horizontal Strain (%)	Maximum Tensile Strains (%)	Damage Category
(Line1)	Hogging	0.0	11.0	0.027	0.032	Negligible
(Line 2)	Hogging	0.0	20	0.026	0.040**	Negligible
	Sagging	20	11.9	-0.018	0.005	Negligible
(Line 3)	Hogging	0.0	5.7	0.003	0.004	Negligible
	Sagging	5.5	17.7	-0.012	0.004	Negligible
(Line 4)	Hogging	0.0	6.5	0.025	0.025	Negligible
(Line 5)	Sagging	0.0	14.4	-0.021	0.006	Negligible
	Hogging	14.4	4.3	0.011	0.011	Negligible

Note: * Tensile horizontal strains are +ve. Compressive horizontal strains are –ve.
** (Line 2) is across two buildings and is not therefore representative of the building

Table 8: Sections analysed, results for worst case tensile strain

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0 for St Marys Abchurch (A14). This corresponds to Negligible damage in accordance with Table 2.

5.2 Heritage and Structural Assessment

Following site inspection, assessment has been made using the scoring methodology set out in Table 9.

Score	Structure (Sensitivity of the structure to ground movements and interaction with adjacent buildings)	Heritage features (Sensitivity to calculated movement of particular features within the building)	Condition (Factors which may affect the sensitivity of structural or heritage features)
0	Masonry buildings with lime mortar and regular openings, not abutted by other buildings, and therefore similar to the buildings on which the original Burland assessment was based.	No particular sensitive features	Good/Fair - not affecting the sensitivity of structural or heritage features
1	Buildings not complying with categories 0 or 2, but still with some sensitive structural features in the zone of settlement e.g.: cantilever stone staircases, long walls without joints or openings, existing cracks where further movements are likely to concentrate, mixed foundations	Brittle finishes, e.g. faience or tight-jointed stonework, which are susceptible to small structural movements and difficult to repair invisibly.	Poor - may change the behaviour of a building in cases of movement. Poor condition of heritage features and finishes. Evidence of previous movement.
2	Buildings which, by their structural form, will tend to concentrate all their movements in one location (e.g.: a long wall without joints and with a single opening).	Finishes which if damaged will have a significant effect on the heritage value of the building, e.g. Delicate frescos, ornate plasterwork ceilings.	Very poor – parlous condition of heritage features and finishes, severe existing damage to structure including evidence of ongoing movement. Essentially buildings where even very small movements could lead to significant damage.

Table 9: Heritage and structural scoring methodology

The results of the heritage assessment carried out for the building are summarised in Table 10.

SENSITIVITY OF THE STRUCTURE
Foundations of the building are an unknown quantity but are likely to be spread brick or simply formed directly onto a compacted soil base. Levels of the foundations will be variable, and while the main body of the church and bell tower would probably have originally been consistent with one another, the crypt areas are lower. Construction of the adjoining building of 15 Abchurch Lane in 1914/15 included the formation of a deep double basement, and although having an apparent separate wall (not shared) would probably have initiated a form of underpinning to the north wall of the church and possible returns, extending the original church foundations to a much deeper level than the remaining church. Variable foundation depths and types will be more damage prone to ground movement than common level foundations, and differential movement and damage is very likely in the event of ground disturbance. The bell tower is mildly out of plumb and leans away from the church building towards the west. It appears to have moved as a single entity in that a gap has developed between the tower and 15 Abchurch Lane, getting wider as it rises in height. This would suggest some foundation settlement on the western side, probably resulting from the more recently constructed building facing the west wall of the church. While the movement appears not particularly recent, additional movement could be aggravated in the event of further ground settlement and disturbance. The parish room facing west is constructed within the rear of 15 Abchurch Lane and linked through into the church internally. There is clearly an additional wall adjoining the bell tower with coping stones leading up to a higher parapet level, which are showing a joint opening up at the abutment. Some dampness is apparent internally, suggesting water ingress at this junction. If foundations to both the bell tower wall and separating wall are not common, ground movement is likely to exacerbate this condition, leading to further opening of the joint and water ingress. Significant movement in the variable foundations leading to the opening up or formation of new brickwork cracking could cause disturbance to the timber roof structures, water ingress at bearing ends, and possible disturbance to the timber dome structure, which is hung from the main trussed roof structure. Damage to the walls would need to be relatively severe to cause this condition.
Score: 2 - The structural form and possible variable depths of foundations make the building particularly vulnerable to the predicted variable settlement and strains arising in the supporting walls across the building footprint
SENSITIVITY OF THE HERITAGE
Considered one of Wren's most important churches, St Mary Abchurch has been listed since 1950 in recognition of its association with Wren, its survival with limited alterations and interior containing many features of communal, architectural and artistic significance. The church presents a paired down classical exterior with little architectural emphasis beyond the window openings. The masonry dressings and carved keystones to the windows are finely jointed and will be vulnerable to the predicted differential settlements. Damage to these elements could undermine the architectural significance of the exterior. Given the simplicity of the exterior design, the internal treatment is unexpectedly rich in detail. Significant internal features that are likely to be sensitive to structural movement are the original wainscoting, the painted lime plaster dome, carved reredos by Grinling Gibbons and a number of richly carved stone monuments fixed onto the north and east walls. Although the interior was badly damaged during WWII and subsequently restored, the church fabric retains a high degree of unity and authenticity. Of primary concern is damage to the delicate interior decoration and furniture. Steep differential settlement and structural disturbance may cause heritage finishes, including wall monument fixings, carved reredos and the plaster dome, to fail in places.
Score: 2 –The building contains brittle and fragile surfaces which, if damaged or lost, will undermine the heritage value of the building. Sensitive elements of its exterior are in areas of steep differential settlement.

SENSITIVITY OF THE CONDITION
The church is in a condition expected given its age and history. There is evidence of structural movement both internally and externally. Historic monitoring of these cracks with tell-tales has suggested that this movement is not active. The walls in both the church and bell tower display a significant amount of cracking, particularly in locations weakened by window and door installations. Extensive cracking is evident throughout the bell tower and there are a large number of repairs in evidence, both historic and more recent. All of these cracked areas of masonry will be particularly vulnerable. There are also structural movement cracks internally at the apex of window reveals in the west elevation which have resulted in some limited damp ingress. In 2011 it has was reported that a section of the dome cornice had to be repaired. Cracks are also visible in the dome intrados indicating that it may be susceptible to damage caused by differential settlement. Furthermore, reports following inspection of the dome extrados indicates that the restoration of the dome following WWII bomb damage utilised a variety of materials that may perform differently in the event of settlement to the original lime plaster. Therefore it is likely that the current condition will be sensitive to the calculated settlement, and cause further damage to features and finishes.
Score: 1 - The church is a robust structure and in an adequate condition despite evidence of historic movement that are likely to be exacerbated by any differential movement caused by ground settlement. However, the condition of some historic finishes, especially the painted dome, is poor, and may exacerbate the sensitivity of the heritage. Due to the cracking and movement already apparent in the internal walls and dome surface, the predicted settlement may cause damage to heritage finishes, including decorative elements.

Table 10: Heritage and structural assessment

5.3 Total Score

The total score is the summation of the damage category, structural sensitivity, heritage sensitivity and condition sensitivity scores:

The damage category is 0

The structural sensitivity score is 2

The heritage sensitivity score is 2

The condition sensitivity score is 1

The total score for this building is 5

6 Conclusion

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0 for St Mary Abchurch. However, specific heritage and structural assessment taking into account the location and extent of settlement and tensile strains indicates that the building has a high level of structural and heritage sensitivity to movement. This assessment has determined that the building has a total score of 5.

It is recommended that a Stage 3 assessment is undertaken to further consider the potential damage to the structural form.

In particular, the Stage 3 assessment will examine the implications of previous movement and repairs, confirm areas of variable foundations, and further assess the behaviour of the rich and fragile finishes and structural elements.

The BSCU Environmental Statement considers the mitigation that could be needed, however, it is recommended that Stage 3 assessment is undertaken to verify how heritage finishes and features may respond and whether such mitigation is required.

7 References

[1] LU Works Information WI 2300 Ground Movement version 3, 19-07-13.

[2] LU Category 1 Standard: S1050 Civil Engineering - Common Requirements, Issue No. A7, Nov. 2013.

[3] Mair R J, Taylor R N and Bracegirdle A (1993). Subsurface settlement profiles above tunnels in clays. Géotechnique 43, No. 2, pp. 315-320.

[4] Mair R J, Taylor R N and Burland J B (1996). Prediction of ground movements and assessment of risk of building damage due to bored tunnelling. (In: International Conference of Geotechnical Aspects of Underground Construction in Soft Ground, London, pp. 713–718.

[5] LU Guidance Document G0058 Civil Engineering Technical Advice Notes, Issue No. A17, Feb. 2013.

[6] Burland J B (1995). Assessment of risk of damage to buildings due to tunnelling and excavation. Proceedings: 1st International Conference of Earthquake Geotechnical Engineering, IS Tokyo, 1995.

[7] Mott MacDonald (2012). Bank Station building data sheets – A list buildings. N133-BCR-MMD-00-Z-DC-S-0003-S0-1.0.

[8] Mott MacDonald (2012) Bank Station – Potential damage assessment of Saint Mary Abchurch. (N133-BCR-MMD-00-Z-DC-Z-0061-S0-1.0)

[9] SES Ltd drawing No:SES/7647/001. (2011)

[10] SES Ltd drawing: SES/7647/005. (2011)

[11] St. Mary Abchurch Report on findings of the structural investigation June 2013 ref LUTSN-0008798-RPT-002739

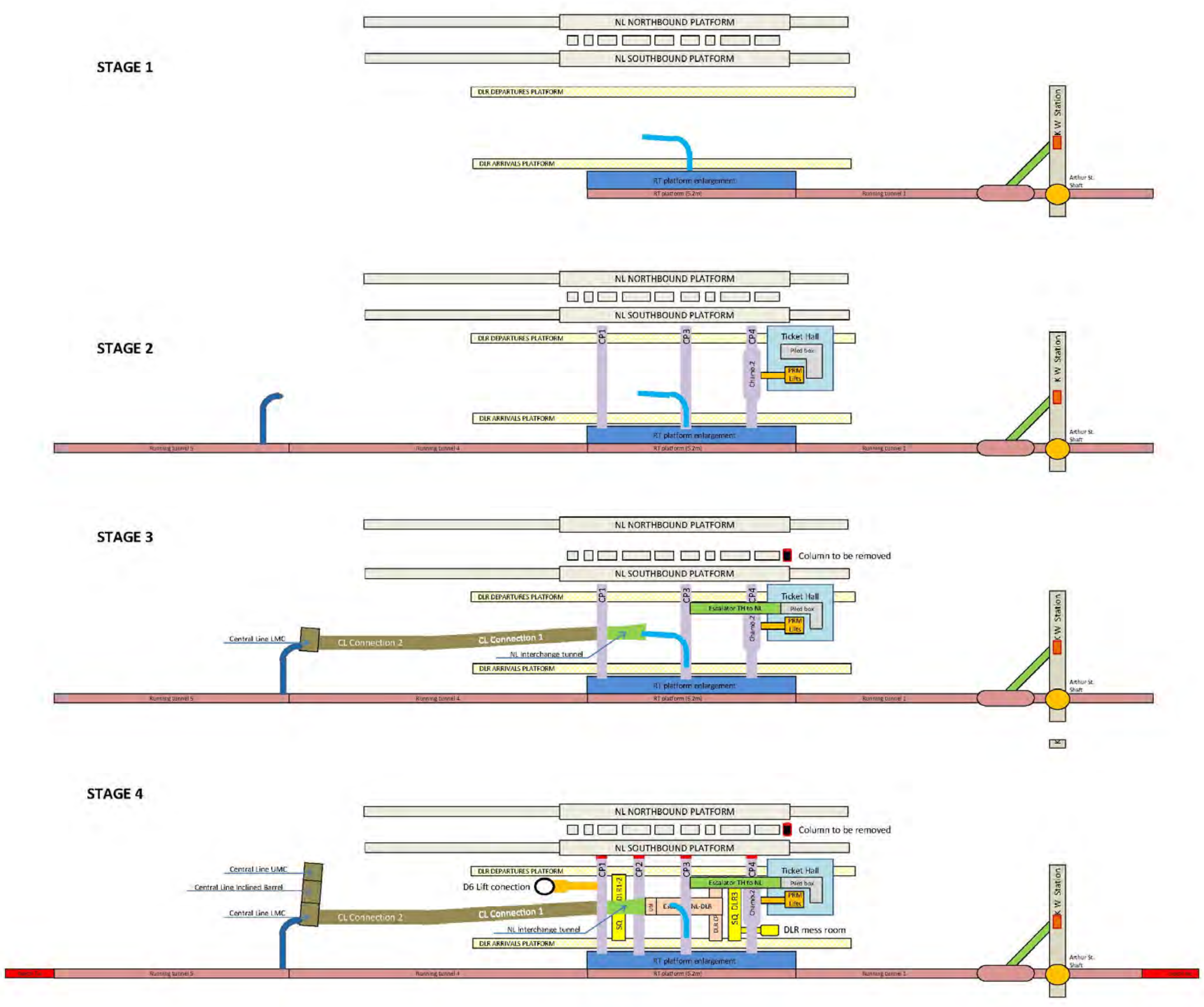


Figure 1: Construction Stage model

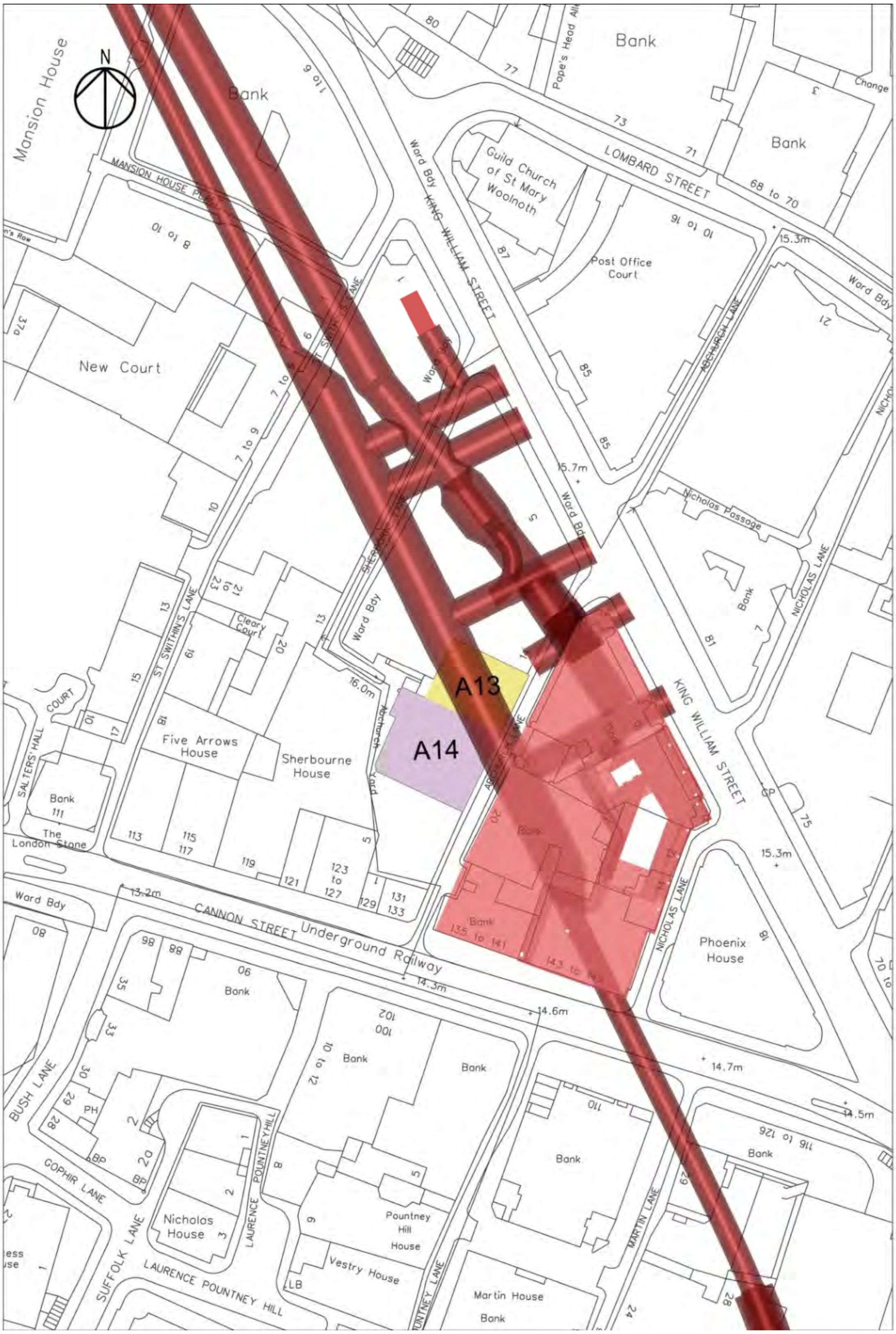


Figure 2: Location plan showing building location in relation to BSCU works

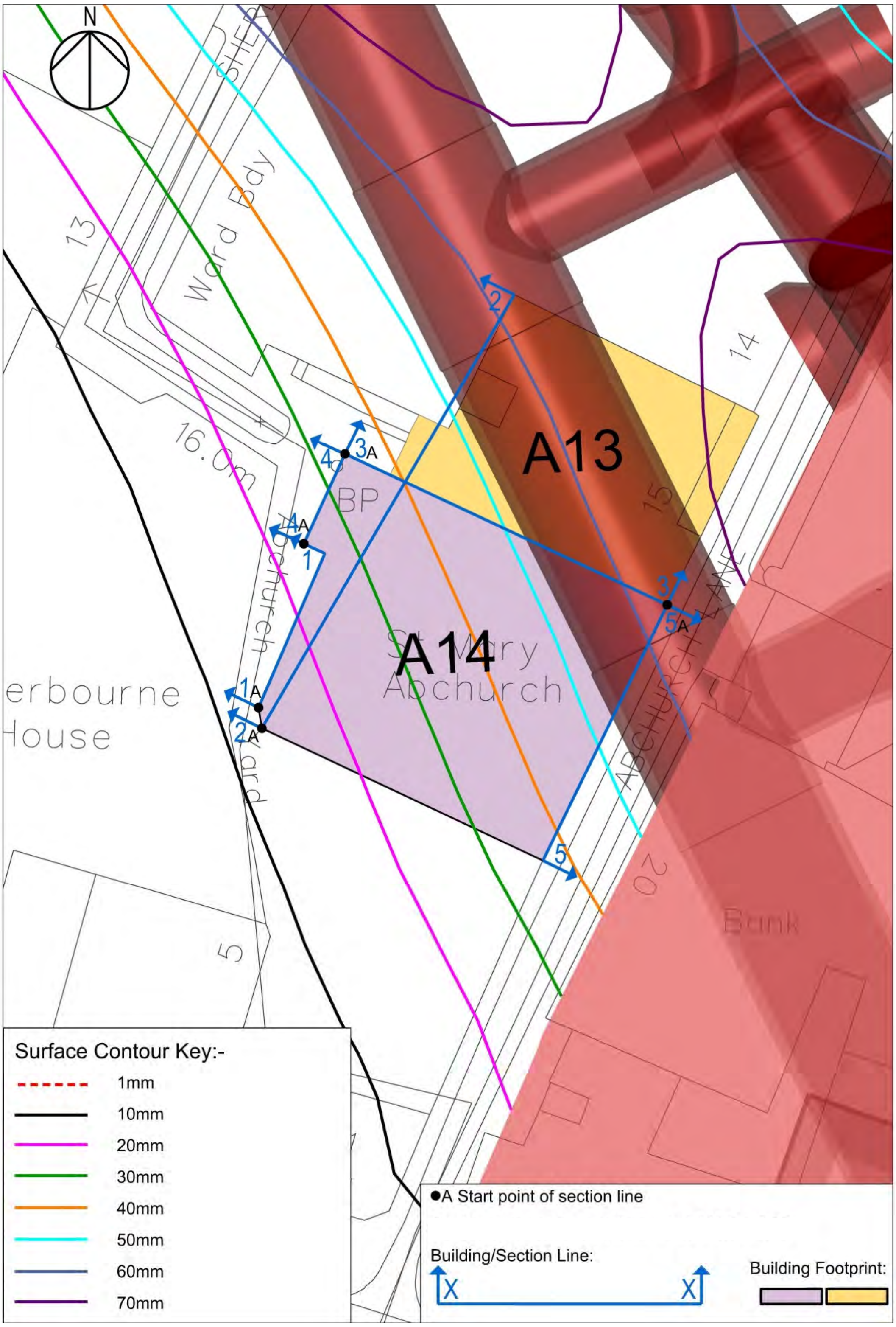


Figure 3: Building location, sections analysed and Settlement Contours at stage of worst case for tensile strains

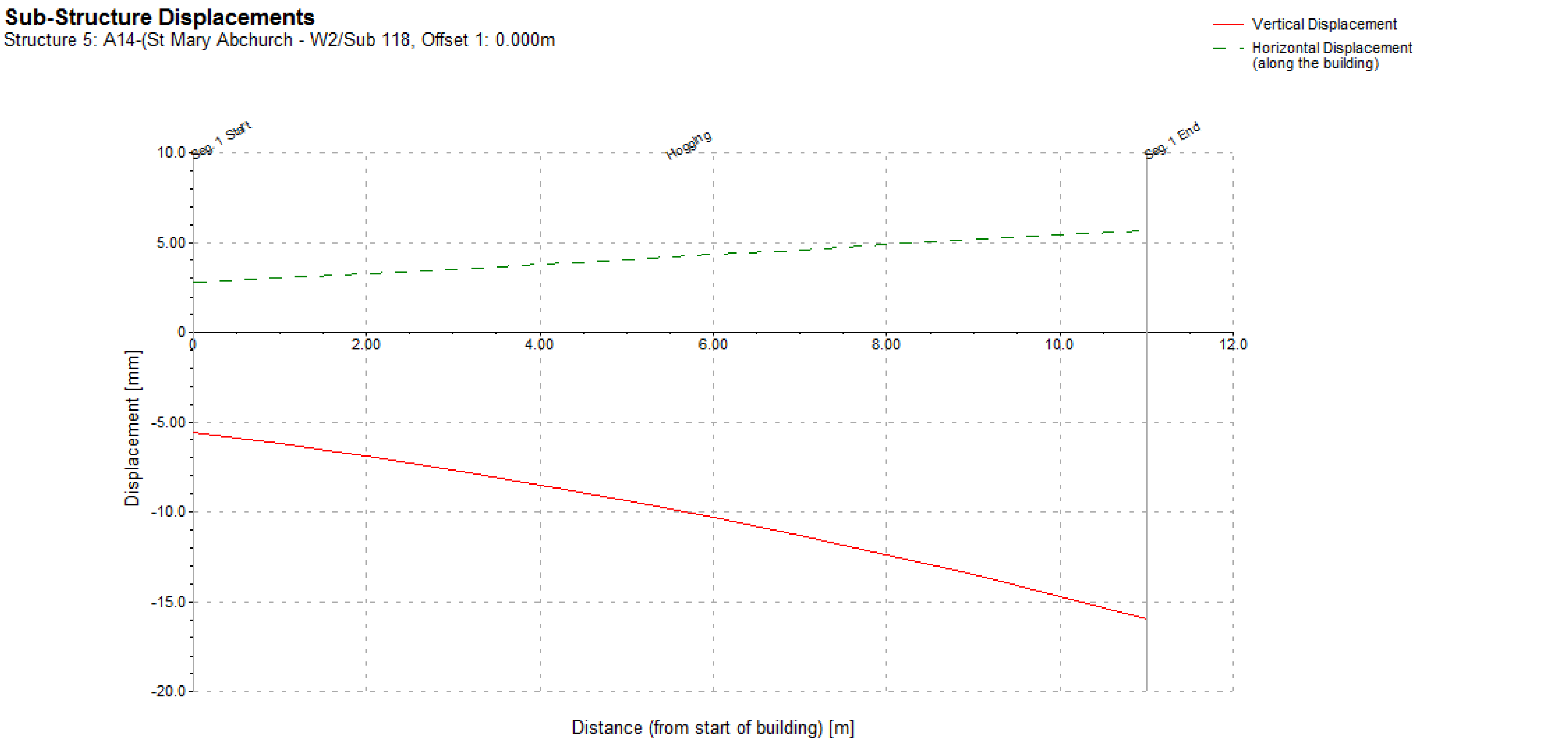
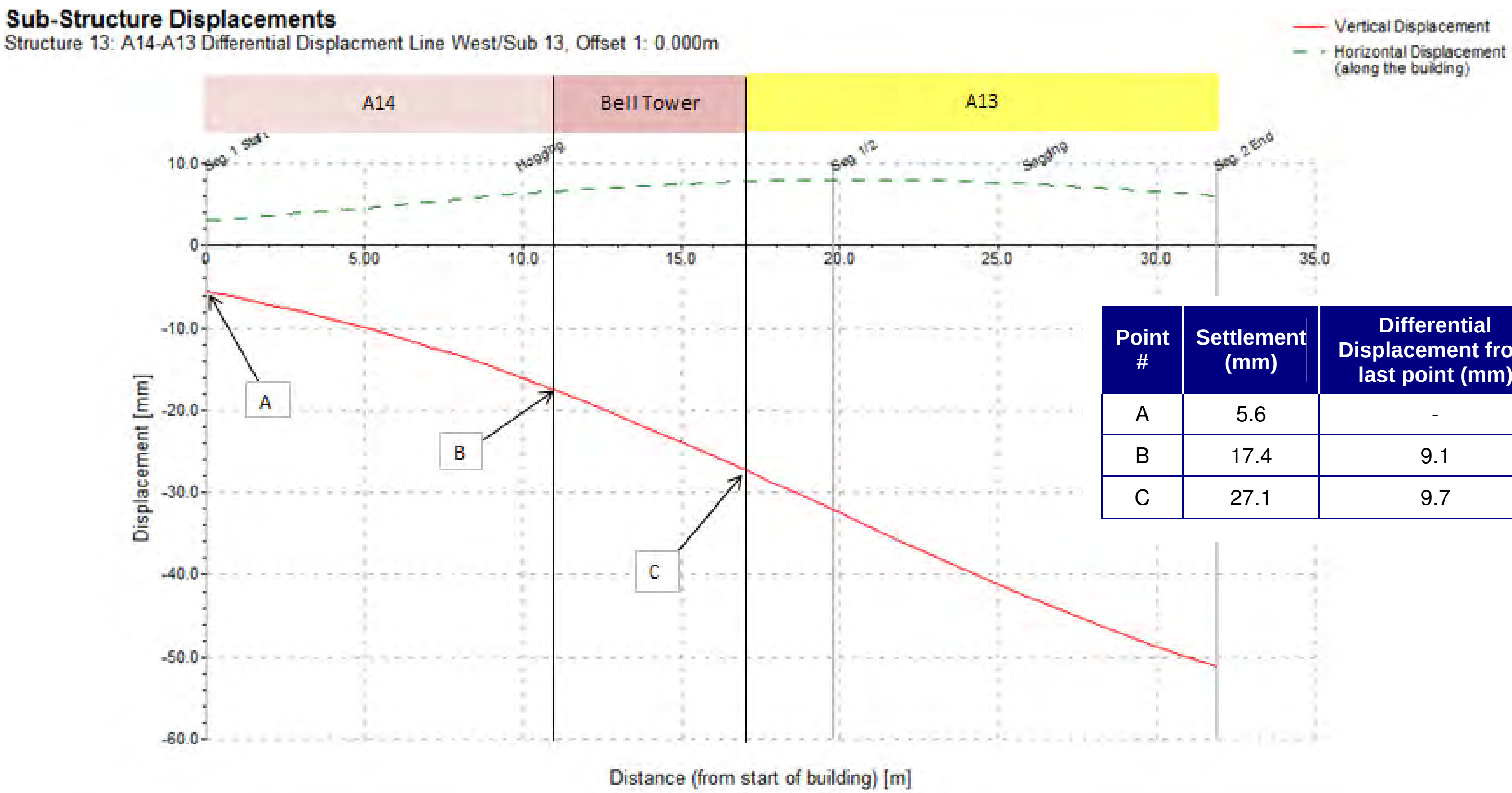


Figure 4: Building displacement at founding level at stage (4) (line 1) of worst case for tensile strains



Point #	Settlement (mm)	Differential Displacement from last point (mm)
A	5.6	-
B	17.4	9.1
C	27.1	9.7

Figure 5: Displacement at founding level at stage of (4) (line 2) worst case for tensile strains

Point #	Settlement (mm)	Differential Displacement from last point (mm)
A	23.5	-
B	30.8	7.3
C	48.2	17.4

Figure 6: Displacement at founding level at stage (4) (line 3) of worst case for tensile strains

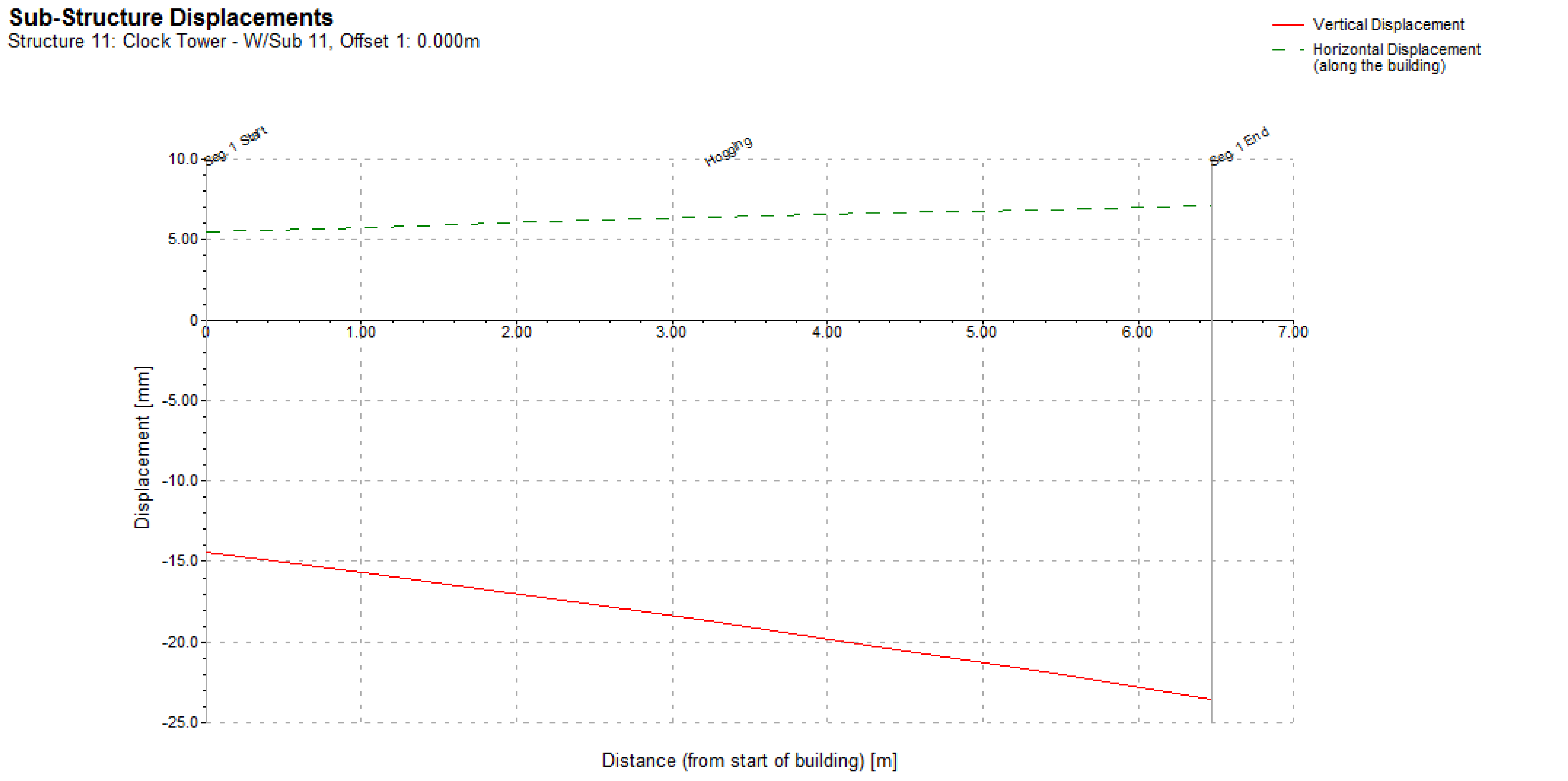


Figure 7: Building's displacement at founding level at stage (4) and (line 4) of worst case for tensile strains

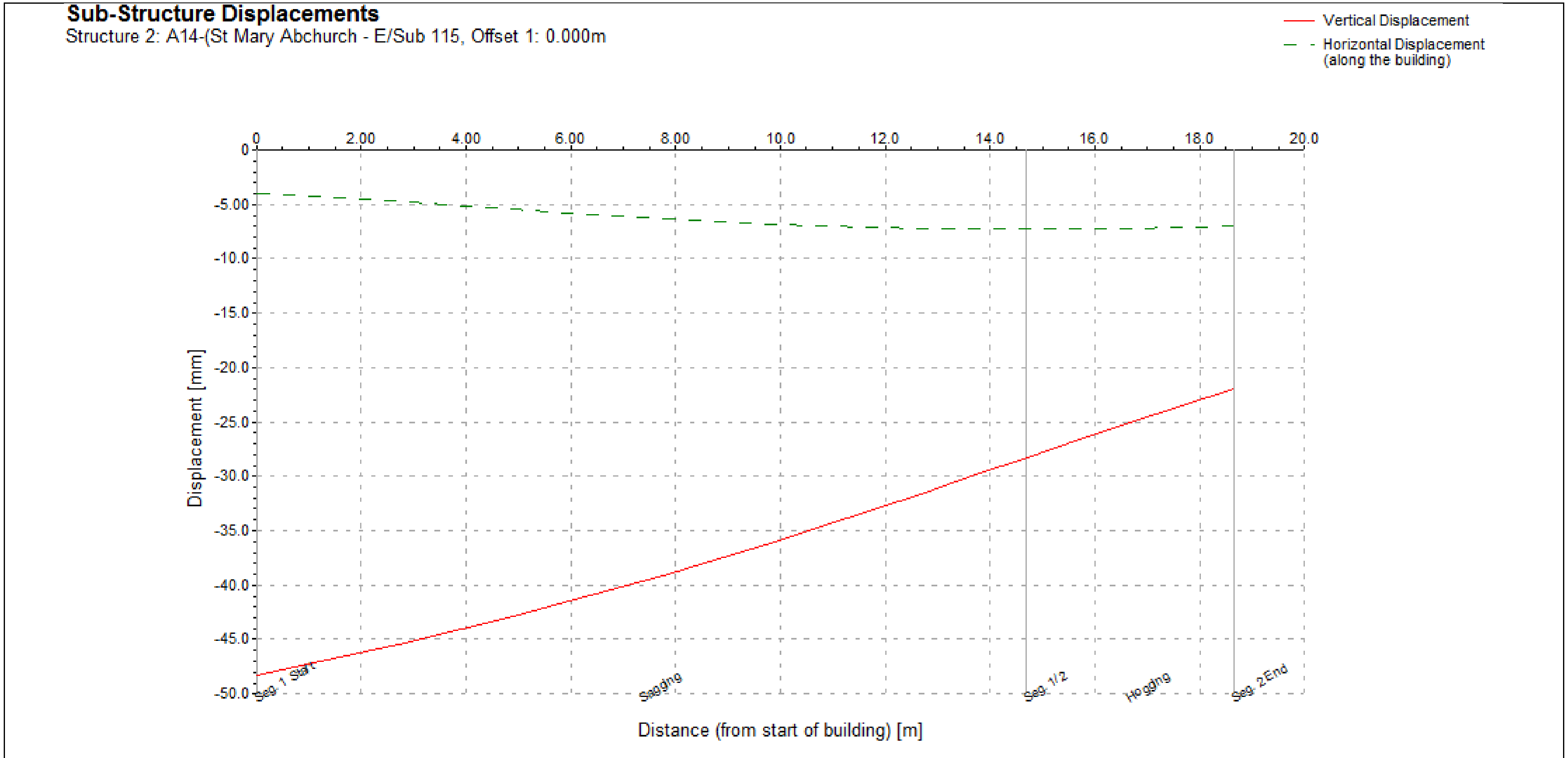
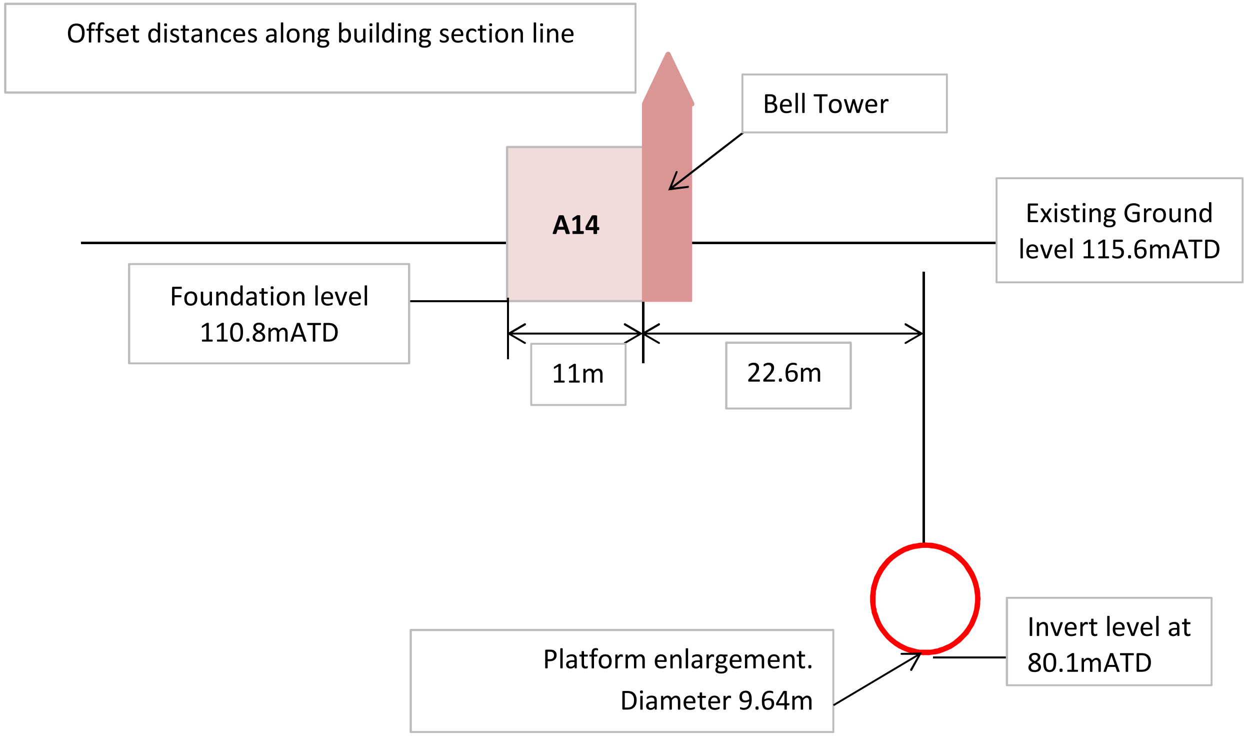


Figure 8: Building's displacement at founding level at stage (4) and (line 5) of worst case for tensile strains



For clarity, temporary access tunnel middle, escalator barrel from NL to DLR and cross passages CP2 are not shown.

Section Line 1 details
Start point (Eastings / Northings) 83073.436, 35615.579
End point (Eastings / Northings) 83077.793, 35625.674

Figure 9: Diagrammatic cross-section of A14 (line 1) relative to tunnel position

LUL Bank Project Office
10 King William Street
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Bank Station Capacity Upgrade

Building Damage Assessment Report

Building A16

121 Cannon Street

URS-8798-RPT-G-001180

Prepared by:	Lisa Perkins Assistant Geotechnical Engineer	L-perkins	18/07/14
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Document Owner	
Company:	URS
Role:	Designer

Document History

Revision	Date	Summary of changes
1.0	March 2014	Issue for Heritage
2.0	April 2014	For Approval
3.0	July 2014	TWAO Issue

For the status of this document, please refer to the Building Damage Assessment Report Register (URS-8798-RGT-001229)

Consultation:

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- Keith Bowers/Neil Moss/Paul Dryden — London Underground
- Olly Newman — Dragados

Contents

FIGURES

TABLES

1 Introduction

This report summarises the results of a Stage 2 damage assessment for 121 Cannon Street.

Stage 2 damage assessments are undertaken for all buildings within the Stage 1 Greenfield ground surface 1mm settlement contour induced by the construction of the Bank Station Capacity Upgrade (BSCU)..

The purpose of the assessment is to determine the potential effect the works will have on the building. This report describes the engineering and heritage assessments undertaken for the building and concludes whether mitigation is likely to be needed and if a further (Stage 3) assessment is recommended in order to verify this.

2 The Building

2.1 General Information

The building is situated on Cannon Street between Sherbourne House and 123-127 Cannon Street. Access is only available through the façade on Cannon Street. Constructed in the early 1900s the building is tall and narrow with a shop front at ground level. It has been assumed to be a steel framed building founded on a raft. General building information used in the assessment has been acquired as part of the structural desktop appraisal. This information is presented in Table 1.

Category	Building Information
BSCU Reference	A16
Location	Cannon Street
Address	121 Cannon Street
Building Type	Steel framed (assumed)
Construction Age	1900
No. of Storeys	5
Basements	2
Eaves Level (mATD)	138.6
Foundation Type	Raft (assumed)
Ground Level (mATD)	114
Listed Grade	II
Note: Levels given are in metres above Tunnel Datum, mATD. Tunnel Datum is 100m below Ordnance Survey Datum at Newlyn.	

Table 1: General building information

A general view of the building exterior is shown in Plate 1. A location plan showing the building in relation to the proposed BSCU works is presented in Figure 2.

Plate 1: General view

2.2 Building Description

121 Cannon Street is a commercial building constructed in 1900. It is of five storeys in stone, with a shop front to the ground floor and classical detailing to the elevation above, including attached Ionic columns under a heavy cornice and entablature to the fourth floor. The rear façade on Abchurch Yard is of red brick and very plain.

The ground floor holds a timber shop front, with a modern shop fit-out within. No internal inspection has been made of the upper storeys.

3 Methodology

This building damage assessment is undertaken in accordance with LU Works Information WI2300[1] and LU Civil Engineering - Common Requirements S1050[2].

The analysis methodology applies to ground-bearing buildings which will be affected by ground movements resulting from the construction of the BSCU. The engineering assessment calculates the potential impact of ground movements and assigns a damage category to the building based on a numeric scale. Additionally, for listed buildings, a heritage assessment is carried out which considers the sensitivity of the structure and the sensitivity of its particular features; a heritage sensitivity score is assigned. The heritage sensitivity score is added to the damage category to obtain the total score. If the total score is 3 or more, a more detailed Stage 3 assessment is triggered.

Oasys Xdisp is used to analyse the Greenfield ground movement in terms of settlement and horizontal displacement. Subsurface tunnelling induced ground movement profiles are determined in accordance with the methodology described by Mair et al[3 & 4].

In order to investigate the relative movements between this building and the neighbour (A17), a displacement line 2 was drawn as shown in Figure 3. It was analysed at A16's founding level. This is not a strictly accurate model since building A17 is founded higher but will give an understanding of the behaviour in this area.

Movements resulting from the Whole Block Scheme (WBS) and shaft excavations have been calculated using LU Guidance Document G0058[5].

The building is modelled as a simple elastic beam which is conservatively assumed to follow the Greenfield ground displacements. The beam is divided into hogging and sagging segments. The tensile strains within each segment are calculated based on the distortion associated with differential settlement (which is characterised by deflection ratio) and the distortion associated with differential horizontal displacement (characterised by horizontal strain).

Xdisp provides a method for calculating the maximum tensile strain within the building superstructure associated with these movements, in accordance with the assessment methodology described by Mair et al[4]. This strain is used to determine the damage category for traditional masonry structures based on the classification system proposed by Burland[6] and in accordance with LU Civil Engineering - Common Requirements S1050[2]. The categories are presented in Table 2.

Damage Category	Description of Degree of Damage	Description of Typical Damage and likely forms of Repair for Typical Masonry Buildings.	Approx. Crack Width (mm)	Max. Tensile Strain %
0	Negligible	Hairline cracks.		< 0.05
1	Very slight	Fine cracks easily treated during normal redecoration. Perhaps isolated slight fracture in building. Cracks in exterior visible upon close inspection.	0.1 to 1.0	0.05 to 0.075
2	Slight	Cracks easily filled. Redecoration probably required. Several slight fractures inside building. Exterior cracks visible; some repainting may be required for weather-tightness. Doors and windows may stick slightly.	1 to 5	0.075 to 0.15
3	Moderate	Cracks may require cutting out and patching. Recurrent cracks can be masked by suitable linings. Tuck pointing and possible replacement of a small amount of exterior brickwork may be required. Doors and windows sticking. Utility services may be interrupted. Weather tightness often impaired.	5 to 15 or a number of cracks > 3	0.15 to 0.3
4	Severe	Extensive repair required involving removal and replacement of walls especially over doors and windows. Window and door frames distorted. Floor slopes noticeably. Walls lean or bulge noticeably. Some loss of bearing in beams. Utility services disrupted.	15 to 25 but also depends on number of cracks	> 0.3
5	Very severe	Major repair required involving partial or complete reconstruction. Beams lose bearing, walls lean badly and require shoring. Windows broken by distortion. Danger of instability.	Usually > 25 but depends on number of cracks	
Note: Please refer LU Civil Engineering - Common Requirements S1050[2].				

Table 2: Building damage classification

4 Input Data

The magnitude and distribution of ground movements and degree of building damage is calculated based on the following input data:

- The Xdisp model coordinates and levels are based on the 3D model (20130212DSPITT Scheme R09);
- Four construction stages are considered in accordance with the proposed programme (November 2013) as illustrated in Figure 1;
- Trough width parameter constant, K=0.5 is used in accordance with WI2300[1].

The input data for the building, tunnels and shaft excavation are summarised in Table 3, Table 4 and Table 5 respectively.

Location	Foundation level (mATD)	Building Height above foundation level (m)	E/G
121 Cannon Street	105.2*	33.4	12.5
Note: Where E / G is the ratio of Young's modulus to shear modulus of the deep beam representing the building. *Basement level at 106.7mATD[8], and assumed 1.5m thick slab beneath floor level.			

Table 3: Building data

Tunnel Item	Level of axis (mATD)	External diameter (m)	Volume Loss (%)
Running tunnels	83.5	5.4	1.5
Square works adits	75.8 to 95.3	4.1 to 7.8	2.5
Platform enlargement	85.6	7.4 to 11.2	1.5
Escalator barrels	Inclined	8.3 to 8.4	1.5
Central Line Connection	Inclined (87.6 to 89.2)	8.6	1.5

Table 4: Tunnel data

Excavation	Excavation Base Level (mATD)
Grout Shaft at King William Street	97
Whole Block Scheme Box excavation	73
Arthur Street Shaft	81

Table 5: Excavation data

The Xdisp model filenames used to undertake this assessment are:

- A16 - Stage 4
- A16 - Stage 3
- A16 - Stage 2
- A16 - Stage 1

5 Results

5.1 Engineering Assessment

The sections through the building which have been analysed are shown on plan in Figure 3. A line perpendicular to Cannon Street was checked and found to be less onerous. Line 2 investigates the junction between this building and its neighbour to the east.

Assessment has been undertaken at three intermediate construction stages and at the end of construction when all major elements of the works including shaft and tunnels have been completed. The damage category assigned to the building is based on the construction stage at which the potential impact on the building is most severe.

The maximum settlement and tensile strain calculated for each of the analysis sections at the most onerous construction stage are presented in Table 6 and Table 7.

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
A16 (line 1)	<1	0.001
A16 (line 2)*	1	0.005
Note * This is strain from an extended line which is not applicable to the building		

Table 6: Building response at most onerous intermediate stage - Construction Stage 2

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
A16 (line 1)	<1	0.001
A16 (line 2)*	1	0.005
Note * This is strain from an extended line which is not applicable to the building		

Table 7: Building response at most onerous intermediate stage - Construction Stage 4

The results of the assessment show that the construction Stage 4 is the critical stage for this building where line 1 experiences the most onerous combined tensile strain. The orientation of this building is shown in Figure 2. The relative position of the building and tunnels along section line 1 is shown in Figure 5. The calculated strains are summarised in Table 8.

Line No.	Strains in section (Curvature)	Position from start (m)	Length (m)	Average* Horizontal Strain (%)	Maximum Tensile Strains (%)	Damage Category
Line 1	Hogging	0.0	5.6	0.001	0.001	Negligible
Line 2**	Hogging	0.0	17.8	0.005	0.005	Negligible
Note: * Tensile horizontal strains are +ve. Compressive horizontal strains are –ve. ** This is strain from an extended line which is not applicable to the building						

Table 8: Section analysed, results for worst case tensile strain

A16 (line 2) along the combined façade for buildings A16 and A17 determines the differential movements between the two buildings. The orientation is shown in Figure 3. The vertical and horizontal ground movements along the section of the building are shown in Figure 4. The junction between A16 and A17 is in hogging mode, which could induce cracking at high level. The tensile strains are very small (Negligible) as shown in Table 8.

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0. This corresponds to Negligible damage in accordance with Table 2.

The maximum settlement of the building at foundation level at the end of construction is less than 1mm.

5.2 Heritage and Structural Assessment

Following site inspection, assessment has been made using the following scoring methodology as set out in Table 9.

Score	STRUCTURE Sensitivity of the structure to ground movements and interaction with adjacent buildings	HERITAGE FEATURES Sensitivity to calculated movement of particular features within the building	CONDITION Factors which may affect the sensitivity of structural or heritage features
0	Masonry buildings with lime mortar and regular openings, not abutted by other buildings, and therefore similar to the buildings on which the original Burland assessment was based.	No particular sensitive features	Good/Fair - not affecting the sensitivity of structural or heritage features
1	Buildings not complying with categories 0 or 2, but still with some sensitive structural features in the zone of settlement e.g.: cantilever stone staircases, long walls without joints or openings, existing cracks where further movements are likely to concentrate, mixed foundations	Brittle finishes, e.g. faience or tight-jointed stonework, which are susceptible to small structural movements and difficult to repair invisibly.	Poor - may change the behaviour of a building in cases of movement. Poor condition of heritage features and finishes. Evidence of previous movement.
2	Buildings which, by their structural form, will tend to concentrate all their movements in one location (e.g.: a long wall without joints and with a single opening).	Finishes which if damaged will have a significant effect on the heritage value of the building, e.g. Delicate frescos, ornate plasterwork ceilings.	Very poor – parlous condition of heritage features and finishes, severe existing damage to structure including evidence of ongoing movement. Essentially buildings where even very small movements could lead to significant damage.

Table 9: Heritage and structural scoring methodology

The results of the heritage assessment carried out for the building are summarised in Table 10.

SENSITIVITY OF THE STRUCTURE
No survey has been carried out and this assessment is based on an external inspection and the listing description. The building is located on the edge of the anticipated settlement zone and predicted settlement is calculated to be very small. The building is assumed to be of framed construction and has a stone clad front elevation. Much of the very narrow elevation is made up of fenestration rather than ashlar.
Score: 0 – there are no structural sensitivities to the predicted levels of settlement
SENSITIVITY OF THE HERITAGE
No internal inspection has been made of the building except for that within the ground floor shop, and it is assumed that the upper storeys contain minimal heritage features. The Cannon Street façade includes a heavy cornice and other classical detailing, but these heritage features will not be susceptible to the small predicted settlements. There are no particular heritage finishes or features to the rear elevation.
Score: 0 – The Cannon Street façade includes heritage features, but these will not be sensitive to the predicted settlement
SENSITIVITY OF THE CONDITION
External inspection has not identified any areas of particular poor condition, and the building appears to be relatively well maintained.
Score: 0 – There are no sensitivities relating to condition

Table 10: Heritage and structural assessment

5.3 Total Score

The total score is the summation of the damage category, structural sensitivity, heritage sensitivity and condition sensitivity scores:

The damage category is 0

The structural sensitivity score is 0

The heritage sensitivity score is 0

The condition sensitivity score is 0

The total score for this building is 0

6 Conclusion

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0 for 121 Cannon Street. Specific heritage and structural assessment, relating only to the exterior and ground floor of the building and taking into account the location and extent of settlement and tensile strains highlights the buildings low level of structural and heritage sensitivity to movement. This assessment has determined that the building has a total score of 0.

It is recommended that the building does not require a Stage 3 assessment.

7 References

[1] LU Works Information WI 2300 Ground Movement version 3, 19-07-13.

[2] LU Category 1 Standard: S1050 Civil Engineering - Common Requirements, Issue No. A7, Nov. 2013.

[3] Mair R J, Taylor R N and Bracegirdle A (1993). Subsurface settlement profiles above tunnels in clays. Géotechnique 43, No. 2, pp. 315-320.

[4] Mair R J, Taylor R N and Burland J B (1996). Prediction of ground movements and assessment of risk of building damage due to bored tunnelling. (In: International Conference of Geotechnical Aspects of Underground Construction in Soft Ground, London, pp. 713–718.

[5] LU Guidance Document G0058 Civil Engineering Technical Advice Notes, Issue No. A17, Feb. 2013.

[6] Burland J B (1995). Assessment of risk of damage to buildings due to tunnelling and excavation. Proceedings: 1st International Conference of Earthquake Geotechnical Engineering, IS Tokyo, 1995.

[7] Mott MacDonald (2012). Bank Station building data sheets – A list buildings. N133-BCR-MMD-00-Z-DC-S-0003-S0-1.0.

[8] William Nimmo & Partners (1981). Architectural drawing. (no. 5011L (--) 15 5).

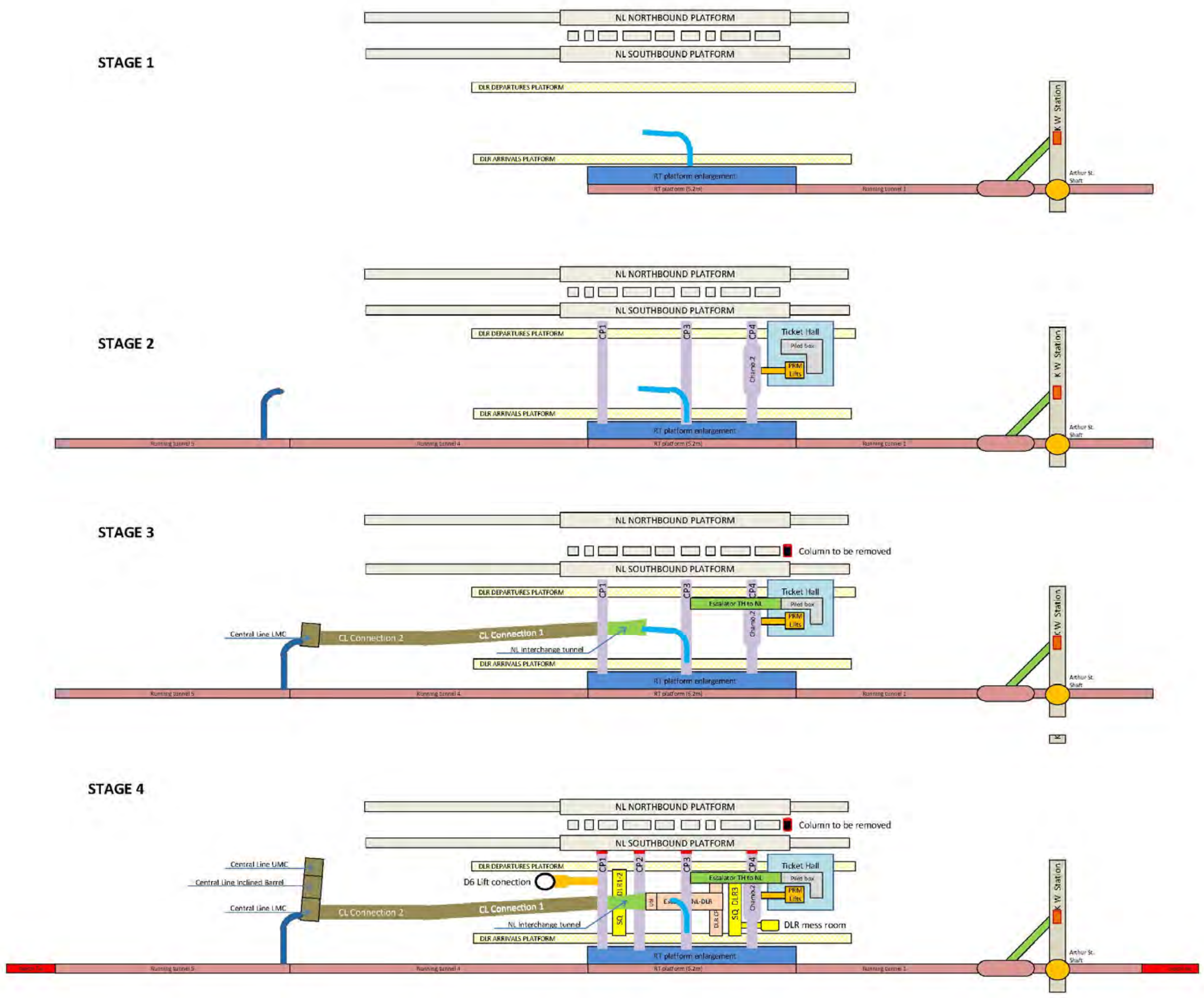

Figure 1: Construction Stage model

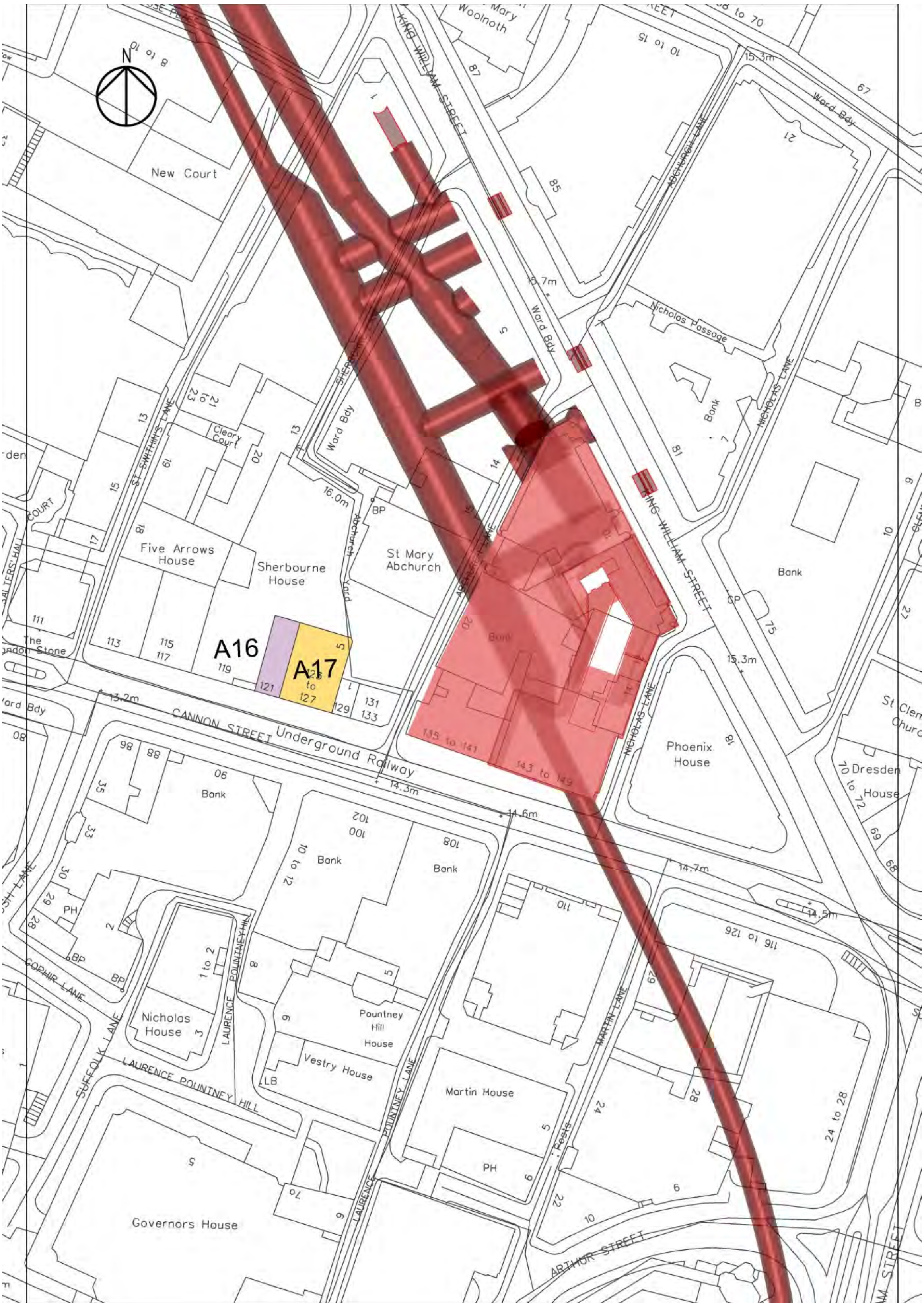

Figure 2: Location plan showing building location in relation to BSCU works

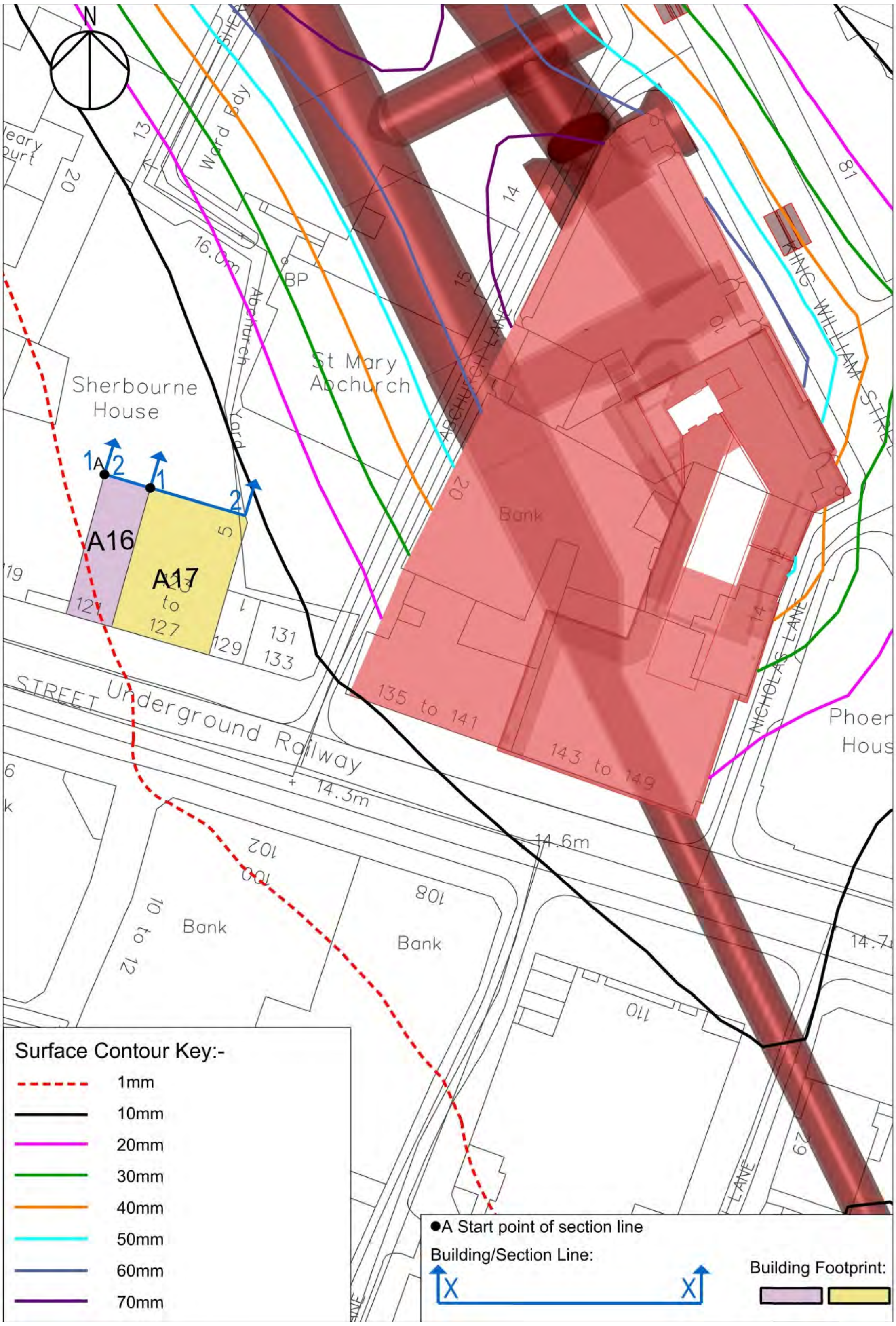

Figure 3: Building location, sections analysed and Settlement Contours at stage of worst case for tensile strains

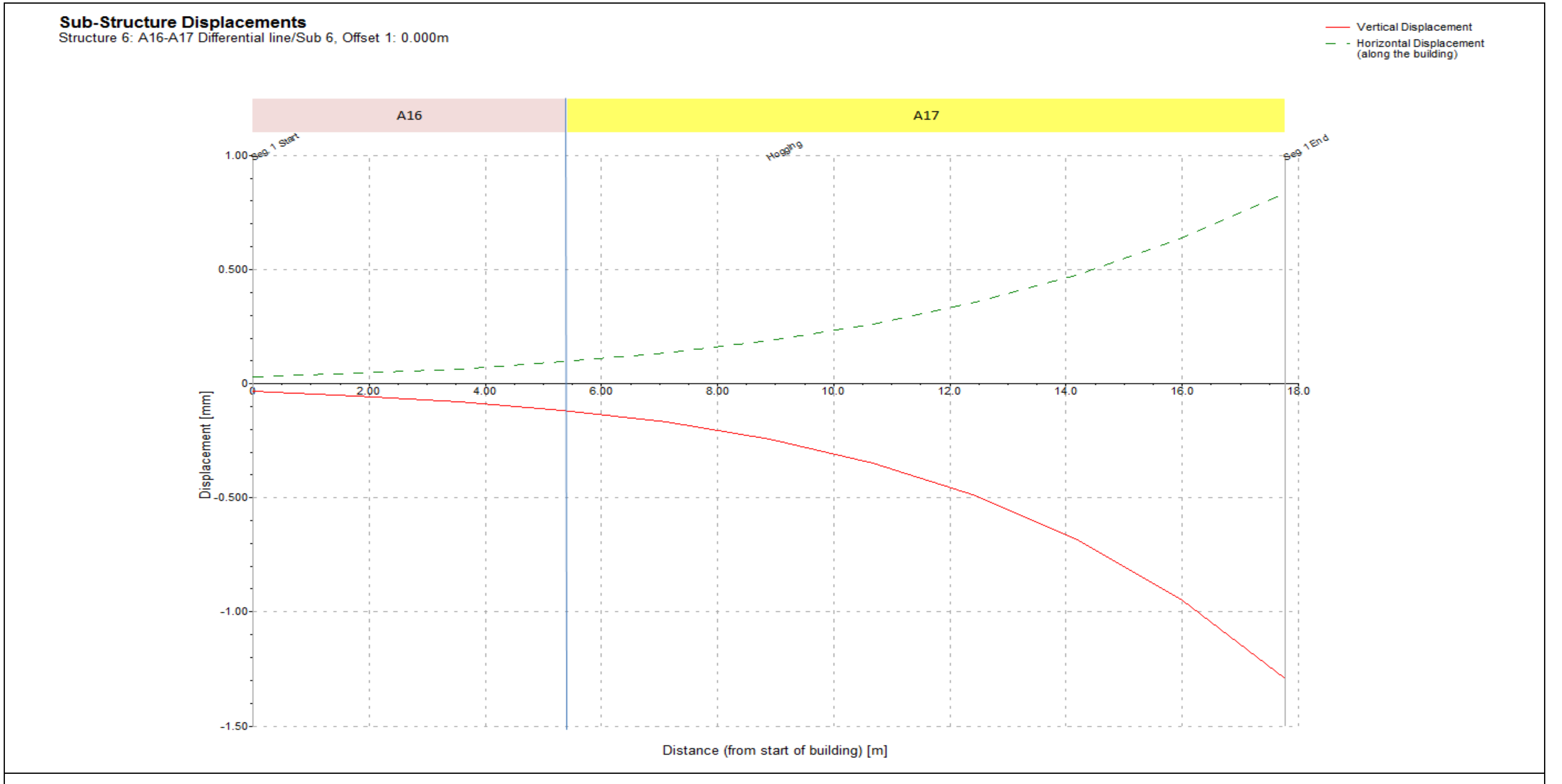

Figure 4: Building displacement at founding level at stage 4 (line 2) of worst case for tensile strains

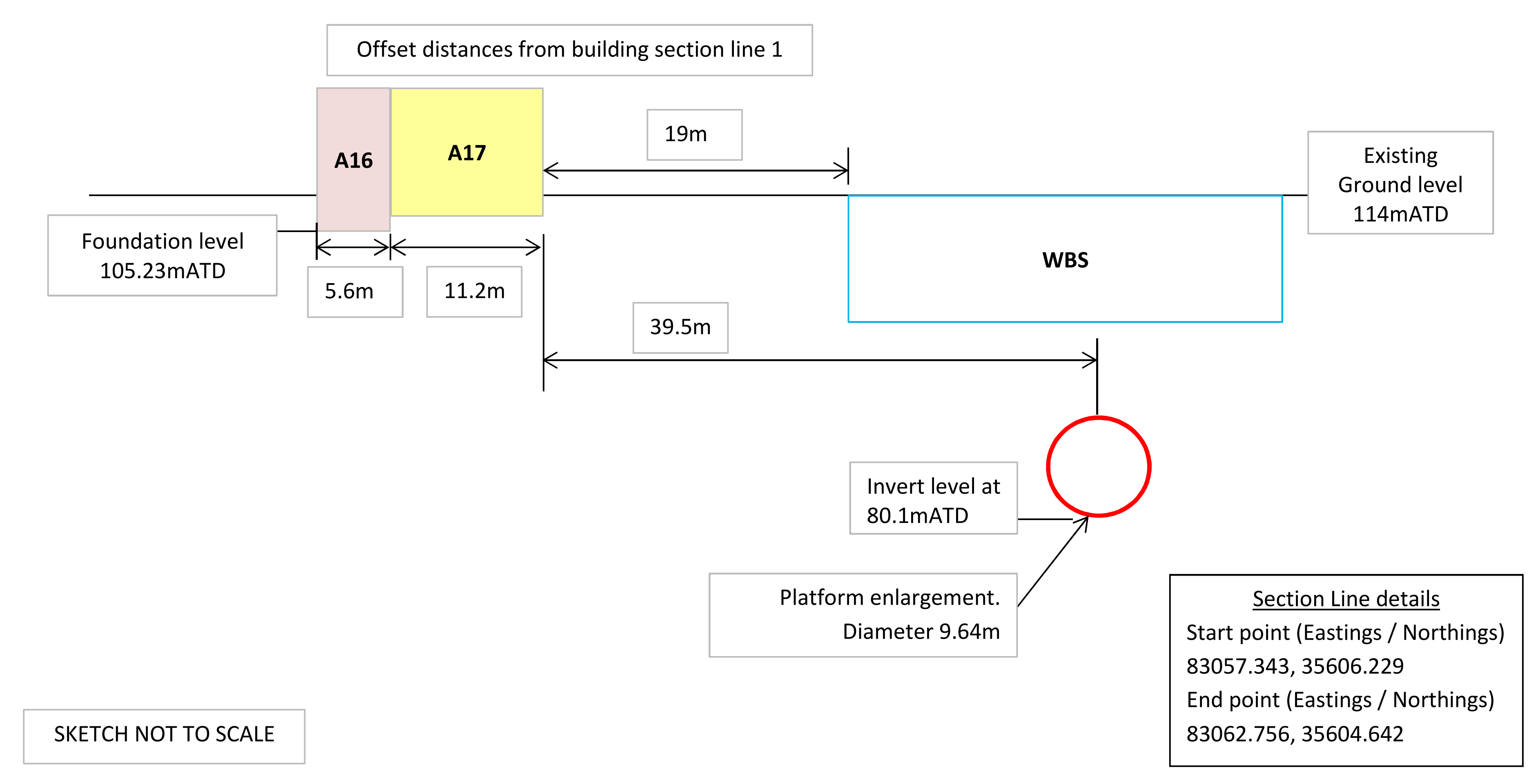

Figure 5: Diagrammatic cross-section of section (line 1) relative to tunnel position

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Bank Station Capacity Upgrade

Building Damage Assessment Report

Building A17

123 – 127 Cannon Street

URS-8798-RPT-G-001181

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Role:	Designer

Document History

Revision	Date	Summary of changes
1.0	March 2014	Issue for Heritage
2.0	April 2014	For Approval
3.0	July 2014	TWAO Issue

For the status of this document, please refer to the Building Damage Assessment Report Register (URS-8798-RGT-001229)

Consultation:

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Contents

FIGURES

TABLES

1 Introduction

This report summarises the results of a Stage 2 damage assessment for 123-127 Cannon Street.

Stage 2 damage assessments are undertaken for all buildings within the Stage 1 Greenfield ground surface 1mm settlement contour induced by the construction of the Bank Station Capacity Upgrade (BSCU).).

The purpose of the assessment is to determine the potential effect the works will have on the building. This report describes the engineering and heritage assessments undertaken for the building and concludes whether mitigation is likely to be needed and if a further (Stage 3) assessment is recommended in order to verify this.

2 The Building

2.1 General Information

No. 123-127 Cannon Street is located opposite the entrance to Laurence Pountney Hill lane. General building information used in the assessment has been acquired as part of the structural desktop appraisal. This information is presented in Table 1.

Category	Building Information
BSCU Reference	A17
Location	Cannon Street
Address	123-127 Cannon Street
Building Type	Assumed load bearing masonry
Construction Age	1895
No. of Storeys	6
Basements	1
Eaves Levels (mATD)	129.9
Foundation Type	Assumed strip footing
Ground Level (mATD)	114.2
Listed Grade	II
Note: Levels given are in metres above Tunnel Datum, mATD. Tunnel Datum is 100m below Ordnance Survey Datum at Newlyn.	

Table 1: General building information

A general view of the building exterior is shown in Plate 1. A location plan showing the building in relation to the proposed BSCU works is presented in Figure 2.

Plate 1: General view

2.2 Building Description

Completed in 1895, 123-127 Cannon Street is six storeys high and assumed to be of load bearing masonry construction supported on strip footings as cited by Alan Baxter's gazette. There is an off centre inserted column within the ground floor extended arch that supports an internal cross wall. The building uses bright red brick and terracotta on the facades with either timber or filler joist floors and a timber roof, and has an asymmetrical composition with Flemish Renaissance and Art Nouveau details to the elevation, and a variety of window types. The rear Abchurch Yard elevation is similar in style but of less complex execution.

It is assume this building has a single level basement.

3 Methodology

This assessment is undertaken in accordance with LUL Works Information WI2300[1] and LU Civil Engineering - Common Requirements S1050[2].

The analysis methodology applies to ground-bearing buildings which will be affected by ground movements resulting from the construction of the BSCU. The engineering assessment calculates the potential impact of ground movements and assigns a damage category to the building based on a numeric scale. Additionally, for listed buildings, a heritage assessment is carried out which considers the sensitivity of the structure and the sensitivity of its particular features; a heritage sensitivity score is assigned. The heritage sensitivity score is added to the damage category to obtain the total score. If the total score is 3 or more, a more detailed Stage 3 assessment is triggered.

Oasys Xdisp is used to analyse the Greenfield ground movement in terms of settlement and horizontal displacement. Subsurface tunnelling induced ground movement profiles are determined in accordance with the methodology described by Mair et al[3 & 4].

In order to investigate the relative movements between this building and the neighbour (A16), a displacement line 2 was drawn as shown in Figure 3. It was analysed at A17's founding level. This is not a strictly accurate model since building A16 is founded lower but will give an understanding of the behaviour in this area.

Movements resulting from the Whole Block Scheme (WBS) and shaft excavations have been calculated using LU Guidance Document G0058[5].

The building is modelled as a simple elastic beam which is conservatively assumed to follow the Greenfield ground displacements. The beam is divided into hogging and sagging segments. The tensile strains within each segment are calculated based on the distortion associated with differential settlement (which is characterised by deflection ratio) and the distortion associated with differential horizontal displacement (characterised by horizontal strain).

Xdisp provides a method for calculating the maximum tensile strain within the building superstructure associated with these movements, in accordance with the assessment methodology described by Mair et al [4]. This strain is used to determine the damage category based on the classification system proposed by Burland[6] and in accordance with LU Civil Engineering - Common Requirements S1050[2]. The categories are presented in Table 2.

Damage Category	Description of Degree of Damage	Description of Typical Damage and likely forms of Repair for Typical Masonry Buildings.	Approx. Crack Width (mm)	Max. Tensile Strain %
0	Negligible	Hairline cracks.		< 0.05
1	Very slight	Fine cracks easily treated during normal redecoration. Perhaps isolated slight fracture in building. Cracks in exterior visible upon close inspection.	0.1 to 1.0	0.05 to 0.075
2	Slight	Cracks easily filled. Redecoration probably required. Several slight fractures inside building. Exterior cracks visible; some repainting may be required for weather-tightness. Doors and windows may stick slightly.	1 to 5	0.075 to 0.15
3	Moderate	Cracks may require cutting out and patching. Recurrent cracks can be masked by suitable linings. Tuck pointing and possible replacement of a small amount of exterior brickwork may be required. Doors and windows sticking. Utility services may be interrupted. Weather tightness often impaired.	5 to 15 or a number of cracks > 3	0.15 to 0.3
4	Severe	Extensive repair required involving removal and replacement of walls especially over doors and windows. Window and door frames distorted. Floor slopes noticeably. Walls lean or bulge noticeably. Some loss of bearing in beams. Utility services disrupted.	15 to 25 but also depends on number of cracks	> 0.3
5	Very severe	Major repair required involving partial or complete reconstruction. Beams lose bearing, walls lean badly and require shoring. Windows broken by distortion. Danger of instability.	Usually > 25 but depends on number of cracks	
Note: Please refer LU Civil Engineering - Common Requirements S1050[2].				

Table 2: Building damage classification

4 Input Data

The magnitude and distribution of ground movements and degree of building damage is calculated based on the following input data:

- The Xdisp model coordinates and levels are based on the 3D model (20130212DSPITT Scheme R09);
- Four construction stages are considered in accordance with the proposed programme (November 2013) as illustrated in Figure 1;
- Trough width parameter constant, K=0.5 is used in accordance with WI2300[1].

The input data for the building, tunnels and shaft excavation are summarised in Table 3, Table 4 and Table 5 respectively.

Location	Foundation level (mATD)	Building Height above foundation level (m)	E/G
123-127 Cannon Street	109.7*	20.2	2.6
Note: Where E / G is the ratio of Young's modulus to shear modulus of the deep beam representing the building. * Assumed level, 1.5m thick slab beneath floor level.			

Table 3: Building data

Tunnel Item	Level of axis (mATD)	External diameter (m)	Volume Loss (%)
Running tunnels	83.5	5.4	1.5
Square works adits	75.8 to 95.3	4.1 to 7.8	2.5
Platform enlargement	85.6	7.4 to 11.2	1.5
Escalator barrels	Inclined	8.3 to 8.4	1.5
Central Line Connection	Inclined (87.6 to 89.2)	8.6	1.5

Table 4: Tunnel data

Excavation	Excavation Base Level (mATD)
Grout Shaft at King William Street	97
Whole Block Scheme Box excavation	73
Arthur Street Shaft	81

Table 5: Excavation data

The Xdisp model filenames used to undertake this assessment are:

- A17 - Stage 4
- A17 - Stage 3
- A17 - Stage 2
- A17 - Stage 1

5 Results

5.1 Engineering Assessment

The sections through the building which have been analysed are shown on plan in Figure 3. The elevation perpendicular to Cannon Street has been checked and is less critical. (Line 2) is drawn across the rear of this building and its neighbour A16 in order to investigate the movements at their junction.

Assessment has been undertaken at three intermediate construction stages and at the end of construction when all major elements of the works including shaft and tunnels have been completed. The damage category assigned to the building is based on the construction stage at which the potential impact on the building is most severe.

The maximum settlement and tensile strain calculated for each of the analysis sections at the most onerous construction stage are presented in Table 6 and Table 7.

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
A17 (line 1)	2	0.011
A17 (line 2)*	2	0.010
Note * This is strain from an extended line which is not applicable to the building		

Table 6: Building response at most onerous intermediate stage - Construction Stage 2

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
A17 (line 1)	3	0.011
A17 (line 2)*	3	0.010
Note * This is strain from an extended line which is not applicable to the building		

Table 7: Building response at most onerous intermediate stage - Construction Stage 4

The results of the assessment show that the construction Stage 4 is the critical stage for this building where (line 1) experiences the most onerous combined tensile strain. The orientation of this building is shown in Figure 2. The vertical and horizontal ground movements along the section of the building are shown in Figure 4. The relative position of the building and tunnels along section (line 1) is shown in Figure 6. The calculated strains are summarised in Table 8.

Line No.	Strains in section (Curvature)	Position from start (m)	Length (m)	Average* Horizontal Strain (%)	Maximum Tensile Strains (%)	Damage Category
(line 1)	Hogging	0.0	12.1	0.009	0.011	Negligible
(line 2)**	Hogging	0.0	17.8	0.007	0.010	Negligible
Note: * Tensile horizontal strains are +ve. Compressive horizontal strains are –ve ** This is strain from an extended line which is not applicable to the building						

Table 8: Section analysed, results for worst case tensile strain

A17 (line 2) examines the differential movements between the building (A17) and the adjacent building (A16). The orientation of the line is shown in Figure 3. The joint area between A17 and A16 is in hogging mode as shown in Figure 5 and Table 8, which could induce cracks at high level, but the tensile strains are very small (negligible).

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0. This corresponds to Negligible damage in accordance with Table 2. The maximum settlement of the building at foundation level at the end of construction is 3mm.

5.2 Heritage and Structural Assessment

Following site inspection, assessment has been made using the following scoring methodology as set out in Table 9.

Score	STRUCTURE Sensitivity of the structure to ground movements and interaction with adjacent buildings	HERITAGE FEATURES Sensitivity to calculated movement of particular features within the building	CONDITION Factors which may affect the sensitivity of structural or heritage features
0	Masonry buildings with lime mortar and regular openings, not abutted by other buildings, and therefore similar to the buildings on which the original Burland assessment was based.	No particular sensitive features	Good/Fair - not affecting the sensitivity of structural or heritage features
1	Buildings not complying with categories 0 or 2, but still with some sensitive structural features in the zone of settlement e.g.: cantilever stone staircases, long walls without joints or openings, existing cracks where further movements are likely to concentrate, mixed foundations	Brittle finishes, e.g. faience or tight-jointed stonework, which are susceptible to small structural movements and difficult to repair invisibly.	Poor - may change the behaviour of a building in cases of movement. Poor condition of heritage features and finishes. Evidence of previous movement.
2	Buildings which, by their structural form, will tend to concentrate all their movements in one location (e.g.: a long wall without joints and with a single opening).	Finishes which if damaged will have a significant effect on the heritage value of the building, e.g. Delicate frescos, ornate plasterwork ceilings.	Very poor – parlous condition of heritage features and finishes, severe existing damage to structure including evidence of ongoing movement. Essentially buildings where even very small movements could lead to significant damage.

Table 9: Heritage and structural scoring methodology

The results of the heritage assessment carried out for the building are summarised in Table 10.

SENSITIVITY OF THE STRUCTURE
No site survey has been carried out to this building and the assessment is based on an external inspection and the available documents. The building is thought to be of load bearing masonry construction and is clad with red brick and painted terracotta, there are regularly spaced windows in the elevation.
Score: 0 - No particular structural sensitivities are thought to be present.
SENSITIVITY OF THE HERITAGE
No internal survey has been carried out to this building and the assessment is based on an external inspection and the available documents. The façade, which includes terracotta facings, is a highly brittle heritage finish; however, the predicted movements are very low, and the possibility of high-level separation between A16 and A17 would not undermine this material. The shop at ground floor has an entirely modern fit out. It is assumed that there may be some delicate heritage finishes to the upper floors, for instance plasterwork, but it is not thought that these will be sensitive to the low levels of movement.
Score: 0 – The terracotta façade is highly brittle, however the predicted settlement would not impact on this finish.
SENSITIVITY OF THE CONDITION
External inspection has not identified any particular areas of poor condition, and the façade is well maintained.
Score: 0 – The building is in good condition with no obvious areas of sensitivity

Table 10: Heritage and structural assessment

5.3 Total Score

The total score is the summation of the damage category, structural sensitivity, heritage sensitivity and condition sensitivity scores:

The damage category is 0

The structural sensitivity score is 0

The heritage sensitivity score is 0

The condition sensitivity score is 0

The total score for this building is 0

6 Conclusion

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0 for 123-127 Cannon Street. Specific heritage and structural assessment, relating only to the exterior and ground floor of the building and taking into account the location and extent of settlement and tensile strains highlights the buildings low level of structural and heritage sensitivity to the predicted settlement, although external finishes to Cannon Street are brittle. This assessment has determined that the building has a total score of 0.

It is recommended that the building does not require a Stage 3 assessment.

7 References

[1] LU Works Information WI 2300 Ground Movement version 3, 19-07-13.

[2] LU Category 1 Standard: S1050 Civil Engineering - Common Requirements, Issue No. A7, Nov. 2013.

[3] Mair R J, Taylor R N and Bracegirdle A (1993). Subsurface settlement profiles above tunnels in clays. Géotechnique 43, No. 2, pp. 315-320.

[4] Mair R J, Taylor R N and Burland J B (1996). Prediction of ground movements and assessment of risk of building damage due to bored tunnelling. (In: International Conference of Geotechnical Aspects of Underground Construction in Soft Ground, London, pp. 713–718.

[5] LU Guidance Document G0058 Civil Engineering Technical Advice Notes, Issue No. A17, Feb. 2013.

[6] Burland J B (1995). Assessment of risk of damage to buildings due to tunnelling and excavation. Proceedings: 1st International Conference of Earthquake Geotechnical Engineering, IS Tokyo, 1995.

[7] Mott MacDonald (2012). Bank Station building data sheets – A list buildings. N133-BCR-MMD-00-Z-DC-S-0003-S0-1.0.

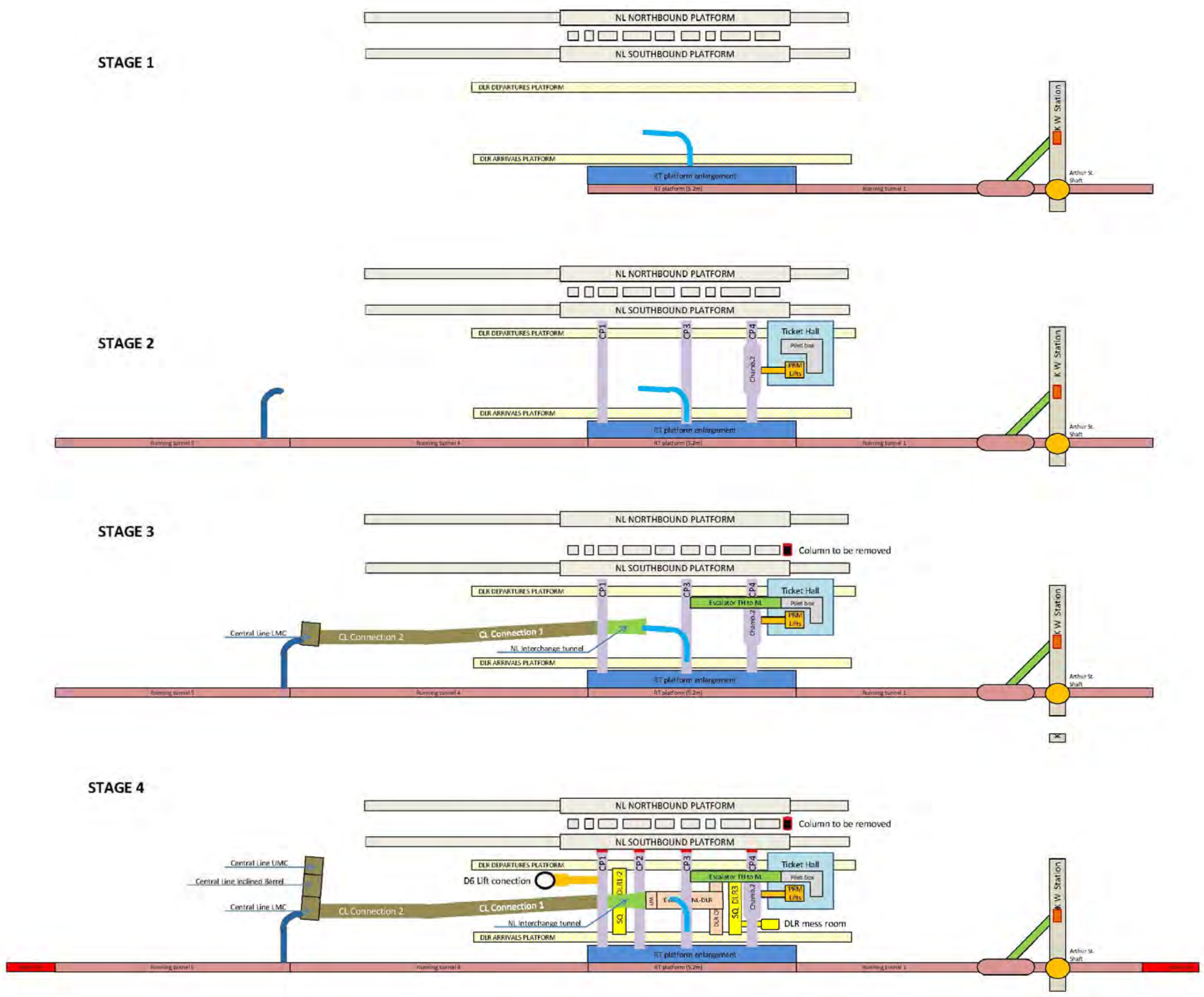

Figure 1: Construction Stage model

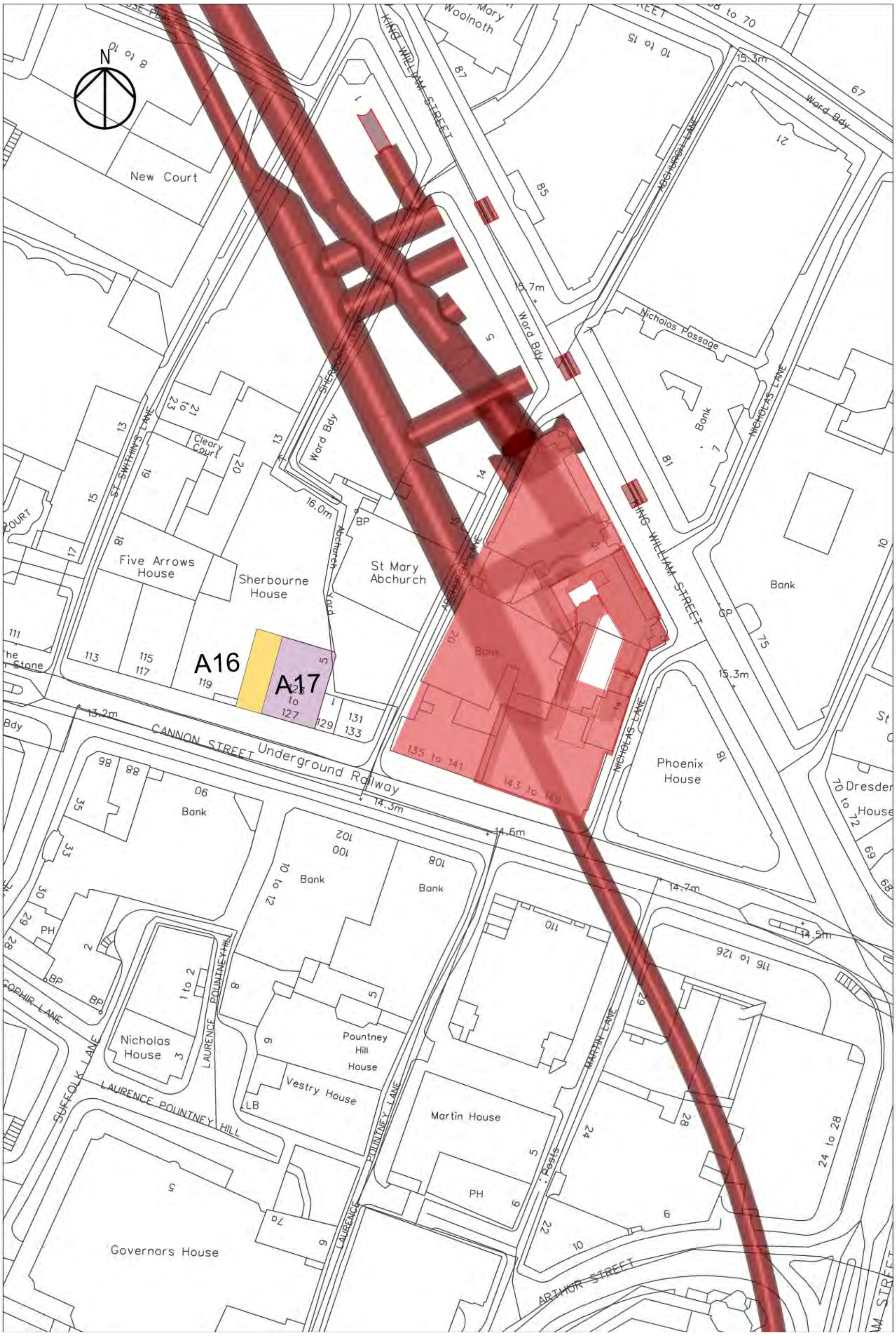

Figure 2: Location plan showing building location in relation to BSCU works

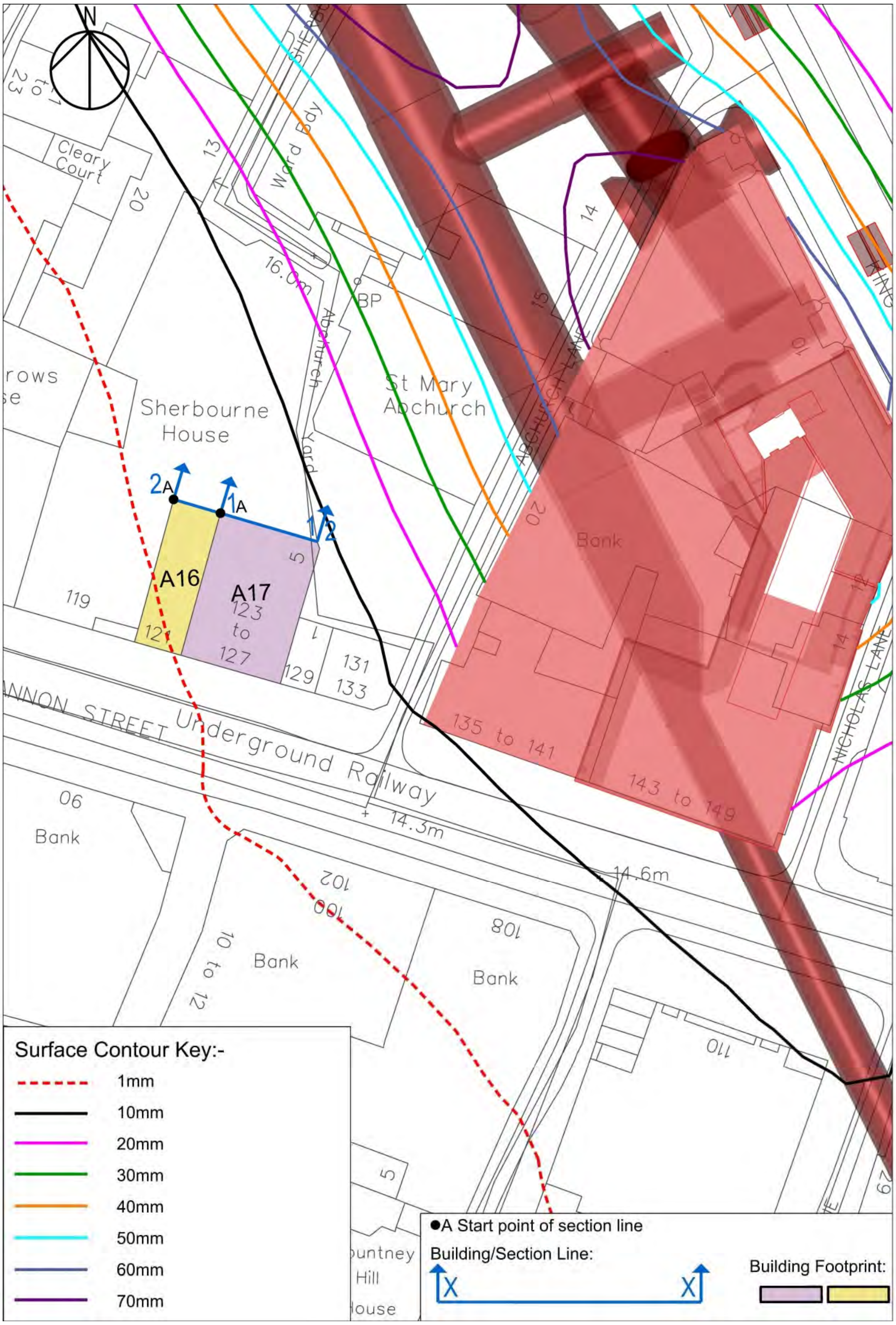

Figure 3: Building location, sections analysed and Settlement Contours at stage of worst case for tensile strains

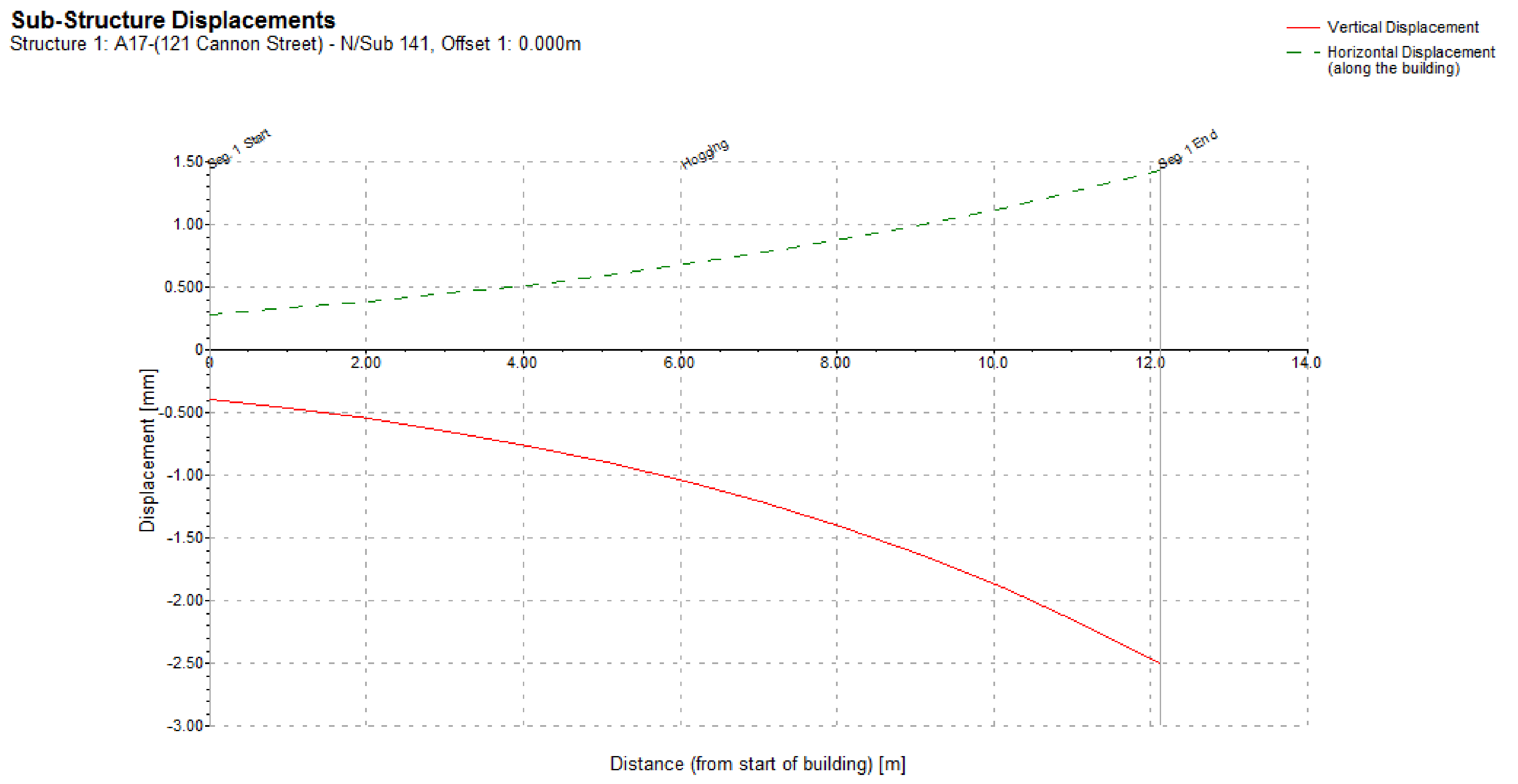

Figure 4: Building displacement at founding level at stage 4 for (line 1) of worst case for tensile strains

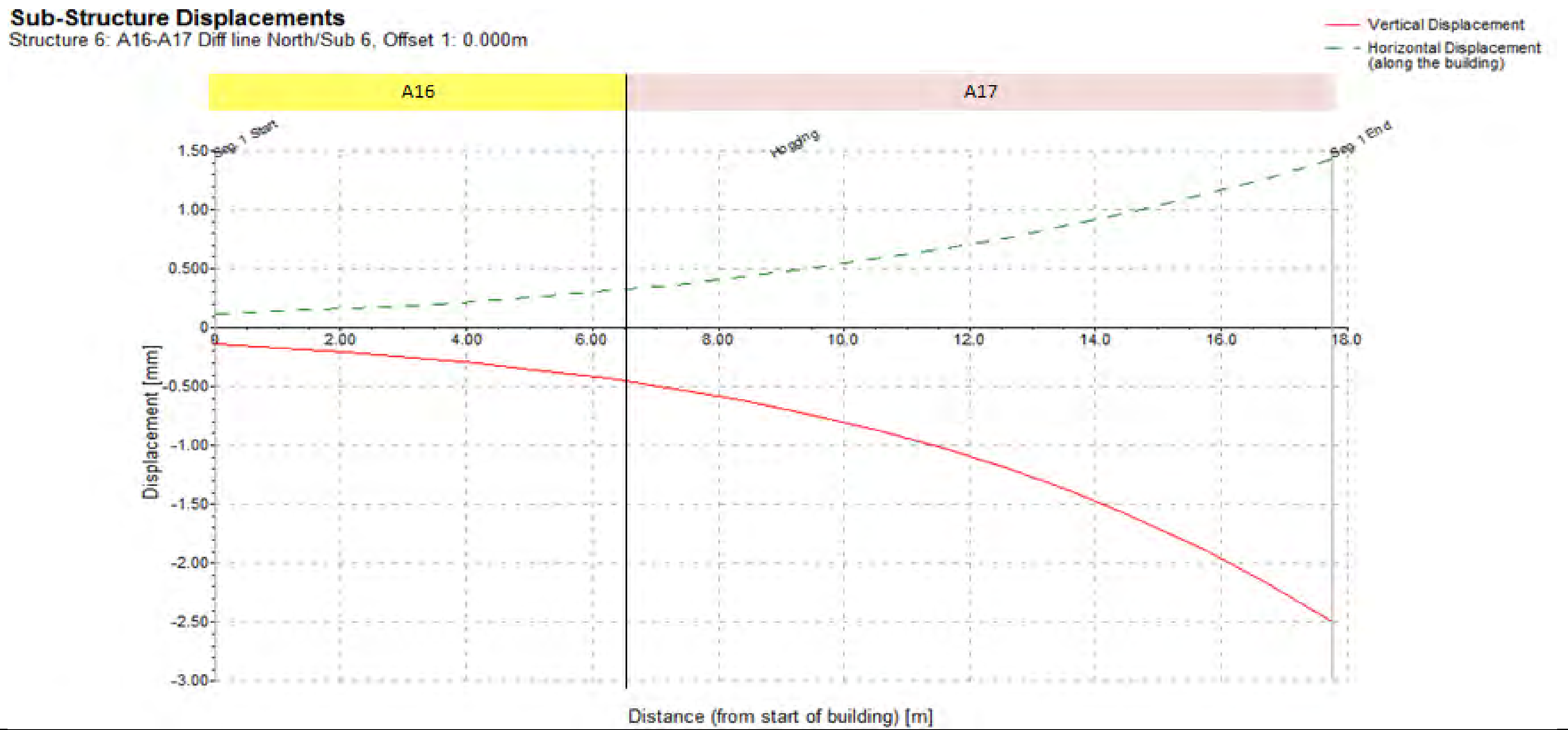

Figure 5: Building displacement at founding level at stage 4 for (line 2) of worst case for tensile strains

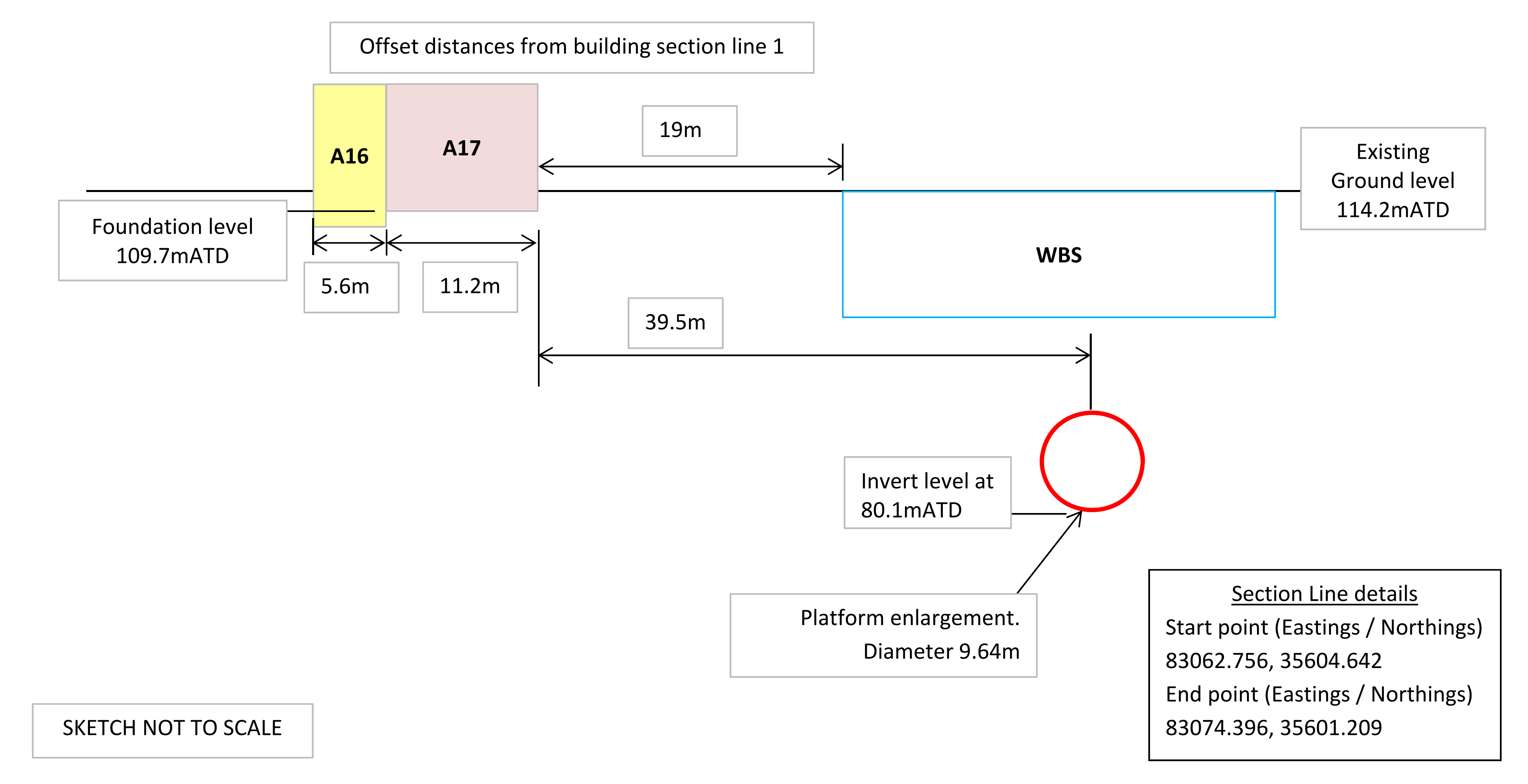

Figure 6: Diagrammatic cross-section of section (line 1) relative to tunnel position

LUL Bank Project Office
10 King William Street
London EC4 N7TW

Bank Station Capacity Upgrade

Building Damage Assessment Report

Building A18

129 Cannon Street

URS-8798-RPT-G-001182

Prepared by:	Lisa Perkins Assistant Geotechnical Engineer	[signature]	18/07/14
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Consultation:

- Ela Palmer — URS Heritage
- Brian Lyons — Dr.Sauer
- Keith Bowers/Neil Moss/Paul Dryden — London Underground
- Olly Newman — Dragados

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1 Introduction

This report summarises the results of a Stage 2 damage assessment for 129 Cannon Street.

Stage 2 damage assessments are undertaken for all buildings within the Stage 1 Greenfield ground surface 1mm settlement contour induced by the construction of the Bank Station Capacity Upgrade (BSCU).

The purpose of the assessment is to determine the potential impact the works will have on the building. This report describes the engineering and heritage assessments undertaken for the building and concludes whether mitigation is likely to be needed and if a further (Stage 3) assessment is recommended in order to verify this.

2 The Building

2.1 General Information

No. 129 Cannon Street is located close to the junction with Abchurch Lane. The general building information used in the assessment has been acquired as part of the structural desktop appraisal. This information is presented in Table 1.

Category	Building Information
BSCU Reference	A18
Location	Cannon Street
Address	129 Cannon Street
Building Type	Assumed load bearing masonry
Construction Age	1899
No. of Storeys	5
Basements	1
Eaves Level (mATD)	126.9
Foundation Type	Assumed strip footings
Ground Level (mATD)	114.3
Listed Grade	II
Note: Levels given are in metres above Tunnel Datum, mATD. Tunnel Datum is 100m below Ordnance Survey Datum at Newlyn.	

Table 1: General building information

A general view of the building exterior is shown in Plate 1. A location plan showing the building in relation to the proposed BSCU works is presented in Figure 2.

Plate 1: General view

2.2 Building Description

129 Cannon Street dates from 1899. This five storey, narrow building is of red brick with Portland stone dressings. There is a shop front at ground floor level, with a cornice above, and the focus of the elevation is a three storey bay window with carved decoration. The shop at ground floor level is modern, with a modern fit-out internally. The rear of the building faces onto Abchurch Yard, and is plain with no particular features.

No full internal inspection has taken place, however it is assumed that this building has a single level of basement.

3 Methodology

This assessment is undertaken in accordance with LU Works Information WI2300[1] and LU Civil Engineering - Common Requirements S1050[2].

The analysis methodology applies to ground-bearing buildings which will be affected by ground movements resulting from the construction of the BSCU. The engineering assessment calculates the potential impact of ground movements and assigns a damage category to the building based on a numeric scale. Additionally, for listed buildings, a heritage assessment is carried out which considers the sensitivity of the structure and the sensitivity of its particular features; a heritage sensitivity score is assigned. The heritage sensitivity score is added to the damage category to obtain the total score. If the total score is 3 or more, a more detailed Stage 3 assessment is triggered.

Oasys Xdisp is used to analyse the Greenfield ground movement in terms of settlement and horizontal displacement. Subsurface tunnelling induced ground movement profiles are determined in accordance with the methodology described by Mair et al[3 & 4].

In order to investigate the relative movements between this building and the neighbour (A19), a displacement line 2 was drawn as shown in Figure 3. It was analysed at A18's founding level which is the same for building A19.

Movements resulting from the Whole Block Scheme (WBS) and shaft excavations have been calculated using LU Guidance Document G0058[5].

The building is modelled as a simple elastic beam which is conservatively assumed to follow the Greenfield ground displacements. The beam is divided into hogging and sagging segments. The tensile strains within each segment are calculated based on the distortion associated with differential settlement (which is characterised by deflection ratio) and the distortion associated with differential horizontal displacement (characterised by horizontal strain).

Xdisp provides a method for calculating the maximum tensile strain within the building superstructure associated with these movements, in accordance with the assessment methodology described by Mair et al [4]. This strain is used to determine the damage category based on the classification system proposed by Burland[6] and in accordance with LU Civil Engineering - Common Requirements S1050[2]. The categories are presented in Table 2.

Damage category	Description of degree of damage	Description of typical damage and likely forms of repair for typical masonry buildings.	Approx. crack width (mm)	Max. tensile strain %
0	Negligible	Hairline cracks.		< 0.05
1	Very slight	Fine cracks easily treated during normal redecoration. Perhaps isolated slight fracture in building. Cracks in exterior visible upon close inspection.	0.1 to 1.0	0.05 to 0.075
2	Slight	Cracks easily filled. Redecoration probably required. Several slight fractures inside building. Exterior cracks visible; some repainting may be required for weather-tightness. Doors and windows may stick slightly.	1 to 5	0.075 to 0.15
3	Moderate	Cracks may require cutting out and patching. Recurrent cracks can be masked by suitable linings. Tuck pointing and possible replacement of a small amount of exterior brickwork may be required. Doors and windows sticking. Utility services may be interrupted. Weather tightness often impaired.	5 to 15 or a number of cracks > 3	0.15 to 0.3
4	Severe	Extensive repair required involving removal and replacement of walls especially over doors and windows. Window and door frames distorted. Floor slopes noticeably. Walls lean or bulge noticeably. Some loss of bearing in beams. Utility services disrupted.	15 to 25 but also depends on number of cracks	> 0.3
5	Very severe	Major repair required involving partial or complete reconstruction. Beams lose bearing, walls lean badly and require shoring. Windows broken by distortion. Danger of instability.	Usually > 25 but depends on number of cracks	
Note: Please refer LU Civil Engineering - Common Requirements S1050[2].				

Table 2: Building damage classification

4 Input Data

The magnitude and distribution of ground movements and degree of building damage is calculated based on the following input data:

- The Xdisp model coordinates and levels are based on the 3D model (20130212DSPITT Scheme R09);
- Four construction stages are considered in accordance with the proposed programme (November 2013) as illustrated in Figure 1;
- Trough width parameter constant, K=0.5 is used in accordance with WI2300[1].

The input data for the building, tunnels and shaft excavation are summarised in Table 3, Table 4 and Table 5 respectively.

Location	Foundation level (mATD)	Building Height above foundation level (m)	E/G
129 Cannon Street	109.8*	17.1	2.6
Note: Where E / G is the ratio of Young's modulus to shear modulus of the deep beam representing the building. * Assumed level, 1.5m thick slab beneath floor level.			

Table 3: Building data

Tunnel Item	Level of axis (mATD)	External diameter (m)	Volume Loss (%)
Running tunnels	83.5	5.4	1.5
Square works adits	75.8 to 95.3	4.1 to 7.8	2.5
Platform enlargement	85.6	7.4 to 11.2	1.5
Escalator barrels	Inclined	8.3 to 8.4	1.5
Central Line Connection	Inclined (87.6 to 89.2)	8.6	1.5

Table 4: Tunnel data

Excavation	Excavation Base Level (mATD)
Grout Shaft at King William Street	97
Whole Block Scheme Box excavation	73
Arthur Street Shaft	81

Table 5: Excavation data

The Xdisp model filenames used to undertake this assessment are:

- A18 - Stage 4
- A18 - Stage 3
- A18 - Stage 2
- A18 - Stage 1

5 Results

5.1 Engineering Assessment

The sections through the building which have been analysed are shown on plan in Figure 3. A line perpendicular to Cannon St was also checked but was not found to be as onerous. Line 2 represents the effects across the rear of the building and its neighbour to the east.

Assessment has been undertaken at three intermediate construction stages and at the end of construction when all major elements of the works including shaft and tunnels have been completed. The damage category assigned to the building is based on the construction stage at which the potential impact on the building is most severe.

The maximum settlement and tensile strain calculated for each of the analysis sections at the most onerous construction stage are presented in Table 6 and Table 7.

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
A18 (line 1)	1	0.008
A18 (line 2)*	4	0.013
Note: * This is strain from an extended line which is not applicable to the building		

Table 6: Building response at most onerous intermediate stage - Construction Stage 2

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
A18 (line 1)	1	0.008
A18 (line 2)*	4	0.013
Note: * This is strain from an extended line which is not applicable to the building		

Table 7: Building response at end of construction – Stage 4

The results of the assessment show that the construction Stage 4 is the critical stage for this building where line 1 experiences the most onerous combined tensile strain. The orientation of this building is shown in Figure 2. The vertical and horizontal ground movements along the section of the building are shown in Figure 4. The relative position of the building and tunnels along section line 1 is shown in Figure 6. The calculated strains are summarised in Table 8 .

Line No	Strains in section (Curvature)	Position from start (m)	Length (m)	Average* Horizontal Strain (%)	Maximum Tensile Strains (%)	Damage Category
Line 1	Hogging	0.0	4.1	0.007	0.008	Negligible
Line 2*	Hogging	0.0	13.3	0.010	0.013	Negligible
Note: * Tensile horizontal strains are +ve. Compressive horizontal strains are –ve. * This is strain from an extended line which is not applicable to the building						

Table 8: Section analysed, results for worst case tensile strain

A18 (line 2) examines the differential movements between the 129 Cannon Street (A18) and the adjacent building (A19). The vertical and horizontal ground movements along the section of the building are shown in Figure 5. The joint area between A18 and A19 is in hogging mode as shown in Figure 5 and Table 8, which could induce cracks at high level, but the tensile strains are very small (negligible).

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0. This corresponds to Negligible damage in accordance with Table 2.

The maximum settlement of the building at foundation level at the end of construction is 1mm.

The building movements are less than those shown by the surface contours on Figure 3. This is correct and reflects the reduction in movement with depth which occurs in this type of analysis.

5.2 Heritage and Structural Assessment

Following site inspection, assessment has been made using the following scoring methodology as set out in Table 9.

Score	STRUCTURE Sensitivity of the structure to ground movements and interaction with adjacent buildings	HERITAGE FEATURES Sensitivity to calculated movement of particular features within the building	CONDITION Factors which may affect the sensitivity of structural or heritage features
0	Masonry buildings with lime mortar and regular openings, not abutted by other buildings, and therefore similar to the buildings on which the original Burland assessment was based.	No particular sensitive features	Good/Fair - not affecting the sensitivity of structural or heritage features
1	Buildings not complying with categories 0 or 2, but still with some sensitive structural features in the zone of settlement e.g.: cantilever stone staircases, long walls without joints or openings, existing cracks where further movements are likely to concentrate, mixed foundations	Brittle finishes, e.g. faience or tight-jointed stonework, which are susceptible to small structural movements and difficult to repair invisibly.	Poor - may change the behaviour of a building in cases of movement. Poor condition of heritage features and finishes. Evidence of previous movement.
2	Buildings which, by their structural form, will tend to concentrate all their movements in one location (e.g.: a long wall without joints and with a single opening).	Finishes which if damaged will have a significant effect on the heritage value of the building, e.g. Delicate frescos, ornate plasterwork ceilings.	Very poor – parlous condition of heritage features and finishes, severe existing damage to structure including evidence of ongoing movement. Essentially buildings where even very small movements could lead to significant damage.

Table 9: Heritage and structural scoring methodology

The results of the heritage assessment carried out for the building are summarised in Table 10.

SENSITIVITY OF THE STRUCTURE
No site visit has been undertaken and this assessment is based on an external inspection and the listing description This building is very narrow and is assumed to be either loadbearing masonry or framed construction. A stone and brick façade is present on both exposed elevations. The predicted settlements are low and there appear to be no structural sensitivities.
Score: 0 – no apparent structural sensitivities
SENSITIVITY OF THE HERITAGE
No internal inspection has been undertaken of this building. The façade of the building has a combination of brick and stone cladding, with decorative elements. However, the predicted settlement is low, and the façade materials will not be sensitive to this level of movement. It is assumed that there are some surviving heritage features within the upper storeys of the building, but it is not thought that they will be sensitive to the predicted settlements.
Score: 0 – the heritage features of the façade will not be sensitive to the predicted settlement.
SENSITIVITY OF THE CONDITION
External inspection has not identified any areas of poor condition or particular condition related sensitivities.
Score: 0 – there are no apparent condition related sensitivities.

Table 10: Heritage and structural assessment

5.3 Total Score

The total score is the summation of the damage category, structural sensitivity, heritage sensitivity and condition sensitivity scores:

The damage category is 0

The structural sensitivity score is 0

The heritage sensitivity score is 0

The condition sensitivity score is 0

The total score for this building is 0

6 Conclusion

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0 for 129 Cannon Street. Specific heritage and structural assessment, relating only to the exterior and ground floor of the building and taking into account the location and extent of settlement and tensile strains highlights the buildings low level of structural and heritage sensitivity to movement. This assessment has determined that the building has a total score of 0.

It is recommended that the building does not require a Stage 3 assessment.

7 References

[1] LU Works Information WI 2300 Ground Movement version 3, 19-07-13.

[2] LU Category 1 Standard: S1050 Civil Engineering - Common Requirements, Issue No. A7, Nov. 2013.

[3] Mair R J, Taylor R N and Bracegirdle A (1993). Subsurface settlement profiles above tunnels in clays. Géotechnique 43, No. 2, pp. 315-320.

[4] Mair R J, Taylor R N and Burland J B (1996). Prediction of ground movements and assessment of risk of building damage due to bored tunnelling. (In: International Conference of Geotechnical Aspects of Underground Construction in Soft Ground, London, pp. 713–718.

[5] LU Guidance Document G0058 Civil Engineering Technical Advice Notes, Issue No. A17, Feb. 2013.

[6] Burland J B (1995). Assessment of risk of damage to buildings due to tunnelling and excavation. Proceedings: 1st International Conference of Earthquake Geotechnical Engineering, IS Tokyo, 1995.

[7] Mott MacDonald (2012). Bank Station building data sheets – A list buildings. N133-BCR-MMD-00-Z-DC-S-0003-S0-1.0.

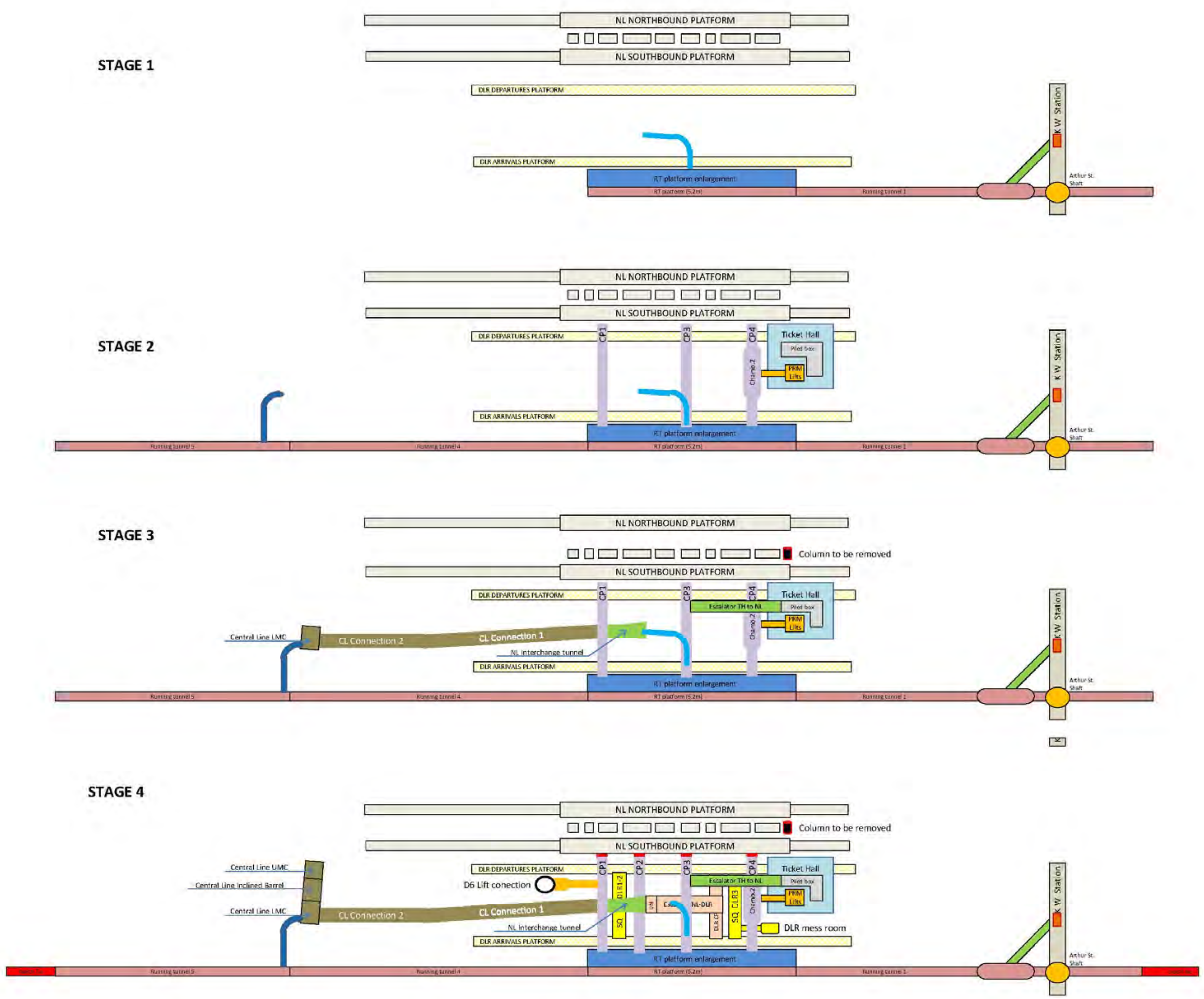

Figure 1: Construction Stage model

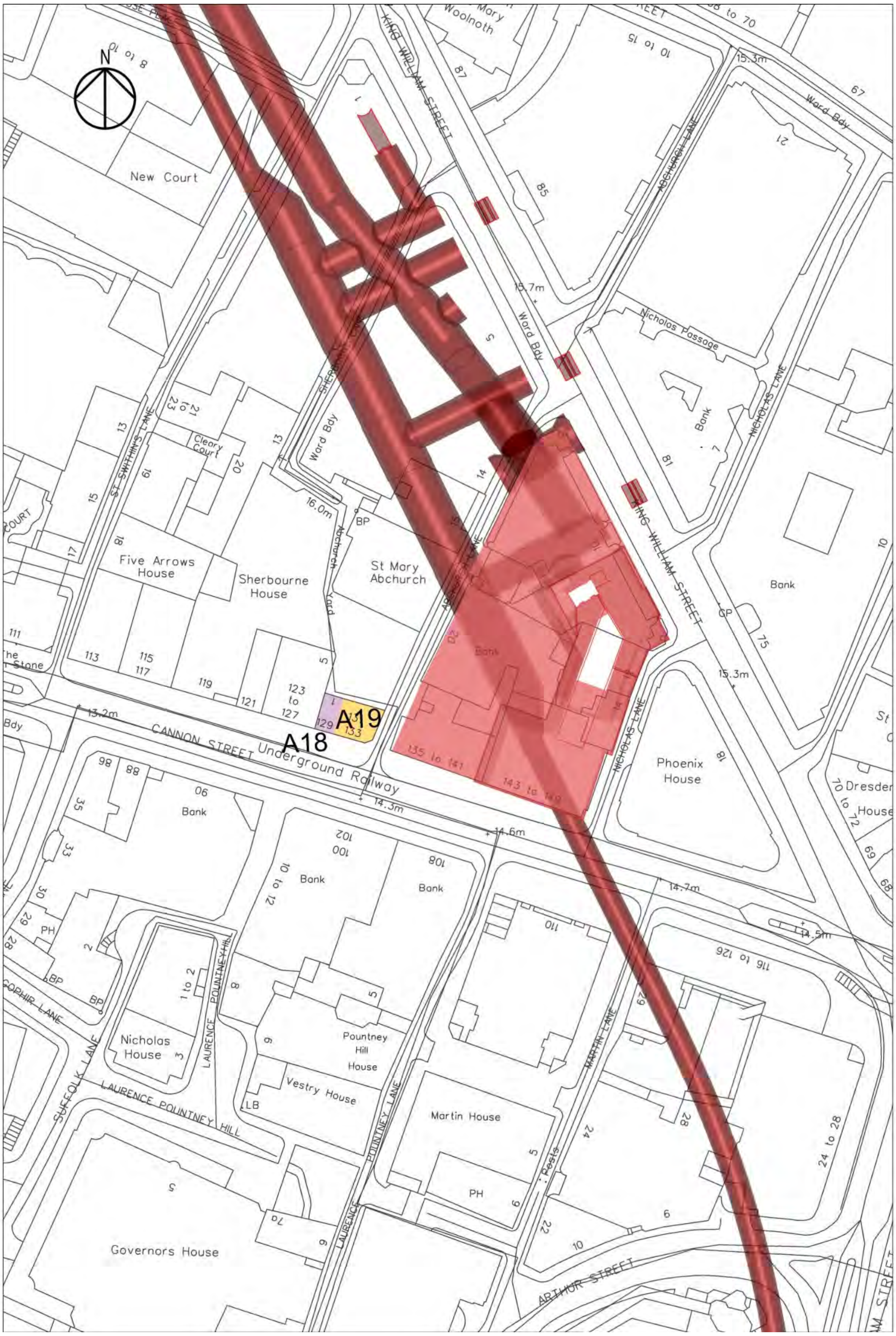

Figure 2: Location plan showing building location in relation to BSCU works

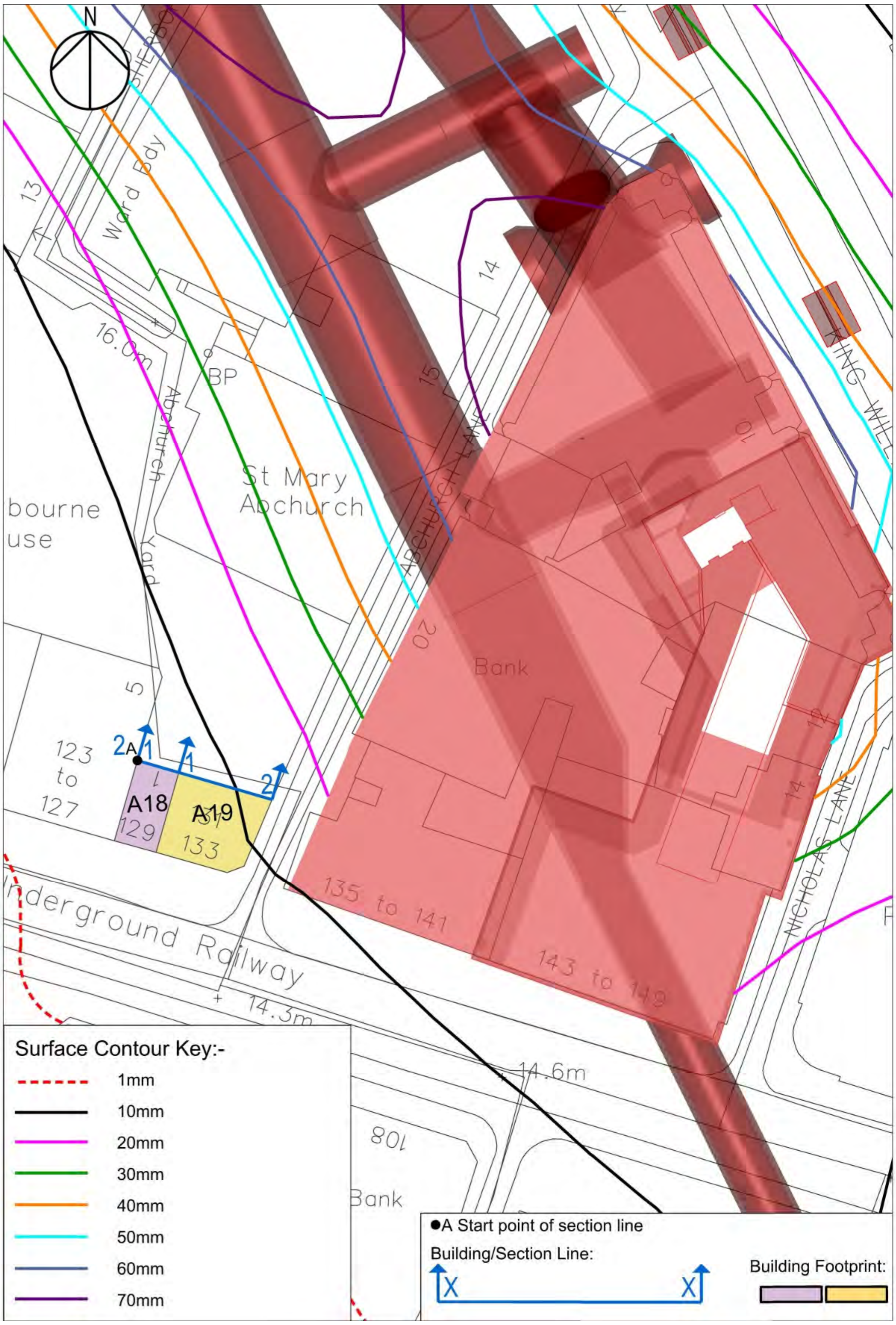

Figure 3: Building location, sections analysed and Settlement Contours at stage of worst case for tensile strains

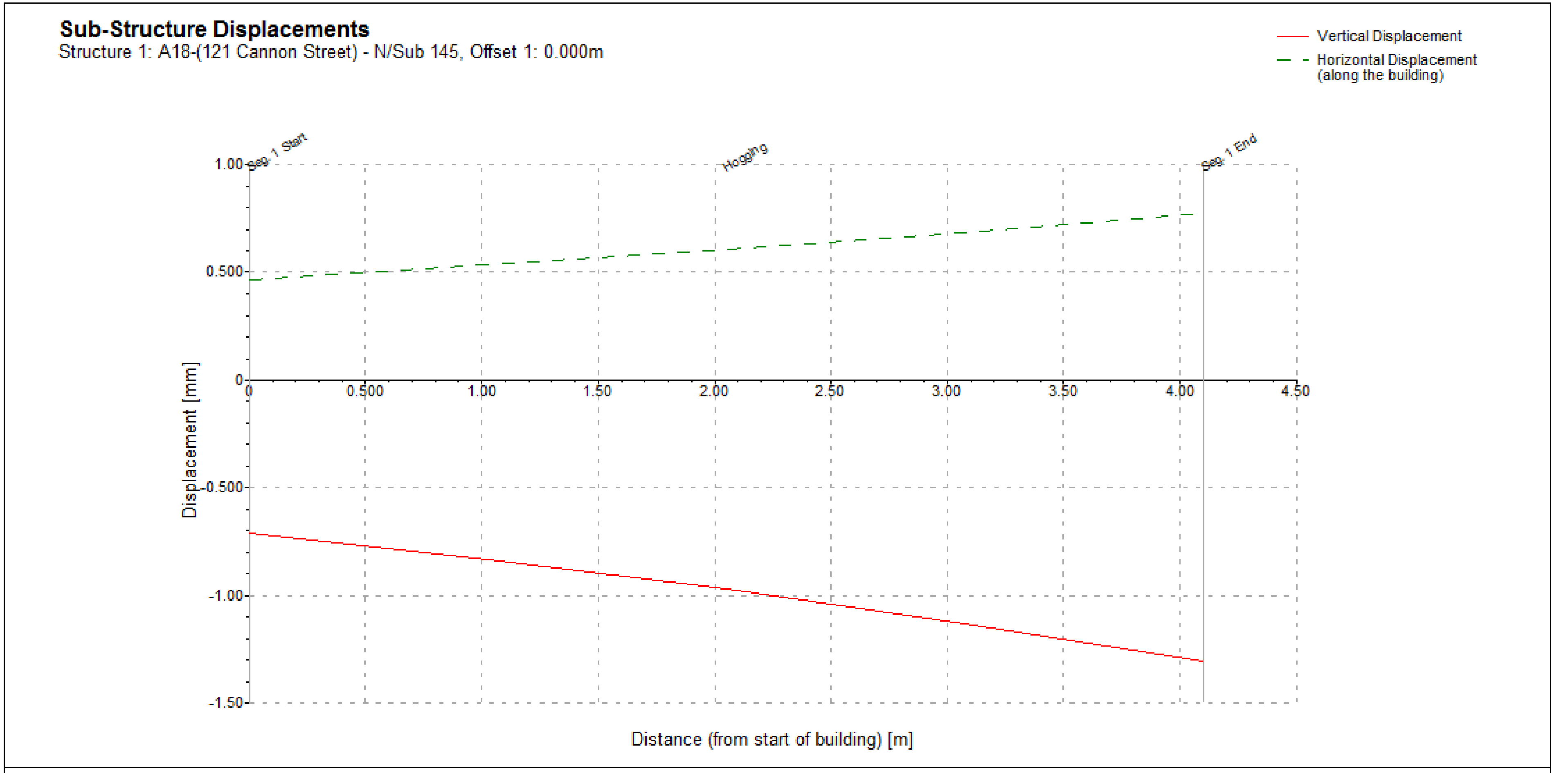

Figure 4: Building displacement at founding level at stage 4 for (line 1) of worst case for tensile strains

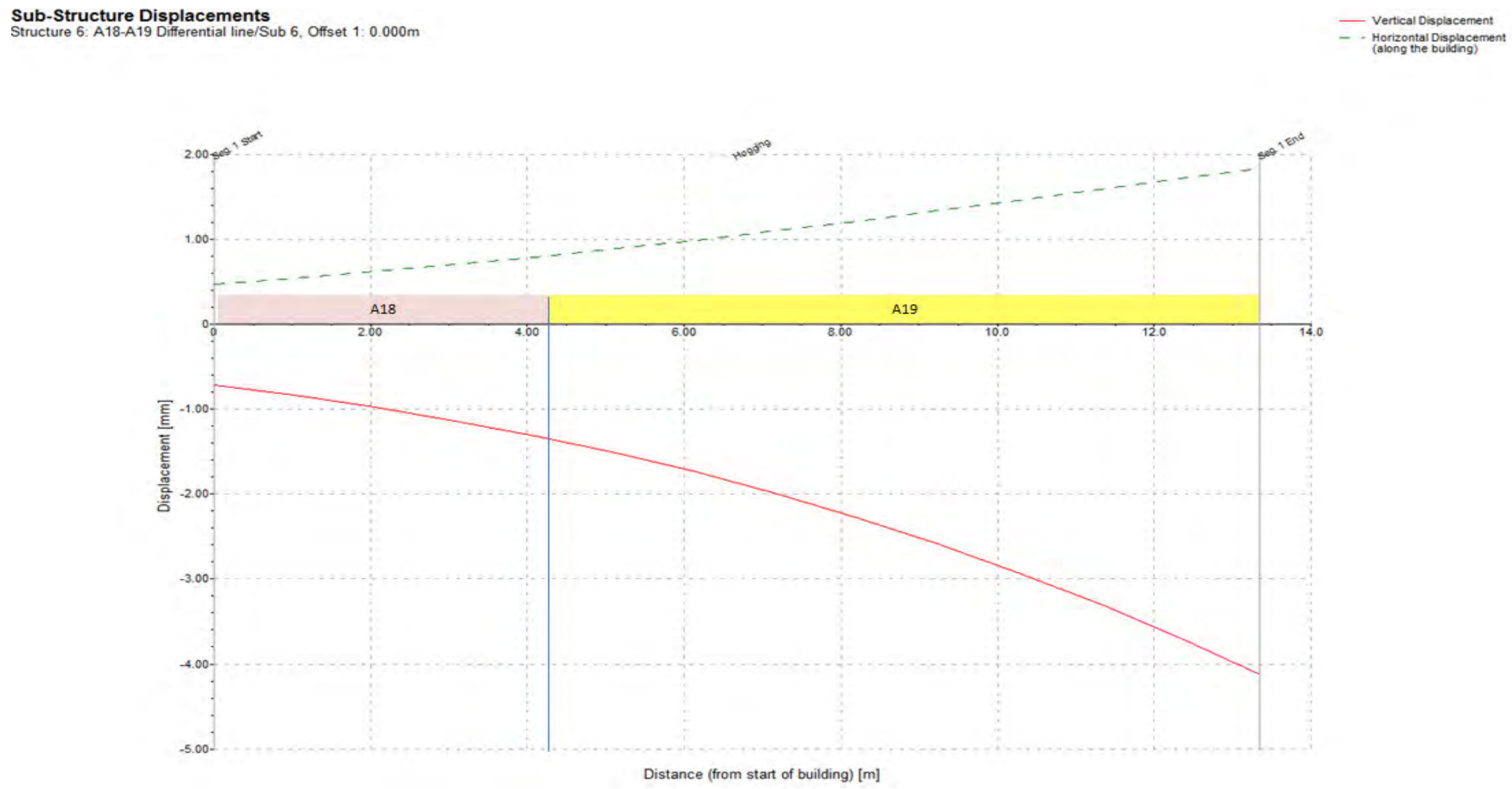

Figure 5: Building displacement at founding level at stage 4 for (line 2) of worst case for tensile strains

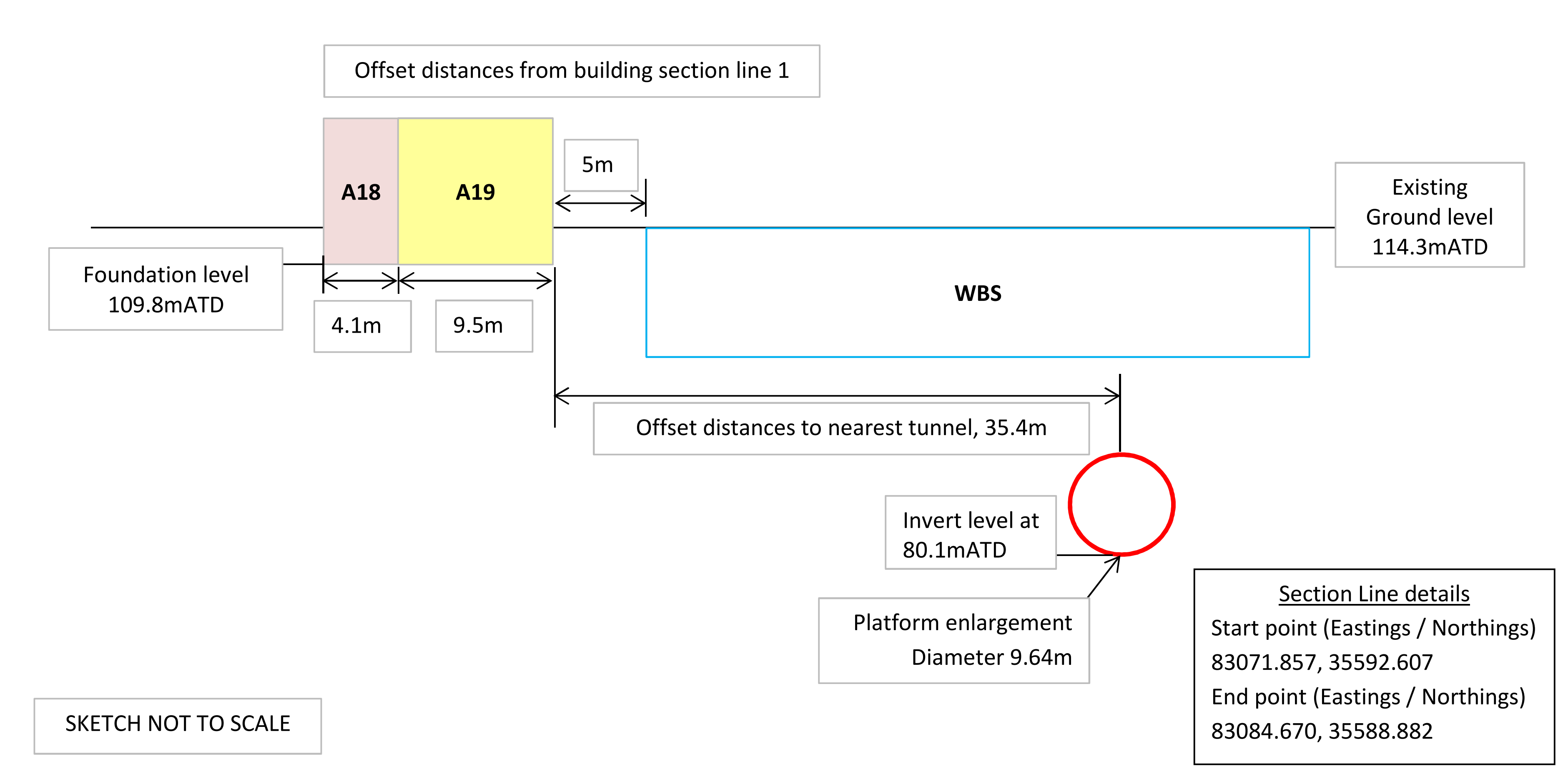

Figure 6: Diagrammatic cross-section of section (line 1) used to determine worst case tensile strain

Bank Station Capacity Upgrade

Building Damage Assessment Report

Building A27

Guild Church of St Mary Woolnoth

URS-8798-RPT-G-001185

Prepared by: Lisa Perkins, Assistant Geotechnical Engineer — L. Perkins — 18/07/14

Checked by: Annaliza Khoo, Principal Geotechnical Engineer — [signature] — 18/07/14

Approved by: John Chantler, Technical Director — [signature] — 18/07/14

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3.0	July 2014	TWAO Issue

For the status of this document, please refer to the Building Damage Assessment Report Register (URS-8798-RGT-001229)

Consultation:

- Ela Palmer — URS Heritage
- Brian Lyons — Dr.Sauer
- Keith Bowers/Neil Moss/Paul Dryden — London Underground
- Olly Newman — Dragados

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FIGURES

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1 Introduction

This report summarises the results of a Stage 2 damage assessment for Guild Church of St Mary Woolnoth, Ref A27.

Stage 2 damage assessments are undertaken for all buildings within the Stage 1 Greenfield ground surface 1mm settlement contour induced by the construction of the Bank Station Capacity Upgrade (BSCU).

The purpose of the assessment is to determine the potential effect the works will have on the building. This report describes the engineering and heritage assessments undertaken for the building and concludes whether mitigation is likely to be needed and if a further (Stage 3) assessment is recommended in order to verify this.

2 The Building

2.1 General Information

Guild Church of St Mary Woolnoth is bounded by King William Street and Lombard Street. General building information used in the assessment has been acquired as part of the structural desktop appraisal. This information is presented in Table 1.

Category	Building Information
BSCU Reference	A27
Location	Guild Church of St Mary Woolnoth
Address	Guild Church of St Mary Woolnoth
Building Type	Load bearing masonry
Construction Age	1716-1727
No. of Storeys	2
Basements	1 (assumed)
Eaves Levels (mATD)	132.8
Foundation Type	Pads and strip footings
Ground Level (mATD)	114.7
Listed Grade	I
Note: Levels given are in metres above Tunnel Datum, mATD. Tunnel Datum is 100m below Ordnance Survey Datum at Newlyn.	

Table 1: General building information

A general view of the building exterior is shown in Plate 1. A location plan showing the building in relation to the proposed BSCU works is presented in Figure 2.

Plate 1: General view

2.2 Building Description & Heritage

Following partial destruction in the Great Fire St Mary Woolnoth was rebuilt in 1670-75 by Sir Robert Vyner. This building was replaced by Hawksmoor's of 1716-27, the only church in the City of London to be built under the New Churches in London and Westminster Act 1710.

The church is constructed from Portland stone in a square plan. The east elevation is blind with the niche for the reredos stepping out. The south elevation, which faced a yard before King William Street was built, is pierced by five round-headed windows, the most westerly of which is blocked. The ground floor is obscured by the 1900 tube entrance (in Baroque style in homage to Hawksmoor) and the extension to the vestry. The north elevation facing Lombard Street is more ornate and contains three openings containing classical columns standing on plinths supported by scrolled brackets either side of blind, round-headed arches.

The west front rises to two storeys with the bell tower, broader than it is deep rising above. The portico is recessed in a round-headed arch with a lunette above. Flanking columns rise to first floor height on either side and the whole arrangement carries deep channelled rustication. The corners of the building are marked with pilasters rising to first floor level.

Internally, the north-west and south-west corners are chamfered to house the stairs to the roof, tower and crypt. The high, square central space is supported by sets of three fluted stone Corinthian angle columns supporting an entablature under a clerestory pierced by lunettes on each side. The ceilings of the ambulatory are divided by structural beams which create oblong, square and triangular spaces. The ceilings at both levels are very heavily decorated.

At the lower level much of the original woodwork survives including the gallery fronts (set onto the walls in the restoration of 1875-76) the west organ gallery with organ case dated 1681, massive baldacchino in a niche over the altar and the pulpit and tester to the north of the nave.

The spiral staircase in the north-west corner of the church rises to the door to the north gallery and then to the ringing chamber and bell chamber above. The chamber contains three bronze bells cast by the Eldridge foundry in Chertsey in 1670 and 1672 for the repaired 15th century church and subsequently rehung in Hawksmoor’s building.

The spiral staircase in the south-west corner of the church leads up to the roof and down to the crypt. The lower level roof is flat and leaded and surmounted by a parapet topped with a balustrade on the north side. All that remains of the crypt is a narrow corridor running east from the bottom of the stairs and sandwiched between the 1900 entrance to Bank Station and the station’s booking hall. The corridor opens out at the east end and appears to have been preserved as access to the church’s boiler.

Hawksmoor’s original church incorporated a small, single storey vestry attached to the south-east corner. There were originally two principal rooms, one parallel to the south aisle of the church and one at right angles to it. There were two entrances to the vestry, one from the interior of the church in the south aisle and one from the exterior behind the east wall. When the Bank tube station entrance was built in 1900 the vestry was extended to the west on the ground floor and a first floor was added.

3 Methodology

This assessment is undertaken in accordance with LU Works Information WI2300[1] and LU Civil Engineering - Common Requirements S1050[2].

The analysis methodology applies to ground-bearing buildings which will be affected by ground movements resulting from the construction of the BSCU. The engineering assessment calculates the potential impact of ground movements and assigns a damage category to the building based on a numeric scale. Additionally, for listed buildings, a heritage assessment is carried out which considers the sensitivity of the structure and the sensitivity of its particular features; a heritage sensitivity score is assigned. The heritage sensitivity score is added to the damage category to obtain the total score. If the total score is 3 or more, a more detailed Stage 3 assessment is triggered.

In order to investigate the relative movements between this building and 87 King William Street (A28), an extended displacement line 2 was drawn along the facades as shown in Figure 3, which was analysed at A27's founding level. The results are shown in Table 6.

Oasys Xdisp is used to analyse the Greenfield ground movement in terms of settlement and horizontal displacement. Subsurface tunnelling induced ground movement profiles are determined in accordance with the methodology described by Mair et al[3 & 4].

Movements resulting from the Whole Block Scheme (WBS) and shaft excavations have been calculated using LU Guidance Document G0058[5].

The building is modelled as a simple elastic beam which is conservatively assumed to follow the Greenfield ground displacements. The beam is divided into hogging and sagging segments. The tensile strains within each segment are calculated based on the distortion associated with differential settlement (which is characterised by deflection ratio) and the distortion associated with differential horizontal displacement (characterised by horizontal strain).

Xdisp provides a method for calculating the maximum tensile strain within the building superstructure associated with these movements, in accordance with the assessment methodology described by Mair et al [4]. This strain is used to determine the damage category based on the classification system proposed by Burland[6] and in accordance with LU Civil Engineering - Common Requirements S1050[2]. The categories are presented in Table 2.

Damage Category	Description of Degree of Damage	Description of Typical Damage and likely forms of Repair for Typical Masonry Buildings.	Approx. Crack Width (mm)	Max. Tensile Strain %
0	Negligible	Hairline cracks.		< 0.05
1	Very slight	Fine cracks easily treated during normal redecoration. Perhaps isolated slight fracture in building. Cracks in exterior visible upon close inspection.	0.1 to 1.0	0.05 to 0.075
2	Slight	Cracks easily filled. Redecoration probably required. Several slight fractures inside building. Exterior cracks visible; some repainting may be required for weather-tightness. Doors and windows may stick slightly.	1 to 5	0.075 to 0.15
3	Moderate	Cracks may require cutting out and patching. Recurrent cracks can be masked by suitable linings. Tuck pointing and possible replacement of a small amount of exterior brickwork may be required. Doors and windows sticking. Utility services may be interrupted. Weather tightness often impaired.	5 to 15 or a number of cracks > 3	0.15 to 0.3
4	Severe	Extensive repair required involving removal and replacement of walls especially over doors and windows. Window and door frames distorted. Floor slopes noticeably. Walls lean or bulge noticeably. Some loss of bearing in beams. Utility services disrupted.	15 to 25 but also depends on number of cracks	> 0.3
5	Very severe	Major repair required involving partial or complete reconstruction. Beams lose bearing, walls lean badly and require shoring. Windows broken by distortion. Danger of instability.	Usually > 25 but depends on number of cracks	
Note: Please refer LU Civil Engineering - Common Requirements S1050[2].				

Table 2: Building damage classification

4 Input Data

The magnitude and distribution of ground movements and degree of building damage is calculated based on the following input data:

- The Xdisp model coordinates and levels are based on the 3D model (20130212DSPITT Scheme R09);
- Four construction stages are considered in accordance with the proposed programme (November 2013) as illustrated in Figure 1;
- Trough width parameter constant, K=0.5 is used in accordance with WI2300[1].

The input data for the building, tunnels and shaft excavation are summarised in Table 3, Table 4 and Table 5 respectively.

Location	Foundation level (mATD)	Building Height above foundation level (m)	E/G
Guild Church of St Mary Woolnoth	107.2*	25.6	2.6
Note: Where E / G is the ratio of Young's modulus to shear modulus of the deep beam representing the building. *Known level. Refer to [9].			

Table 3: Building data

Tunnel Item	Level of axis (mATD)	External diameter (m)	Volume Loss (%)
Running tunnels	83.5	5.4	1.5
Square works adits	75.8 to 95.3	4.1 to 7.8	2.5
Access tunnel to D6 lift Square works	86.3	4.1	2.5
Platform enlargement	85.6	7.4 to 11.2	1.5
Escalator barrels	Inclined	8.3 to 8.4	1.5
Central Line Connection	Inclined (87.6 to 89.2)	8.6	1.5

Table 4: Tunnel data

Excavation	Excavation Base Level (mATD)
Grout Shaft at King William Street	97
Whole Block Scheme Box excavation	73
Arthur Street Shaft	81

Table 5: Excavation data

The distance of Guild Church of St Mary Woolnoth (A27) relative to excavation elements listed in Table 5 is sufficiently large that this building will not be affected by their construction.

The Xdisp model filenames used to undertake this assessment are:

- A27 - Stage 4
- A27 - Stage 3
- A27 - Stage 2
- A27 - Stage 1

5 Results

5.1 Engineering Assessment

The sections through the building which have been analysed are shown on plan in Figure 3.

Assessment has been undertaken at three intermediate construction stages and at the end of construction when all major elements of the works including shaft and tunnels have been completed. The damage category assigned to the building is based on the construction stage at which the potential impact on the building is most severe.

The maximum settlement and tensile strain calculated for each of the analysis sections at the most onerous intermediate construction stage and at the end of construction are presented in Table 6 and Table 7.

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
A27 (line 1)	<1	0.001
A27 (line 2)	<1	0.003
A27 (line 3)	<1	<0.001

Table 6: Building response at most onerous intermediate stage - Construction Stage 3

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
A27 (line 1)	<1	0.004
A27 (line 2)*	1	0.007
A27 (line 3)	1	<0.001
Note: * This is strain from an extended line which is not applicable to the building		

Table 7: Building response at end of construction stage - Construction Stage 4

The results of the assessment show construction Stage 4 is the critical stage for this building where line 1 experiences the most onerous combined tensile strain. The orientation of the building is shown in Figure 2. The relative position of the building and tunnels along section line 1 is shown in Figure 5. The calculated strains are summarised in Table 8.

A27 (line 2) examines the differential movements between 87 King William Street (A28) and St Mary Woolnoth Church (A27), see Figure 4. The area between A27 and A28 is in a hogging mode which could induce cracking at the joints between these buildings. The tensile strain is very small (Negligible) as shown in Table 8.

Line #	Strains in section (Curvature)	Position from start (m)	Length (m)	Average* Horizontal Strain (%)	Maximum Tensile Strains (%)	Damage Category
Line 1	Hogging	0.0	18.7	0.003	0.004	Negligible
Line 2**	Hogging	0.0	24.2	0.005	0.007	Negligible
Note: * Tensile horizontal strains are +ve. Compressive horizontal strains are –ve. ** This is strain from an extended line which is not applicable to the building						

Table 8: Section analysed, results for worst case tensile strain

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0. This corresponds to Negligible damage in accordance with Table 2.

The maximum settlement of the building at foundation level at the end of construction is 1mm.

5.2 Heritage and Structural Assessment

Following site inspection, assessment has been made using the following scoring methodology set out in Table 9.

Score	STRUCTURE Sensitivity of the structure to ground movements and interaction with adjacent buildings	HERITAGE FEATURES Sensitivity to calculated movement of particular features within the building	CONDITION Factors which may affect the sensitivity of structural or heritage features
0	Masonry buildings with lime mortar and regular openings, not abutted by other buildings, and therefore similar to the buildings on which the original Burland assessment was based.	No particular sensitive features	Good/Fair - not affecting the sensitivity of structural or heritage features
1	Buildings not complying with categories 0 or 2, but still with some sensitive structural features in the zone of settlement e.g.: cantilever stone staircases, long walls without joints or openings, existing cracks where further movements are likely to concentrate, mixed foundations	Brittle finishes, e.g. faience or tight-jointed stonework, which are susceptible to small structural movements and difficult to repair invisibly.	Poor - may change the behaviour of a building in cases of movement. Poor condition of heritage features and finishes. Evidence of previous movement.
2	Buildings which, by their structural form, will tend to concentrate all their movements in one location (e.g.: a long wall without joints and with a single opening).	Finishes which if damaged will have a significant effect on the heritage value of the building, e.g. Delicate frescos, ornate plasterwork ceilings.	Very poor – parlous condition of heritage features and finishes, severe existing damage to structure including evidence of ongoing movement. Essentially buildings where even very small movements could lead to significant damage.

Table 9: – Heritage and structural scoring methodology

The results of the heritage assessment carried out for the building are summarised in Table 10.

SENSITIVITY OF THE STRUCTURE
The church is located directly over LUL booking hall. The booking hall was constructed in the late 19th Century within and beneath the crypt of the church. It is understood that the original structure of the church is now supported on a series of beams over the ticket hall below. There are numerous areas of existing cracks and signs of previous movement having been made good. The intrados over each of the windows on the west elevation is cracked, probably between two voussoirs. In addition the down stand beams that form part of the coffered ceiling between the principal columns and the external wall generally show signs of cracking having previously been made good. The condition of the underlying structure is not clear; however there are signs of water penetration in various areas which may have caused damage. In the floor of the church a significant crack exists in the timber parquet flooring, indicating structural movement of the supporting slab.
Score: 1 - There are areas of existing damage which may concentrate any further movements. The Quinquennial report suggests further areas of sensitivity within the structure
SENSITIVITY OF THE HERITAGE
Though restored in 1875-76 by William Butterfield the church has survived with limited alterations and contains a great many features of architectural and artistic significance. The masonry is finely jointed and will be vulnerable to the predicted differential settlements. Damage to these elements could undermine the architectural significance of the exterior. The interior is particularly rich in decorative plasterwork detail. Significant internal features that are likely to be sensitive to structural movement, particularly those on the south west side of the church, are the angle columns at the corners of the nave; the entablature and cornice; the arches and decorated keystones to the lunettes; the decorative panels above the ambulatory, plaster ceiling and the baldacchino and the decorated segmental arch above the altar.
Score: 1 – the interior contains highly sensitive, brittle plaster surfaces. The exterior is of finely jointed stonework.
SENSITIVITY OF THE CONDITION
Based on the conditions apparent in the survey there are areas of water penetration through roofs and gutters and cracking in the walls and floor. It is not clear whether the cracking in the floor and windows is due to active or historic movement. During the visit the City Churches representative made reference to the most recent Quinquennial inspection which recommended a significant programme of repairs and stabilisation to the external fabric. It is understood this includes works in connection with corroded cramps within the stonework of the façade.
Score: 1 – the structure and finishes show evidence of previous movement, with the Quinquennial report confirming the need for repair

Table 10: – Heritage and structural assessment

5.3 Total Score

The total score is the summation of the damage category, structural sensitivity, heritage sensitivity and condition sensitivity scores:

The damage category is 0

The structural sensitivity score is 1

The heritage sensitivity score is 1

The condition sensitivity score is 1

The total score for this building is 3

6 Conclusion

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0 for St Mary Woolnoth. However, specific heritage and structural assessment taking into account the location and extent of settlement and tensile strains highlights the building's high level of structural and heritage sensitivity to movement, notwithstanding the small predicted tensile strains and movements in this area. In addition, potential sensitivities due to poor condition have been identified. This assessment has determined that the building has a total score of 3 including a score of 1 for condition.

According to the methodology presented within LU Standard S1050, which does not take in to account condition scoring, a Stage 3 assessment is not required. Acknowledging the existing condition of the building, it will be necessary to undertake a condition survey before and after the works.

7 References

[1] LU Works Information WI 2300 Ground Movement version 3, 19-07-13.

[2] LU Category 1 Standard: S1050 Civil Engineering - Common Requirements, Issue No. A7, Nov. 2013.

[3] Mair R J, Taylor R N and Bracegirdle A (1993). Subsurface settlement profiles above tunnels in clays. Géotechnique 43, No. 2, pp. 315-320.

[4] Mair R J, Taylor R N and Burland J B (1996). Prediction of ground movements and assessment of risk of building damage due to bored tunnelling. (In: International Conference of Geotechnical Aspects of Underground Construction in Soft Ground, London, pp. 713–718.

[5] LU Guidance Document G0058 Civil Engineering Technical Advice Notes, Issue No. A17, Feb. 2013.

[6] Burland J B (1995). Assessment of risk of damage to buildings due to tunnelling and excavation. Proceedings: 1st International Conference of Earthquake Geotechnical Engineering, IS Tokyo, 1995.

[7] Mott MacDonald (2012). Bank Station building data sheets – A list buildings. N133-BCR-MMD-00-Z-DC-S-0003-S0-1.0.

[8] Selemetas.D et al (2005). The response of full scale piles to tunnelling. Geotechnical aspects of underground construction in soft ground (Bakker et al (eds)) pp.763-769.

[9] City and South London Railway Ext, Bank Station, St Mary Woolnoth Church, Drawing E, (date unknown).

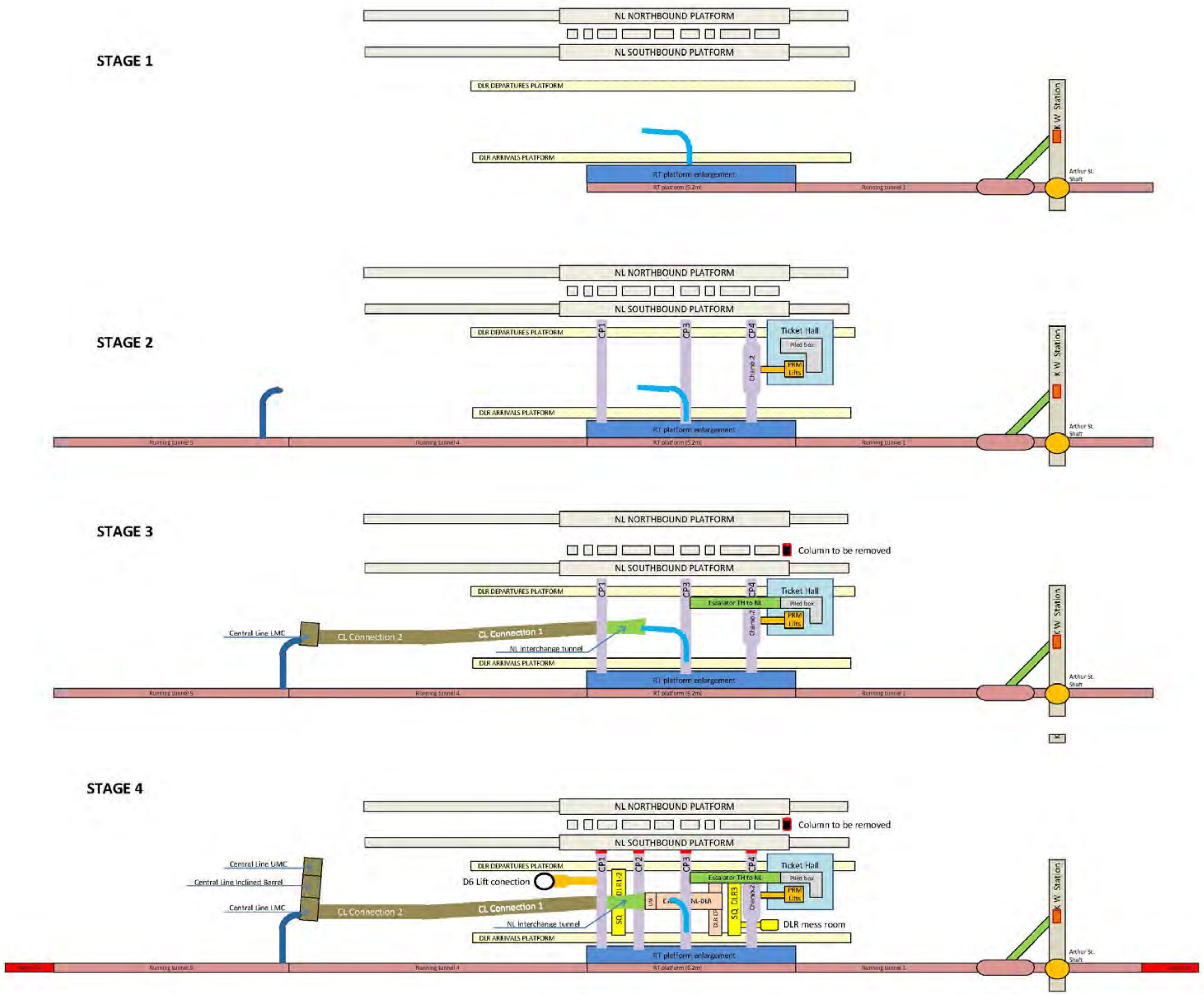

Figure 1: Construction Stage model

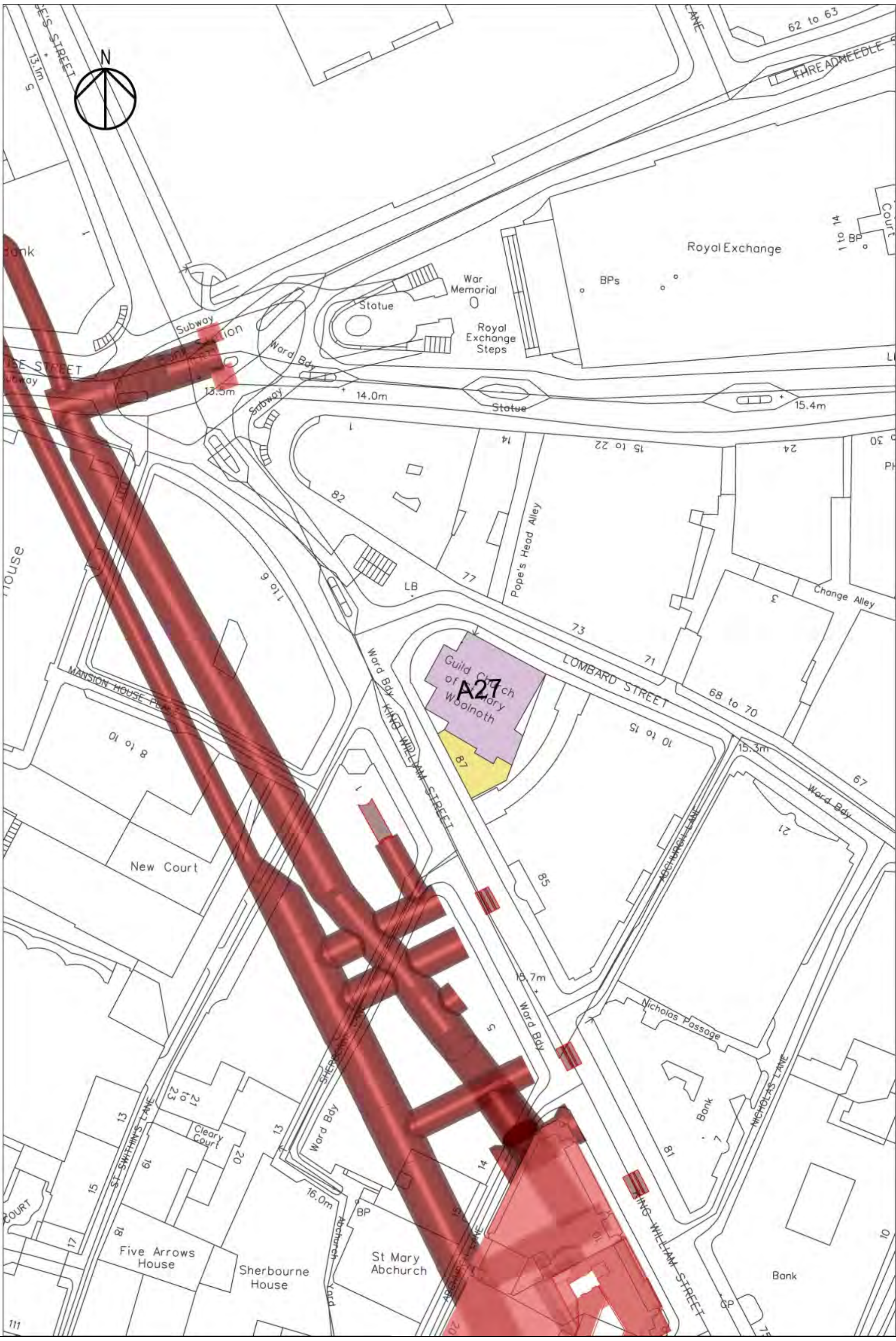

Figure 2: Location plan showing building location in relation to BSCU works

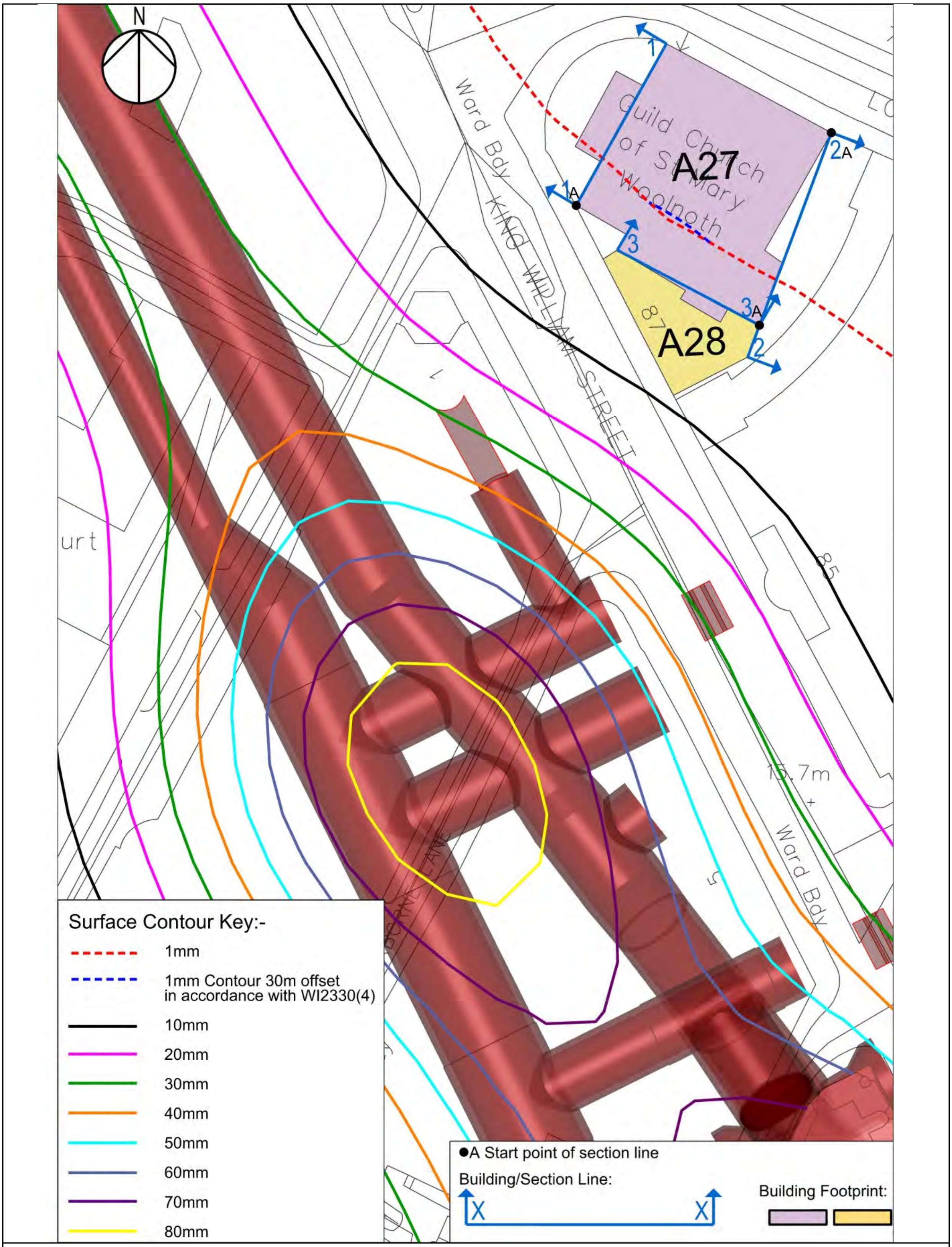

Figure 3: Building location, sections analysed and Settlement Contours at stage of worst case for tensile strains

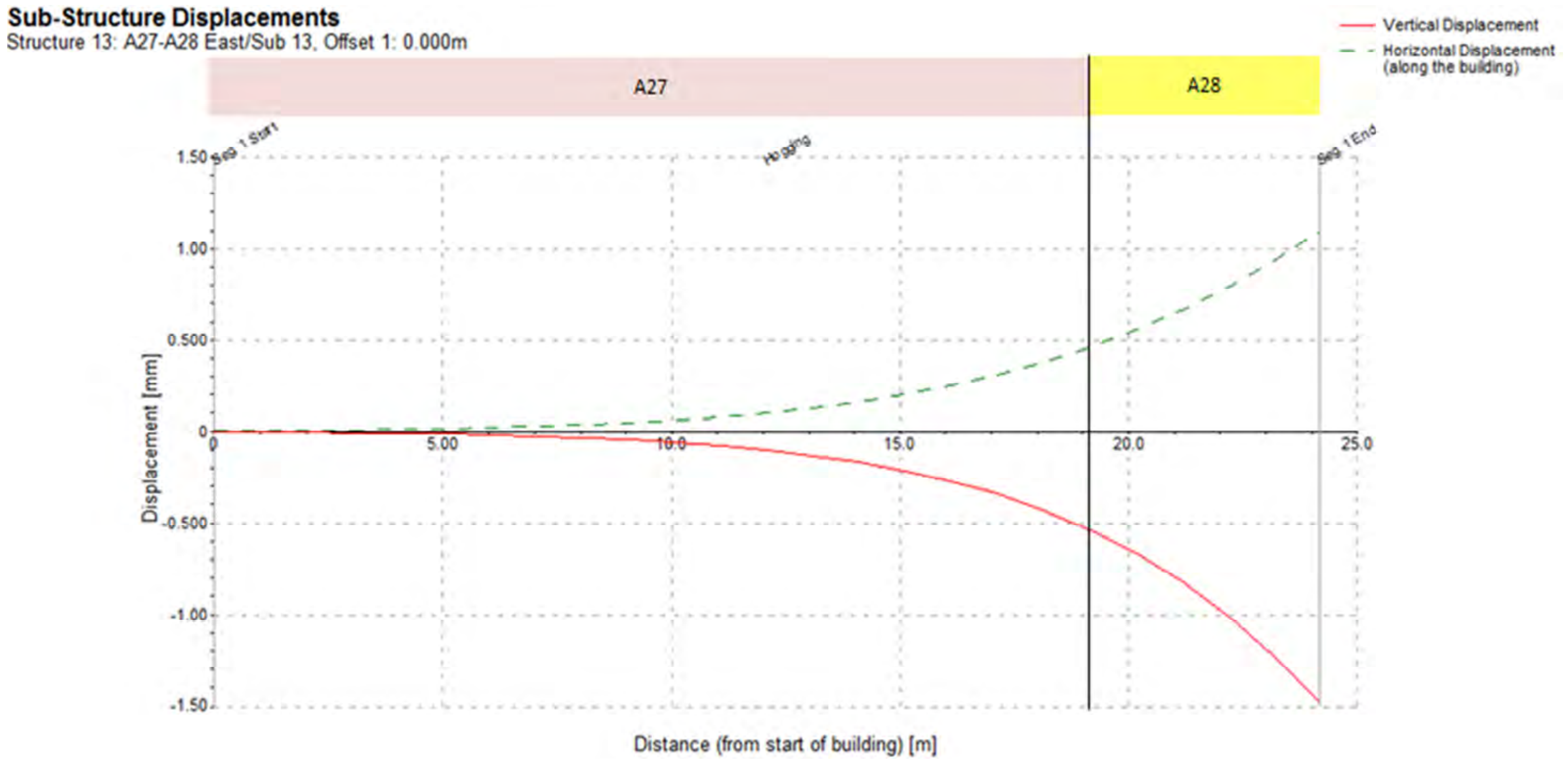

Figure 4: Building displacement at founding level at stage 4 (line 2)

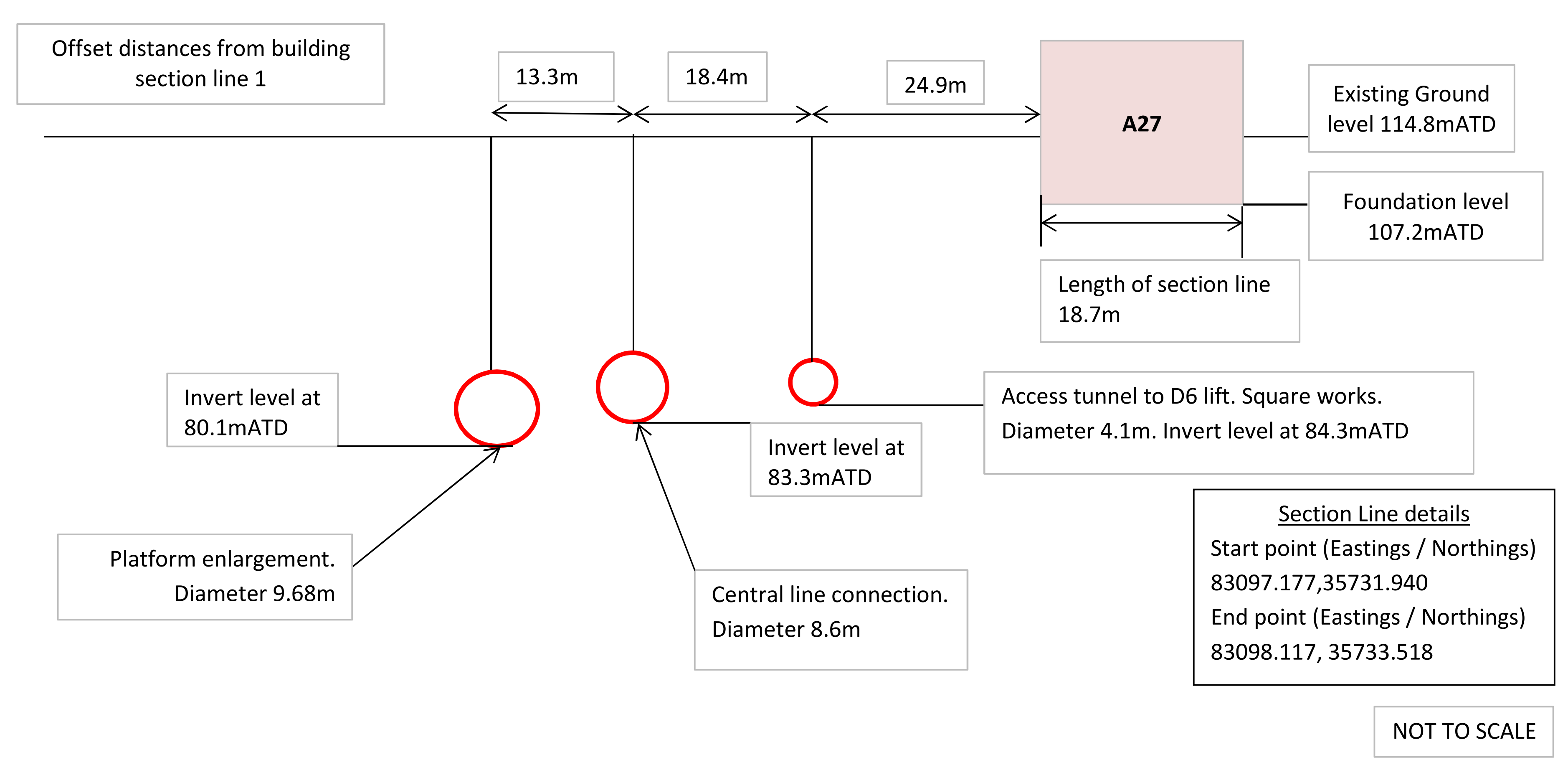

Figure 5: Diagrammatic cross-section of section (line 1) relative to tunnel position

DRAGADOS
Safely Together

LUL Bank Project Office
10 King William Street
London EC4 N7TW

Bank Station Capacity Upgrade

Building Damage Assessment Report

Building A34

29 Martin Lane

URS-8798-RPT-G-001192

Prepared by: Lisa Perkins, Assistant Geotechnical Engineer — 18/07/14

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1 Introduction

This report summarises the results of a Stage 2 damage assessment for 29 Martin Lane.

Stage 2 damage assessments are undertaken for all buildings within the Stage 1 Greenfield ground surface 1mm settlement contour induced by the construction of the Bank Station Capacity Upgrade (BSCU).

The purpose of the assessment is to determine the potential effect the works will have on the building. This report describes the engineering and heritage assessments undertaken for the building and concludes whether mitigation is likely to be needed and if a further (Stage 3) assessment is recommended in order to verify this.

2 The Building

2.1 General Information

No. 29 Martin Lane is located in the eponymous lane sloping down to the south from Cannon Street. The building has been assumed to be load bearing masonry construction, using Flemish bond red brick with some dressings. The building has a single level storey below ground with the structure likely to be founded on strip footings[7]. General building information used in the assessment has been acquired as part of the structural desktop appraisal. This information is presented in Table 1.

Category	Building Information
BSCU Reference	A34
Location	Martin Lane
Address	29 Martin Lane
Building Type	Load bearing masonry
Construction Age	1853
No. of Storeys	5
Basements	1
Eaves Level (mATD)	131.5
Foundation Type	Strip footings (assumed)
Ground Level (mATD)	113.8
Listed	Grade II
Note: Levels given are in metres above Tunnel Datum, mATD. Tunnel Datum is 100m below Ordnance Survey Datum at Newlyn.	

Table 1: General building information

A general view of the building exterior is shown in Plate 1. A location plan showing the building in relation to the proposed BSCU works is presented in Figure 2.

Plate 1: General view

2.2 Building Description

This Grade II listed building was built in 1853, and a roof extension was completed between 1978 and 1980. The building is occupied as solicitors' offices, and comprises five storeys plus one basement. There is a bell tower at the south western corner. The construction is of framed cellular masonry walls, with timber floors and a mansard roof.

The main façade on St Martin's Lane is characterised by three bays and three storeys in Flemish bond red brick with painted stucco dressings. The main entrance is through a projecting arched porch in stucco, flanked by round-headed windows with stucco architraves to the left, and a red brick bell tower with painted stucco quoins to the right.

The west elevation, including the bell tower is characterised by a large bracketed clock with a segmental pediment facing Martin Lane, a canted bow window to first and second floors and two attic storeys within a slated mansard roof rising behind plain parapet. Windows to the main elevation and to the east elevation have stucco surrounds and moulded architraves.

The building shows a compact, rectangular plan with a service block hosting the original stair, lift and toilets located to middle of rear elevation facing north. The service block is repeated on each floor, serving all floors from basement to fourth. The original interiors have been evidently altered over the centuries as room layouts and distribution follows functional needs and few of the original finishes are still in place aside from some plaster enrichments; the building is currently partitioned to suit the various office activities, and there are suspended ceilings to most rooms.

3 Methodology

This building damage assessment is undertaken in accordance with LU Works Information WI2300[1] and LU Civil Engineering - Common Requirements S1050[2].

The analysis methodology applies to ground-bearing buildings which will be affected by ground movements resulting from the construction of the BSCU. The engineering assessment calculates the potential impact of ground movements and assigns a damage category to the building based on a numeric scale. Additionally, for listed buildings, a heritage assessment is carried out which considers the sensitivity of the structure and the sensitivity of its particular features; a heritage sensitivity score is assigned. The heritage sensitivity score is added to the damage category to obtain the total score. If the total score is 3 or more, a more detailed Stage 3 assessment is triggered.

Oasys Xdisp is used to analyse the Greenfield ground movement in terms of settlement and horizontal displacement. Subsurface tunnelling induced ground movement profiles are determined in accordance with the methodology described by Mair et al[3 & 4].

Movements resulting from the Whole Block Scheme (WBS) and shaft excavations have been calculated using LU Guidance Document G0058[5].

The building is modelled as a simple elastic beam which is conservatively assumed to follow the Greenfield ground displacements. The beam is divided into hogging and sagging segments. The tensile strains within each segment are calculated based on the distortion associated with differential settlement (which is characterised by deflection ratio) and the distortion associated with differential horizontal displacement (characterised by horizontal strain).

Xdisp provides a method for calculating the maximum tensile strain within the building superstructure associated with these movements, in accordance with the assessment methodology described by Mair et al [4]. This strain is used to determine the damage category based on the classification system proposed by Burland[6] and in accordance with LU Civil Engineering - Common Requirements S1050[2]. The categories are presented in Table 2.

Damage Category	Description of Degree of Damage	Description of Typical Damage and likely forms of Repair for Typical Masonry Buildings.	Approx. Crack Width (mm)	Max. Tensile Strain %
0	Negligible	Hairline cracks.		< 0.05
1	Very slight	Fine cracks easily treated during normal redecoration. Perhaps isolated slight fracture in building. Cracks in exterior visible upon close inspection.	0.1 to 1.0	0.05 to 0.075
2	Slight	Cracks easily filled. Redecoration probably required. Several slight fractures inside building. Exterior cracks visible; some repainting may be required for weather-tightness. Doors and windows may stick slightly.	1 to 5	0.075 to 0.15
3	Moderate	Cracks may require cutting out and patching. Recurrent cracks can be masked by suitable linings. Tuck pointing and possible replacement of a small amount of exterior brickwork may be required. Doors and windows sticking. Utility services may be interrupted. Weather tightness often impaired.	5 to 15 or a number of cracks > 3	0.15 to 0.3
4	Severe	Extensive repair required involving removal and replacement of walls especially over doors and windows. Window and door frames distorted. Floor slopes noticeably. Walls lean or bulge noticeably. Some loss of bearing in beams. Utility services disrupted.	15 to 25 but also depends on number of cracks	> 0.3
5	Very severe	Major repair required involving partial or complete reconstruction. Beams lose bearing, walls lean badly and require shoring. Windows broken by distortion. Danger of instability.	Usually > 25 but depends on number of cracks	
Note: Please refer LU Civil Engineering - Common Requirements S1050[2].				

Table 2: Building damage classification

4 Input Data

The magnitude and distribution of ground movements and degree of building damage is calculated based on the following input data:

- The Xdisp model coordinates and levels are based on the 3D model (20130212DSPITT Scheme R09);
- Four construction stages are considered in accordance with the proposed programme (November 2013) as illustrated in Figure 1;
- Trough width parameter constant, K=0.5 is used in accordance with WI2300[1].

The input data for the building, tunnels and shaft excavation are summarised in Table 3, Table 4 and Table 5 respectively.

Location	Foundation level (mATD)	Building Height above foundation level (m)	E/G
29 Martin Lane	109.3*	22.2	2.6
Note: Where E / G is the ratio of Young's modulus to shear modulus of the deep beam that is to represent the building. * Assumed level, 1.5m thick slab beneath floor level.			

Table 3: Building data

Tunnel Item	Level of axis (mATD)	External diameter (m)	Volume Loss (%)
Running tunnels	84.9	5.4	1.5
Square works adits	75.8 to 95.3	4.1 to 7.8	2.5
Platform enlargement	85.6	7.4 to 11.2	1.5
Escalator barrels	Inclined	8.3 to 8.4	1.5
Central Line Connection	Inclined (87.6 to 89.2)	8.6	1.5

Table 4: Tunnel data

Excavation	Excavation Base Level (mATD)
Grout Shaft at King William Street	97
Whole Block Scheme Box excavation	73
Arthur Street Shaft	81

Table 5: Excavation data

The Xdisp model filenames used to undertake this assessment are:

- A34 - Stage 4
- A34 - Stage 3
- A34 - Stage 2
- A34 - Stage 1

5 Results

5.1 Engineering Assessment

The sections through the building which have been analysed are shown on plan in Figure 3.

Assessment has been undertaken at three intermediate construction stages and at the end of construction when all major elements of the works including shaft and tunnels have been completed. The damage category assigned to the building is based on the construction stage at which the potential impact on the building is most severe.

The maximum settlement and tensile strain calculated for each of the analysis sections at the most onerous intermediate construction stage and at the end of construction are presented in Table 6 and Table 7.

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
A34 (line 1)	10	0.003
A34 (line 2)	10	0.004
A34 (line 3)	10	0.003
A34 (line 4)	10	0.002

Table 6: Building response at most onerous intermediate stage - Construction Stage 1

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
A34 (line 1)	10	0.003
A34 (line 2)	10	0.004
A34 (line 3)	10	0.003
A34 (line 4)	10	0.002

Table 7: Building response at end of construction – Construction stage 4

The results of the assessment show that the intermediate construction Stage 1 is the critical stage for this building where (line 1) experiences the most onerous combined tensile strain. The orientation is shown in Figure 3. The vertical and horizontal Greenfield ground movements along the section of the building are shown in Figure 4. The relative position of the building and tunnels along section (line 1) is shown in Figure 8. The calculated strains are summarised in Table 8.

Line #	Strains in section (Curvature)	Position from start (m)	Length (m)	Average* Horizontal Strain (%)	Maximum Tensile Strains (%)	Damage Category
(line 1)	Sagging	0	9.3	-0.011	0.003	Negligible
(line 2)	Sagging	0	21.2	-0.009	0.004	Negligible
(line 3)	Sagging	0	13.7	-0.009	0.003	Negligible
Note: * Tensile horizontal strains are +ve. Compressive horizontal strains are –ve.						

Table 8: Section analysed, results for worst case tensile strain

A34 (line 2) examines the differential movements between this building and the adjacent building 116-126 Cannon Street (A33). It is a simplified line that represents both buildings' façades. The results along (line 2) can be seen in Figure 5 and Table 8 which shows that the area between A34 and A33 building is in a sagging mode, with very small tensile strains (negligible).

A34 (line 3) shows the movements between the façade and the bell tower. The orientation is shown in Figure 3. The vertical and horizontal Greenfield ground movements along the section of the building are shown in Figure 6. The displacement line between the building and the bell tower is in a sagging mode. The tensile strains are very small (Negligible) as shown in Table 8.

A34 (line 4) shows the façade of the bell tower that undergoes the most onerous maximum tensile strains. The tensile strains are very small (Negligible) as shown in Table 7.

The Stage 2 engineering assessment has predicted that the maximum tensile strain for the building falls within damage category 0. This corresponds to negligible damage in accordance with Table 2.

The maximum settlement of the building at foundation level is 10mm which occurs at the construction stage 1, is fairly uniform across the site.

5.2 Heritage and Structural Assessment

Following site inspection, assessment has been made using the following scoring methodology set out in Table 9.

Score	STRUCTURE Sensitivity of the structure to ground movements and interaction with adjacent buildings	HERITAGE FEATURES Sensitivity to calculated movement of particular features within the building	CONDITION Factors which may affect the sensitivity of structural or heritage features
0	Masonry buildings with lime mortar and regular openings, not abutted by other buildings, and therefore similar to the buildings on which the original Burland assessment was based.	No particular sensitive features	Good/Fair - not affecting the sensitivity of structural or heritage features
1	Buildings not complying with categories 0 or 2, but still with some sensitive structural features in the zone of settlement e.g.: cantilever stone staircases, long walls without joints or openings, existing cracks where further movements are likely to concentrate, mixed foundations	Brittle finishes, e.g. faience or tight-jointed stonework, which are susceptible to small structural movements and difficult to repair invisibly.	Poor - may change the behaviour of a building in cases of movement. Poor condition of heritage features and finishes. Evidence of previous movement.
2	Buildings which, by their structural form, will tend to concentrate all their movements in one location (e.g.: a long wall without joints and with a single opening).	Finishes which if damaged will have a significant effect on the heritage value of the building, e.g. Delicate frescos, ornate plasterwork ceilings.	Very poor – parlous condition of heritage features and finishes, severe existing damage to structure including evidence of ongoing movement. Essentially buildings where even very small movements could lead to significant damage.

Table 9: Heritage and structural scoring methodology

The results of the heritage assessment carried out for the building are summarised in Table 10.

SENSITIVITY OF THE STRUCTURE

The brick bell tower is taller and heavier than the rest of the building. If the ground is disturbed by tunnelling there is a risk that the tower will settle more than the rest of the building, crack the adjoining walls, and possibly tilt out of vertical. British Geographical Society sheet 256 indicates the outcropping stratum to be Alluvium overlying London Clay to considerable depth. For a solid foundation London Clay would be capable of carrying the building on shallow spread footings immediately below the basement. The bell tower would need a raft. Piles would not have been necessary but their use cannot be ruled out. Given the age of the tower, if piles were used they would have been timber but as such their depth would have been limited.

The three storey bay window will be sensitive to any movement; as such structures are a skeleton of mullions and lintels poorly held together by gravity and friction.
Drawing nos. BSCU-DRG-CA1-N133-1-DR-C-0100 and 010 (both rev P01) show the building to be fully within the 1mm settlement contour and bracketed by two 10mm settlement contours.

There is a risk that the tower will tilt slightly, generally cracking the junctions between the tower and the adjoining walls, with racking of the bay-window elevation. Consideration should be given to the design of contingency measures such as temporary bracing of the bay window elevation during tunnelling. A methodology to ensure the building is in equilibrium before removing the bracing should be included. The bay window may crack at its joints, and pull away from the main external wall, requiring remedial strapping restraint.

Score: 2 – the building is likely to concentrate its movements in specific, sensitive locations due to its structural form

SENSITIVITY OF THE HERITAGE

This building still retains all its character to exterior elevations. The bell tower, its pediment, and bracketed clock are recognisable landmarks respectively at urban and street level. The few surviving internal features, all concentrated within east wing, are decorative cornices to rooms located to ground, first and second floor, original bay windows and sash window, plus some wooden panelling to meeting rooms. The highest heritage sensitivities are located to north east and south west corner rooms where surviving plaster cornices and bell tower are.

Other vulnerable features to exterior are the cornice to the tower, window architraves and stucco dressings, and the bay window. Should the tower tilt, the movement might throw the clock out of beat requiring its adjustment by a horologist.

Score: 1 - The overall heritage sensitivity to damage is low but elements such as plasterwork to principal office rooms, bay windows and stuccoed windows and bell tower are fragile and may react to small movements.

SENSITIVITY OF THE CONDITION
The exterior is in good condition, with no visible defects apart from ponding water in side parapet gutter, and efflorescence under grand cornice on tower. Interior condition is average, with bouncy timber floors, falling damp to ground and first floor side bay window, water damaged roof over spiral stairs, and water damaged ceiling over clock-room in tower. The external walls appear plumb and true, without cracks, or distortion of door and window openings. This indicates that the building is solidly founded and not suffering from differential settlement. The suspended timber floors are variously rigid, bouncy, squeaky, or uneven, but not more than usual for old buildings, arising from miscellaneous causes such as notches for modern services, beetle, rot, previous structural alterations, overloading, etc. Localised falling damp, water damage, and efflorescence are present in some walls, indicating lack of maintenance of parapet gutters and rainwater goods, due to their inaccessible locations. The basement is dry. There was no access to the upper surfaces of the mansard roof or the tower.
Score: 0 - Building variously partitioned and refurbished with no major structural alterations. Localised dampness and general wear and tear due to lack of maintenance.

Table 10: Heritage and structural assessment

5.3 Total Score

The total score is the summation of the damage category, structural sensitivity, heritage sensitivity and condition sensitivity scores:

The damage category is 0

The structural sensitivity score is 2

The heritage sensitivity score is 1

The condition sensitivity score is 0

The total score for this building is 3

6 Conclusion

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0 for 29 Martin Lane. However, specific heritage and structural assessment taking into account the location and extent of settlement and tensile strains indicates that there are specific areas of structural and heritage sensitivity to movement. This assessment has determined that the building has a total score of 3.

It is recommended that a Stage 3 assessment is undertaken to further consider the potential damage to the structural form.

The BSCU Environmental Statement considers the mitigation that could be needed, however, it is recommended that Stage 3 assessment is undertaken to verify how heritage finishes may respond and whether such mitigation is required.

7 References

[1] LU Works Information WI 2300 Ground Movement version 3, 19-07-13.

[2] LU Category 1 Standard: S1050 Civil Engineering - Common Requirements, Issue No. A7, Nov. 2013.

[3] Mair R J, Taylor R N and Bracegirdle A (1993). Subsurface settlement profiles above tunnels in clays. Géotechnique 43, No. 2, pp. 315-320.

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[5] LU Guidance Document G0058 Civil Engineering Technical Advice Notes, Issue No. A17, Feb. 2013.

[6] Burland J B (1995). Assessment of risk of damage to buildings due to tunnelling and excavation. Proceedings: 1st International Conference of Earthquake Geotechnical Engineering, IS Tokyo, 1995.

[7] Mott MacDonald (2012). Bank Station building data sheets – A list buildings. N133-BCR-MMD-00-Z-DC-S-0003-S0-1.0.

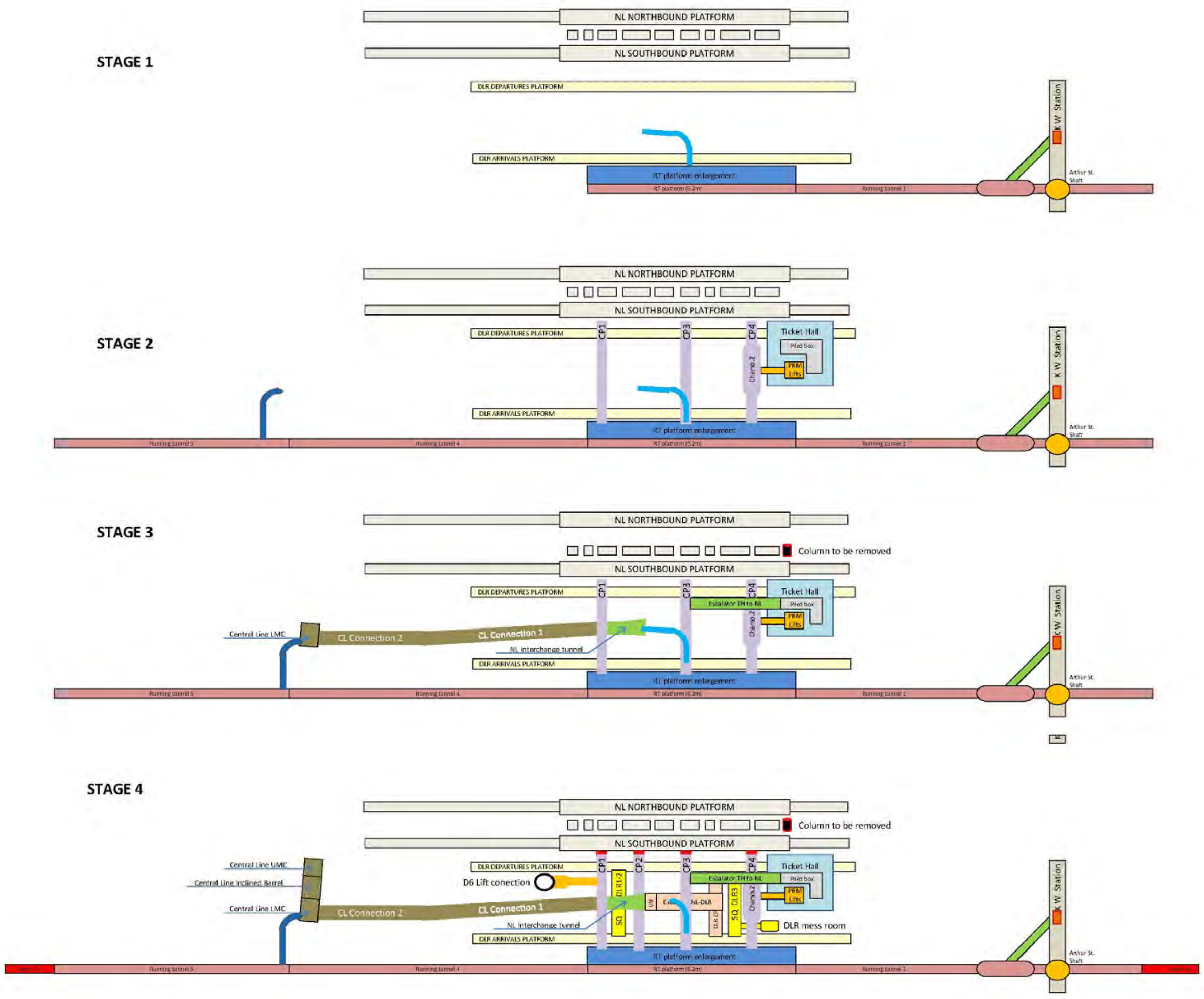

Figure 1: Construction Stage model

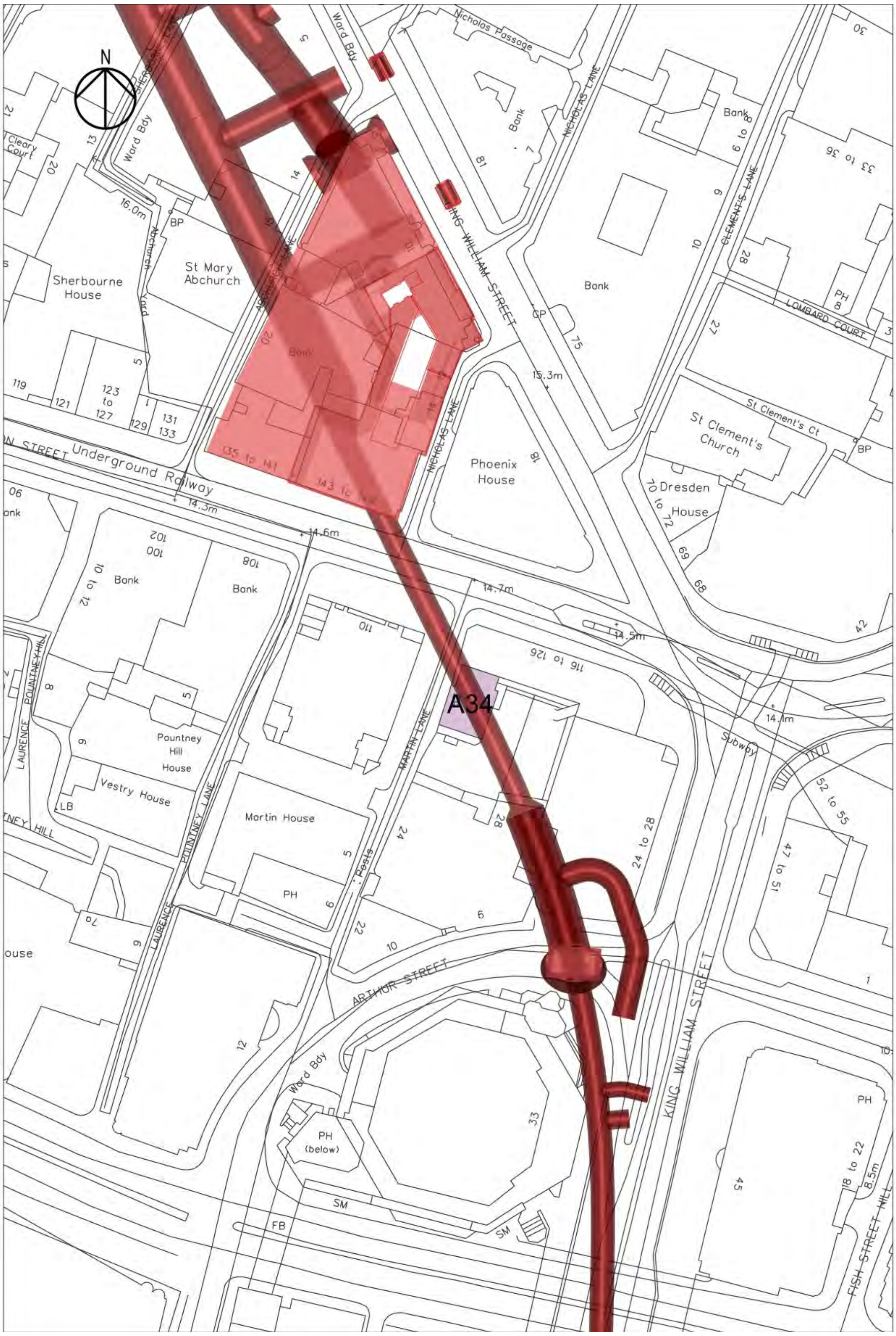

Figure 2: Location plan showing building location in relation to BSCU works

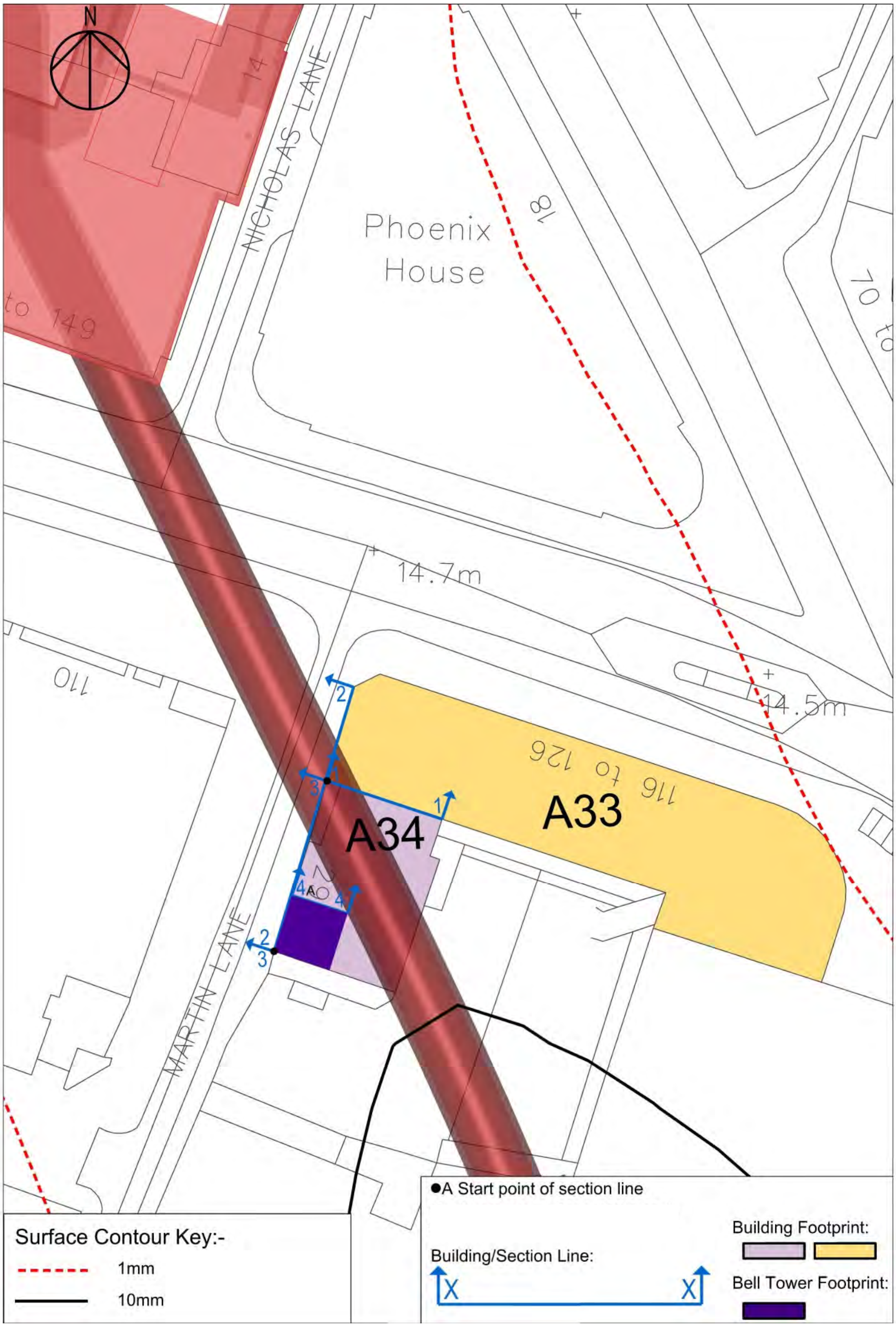

Figure 3: Building location, sections analysed and Settlement Contours at stage of worst case for tensile strains

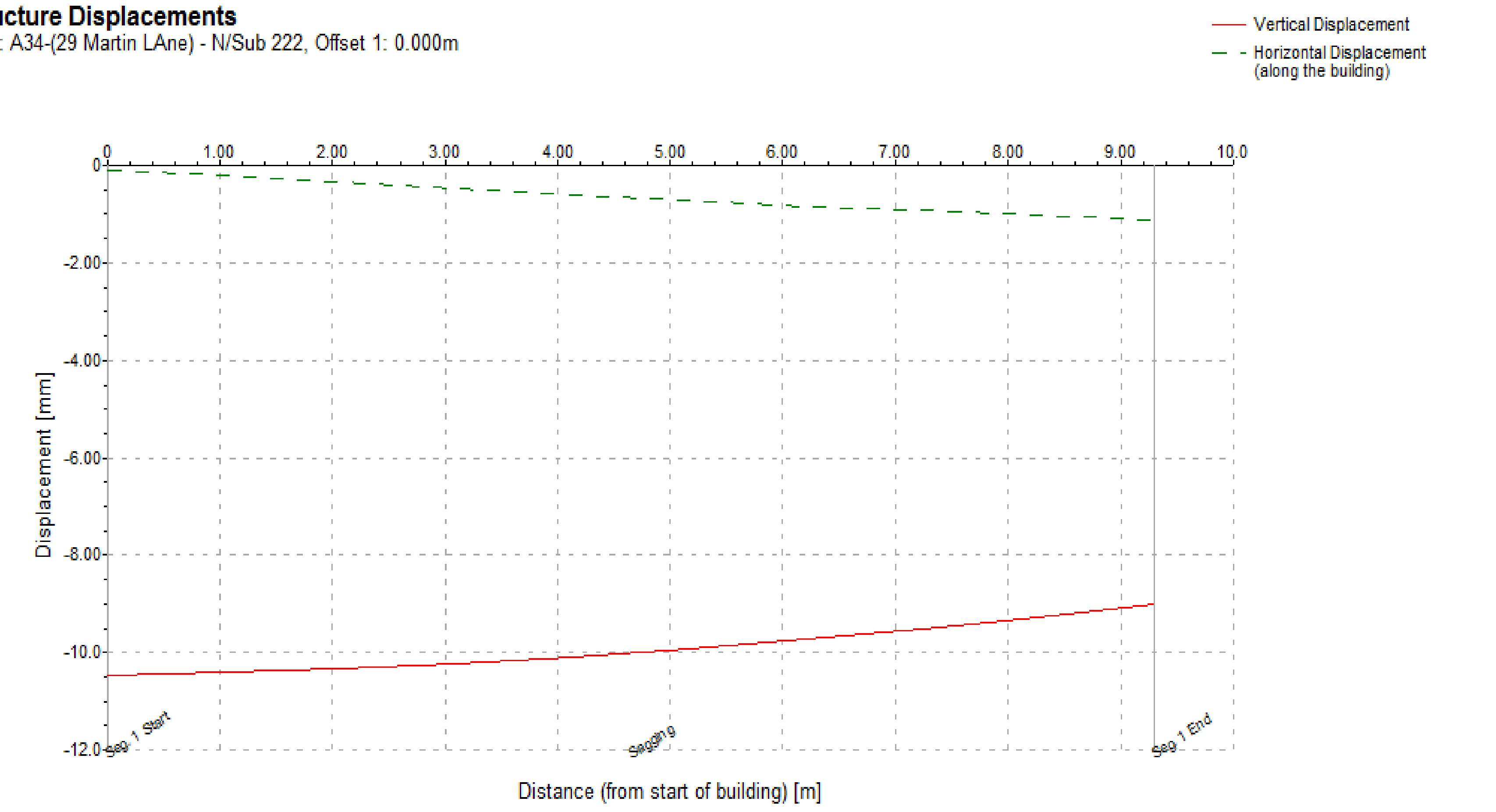

Figure 4: Building displacement at founding level at stage 1 (line 1) of worst case for tensile strains

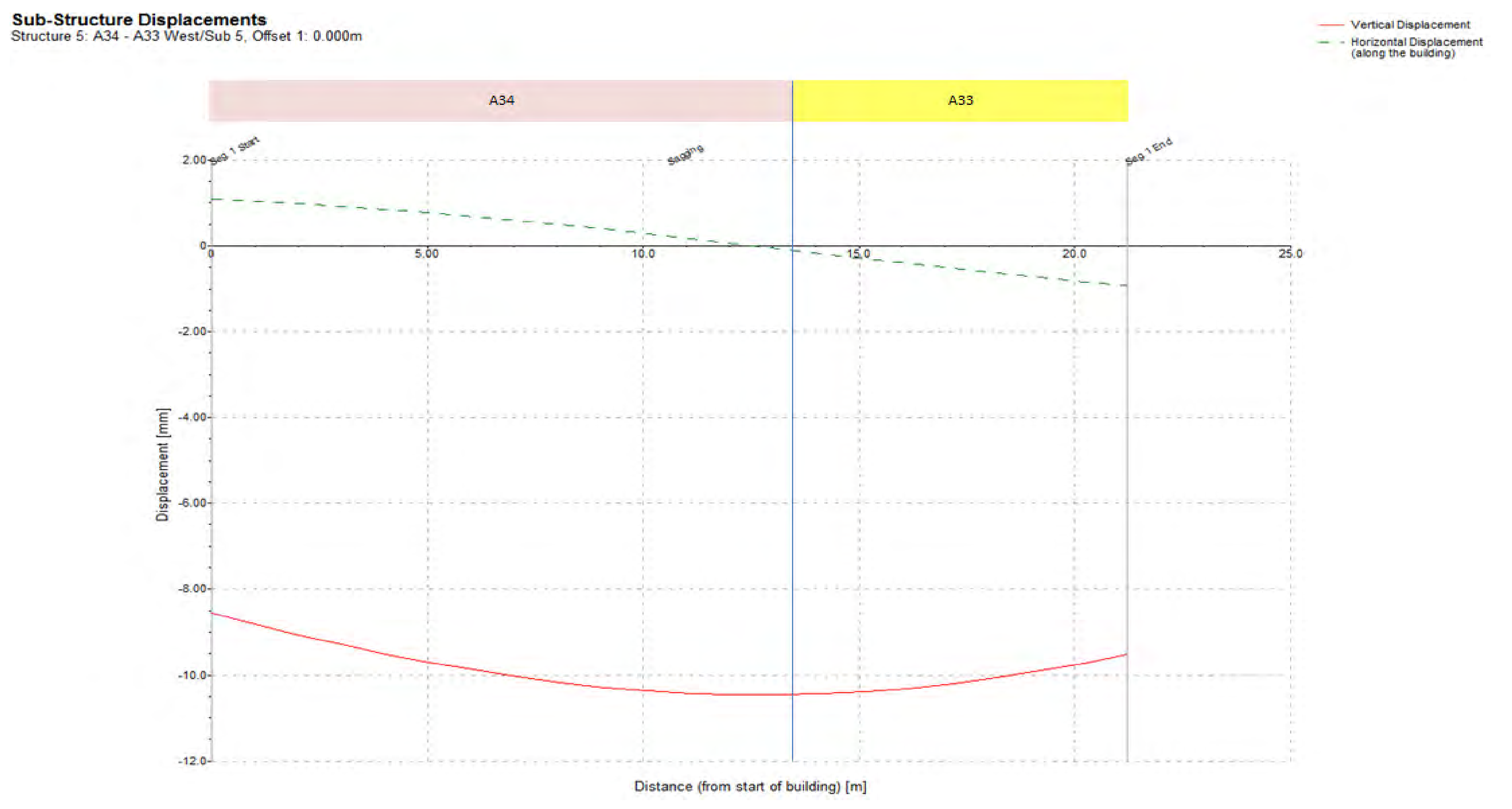

Figure 5: Building displacement at founding level at stage 1 (line 2) of worst case for tensile strains

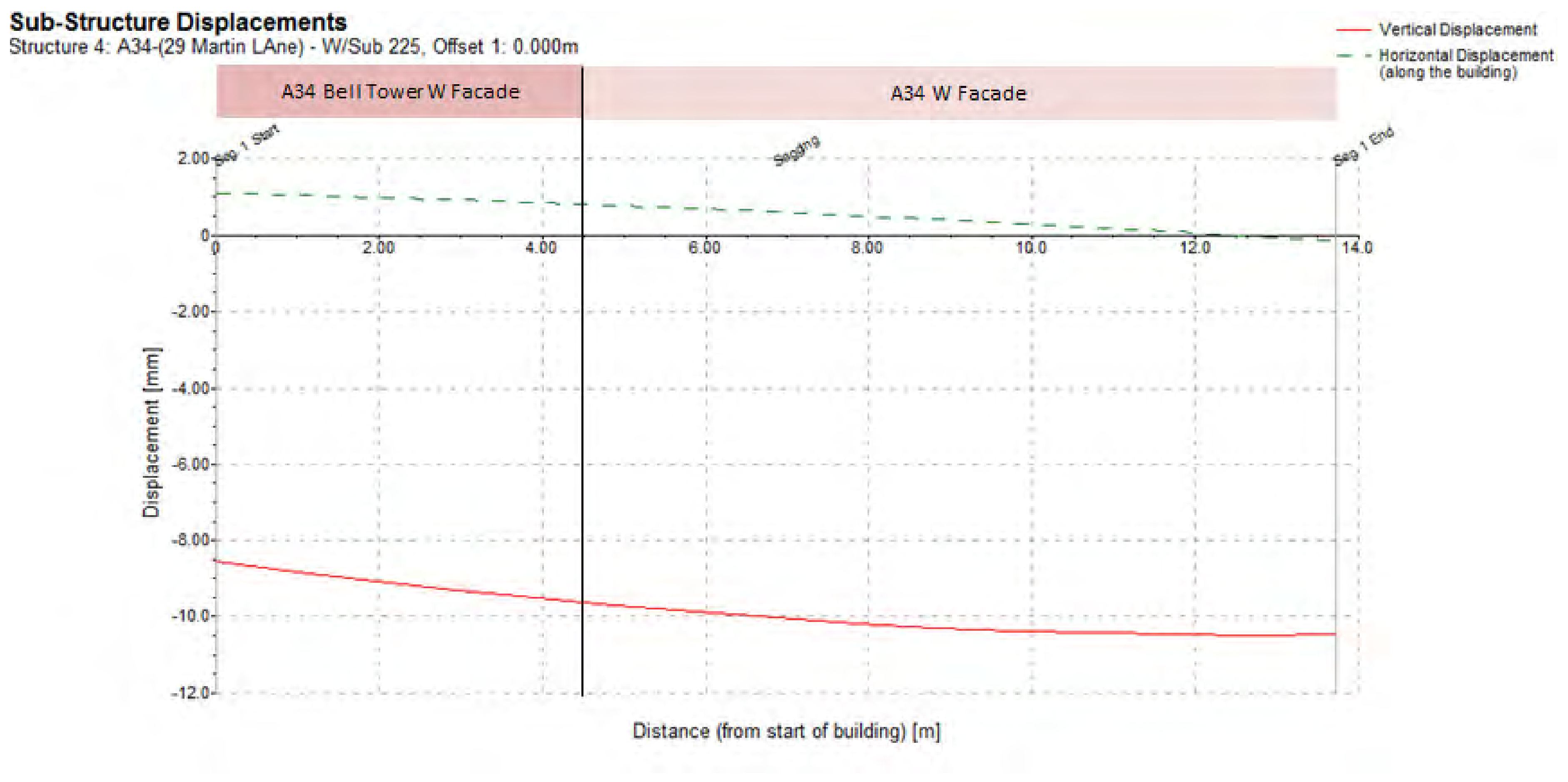

Figure 6: Building displacement at founding level at stage 1 (line 3) of worst case for tensile strains

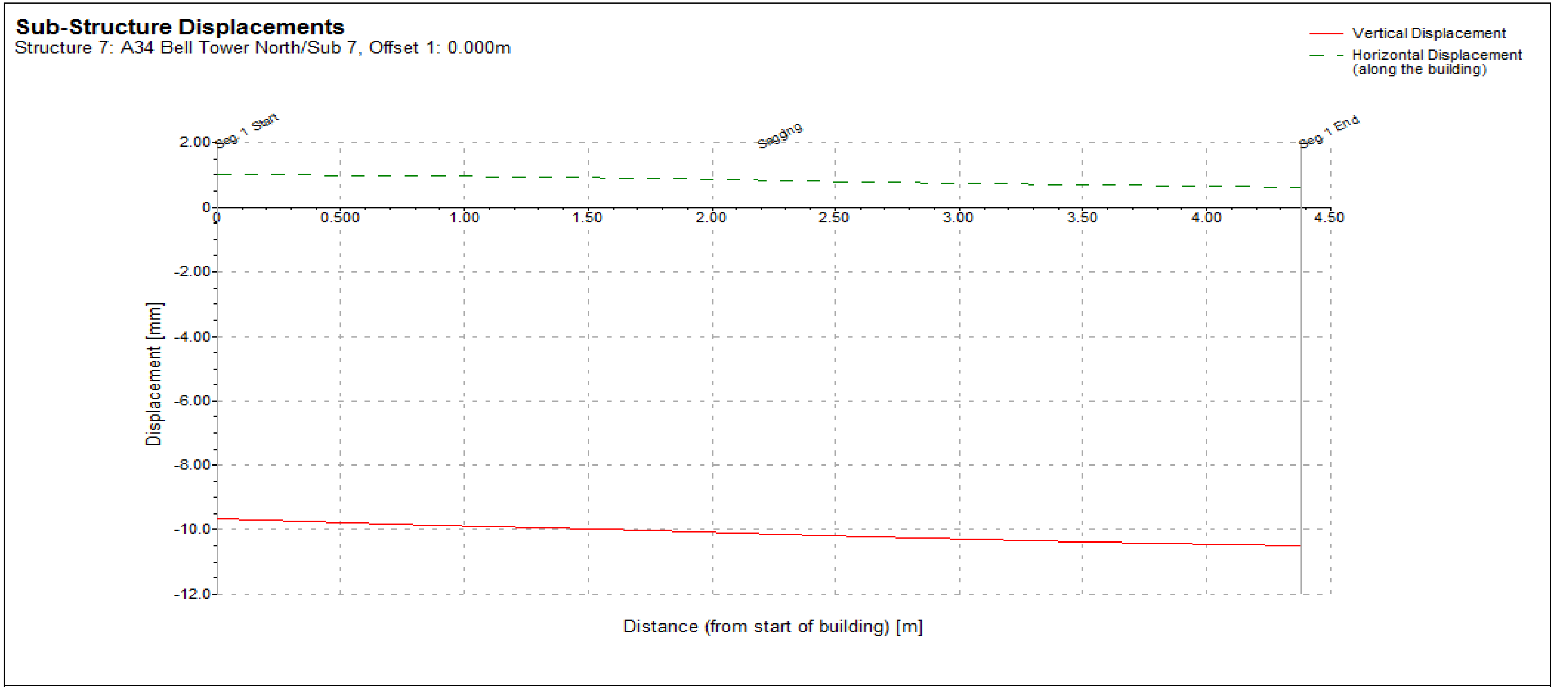

Figure 7: Building displacement at founding level (Bell Tower) at stage 1 (line 4) of worst case for tensile strains

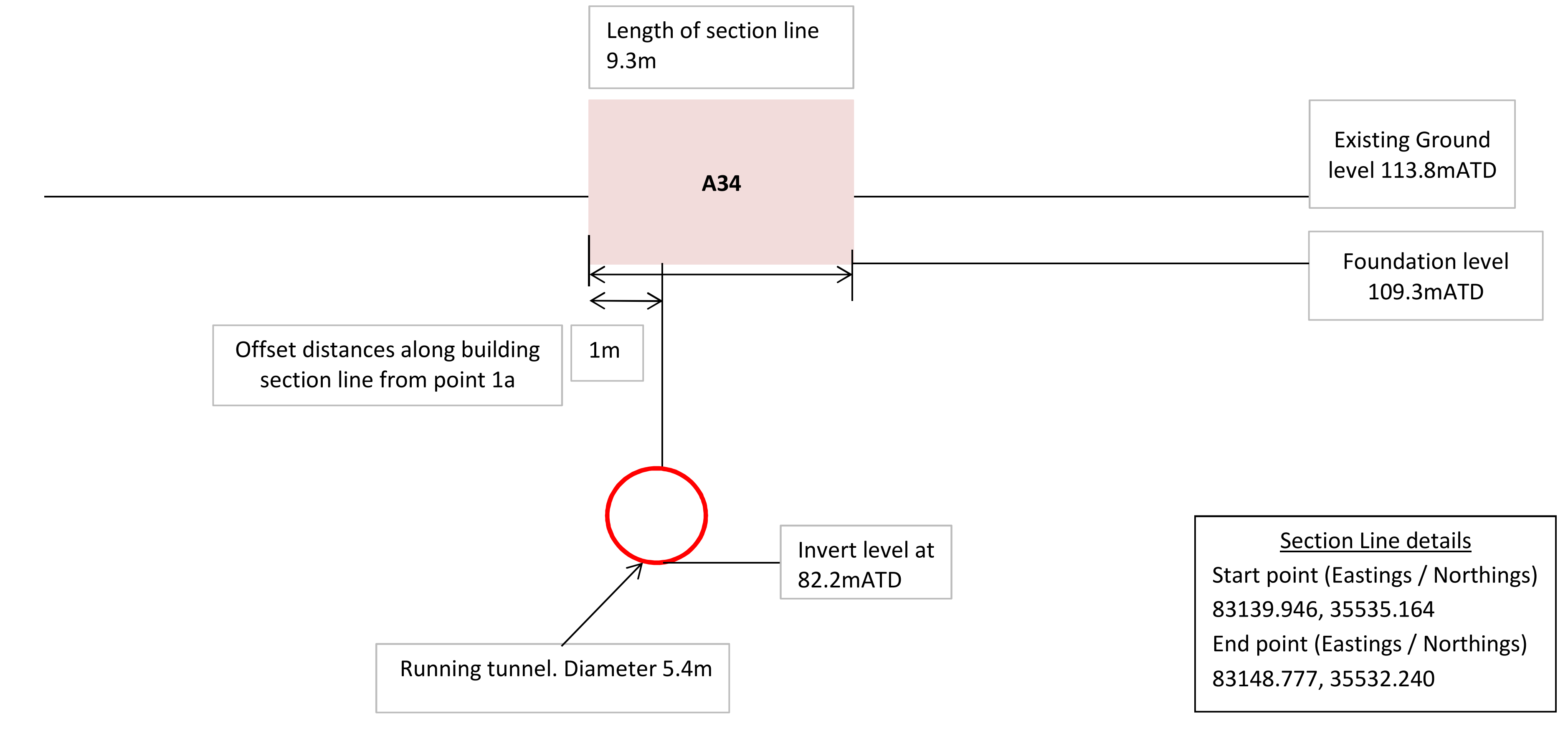

Figure 8: Diagrammatic cross-section of section (line 1) relative to tunnel position

LUL Bank Project Office
10 King William Street
London EC4 N7TW

Bank Station Capacity Upgrade

Building Damage Assessment Report

Building A39

Adelaide House

URS-8798-RPT-G-001197

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Consultation:

• Ela Palmer	URS Heritage
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1 Introduction

This report summarises the results of a Stage 2 damage assessment for Adelaide House, (Building ref. A39).

Stage 2 damage assessments are undertaken for all buildings within the Stage 1 Greenfield ground surface 1mm settlement contour induced by the construction of the Bank Station Capacity Upgrade (BSCU).

The purpose of the assessment is to determine the potential effect the works will have on the building. This report describes the engineering and heritage assessments undertaken for the building and concludes whether mitigation is likely to be needed and if a further (Stage 3) assessment is recommended in order to verify this..

2 The Building

2.1 General Information

Adelaide House is bounded by London Bridge and Lower Thames Street. General building information used in the assessment has been acquired as part of the structural desktop appraisal. This information is presented in Table 1.

Category	Building Information
BSCU Reference	A39
Location	Adelaide House
Address	Adelaide House
Building Type	Assumed steel framed
Construction Age	1921-1925
No. of Storeys	9
Basements	3
Eaves Levels (mATD)	138.8
Foundation Type	Timber Piles
Ground Level (mATD)	106.5
Listed Grade	II
Note: Levels given are in metres above Tunnel Datum, mATD. Tunnel Datum is 100m below Ordnance Survey Datum at Newlyn.	

Table 1: General building information

A general view of the building exterior is shown in Plate 1. A location plan showing the building in relation to the proposed BSCU works is presented in Figure 2.

Plate 1: General view

2.2 Building Description

The grade II listed building dating 1921 – 1925 lies on the north bank of the River Thames on a rectangular shaped lot to the east side of London Bridge. Externally, the south, west and north elevations are clad in grey granite below and around the main entrance on London Bridge, with Portland stone cladding above and on the roof enclosures. The east elevation has yellow and white glazed brickwork. The building was completed as an independent structure in 1925 housing warehouses in the lower levels and offices above. Originally built with 8 storeys above the London Bridge approach road and main entrance, there are a further 3 levels dropping down to Lower Thames Street on the north side. In 1959 a further level was added forming the 8th floor, present flat roof level and plant enclosures. On the south side adjoining London Bridge are two large light wells housing steel staircases, leading to the lower levels. From Lower Thames Street is an access and service road leading under parts of the building through to the river wharf. A major refurbishment on 2007 has altered the auditorium to west wing of ground floor, the reception room and clients' suites to east wing of ground floor, and the first basement level have been refurbished in high spec contemporary style. All office floors are finished to modern office standard with carpeted floors, suspended ceilings and dry lined, painted walls.

Construction appears to be steel framed with concrete cased beams and columns, and screeded concrete trough floors in all areas that were visible. At the lowest basement level is a mix of concrete and brick retaining walls, with floors above generally steel encased and of concrete trough construction, but there are some small and much older areas of concrete and steel jack arches. On the south side at this level was some encroachment of foundation buttresses for the London Bridge. Mott MacDonald's report Feb 2012 notes the foundations as timber piles.

3 Methodology

This building damage assessment is undertaken in accordance with LU Works Information WI2300[1] and LU Civil Engineering – Common Requirements S1050[2].

The analysis methodology applies to piled buildings which will be affected by ground movements resulting from the construction of the BSCU. The engineering assessment calculates the potential impact of ground movements and assigns a damage category to the building based on a numeric scale. Additionally, for listed buildings, a heritage assessment is carried out which considers the sensitivity of the structure and the sensitivity of its particular features; a heritage sensitivity score is assigned. The heritage sensitivity score is added to the damage category to obtain the total score. If the total score is 3 or more, a more detailed Stage 3 assessment is triggered.

Since the building is piled the movement assessment should be based on a combination of assumptions. This is in accordance with Selemetas.D et al (2005)[8]. In the region above the tunnel alignment piles with a toe level within 20% of the depth of the tunnel are assumed to move the same amount as the soil at the toe level using the method given by New & Bowers. Piles to either side are assumed to move the same amount as the greenfield settlement prediction at the base of building level using the methods of Mair et al[3, 4]. The deflected shape is assessed from these two approaches and the tensile strains calculated using the method given by Burland et al[6].

Due to its location to the east of the BSCU works and the relatively shallow level of the pile toes, this building has been analysed at assumed pile cap level as having shallow foundations.

Oasys Xdisp is used to analyse the Greenfield ground movement in terms of settlement and horizontal displacement. Subsurface tunnelling induced ground movement profiles are determined in accordance with the methodology described by Mair et al[3 & 4].

Movements resulting from the Whole Block Scheme (WBS) and shaft excavations have been calculated using LU Guidance Document G0058[5].

The building is modelled as a simple elastic beam which is conservatively assumed to follow the Greenfield ground displacements. The beam is divided into hogging and sagging segments. The tensile strains within each segment are calculated based on the distortion associated with differential settlement (which is characterised by deflection ratio) and the distortion associated with differential horizontal displacement (characterised by horizontal strain).

Xdisp provides a method for calculating the maximum tensile strain within the building superstructure associated with these movements, in accordance with the assessment methodology described by Mair et al [4]. This strain is used to determine the damage category based on the classification system proposed by Burland[6] and in accordance with LU Civil Engineering - Common Requirements S1050[2]. The categories are presented in Table 2.

Damage Category	Description of Degree of Damage	Description of Typical Damage and likely forms of Repair for Typical Masonry Buildings.	Approx. Crack Width (mm)	Max. Tensile Strain %
0	Negligible	Hairline cracks.		< 0.05
1	Very slight	Fine cracks easily treated during normal redecoration. Perhaps isolated slight fracture in building. Cracks in exterior visible upon close inspection.	0.1 to 1.0	0.05 to 0.075
2	Slight	Cracks easily filled. Redecoration probably required. Several slight fractures inside building. Exterior cracks visible; some repainting may be required for weather-tightness. Doors and windows may stick slightly.	1 to 5	0.075 to 0.15
3	Moderate	Cracks may require cutting out and patching. Recurrent cracks can be masked by suitable linings. Tuck pointing and possible replacement of a small amount of exterior brickwork may be required. Doors and windows sticking. Utility services may be interrupted. Weather tightness often impaired.	5 to 15 or a number of cracks > 3	0.15 to 0.3
4	Severe	Extensive repair required involving removal and replacement of walls especially over doors and windows. Window and door frames distorted. Floor slopes noticeably. Walls lean or bulge noticeably. Some loss of bearing in beams. Utility services disrupted.	15 to 25 but also depends on number of cracks	> 0.3
5	Very severe	Major repair required involving partial or complete reconstruction. Beams lose bearing, walls lean badly and require shoring. Windows broken by distortion. Danger of instability.	Usually > 25 but depends on number of cracks	
Note: Please refer LU Civil Engineering - Common Requirements S1050[2].				

Table 2: Building damage classification

4 Input Data

The magnitude and distribution of ground movements and degree of building damage is calculated based on the following input data:

- The Xdisp model coordinates and levels are based on the 3D model (20130212DSPITT Scheme R09);
- Four construction stages are considered in accordance with the proposed programme (November 2013) as illustrated in Figure 1;
- Trough width parameter constant, K=0.5 is used in accordance with WI2300[1].

The input data for the building, tunnels and shaft excavation are summarised in Table 3, Table 4 and Table 5 respectively.

Location	Foundation level (mATD)	Building Height above foundation level (m)	E/G
Adelaide House	102.5*	36.2	12.5
Note: Where E / G is the ratio of Young's modulus to shear modulus of the deep beam representing the building. * Known basement level [9], base level is then assumed as 1.5m thick slab beneath floor level.			

Table 3: Building data

Tunnel Item	Level of axis (mATD)	External diameter (m)	Volume Loss (%)
Running tunnel Southern tie in	83.4	5.4	1.5
Square works adits	75.8 to 95.3	4.1 to 7.8	2.5
Platform enlargement	85.6	7.4 to 11.2	1.5
Escalator barrels	Inclined	8.3 to 8.4	1.5
Central Line Connection	Inclined (87.6 to 89.2)	8.6	1.5

Table 4: Tunnel data

Excavation	Excavation Base Level (mATD)
Grout Shaft at King William Street	97
Whole Block Scheme Box excavation	73
Arthur Street Shaft	81

Table 5: Excavation data

Whole Block Scheme box excavation and grout shaft at King William Street are remote to this building and will have little or no effect on the ground movements.

The Xdisp model filenames used to undertake this assessment are:

- A39 - Stage 4
- A39 - Stage 3
- A39 - Stage 2
- A39 - Stage 1

5 Results

5.1 Engineering Assessment

The sections through the building which have been analysed are shown on plan in Figure 3.

Assessment has been undertaken at three intermediate construction stages and at the end of construction when all major elements of the works including shaft and tunnels have been completed. The damage category assigned to the building is based on the construction stage at which the potential impact on the building is most severe.

The maximum settlement and tensile strain calculated for each of the analysis sections at the most onerous construction stage are presented in Table 6 and Table 7.

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
A39 (line 1)	<1	<0.001
A39 (line 2)	<1	<0.001

Table 6: Building response at most onerous intermediate stage - Construction Stage 1

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
A39 (line 1)	3	0.011
A39 (line 2)	3	0.004

Table 7: Building response at end of construction stage

The results of the assessment show that construction Stage 4 is the critical stage for this building when line 1 experiences the most onerous combined tensile strain. The orientation is shown in Figure 3. The vertical and horizontal Greenfield ground movements along the section of the building are shown in Figure 4. The relative position of the building and tunnels along line 1 is shown in Figure 5. The calculated strains are summarised in Table 8.

Line No	Strains in section (Curvature)	Position from start (m)	Length (m)	Average* Horizontal Strain (%)	Maximum Tensile Strains (%)	Damage Category
(line 1)	Hogging	0.0	18.6	0.008	0.011	Negligible
Note: * Tensile horizontal strains are +ve. Compressive horizontal strains are –ve.						

Table 8: Section analysed, results for worst case tensile strain

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0. This corresponds to negligible damage in accordance with Table 2.

The maximum settlement of the building at foundation level at the end of construction is 3mm.

5.2 Heritage and Structural Assessment

Following site inspection, assessment has been made using the following scoring methodology set out in Table 9.

Score	STRUCTURE Sensitivity of the structure to ground movements and interaction with adjacent buildings	HERITAGE FEATURES Sensitivity to calculated movement of particular features within the building	CONDITION Factors which may affect the sensitivity of structural or heritage features
0	Masonry buildings with lime mortar and regular openings, not abutted by other buildings, and therefore similar to the buildings on which the original Burland assessment was based.	No particular sensitive features	Good/Fair - not affecting the sensitivity of structural or heritage features
1	Buildings not complying with categories 0 or 2, but still with some sensitive structural features in the zone of settlement e.g.: cantilever stone staircases, long walls without joints or openings, existing cracks where further movements are likely to concentrate, mixed foundations	Brittle finishes, e.g. faience or tight-jointed stonework, which are susceptible to small structural movements and difficult to repair invisibly.	Poor - may change the behaviour of a building in cases of movement. Poor condition of heritage features and finishes. Evidence of previous movement.
2	Buildings which, by their structural form, will tend to concentrate all their movements in one location (e.g.: a long wall without joints and with a single opening).	Finishes which if damaged will have a significant effect on the heritage value of the building, e.g. Delicate frescos, ornate plasterwork ceilings.	Very poor – parlous condition of heritage features and finishes, severe existing damage to structure including evidence of ongoing movement. Essentially buildings where even very small movements could lead to significant damage.

Table 9: Heritage and structural scoring methodology

The results of the heritage assessment carried out for the building are summarised in Table 10.

SENSITIVITY OF THE STRUCTURE
The small predicted ground movement is unlikely to impact on the building foundations or frame, which should accept minor differential movement without damage to the structure, internal finishes, or external cladding attached and supported by the structural frame. Variable movement in the foundations and those of the London Bridge could cause some minor damage and separation within the lower basement level.
Score: 0 the predicted movements will not significantly affect the structures or the foundations
SENSITIVITY OF THE HERITAGE
Designed by Sir John Burnet and Tait (1921-25) and led by engineers Sir Douglas Fox and Partners Adelaide House was originally built as offices and warehousing to replace an earlier building that occupied the site until 1920. The building was first listed in 1972 and retains its architectural character to north, south and west elevations which have been kept intact; Interiors have been heavily altered except for the entrance hall and the main staircase which have been kept almost intact. The most sensitive elements are the internal marble claddings and decorative features, original windows, entrance hall with columns, original stair. The predicted movements don't have potential to significantly harm the surviving historic features.
Score: 0 The predicted settlement will not cause damage to sensitive heritage features
SENSITIVITY OF THE CONDITION
The building is in overall good condition with minor localised defects to basements, mainly due to lack of maintenance. Externally the granite and Portland stone cladding appears in excellent condition throughout, and while the yellow and white glazed brickwork to the west elevation, despite a less pleasing appearance, has a generally sound appearance. The roof is also very well maintained and largely accessible. The property has recently undergone a complete and high quality internal refurbishment by the present tenant, and is in immaculate condition throughout. The maintenance engineer noted that the lower basement level had experienced some very occasional flooding in recent years, believed to be from drainage surcharges and backing up. No significant structural defects were noted other than some lamination of steel beams forming the older jack arched floors above the lower basement level.
Score: 0 The localised defects within the less maintained areas do not affect the sensitivity of the structure or heritage

Table 10: Heritage and structural assessment

5.3 Total Score

The total score is the summation of the damage category, structural sensitivity, heritage sensitivity and condition sensitivity scores:

The damage category is 0

The structural sensitivity score is 0

The heritage sensitivity score is 0

The condition sensitivity score is 0

The total score for this building is 0

6 Conclusion

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0 for Adelaide House. Specific heritage and structural assessment taking into account the location and extent of settlement and tensile strains indicates that the building has a low level of structural and heritage sensitivity to the predicted settlement. This assessment has determined that the building has a total score of 0.

It is recommended that the building does not require a Stage 3 assessment.

7 References

[1] LU Works Information WI 2300 Ground Movement version 3, 19-07-13.

[2] LU Category 1 Standard: S1050 Civil Engineering - Common Requirements, Issue No. A7, Nov. 2013.

[3] Mair R J, Taylor R N and Bracegirdle A (1993). Subsurface settlement profiles above tunnels in clays. Géotechnique 43, No. 2, pp. 315-320.

[4] Mair R J, Taylor R N and Burland J B (1996). Prediction of ground movements and assessment of risk of building damage due to bored tunnelling. (In: International Conference of Geotechnical Aspects of Underground Construction in Soft Ground, London, pp. 713–718.

[5] LU Guidance Document G0058 Civil Engineering Technical Advice Notes, Issue No. A17, Feb. 2013.

[6] Burland J B (1995). Assessment of risk of damage to buildings due to tunnelling and excavation. Proceedings: 1st International Conference of Earthquake Geotechnical Engineering, IS Tokyo, 1995.

[7] Mott MacDonald (2012). Bank Station building data sheets – A list buildings. N133-BCR-MMD-00-Z-DC-S-0003-S0-1.0.

[8] Selemetas.D et al (2005). The response of full scale piles to tunnelling. Geotechnical aspects of underground construction in soft ground (Bakker et al (eds)) pp.763-769.

[9] Sir Douglas Fox and partners (1921). Adelaide House architectural drawing.

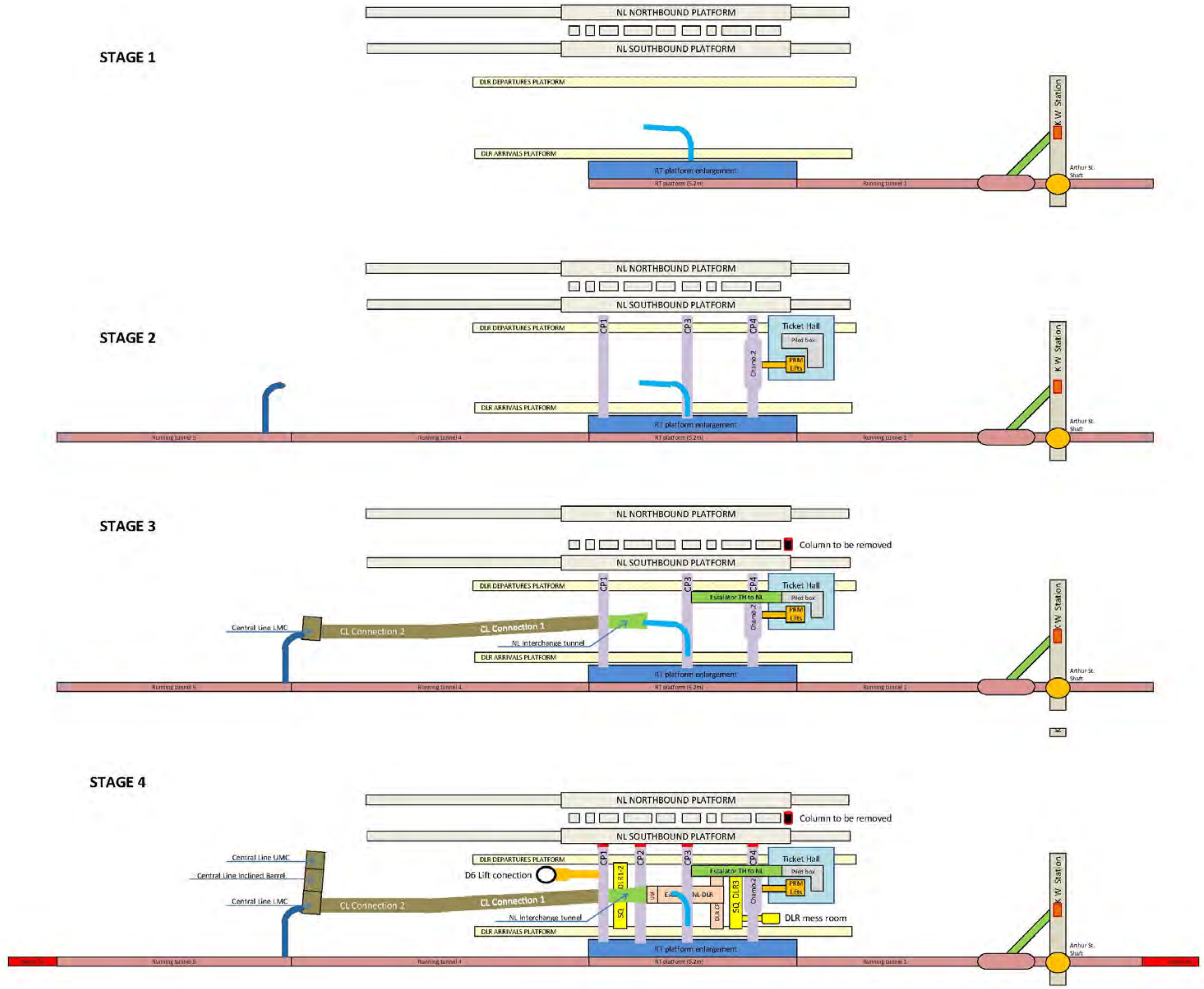

Figure 1: Construction Stage model

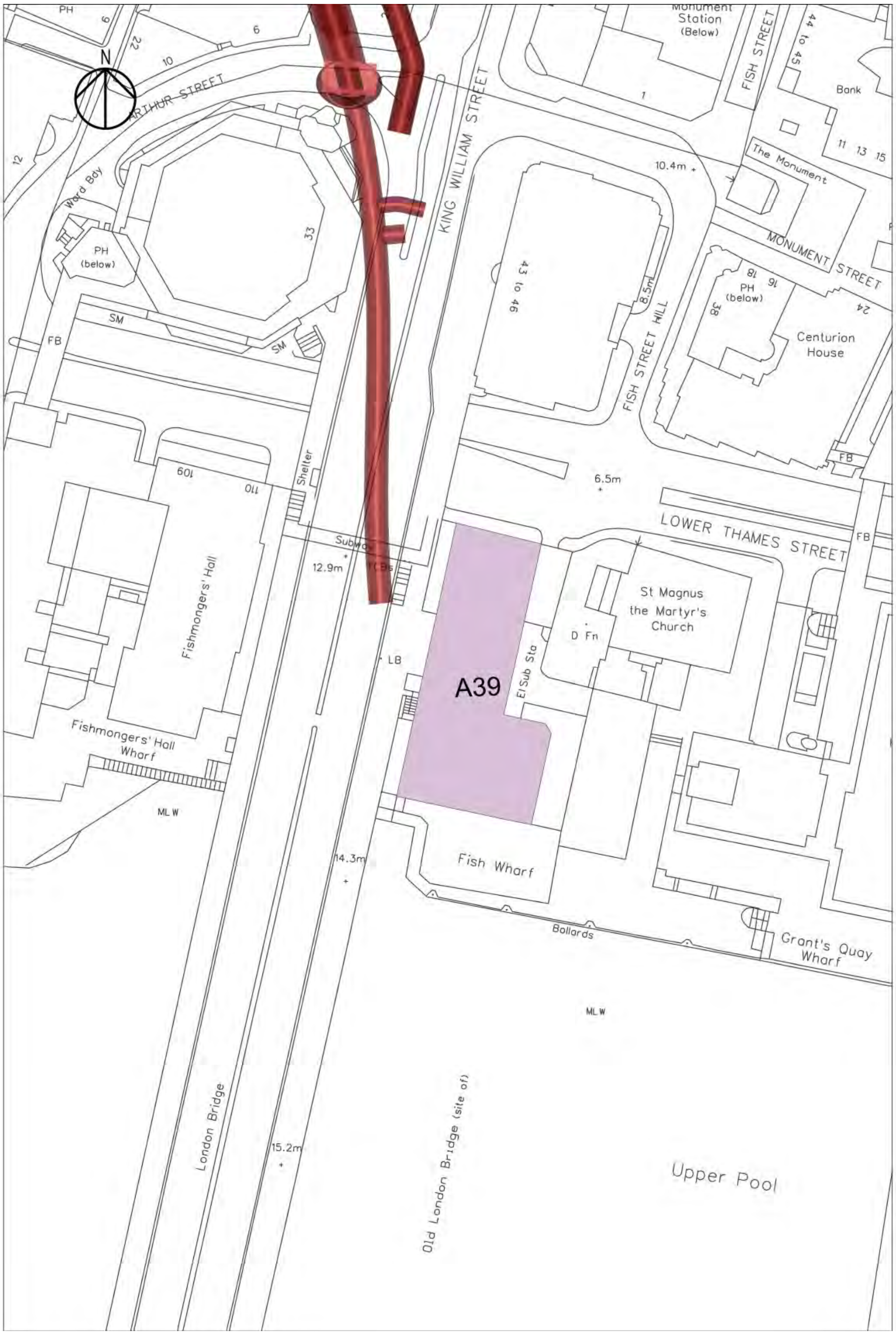

Figure 2: Location plan showing building location in relation to BSCU works

MAYOR OF LONDON

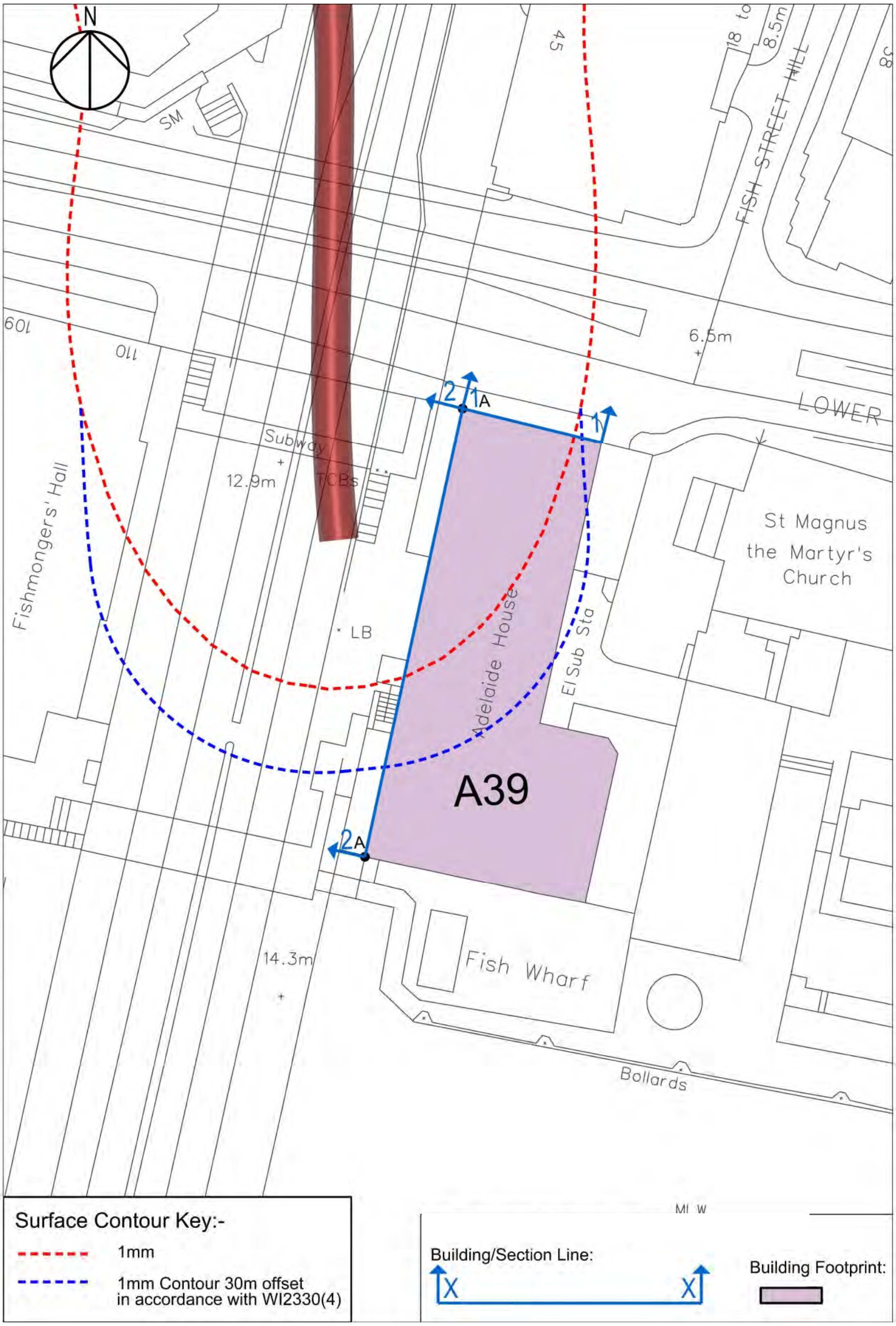

Figure 3: Building location, sections analysed and Settlement Contours at stage of worst case for tensile strains

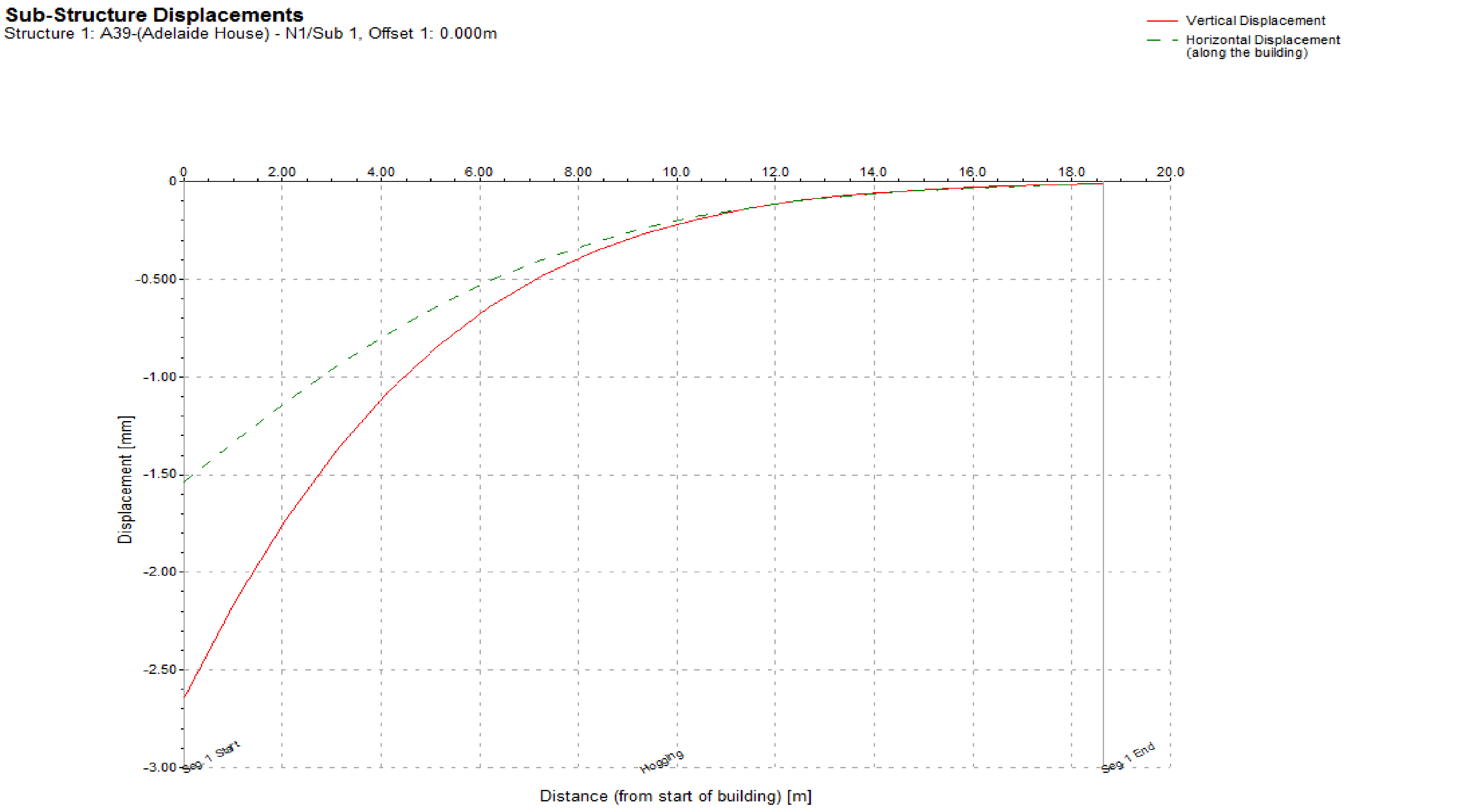

Figure 4: Building displacement at founding level at stage 4 (line 1) of worst case for tensile strains

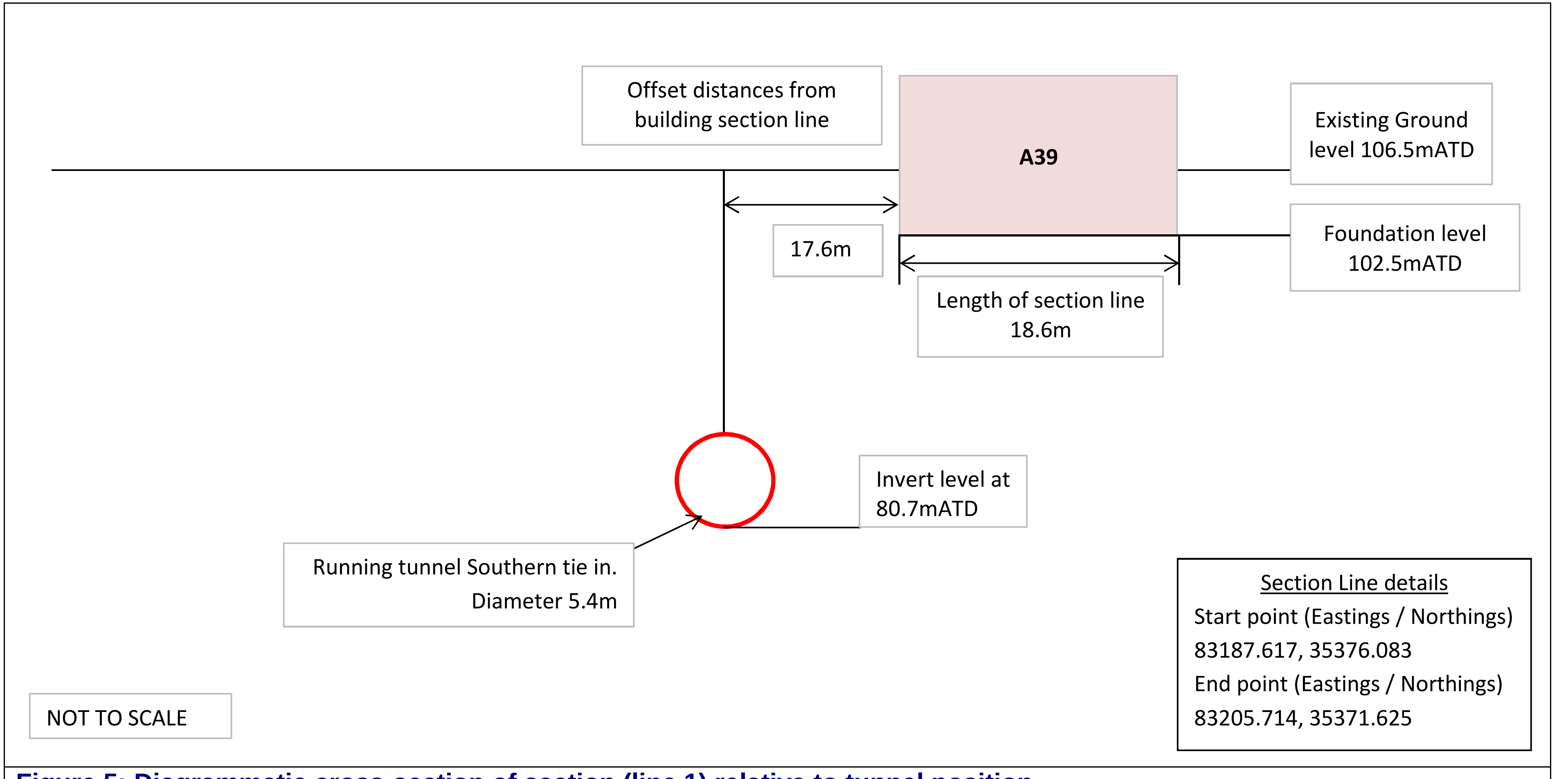

Figure 5: Diagrammatic cross-section of section (line 1) relative to tunnel position

LUL Bank Project Office
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Bank Station Capacity Upgrade

Building Damage Assessment Report

Building B1

3 – 4 Lothbury

URS-8798-RPT-G-001199

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Document History

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3.0	July 2014	TWAO Issue

For the status of this document, please refer to the Building Damage Assessment Report Register (URS-8798-RGT-001229)

Consultation:

• Ela Palmer	URS Heritage
• Brian Lyons	Dr.Sauer
• Keith Bowers/Neil Moss/Paul Dryden	London Underground
• Olly Newman	Dragados

Contents

FIGURES

TABLES

1 Introduction

This report summarises the results of a Stage 2 damage assessment for 3 - 4 Lothbury Street.

Stage 2 damage assessments are undertaken for all buildings within the Stage 1 Greenfield ground surface 1mm settlement contour induced by the construction of the Bank Station Capacity Upgrade (BSCU).

The purpose of the assessment is to determine the potential effect the works will have on the building. This report describes the engineering and heritage assessments undertaken for the building and concludes whether mitigation is likely to be needed and if a further (Stage 3) assessment is recommended in order to verify this.

2 The Building

2.1 General Information

General building information used in the assessment has been acquired as part of the structural desktop appraisal. Where data was not available, conservative assumptions were made instead. This information is presented in Table 1.

Category	Building Information
BSCU Reference	B1
Location	Lothbury
Address	3-4 Lothbury
Building Type	Masonry (assumed)
Construction Age	1906
No. of Storeys	7
Basements	1 (assumed)
Eaves Level (mATD)	137.8
Foundation Type	Assume shallow footing
Ground Level (mATD)	112.8
Listed Grade	II
Note: Levels given are in metres above Tunnel Datum, m ATD. Tunnel Datum is 100m below Ordnance Survey Datum at Newlyn	

Table 1: General building information

A general view of the building exterior is shown in Plate 1. A location plan showing the building in relation to the proposed BSCU works is presented in Figure 2.

Plate 1: General view

2.2 Building Description

No. 3 – 4 Lothbury Street is situated at the end of Prince's Street. The building is seven storeys high with one (assumed) level of basement.

3-4 Lothbury includes Nos. 1 to 5 (odd) Moorgate, and was constructed in 1906 by Mountford and Gruning. This is a Portland stone faced building in the classical style with six main storeys plus one level of set-back attic, and curved corners to returns at either end. Although internally it has been redeveloped the original façade survives. The ground floor is of banded ashlar with semi-circular arched windows within deep splayed reveals. The entrance doors are carved in relief featuring two women above crests and flanked by engaged ionic columns and festoons. The first, second, and third floors are united by order of engaged Ionic columns. The attic storeys are of modern construction.

A masonry type structure on shallow foundation such as strip footing is considered most conservative is assessing strains for the building facades. The assessment is carried out at the likely founding level of the facades since this is considered a conservative assumption.

3 Methodology

This assessment is undertaken in accordance with LU Works Information WI2300[1] and LU Civil Engineering - Common Requirements S1050[2].

The analysis methodology applies to ground-bearing buildings which will be affected by ground movements resulting from the construction of the BSCU. The engineering assessment calculates the potential impact of ground movements and assigns a damage category to the building based on a numeric scale. Additionally, for listed buildings, a heritage assessment is carried out which considers the sensitivity of the structure and the sensitivity of its particular features; a heritage sensitivity score is assigned. The heritage sensitivity score is added to the damage category to obtain the total score. If the total score is 3 or more, a more detailed Stage 3 assessment is triggered.

Oasys Xdisp is used to analyse the Greenfield ground movement in terms of settlement and horizontal displacement. Subsurface tunnelling induced ground movement profiles are determined in accordance with the methodology described by Mair et al[3 & 4].

Movements resulting from the Whole Block Scheme (WBS) and shaft excavations have been calculated using LU Guidance Document G0058[5].

The building is modelled as a simple elastic beam which is conservatively assumed to follow the Greenfield ground displacements. The beam is divided into hogging and sagging segments. The tensile strains within each segment are calculated based on the distortion associated with differential settlement (which is characterised by deflection ratio) and the distortion associated with differential horizontal displacement (characterised by horizontal strain).

Xdisp provides a method for calculating the maximum tensile strain within the building superstructure associated with these movements, in accordance with the assessment methodology described by Mair et al [4]. This strain is used to determine the damage category based on the classification system proposed by Burland[6] and in accordance with LU Civil Engineering - Common Requirements S1050[2]. The categories are presented in Table 2.

Damage category	Description of degree of damage	Description of typical damage and likely forms of repair for typical masonry buildings.	Approx. crack width (mm)	Max. tensile strain %
0	Negligible	Hairline cracks.		< 0.05
1	Very slight	Fine cracks easily treated during normal redecoration. Perhaps isolated slight fracture in building. Cracks in exterior visible upon close inspection.	0.1 to 1.0	0.05 to 0.075
2	Slight	Cracks easily filled. Redecoration probably required. Several slight fractures inside building. Exterior cracks visible; some repainting may be required for weather-tightness. Doors and windows may stick slightly.	1 to 5	0.075 to 0.15
3	Moderate	Cracks may require cutting out and patching. Recurrent cracks can be masked by suitable linings. Tuck pointing and possible replacement of a small amount of exterior brickwork may be required. Doors and windows sticking. Utility services may be interrupted. Weather tightness often impaired.	5 to 15 or a number of cracks > 3	0.15 to 0.3
4	Severe	Extensive repair required involving removal and replacement of walls especially over doors and windows. Window and door frames distorted. Floor slopes noticeably. Walls lean or bulge noticeably. Some loss of bearing in beams. Utility services disrupted.	15 to 25 but also depends on number of cracks	> 0.3
5	Very severe	Major repair required involving partial or complete reconstruction. Beams lose bearing, walls lean badly and require shoring. Windows broken by distortion. Danger of instability.	Usually > 25 but depends on number of cracks	
Note: Please refer LU Civil Engineering - Common Requirements S1050[2].				

Table 2: Building damage classification

4 Input Data

The magnitude and distribution of ground movements and degree of building damage is calculated based on the following input data:

- The Xdisp model coordinates and levels are based on the 3D model (20130212DSPITT Scheme R09);
- Four construction stages are considered in accordance with the proposed programme (November 2013) as illustrated in Figure 1;
- Trough width parameter constant, K=0.5 is used in accordance with WI2300[1]

The input data for the building, tunnels and shaft excavation are summarised in Table 3, Table 4 and Table 5 respectively.

Location	Foundation level (mATD)	Building Height above foundation level (m)	E/G
3 – 4 Lothbury Street	108.3*	29.5	2.6
Note: Where E / G is the ratio of Young's modulus to shear modulus of the deep beam that is to represent the building. * Assumed level, 1.5m thick slab beneath floor level.			

Table 3: Building data

Tunnel Item	Level of axis (mATD)	External diameter (m)	Volume Loss (%)
Running tunnels	Inclined (82.9 to 85.8)	5.4	1.5
Running tunnel northern tie in	Inclined (83 to 83.6)	4.8	1.5
Square works adits	75.8 to 95.3	4.1 to 7.8	2.5
Platform enlargement	85.6	7.4 to 11.2	1.5
Tunnel enlargement	Inclined (82.9 to 83)	8	1.5
Escalator barrels	Inclined	8.3 to 8.4	1.5
Central Line Connection	Inclined (87.6 to 89.2)	8.6	1.5

Table 4: Tunnel data

Excavation	Excavation Base Level (mATD)
Grout Shaft at King William Street	97
Whole Block Scheme Box excavation	73
Arthur Street Shaft	81

Table 5: Excavation data

The distance of building 3 -4 Lothbury (B1) relative to the excavation elements listed in Table 5 is sufficiently large that this building should not be affected by their construction.

The Xdisp model filenames used to undertake this assessment are:

- B1 - Stage 4
- B1 - Stage 3
- B1 - Stage 2
- B1 - Stage 1

5 Results

5.1 Engineering Assessment

The sections through the building which have been analysed are shown on plan in Figure 3.

Assessment has been undertaken at three intermediate construction stages and at the end of construction when all major elements of the works including shaft and tunnels have been completed. The damage category assigned to the building is based on the construction stage at which the potential impact on the building is most severe.

The maximum settlement and tensile strain calculated for each of the analysis sections at the most onerous intermediate construction stage and at the end of construction are presented in Table 6 and Table 7.

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
B1 (line 1)	<1	<0.001
B1 (line 2)	<1	<0.001

Table 6: Building response at most onerous intermediate stage - Construction Stage 2

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
B1 (line (1)	5	0.005
B1 (line 2)	5	0.005

Table 7: Building response at end of construction stage

The results of the assessment show construction Stage 4 is the critical stage for this building, where line 1 experiences the most onerous combined tensile strain. The orientation of this building is shown in Figure 2. The vertical and horizontal Greenfield ground movements along the section of the building are shown in Figure 4. The relative position of the building and tunnels along section line 1 is shown in Figure 5. The calculated strains are summarised in Table 8.

Strains in section (Curvature)	Position from start (m)	Length (m)	Average* Horizontal Strain (%)	Maximum Tensile Strains (%)	Damage Category
Sagging	0.0	7.8	-0.005	0.001	Negligible
Hogging	7.8	21.2	0.004	0.005	Negligible
Note: * Tensile horizontal strains are +ve. Compressive horizontal strains are –ve.					

Table 8: Section analysed, results for worst case tensile strain

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0. This corresponds to negligible damage in accordance with Table 2.

The maximum settlement of the building at foundation level at the end of construction is less than 5mm.

5.2 Heritage and Structural Assessment

Following site inspection, assessment has been made using the following scoring methodology as set out in Table 9.

Score	STRUCTURE Sensitivity of the structure to ground movements and interaction with adjacent buildings	HERITAGE FEATURES Sensitivity to calculated movement of particular features within the building	CONDITION Factors which may affect the sensitivity of structural or heritage features
0	Masonry buildings with lime mortar and regular openings, not abutted by other buildings, and therefore similar to the buildings on which the original Burland assessment was based.	No particular sensitive features	Good/Fair - not affecting the sensitivity of structural or heritage features
1	Buildings not complying with categories 0 or 2, but still with some sensitive structural features in the zone of settlement e.g.: cantilever stone staircases, long walls without joints or openings, existing cracks where further movements are likely to concentrate, mixed foundations	Brittle finishes, e.g. faience or tight-jointed stonework, which are susceptible to small structural movements and difficult to repair invisibly.	Poor - may change the behaviour of a building in cases of movement. Poor condition of heritage features and finishes. Evidence of previous movement.
2	Buildings which, by their structural form, will tend to concentrate all their movements in one location (e.g.: a long wall without joints and with a single opening).	Finishes which if damaged will have a significant effect on the heritage value of the building, e.g. Delicate frescos, ornate plasterwork ceilings.	Very poor – parlous condition of heritage features and finishes, severe existing damage to structure including evidence of ongoing movement. Essentially buildings where even very small movements could lead to significant damage.

Table 9: Heritage and structural scoring methodology

The results of the heritage assessment carried out for the building are summarised in Table 10.

SENSITIVITY OF THE STRUCTURE
Since no visit of this property has been possible the assessment below is based on the external appearance of the building and the information contained in the documents available to us. The building is believed to be founded on a raft and to be of famed construction. The facades are of closely jointed masonry.
Score: - Based on the available information there are no particular structural sensitivities.
SENSITIVITY OF THE HERITAGE
Since no visit of this property has been possible the assessment below is based on the external appearance of the building and the information contained in the documents available to us. The building façade is not decorative, and though it is fine jointed, will not be sensitive to the predicted settlement. The available information suggests that the building has been subject to façade retention, and it is assumed that the interior is entirely modern.
Score: 0 – Based on the available information there are no apparent heritage sensitivities
SENSITIVITY OF THE CONDITION
The exterior of the building appears to be in good condition and no cracking or signs of previous movement were noted from external inspection.
Score: 0 – External inspection did not identify any condition related sensitivities

Table 10: Heritage and structural assessment

5.3 Total Score

The total score is the summation of the damage category, structural sensitivity, heritage sensitivity and condition sensitivity scores:

The damage category is 0

The structural sensitivity score is 0

The heritage sensitivity score is 0

The condition sensitivity score is 0

The total score for this building is 0

6 Conclusion

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0 for 3-4 Lothbury. Specific heritage and structural assessment taking into account the location and extent of settlement and tensile strains highlights the buildings low level of structural and heritage sensitivity to movement. This assessment has determined that the building has a total score of 0.

1-5 Moorgate is located to the north of the Bank Station Capacity Upgrade tunnelling works, beyond the 1mm contour but touching the 30m Offset Line. These works are predicted to result in negligible settlement which is not expected to result in damage to the heritage finishes and features of the building.

It is recommended that the building does not require a Stage 3 assessment.

7 References

[1] LU Works Information WI 2300 Ground Movement version 3, 19-07-13.

[2] LU Category 1 Standard: S1050 Civil Engineering - Common Requirements, Issue No. A7, Nov. 2013.

[3] Mair R J, Taylor R N and Bracegirdle A (1993). Subsurface settlement profiles above tunnels in clays. Géotechnique 43, No. 2, pp. 315-320.

[4] Mair R J, Taylor R N and Burland J B (1996). Prediction of ground movements and assessment of risk of building damage due to bored tunnelling. (In: International Conference of Geotechnical Aspects of Underground Construction in Soft Ground, London, pp. 713–718.

[5] LU Guidance Document G0058 Civil Engineering Technical Advice Notes, Issue No. A17, Feb. 2013.

[6] Burland J B (1995). Assessment of risk of damage to buildings due to tunnelling and excavation. Proceedings: 1st International Conference of Earthquake Geotechnical Engineering, IS Tokyo, 1995.

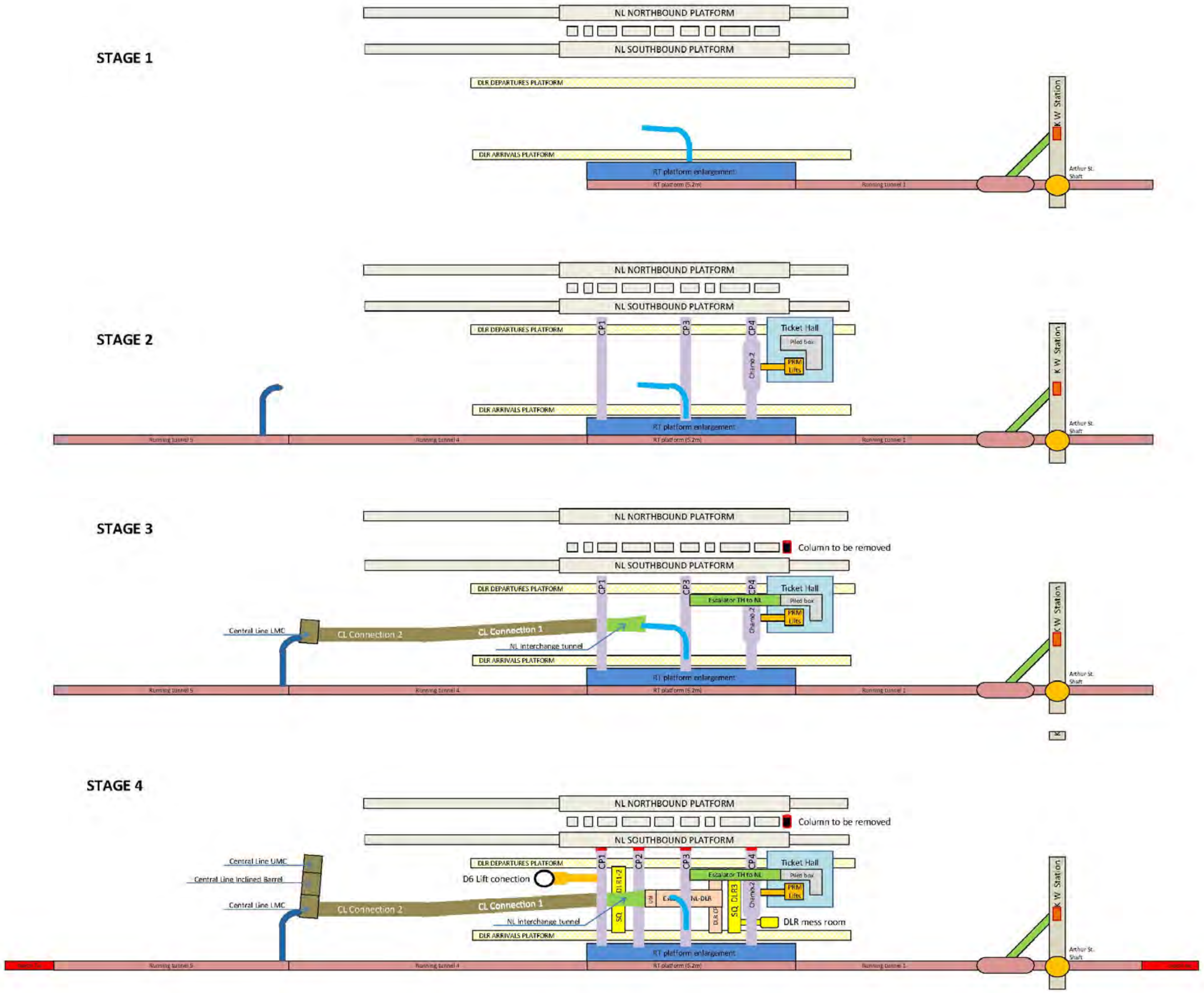

Figure 1: Construction Stage model

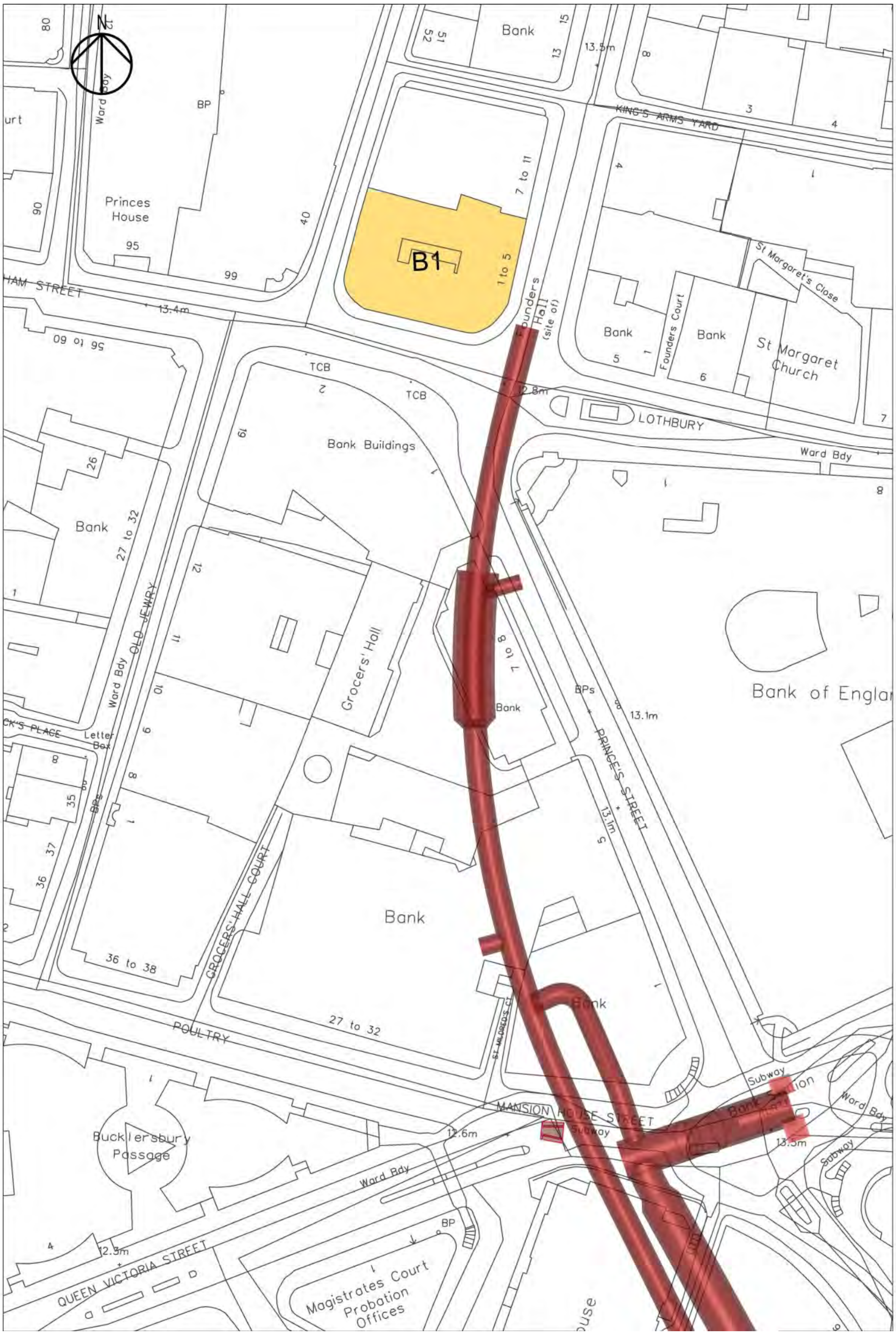

Figure 2: Location plan showing building location in relation to BSCU works

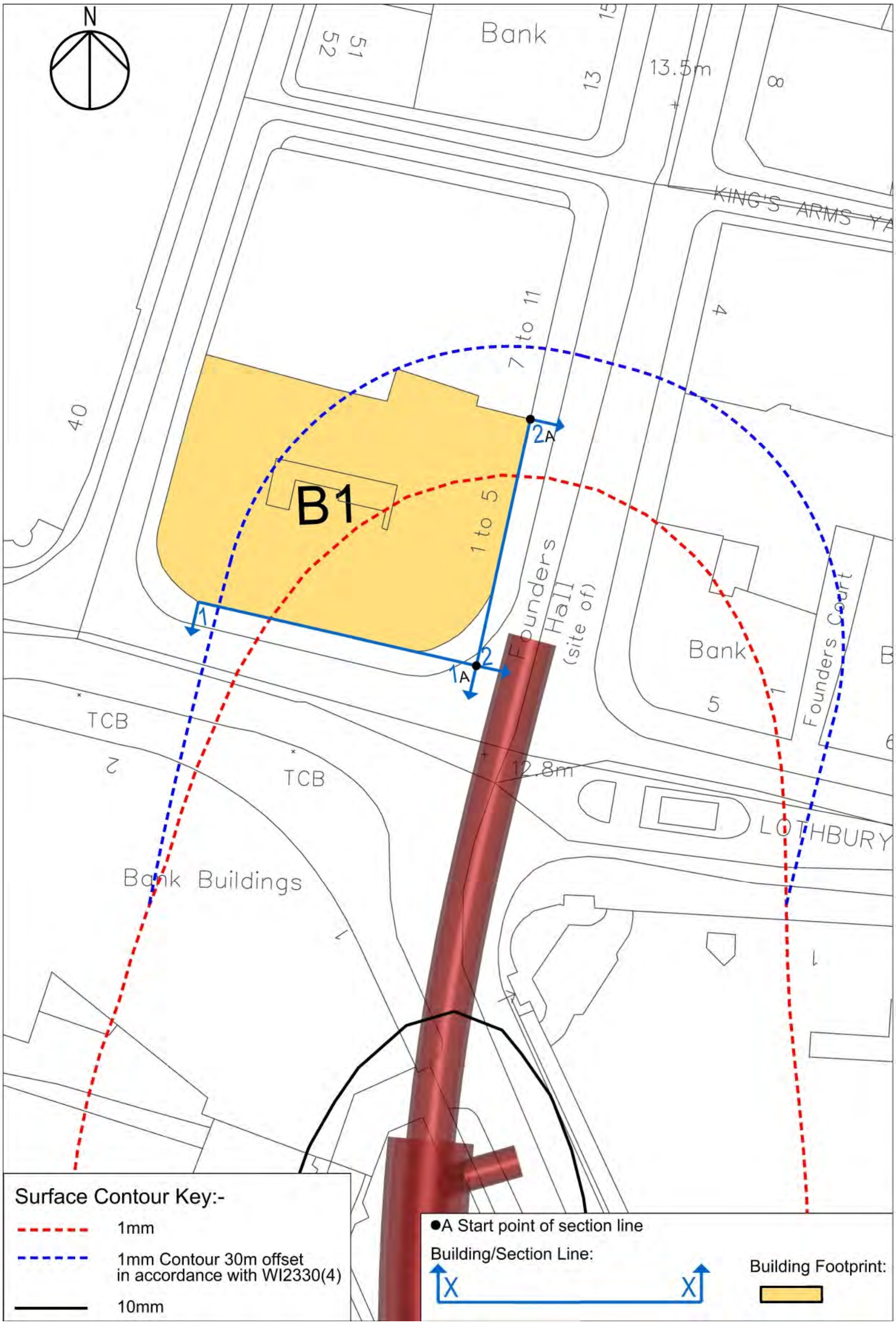

Figure 3: Building location, sections analysed and Settlement Contours at stage of worst case for tensile strains

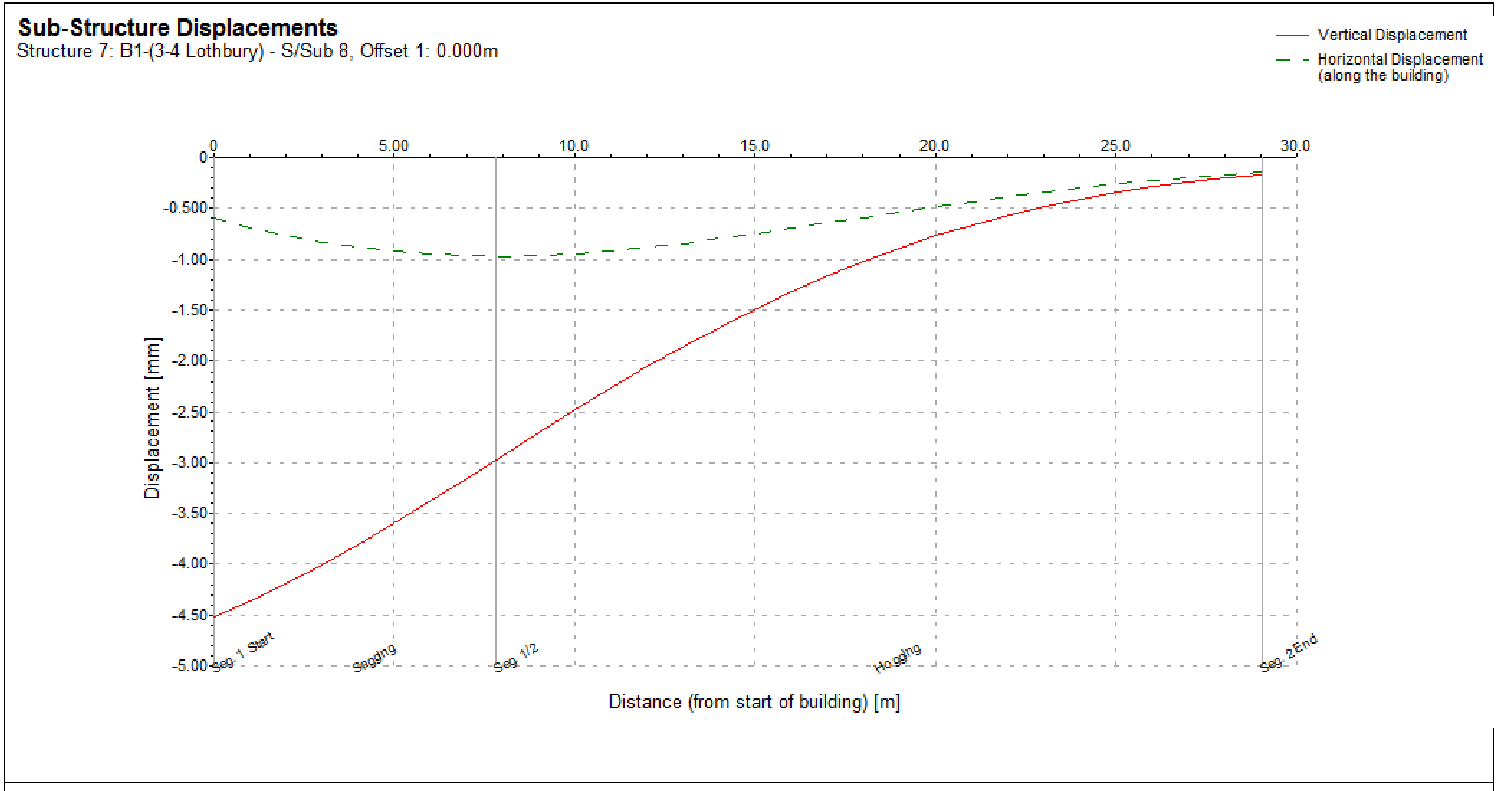

Figure 4: Building displacement at founding level at stage 4 (line 1) of worst case for tensile strains

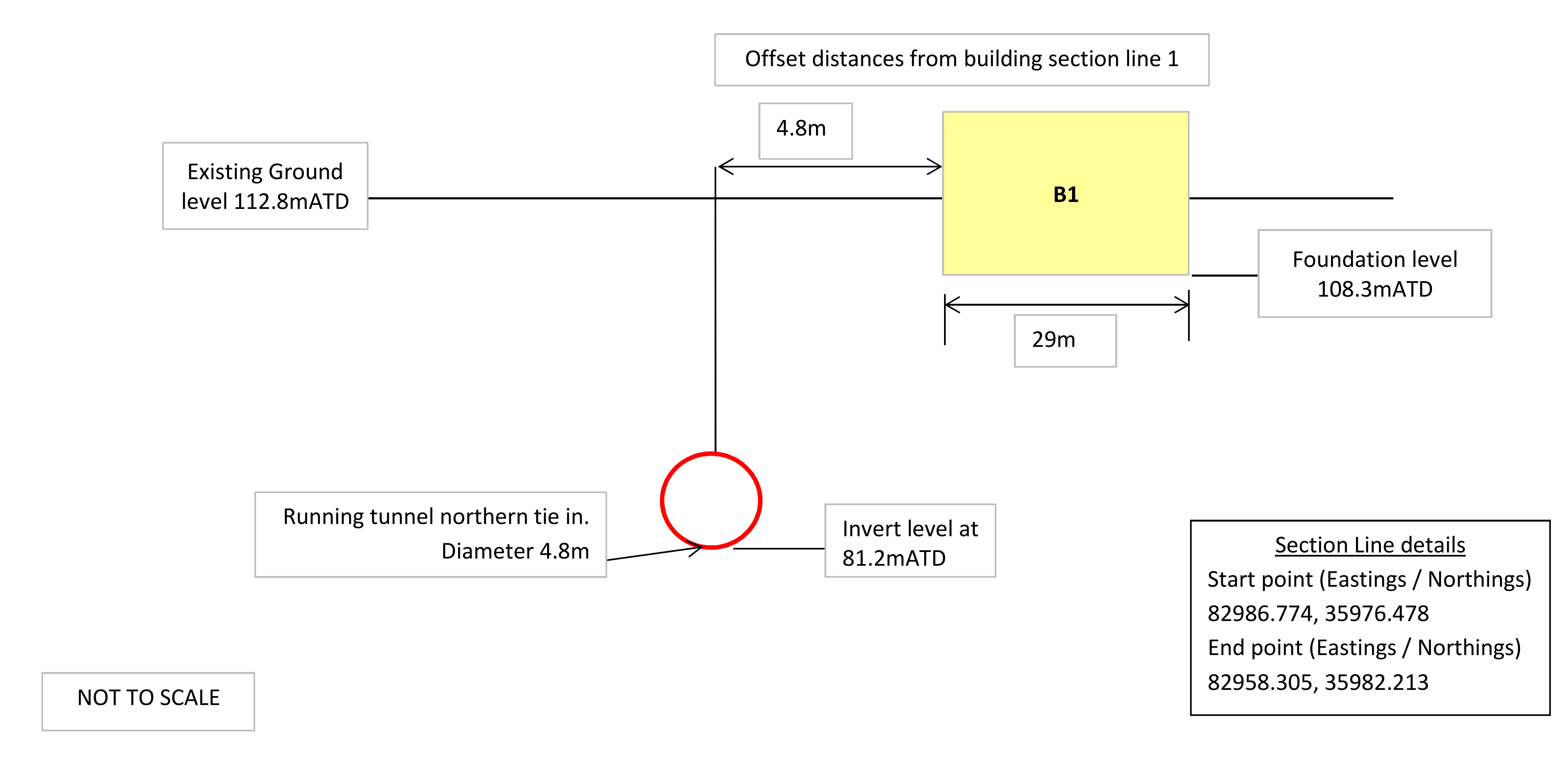

Figure 5: Diagrammatic cross-section of section (line 1) relative to tunnel position

Bank Station Capacity Upgrade

Building Damage Assessment Report

Building B3

Bank of England

URS-8798-RPT-G-001201

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Document Owner	
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Document History

Revision	Date	Summary of changes
1.0	March 2014	Issue for Heritage
2.0	March 2014	For approval
3.0	July 2014	TWAO Issue

For the status of this document, please refer to the Building Damage Assessment Report Register (URS-8798-RGT-001229)

Consultation:

- Ela Palmer — URS Heritage
- Brian Lyons — Dr.Sauer
- Keith Bowers/Neil Moss/Paul Dryden — London Underground
- Olly Newman — Dragados

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FIGURES

TABLES

1 Introduction

This report summarises the results of a Stage 2 damage assessment for Bank of England.

Stage 2 damage assessments are undertaken for all listed buildings within the Stage 1 Greenfield ground surface 1mm settlement contour induced by the construction of the Bank Station Capacity Upgrade (BSCU).

The purpose of the assessment is to determine the potential effect the works will have on the building. This report describes the engineering and heritage assessments undertaken for the building and concludes whether mitigation is likely to be needed and if a further (Stage 3) assessment is recommended in order to verify this..

2 The Building

2.1 General Information

General building information used in the assessment has been acquired as part of the structural desktop appraisal. Where data was not available, conservative assumptions were made instead. This information is presented in Table 1.

Category	Building Information
BSCU Reference	B3
Location	Bank of England
Address	Bank of England
Building Type	Load bearing masonry (assumed appropriate for the flank wall)
Construction Age	1734 et seq. Major refurb 1923-42
No. of Storeys	7
Basements	3
Eaves Level (mATD)	143.1
Foundation Type	Shallow (assumed)
Ground Level (mATD)	113.1
Listed Grade	I
Note: Levels given are in metres above Tunnel Datum, mATD. Tunnel Datum is 100m below Ordnance Survey Datum at Newlyn.	

Table 1: General building information

A general view of the building exterior is shown in Plate 1. A location plan showing the building in relation to the proposed BSCU works is presented in Figure 2.

Plate 1: General view

2.2 Building Description

Bank of England is a standalone structure bounded by Prince's Street, Lothbury , Bartholomew Lane and Threadneedle Street. The building is seven storeys high with three levels of basements. The Bank was largely rebuilt by Sir Herbert Baker in 1921 to 1937; however, it retains elements of the former building by Sir John Soane, including the altered screen wall dating from the late 18th to early 19th centuries. The screen wall has a portico with eight columns to its main entrance in Threadneedle Street and a similar colonnade to Bartholomew Lane. The screen wall elevations partially obscure the main buildings of the Bank of England

This building has not been subject to internal inspection during this assessment.

3 Methodology

This building damage assessment is undertaken in accordance with LU Works Information WI2300[1] and LU Civil Engineering - Common Requirements S1050[2].

The analysis methodology applies to ground-bearing buildings which will be affected by ground movements resulting from the construction of the BSCU. The engineering assessment calculates the potential impact of ground movements and assigns a damage category to the building based on a numeric scale. Additionally, for listed buildings, a heritage assessment is carried out which considers the sensitivity of the structure and the sensitivity of its particular features; a heritage sensitivity score is assigned. The heritage sensitivity score is added to the damage category to obtain the total score. If the total score is 3 or more, a more detailed Stage 3 assessment is triggered.

Oasys Xdisp is used to analyse the Greenfield ground movement in terms of settlement and horizontal displacement. Subsurface tunnelling induced ground movement profiles are determined in accordance with the methodology described by Mair et al[3 & 4].

Movements resulting from the Whole Block Scheme (WBS) and shaft excavations have been calculated using LU Guidance Document G0058[5].

The building is modelled as a simple elastic beam which is conservatively assumed to follow the Greenfield ground displacements. The beam is divided into hogging and sagging segments. The tensile strains within each segment are calculated based on the distortion associated with differential settlement (which is characterised by deflection ratio) and the distortion associated with differential horizontal displacement (characterised by horizontal strain).

Xdisp provides a method for calculating the maximum tensile strain within the building superstructure associated with these movements, in accordance with the assessment methodology described by Mair et al [4]. This strain is used to determine the damage category based on the classification system proposed by Burland[6] and in accordance with LU Civil Engineering - Common Requirements S1050[2]. The categories are presented in Table 2.

Damage Category	Description of Degree of Damage	Description of Typical Damage and likely forms of Repair for Typical Masonry Buildings.	Approx. Crack Width (mm)	Max. Tensile Strain %
0	Negligible	Hairline cracks.		< 0.05
1	Very slight	Fine cracks easily treated during normal redecoration. Perhaps isolated slight fracture in building. Cracks in exterior visible upon close inspection.	0.1 to 1.0	0.05 to 0.075
2	Slight	Cracks easily filled. Redecoration probably required. Several slight fractures inside building. Exterior cracks visible; some repainting may be required for weather-tightness. Doors and windows may stick slightly.	1 to 5	0.075 to 0.15
3	Moderate	Cracks may require cutting out and patching. Recurrent cracks can be masked by suitable linings. Tuck pointing and possible replacement of a small amount of exterior brickwork may be required. Doors and windows sticking. Utility services may be interrupted. Weather tightness often impaired.	5 to 15 or a number of cracks > 3	0.15 to 0.3
4	Severe	Extensive repair required involving removal and replacement of walls especially over doors and windows. Window and door frames distorted. Floor slopes noticeably. Walls lean or bulge noticeably. Some loss of bearing in beams. Utility services disrupted.	15 to 25 but also depends on number of cracks	> 0.3
5	Very severe	Major repair required involving partial or complete reconstruction. Beams lose bearing, walls lean badly and require shoring. Windows broken by distortion. Danger of instability.	Usually > 25 but depends on number of cracks	
Note: Please refer LU Civil Engineering - Common Requirements S1050[2].				

Table 2: Building damage classification

4 Input Data

The magnitude and distribution of ground movements and degree of building damage is calculated based on the following input data:

- The Xdisp model coordinates and levels are based on the 3D model (20130212DSPITT Scheme R09);
- Four construction stages are considered in accordance with the proposed programme (November 2013) as illustrated in Figure 1;
- Trough width parameter constant, K=0.5 is used in accordance with WI2300[1].

The input data for the building, tunnels and shaft excavation are summarised in Table 3, Table 4 and Table 5 respectively.

Location	Foundation level (mATD)	Building Height above foundation level (m)	E/G
Bank of England	98.1*	45	2.6
Note: Where E / G is the ratio of Young's modulus to shear modulus of the deep beam that is to represent the building. * Assumed level, 1.5m thick slab beneath floor level.			

Table 3: Building data

Tunnel Item	Level of axis (mATD)	External diameter (m)	Volume Loss (%)
Running tunnels	83.5	5.4	1.5
Running tunnels northern tie in	83	4.8	1.5
Square works adits	75.8 to 95.3	4.1 to 7.8	2.5
Platform enlargement	85.6	7.4 to 11.2	1.5
Escalator barrels	Inclined	8.3 to 8.4	1.5
Central Line Connection	Inclined (87.6 to 89.2)	8.6	1.5

Table 4: Tunnel data

Excavation	Excavation Base Level (mATD)
Grout Shaft at King William Street	97
Whole Block Scheme Box excavation	73
Arthur Street Shaft	81

Table 5: Excavation data

The distance of building Bank of England (B3) relative to the excavation elements listed in Table 5 is sufficiently large that this building should not be affected by their construction.

The Xdisp models filename used to undertake this assessment are:

- B3 - Stage 4
- B3 - Stage 3
- B3 - Stage 2
- B3 - Stage 1

5 Results

5.1 Engineering Assessment

The sections through the building which have been analysed are shown on plan in Figure 3.

Assessment has been undertaken at three intermediate construction stages and at the end of construction when all major elements of the works including shaft and tunnels have been completed. The damage category assigned to the building is based on the construction stage at which the potential impact on the building is most severe.

The maximum settlement and tensile strain calculated for each of the analysis sections at the most onerous intermediate construction stage and at the end of construction are presented in Table 6 and Table 7.

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
B3 (line 1)	<1	<0.001
B3 (line 2)	4	0.005
B3 (line 3)	<1	<0.001

Table 6: Building response at most onerous intermediate stage - Construction Stage 2

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
B3 (line 1)	4	0.009
B3 (line 2)	10	0.006
B3 (line 3)	1	0.003

Table 7: Building response at end of construction stage

The results of the assessment show construction Stage 4 is the critical stage for this building, where (line 1) experiences the most onerous combined tensile strain. The orientation is shown in Figure 3. The vertical and horizontal Greenfield ground movements along the section of the building are shown in Figure 4. The relative position of the building and tunnels along section (line 1) is shown in Figure 5. The calculated strains are summarised in Table 8.

Line No	Strains in section (Curvature)	Position from start (m)	Length (m)	Average* Horizontal Strain (%)	Maximum Tensile Strains (%)	Damage Category
(line 1)	Hogging	0.0	41.2	0.005	0.009	Negligible
	Sagging	41.2	2.5	<0.001	<0.001	Negligible
	Hogging	43.7	2.5	<0.001	<0.001	Negligible
	Hogging	46.2	70.3	<0.001	<0.001	Negligible
Note: * Tensile horizontal strains are +ve. Compressive horizontal strains are –ve.						

Table 8: Section analysed, results for worst case tensile strain

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0. This corresponds to Negligible damage in accordance with Table 2.

The maximum settlement of the building at foundation level at the end of construction is 10mm.

5.2 Heritage and Structural Assessment

Assessment has been made using the following scoring methodology set out in Table 9.

Score	STRUCTURE Sensitivity of the structure to ground movements and interaction with adjacent buildings	HERITAGE FEATURES Sensitivity to calculated movement of particular features within the building	CONDITION Factors which may affect the sensitivity of structural or heritage features
0	Masonry buildings with lime mortar and regular openings, not abutted by other buildings, and therefore similar to the buildings on which the original Burland assessment was based.	No particular sensitive features	Good/Fair - not affecting the sensitivity of structural or heritage features
1	Buildings not complying with categories 0 or 2, but still with some sensitive structural features in the zone of settlement e.g.: cantilever stone staircases, long walls without joints or openings, existing cracks where further movements are likely to concentrate, mixed foundations	Brittle finishes, e.g. faience or tight-jointed stonework, which are susceptible to small structural movements and difficult to repair invisibly.	Poor - may change the behaviour of a building in cases of movement. Poor condition of heritage features and finishes. Evidence of previous movement.
2	Buildings which, by their structural form, will tend to concentrate all their movements in one location (e.g.: a long wall without joints and with a single opening).	Finishes which if damaged will have a significant effect on the heritage value of the building, e.g. Delicate frescos, ornate plasterwork ceilings.	Very poor – parlous condition of heritage features and finishes, severe existing damage to structure including evidence of ongoing movement. Essentially buildings where even very small movements could lead to significant damage.

Table 9: Heritage and structural scoring methodology

The results of the heritage assessment carried out for the building are summarised in Table 10.

SENSITIVITY OF THE STRUCTURE
No inspection has been carried out as part of this assessment and very limited historic information is available. Our understanding of the buildings structure is based on the Alan Baxter's document "BANK OF ENGLAND_ Combined gazetteers_July 2013." It is understood that much of the existing structure was constructed during the first half of the 20th centuary, when the site was excavated to a depth of 15m and a new raft foundation installed to support a steel frame. The earlier screen wall was underpinned with a 2.44m wide concrete retaining wall. Based on our current knowledge the most structurally sensitive element of the building is the largely blank screen wall to the perimeter of the building. Of particular concern is the "Tivoli Corner" at the north west corner of the site (refer to Plate 1). This is the area of maximum displacement, at the end of line 1 (refer to figure 4). Since the arched opening is the only significant opening on this part of the elevation it is likely that much of the movement will be concentrated here. It is noted that the screen wall is topped by a bottled balustrade, which is also sensitive to movement.
Score: 2 The long blank elevations which terminate with the "Tivoli Corner" are vulnerable to movement, particularly as the openings in this corner are located over an area of maximum movement.
SENSITIVITY OF THE HERITAGE
To date, it has not been possible to gain access to the building to carry out inspection as part of this assessment. On the basis of current knowledge, the screen wall is the heritage feature which has the highest sensitivity to movement, with its columned walkway at Tivoli Corner having particular heritage value. As no internal inspection has taken place, it is assumed that the interiors of the building contain fine and brittle finishes, as well as vaults and safes, which may be sensitive to small movements.
Score: 1 – the screen wall and Tivoli Corner are sensitive to settlement. It is assumed that the interiors of the Bank contain brittle or otherwise sensitive heritage features.
SENSITIVITY OF THE CONDITION
The condition of the building from the exterior (screen wall) looks to be good.
Score: 0 – the condition of the building will not exacerbate the sensitivity of the heritage and structural features.

Table 10: Heritage and structural assessment

5.3 Total Score

The total score is the summation of the damage category, structural sensitivity, heritage sensitivity and condition sensitivity scores:

The damage category is 0

The structural sensitivity score is 2

The heritage sensitivity score is 1

The condition sensitivity score is 0

The total score for this building is 3

6 Conclusion

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0 for the Bank of England. However, a high level heritage and structural assessment, not including a site inspection but taking into account the location and extent of settlement and tensile strains indicates that the building potentially has a high level of structural sensitivity. This assessment has determined that the building has a total score of 3.

Whilst the total score of 3 indicates that a Stage 3 report should be recommended, it is recognised that the levels of settlement in the area of the Bank of England are relatively low. It is recommended that a site inspection and consultation be undertaken for verification purposes of whether a Stage 3 assessment is necessary.

In particular, this verification should include inspection of the building, and further understanding of its foundations, particularly in the area of Tivoli Corner.

7 References

[1] LU Works Information WI 2300 Ground Movement version 3, 19-07-13.

[2] LU Category 1 Standard: S1050 Civil Engineering - Common Requirements, Issue No. A7, Nov. 2013.

[3] Mair R J, Taylor R N and Bracegirdle A (1993). Subsurface settlement profiles above tunnels in clays. Géotechnique 43, No. 2, pp. 315-320.

[4] Mair R J, Taylor R N and Burland J B (1996). Prediction of ground movements and assessment of risk of building damage due to bored tunnelling. (In: International Conference of Geotechnical Aspects of Underground Construction in Soft Ground, London, pp. 713–718.

[5] LU Guidance Document G0058 Civil Engineering Technical Advice Notes, Issue No. A17, Feb. 2013.

[6] Burland J B (1995). Assessment of risk of damage to buildings due to tunnelling and excavation. Proceedings: 1st International Conference of Earthquake Geotechnical Engineering, IS Tokyo, 1995.

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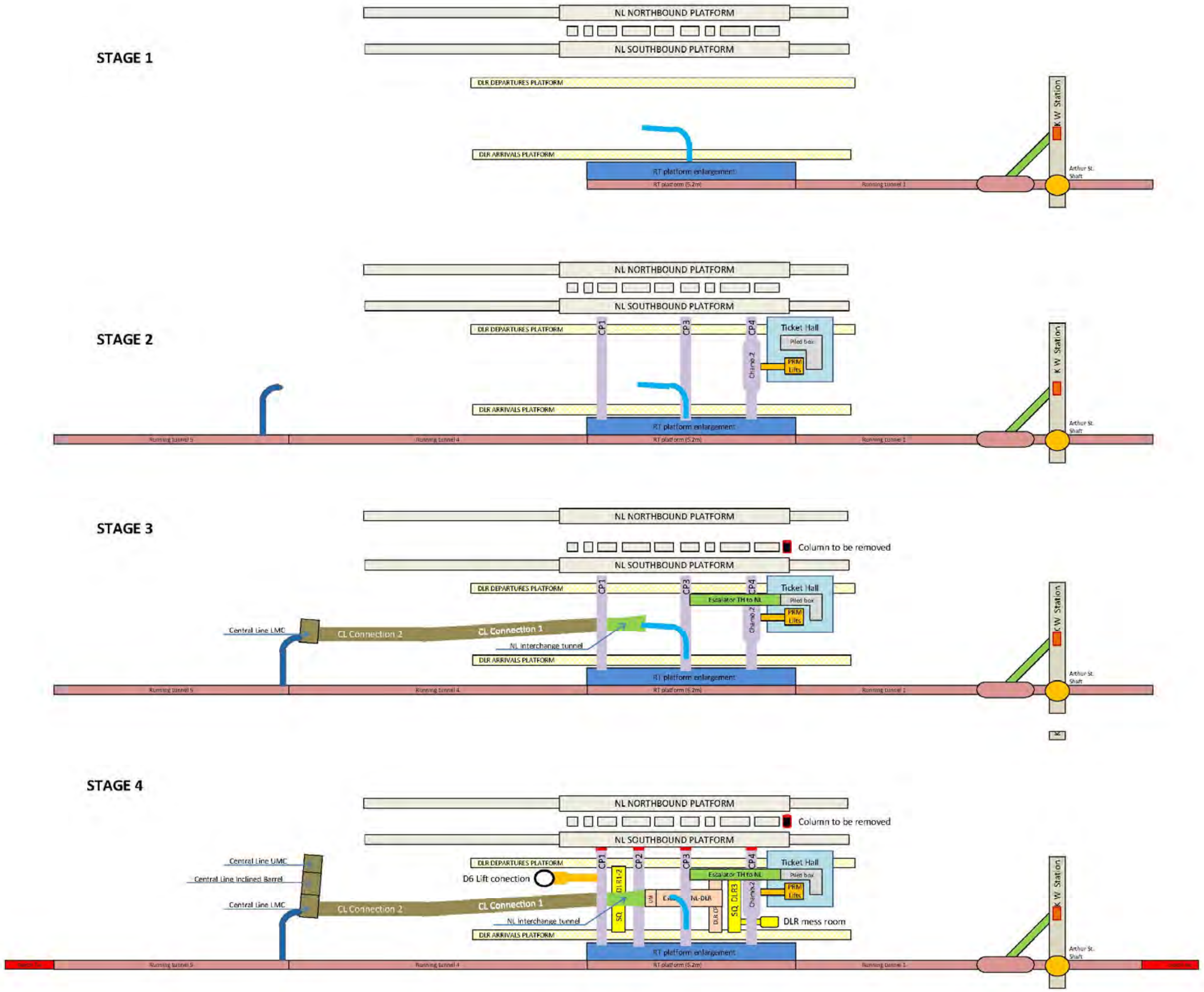

Figure 1: Construction Stage model

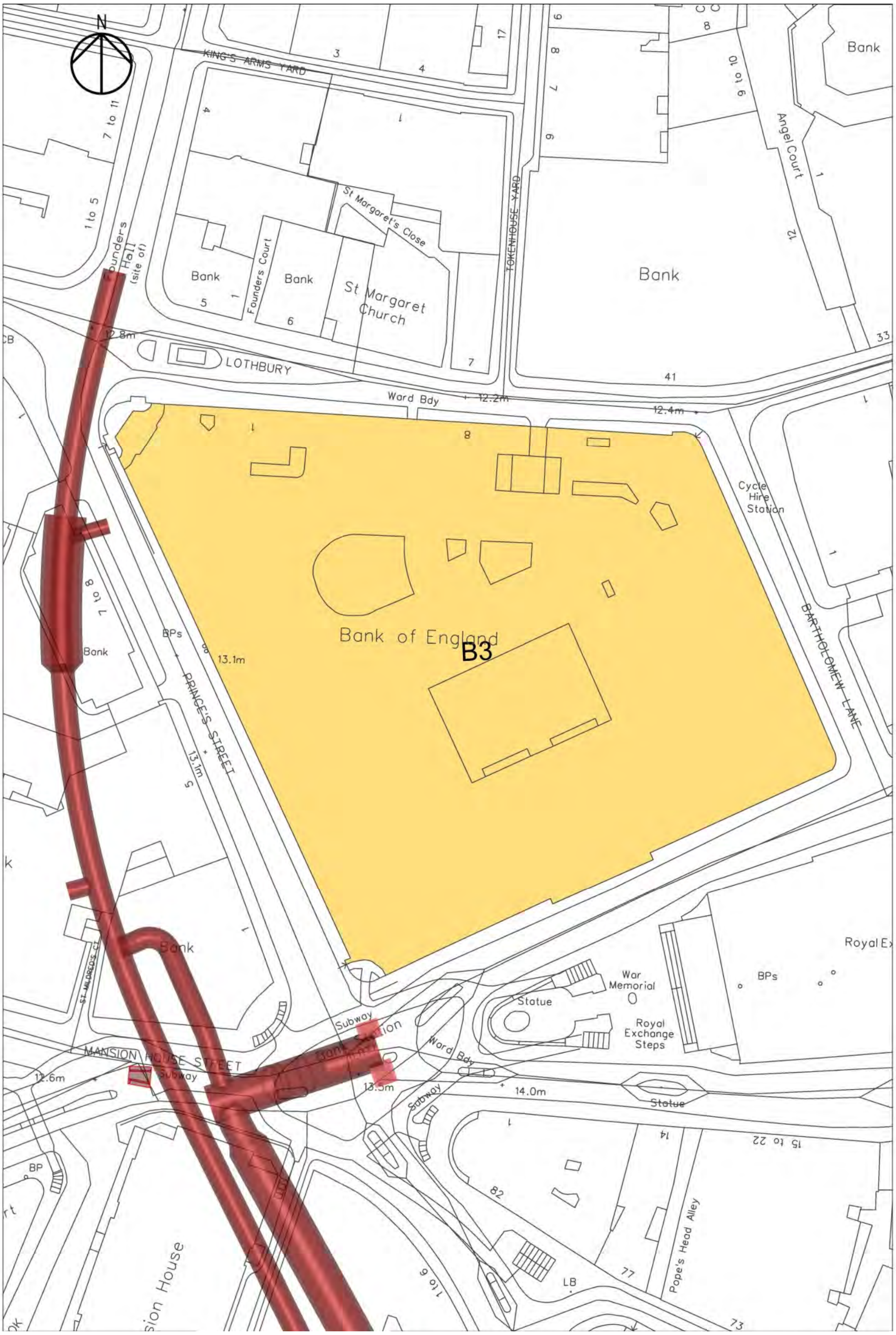

Figure 2: Location plan showing building location in relation to BSCU works

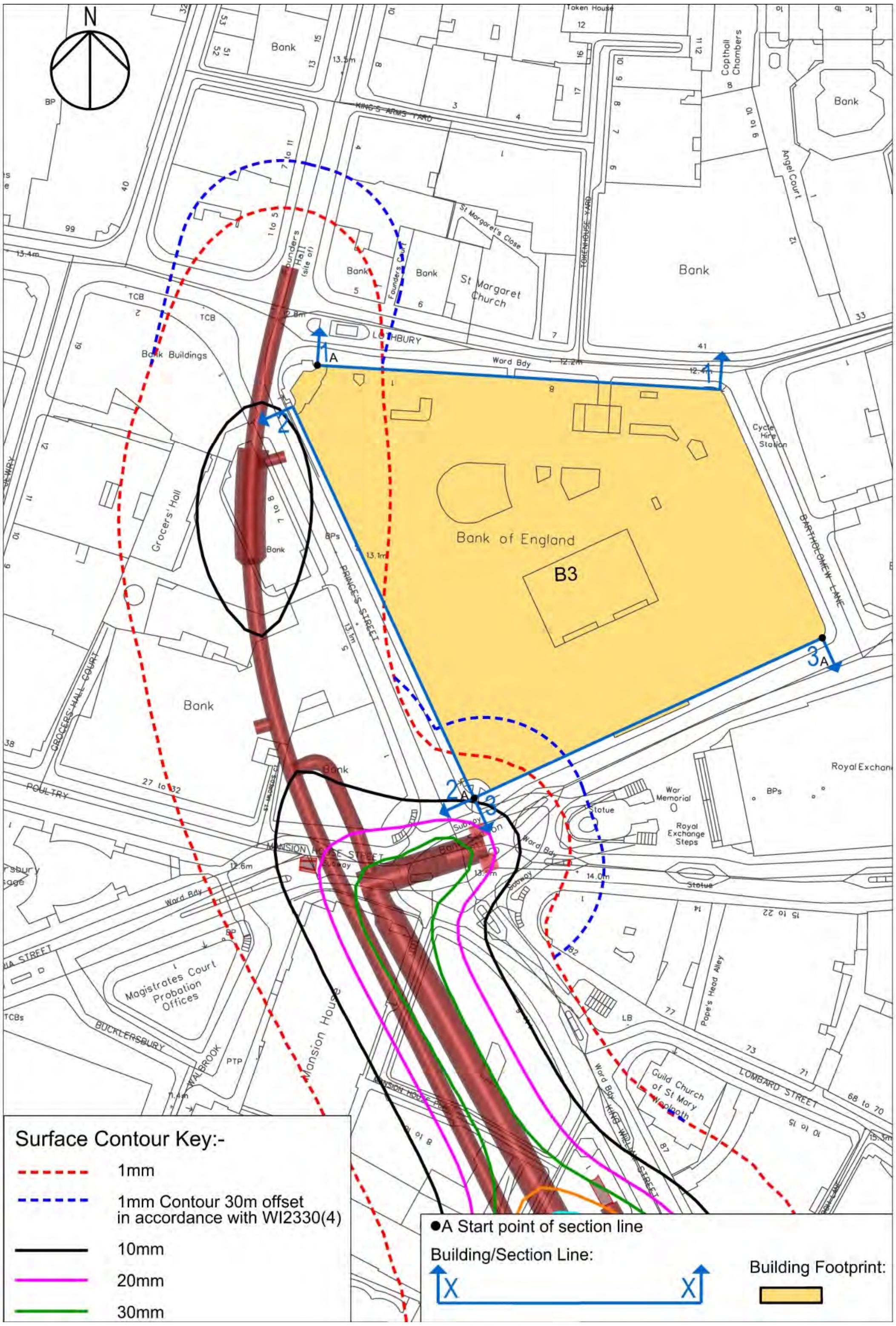

Figure 3: Building location, sections analysed and Settlement Contours at stage of worst case for tensile strains

Figure 4: Building displacement at founding level at stage 4 (line 1) of worst case for tensile strains

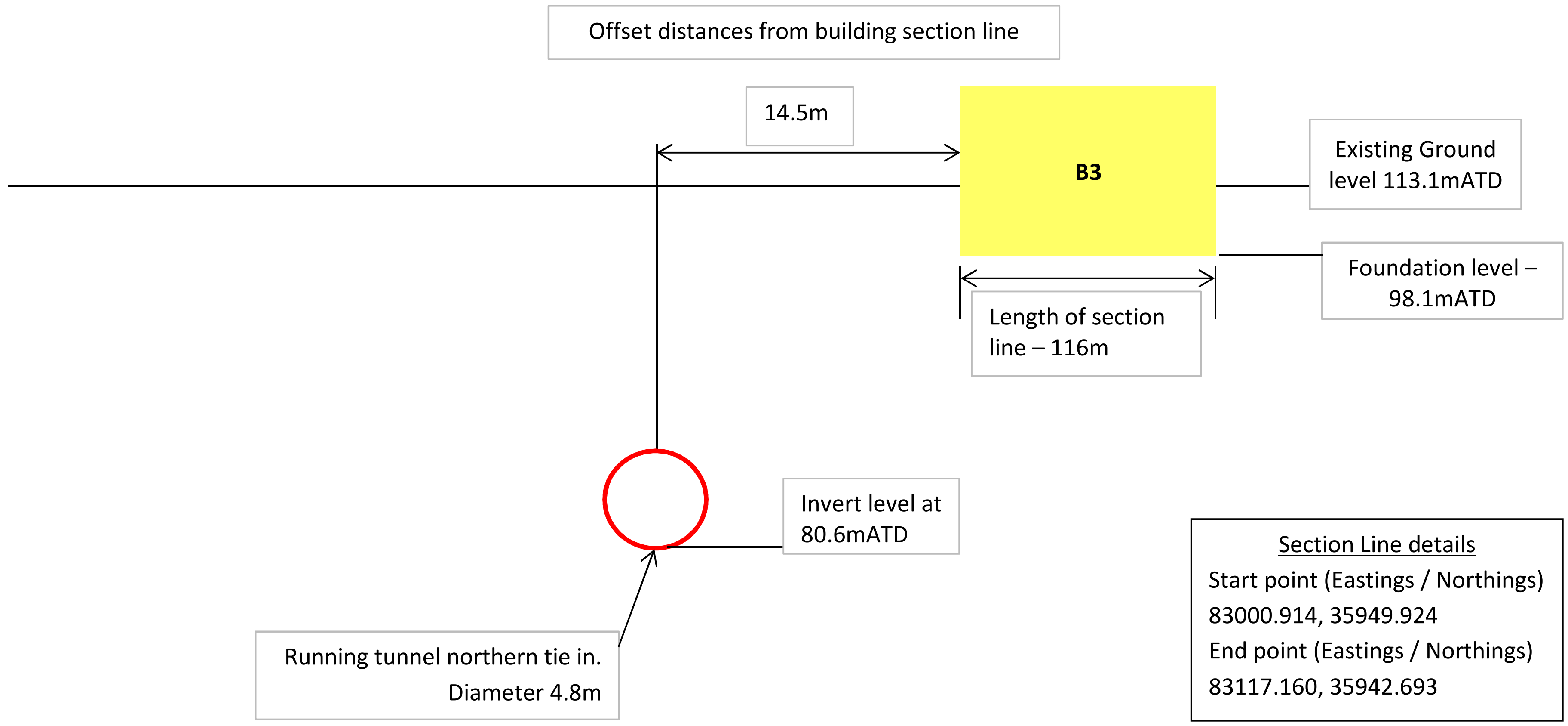

Figure 5: Diagrammatic cross-section of section (line 1) relative to tunnel position

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Bank Station Capacity Upgrade

Building Damage Assessment Report

Building B5

1 Queen Victoria, Magistrates Court

URS-8798-RPT-G-001203

Prepared by:	Lisa Perkins Assistant Geotechnical Engineer	L. Perkins	21/07/14
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Document History

Revision	Date	Summary of changes
1.0	March 2014	Issue for Heritage
2.0	April 2014	For Approval
3.0	July 2014	TWAO Issue

For the status of this document, please refer to the Building Damage Assessment Report Register (URS-8798-RGT-001229)

Consultation:

- Ela Palmer — URS Heritage
- Brian Lyons — Dr.Sauer
- Keith Bowers/Neil Moss/Paul Dryden — London Underground
- Olly Newman — Dragados

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1 Introduction

This report summarises the results of a Stage 2 damage assessment for 1 Queen Victoria, Magistrates Court.

Stage 2 damage assessments are undertaken for all buildings within the Stage 1 Greenfield ground surface 1mm settlement contour induced by the construction of the Bank Station Capacity Upgrade (BSCU).

The purpose of the assessment is to determine the potential effect the works will have on the building. This report describes the engineering and heritage assessments undertaken for the building and concludes whether mitigation is likely to be needed and if a further (Stage 3) assessment is recommended in order to verify this.

2 The Building

2.1 General Information

General building information used in the assessment has been acquired as part of the structural desktop appraisal. Where data was not available, conservative assumptions were made instead. This information is presented in Table 1.

Category	Building Information
BSCU Reference	B5
Location	Queen Victoria
Address	1 Queen Victoria, Magistrates Court
Building Type	Load bearing masonry (assumed)
Construction Age	1872
No. of Storeys	4
Basements	5
Eaves Level (mATD)	131.2
Foundation Type	Shallow
Ground Level (mATD)	113.2
Listed Grade	II
Note: Levels given are in metres above Tunnel Datum, mATD. Tunnel Datum is 100m below Ordnance Survey Datum at Newlyn.	

Table 1: General building information

A general view of the building exterior is shown in Plate 1. A location plan showing the building in relation to the proposed BSCU works is presented in Figure 2.

Plate 1: General view

2.2 Building Description & Heritage

Designed by John Whichcord Jr. and constructed in 1872, 1 Queen Victoria Street is the location of the City of London Magistrates Courts. The building has three entrances: general public on the corner of Walbrook and Queen Victoria Street; Magistrates on the corner of Queen Victoria Street and Bucklersbury Street; and cells on Bucklersbury Street.

The building, which is triangular in plan, detached with curved corners, consists of 3 stories with mansard above ground level and 5 basement levels and is constructed of load bearing masonry. The structure below street level is constructed of a combination of mass concrete and masonry. The mortar used is cementitious. The external facades are constructed with buff coloured sandstone with rich Italianate architectural carving and detailing. The slate tiled mansard roof has a wrought iron balustrade and series of dormer windows. The later copper capped parapet obscures an asphalt flat roof accommodating plant and other services.

The building was originally constructed by the National Safe Deposit Company Ltd, thought to be the first safe deposit building in the UK designed specifically for that purpose. Within the substantial 5 level basement survives the massive and impregnable vault measuring approximately 24.4m by 14m by 14m, constructed of 2000 tons of steel and founded on independent brick arches above the river Walbrook to discourage tunnelling. The basement is accessed via a grand cantilevered staircase. In 1987 permission was granted for the building to be converted for use as a Magistrates Court. As a result the above ground levels of the building have been almost entirely renovated. The building has been fitted out to function as a court with cells in the basement (not visible during the site inspection), reception, courts and a series of antechambers on the ground and first floor and offices on the third floor and mansard level. Below ground level a variety of the walk-in vaults and strong rooms survive accessed by a cantilevered staircase.

3 Methodology

This building damage assessment is undertaken in accordance with LU Works Information WI2300[1] and LU Civil Engineering - Common Requirements S1050[2].

The analysis methodology applies to ground-bearing buildings which will be affected by ground movements resulting from the construction of the BSCU. The engineering assessment calculates the potential impact of ground movements and assigns a damage category to the building based on a numeric scale. Additionally, for listed buildings, a heritage assessment is carried out which considers the sensitivity of the structure and the sensitivity of its particular features; a heritage sensitivity score is assigned. The heritage sensitivity score is added to the damage category to obtain the total score. If the total score is 3 or more, a more detailed Stage 3 assessment is triggered.

Oasys Xdisp is used to analyse the Greenfield ground movement in terms of settlement and horizontal displacement. Subsurface tunnelling induced ground movement profiles are determined in accordance with the methodology described by Mair et al[3 & 4].

Movements resulting from the Whole Block Scheme (WBS) and shaft excavations have been calculated using LU Guidance Document G0058[5].

The building is modelled as a simple elastic beam which is conservatively assumed to follow the Greenfield ground displacements. The beam is divided into hogging and sagging segments. The tensile strains within each segment are calculated based on the distortion associated with differential settlement (which is characterised by deflection ratio) and the distortion associated with differential horizontal displacement (characterised by horizontal strain).

Xdisp provides a method for calculating the maximum tensile strain within the building superstructure associated with these movements, in accordance with the assessment methodology described by Mair et al [4]. This strain is used to determine the damage category based on the classification system proposed by Burland[6] and in accordance with LU Civil Engineering - Common Requirements S1050[2]. The categories are presented in Table 2.

Damage Category	Description of Degree of Damage	Description of Typical Damage and likely forms of Repair for Typical Masonry Buildings.	Approx. Crack Width (mm)	Max. Tensile Strain %
0	Negligible	Hairline cracks.		< 0.05
1	Very slight	Fine cracks easily treated during normal redecoration. Perhaps isolated slight fracture in building. Cracks in exterior visible upon close inspection.	0.1 to 1.0	0.05 to 0.075
2	Slight	Cracks easily filled. Redecoration probably required. Several slight fractures inside building. Exterior cracks visible; some repainting may be required for weather-tightness. Doors and windows may stick slightly.	1 to 5	0.075 to 0.15
3	Moderate	Cracks may require cutting out and patching. Recurrent cracks can be masked by suitable linings. Tuck pointing and possible replacement of a small amount of exterior brickwork may be required. Doors and windows sticking. Utility services may be interrupted. Weather tightness often impaired.	5 to 15 or a number of cracks > 3	0.15 to 0.3
4	Severe	Extensive repair required involving removal and replacement of walls especially over doors and windows. Window and door frames distorted. Floor slopes noticeably. Walls lean or bulge noticeably. Some loss of bearing in beams. Utility services disrupted.	15 to 25 but also depends on number of cracks	> 0.3
5	Very severe	Major repair required involving partial or complete reconstruction. Beams lose bearing, walls lean badly and require shoring. Windows broken by distortion. Danger of instability.	Usually > 25 but depends on number of cracks	
Note: Please refer LU Civil Engineering - Common Requirements S1050[2].				

Table 2: Building damage classification

4 Input Data

The magnitude and distribution of ground movements and degree of building damage is calculated based on the following input data:

- The Xdisp model coordinates and levels are based on the 3D model (20130212DSPITT Scheme R09);
- Four construction stages are considered in accordance with the proposed programme (November 2013) as illustrated in Figure 1;
- Trough width parameter constant, K=0.5 is used in accordance with WI2300[1].

The input data for the building, tunnels and shaft excavation are summarised in Table 3, Table 4 and Table 5 respectively.

Location	Foundation level (mATD)	Building Height above foundation level (m)	E/G
1 Queen Victoria	99.7*	31.5	2.6
Note: Where E / G is the ratio of Young's modulus to shear modulus of the deep beam that is to represent the building. * Assumed level, 1.5m thick slab beneath floor level.			

Table 3: Building data

Tunnel Item	Level of axis (mATD)	External diameter (m)	Volume Loss (%)
Running tunnels	83.2	5.4	1.5
Square works adits	75.8 to 95.3	4.1 to 7.8	2.5
Platform enlargement	85.6	7.4 to 11.2	1.5
Escalator barrels	Inclined	8.4	1.5
Central Line Connection	Inclined (87.6 to 89.2)	8.6	1.5
Central Line Lower Machine Chamber (LMC)	89.2	6.7	1.5

Table 4: Tunnel data

Excavation	Excavation Base Level (mATD)
Grout Shaft at King William Street	97
Whole Block Scheme Box excavation	73
Arthur Street Shaft	81

Table 5: Excavation data

The distances of building 1 Queen Victoria (B5) relative to the excavation elements listed in Table 5 are sufficiently large that this building should not be affected by their construction.

The Xdisp models filename used to undertake this assessment are:

- B5 - Stage 4
- B5 - Stage 3
- B5 - Stage 2
- B5 - Stage 1

5 Results

5.1 Engineering Assessment

The sections through the building which have been analysed are shown on plan in Figure 3.

Assessment has been undertaken at three intermediate construction stages and at the end of construction when all major elements of the works including shaft and tunnels have been completed. The damage category assigned to the building is based on the construction stage at which the potential impact on the building is most severe.

The maximum settlement and tensile strain calculated for each of the analysis sections at the most onerous intermediate construction stage and at the end of construction are presented in Table 6 and Table 7.

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
B5 (line 1)	<1	<0.001
B5 (line 2)	<1	<0.001

Table 6: Building response at most onerous intermediate stage - Construction Stage 3

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
B5 (line 1)	<1	<0.001
B5 (line 2)	<1	<0.001

Table 7: Building response at end of construction stage

The results of the assessment show construction stage 4 is the critical stage for this building with the results close to intermediate construction stage 3. At this stage, section B5 (line 1) experiences the maximum calculated combined tensile strain. The orientation is shown in Figure 3. The relative position of the building and tunnels along section (line 1) is shown in Figure 4. The calculated strains are summarised in Table 8.

Line #	Strains in section (Curvature)	Position from start (m)	Length (m)	Average* Horizontal Strain (%)	Maximum Tensile Strains (%)	Damage Category
(line 1)	Hogging	0	7.0	<0.001	<0.001	Negligible
	Hogging	7.0	2.5	<0.001	<0.001	Negligible
	Sagging	9.5	2.5	<0.001	<0.001	Negligible
	Hogging	12.0	21.0	<0.001	<0.001	Negligible
Note: * Tensile horizontal strains are +ve. Compressive horizontal strains are –ve.						

Table 8: Section analysed, results for worst case tensile strain

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0. This corresponds to Negligible damage in accordance with Table 2.

The maximum settlement of the building at foundation level at the end of construction is less than 1mm.

5.2 Heritage and Structural Assessment

Following site inspection, assessment has been made using the following scoring methodology as set out in Table 9.

Score	STRUCTURE Sensitivity of the structure to ground movements and interaction with adjacent buildings	HERITAGE FEATURES Sensitivity to calculated movement of particular features within the building	CONDITION Factors which may affect the sensitivity of structural or heritage features
0	Masonry buildings with lime mortar and regular openings, not abutted by other buildings, and therefore similar to the buildings on which the original Burland assessment was based.	No particular sensitive features	Good/Fair - not affecting the sensitivity of structural or heritage features
1	Buildings not complying with categories 0 or 2, but still with some sensitive structural features in the zone of settlement e.g.: cantilever stone staircases, long walls without joints or openings, existing cracks where further movements are likely to concentrate, mixed foundations	Brittle finishes, e.g. faience or tight-jointed stonework, which are susceptible to small structural movements and difficult to repair invisibly.	Poor - may change the behaviour of a building in cases of movement. Poor condition of heritage features and finishes. Evidence of previous movement.
2	Buildings which, by their structural form, will tend to concentrate all their movements in one location (e.g.: a long wall without joints and with a single opening).	Finishes which if damaged will have a significant effect on the heritage value of the building, e.g. Delicate frescos, ornate plasterwork ceilings.	Very poor – parlous condition of heritage features and finishes, severe existing damage to structure including evidence of ongoing movement. Essentially buildings where even very small movements could lead to significant damage.

Table 9: Heritage and structural scoring methodology

The results of the heritage assessment carried out for the building are summarised in Table 10.

SENSITIVITY OF THE STRUCTURE
The building appears to be a robust structure, with little alteration since original construction. The building is founded deeply and is on the edge of the 1mm contour and so little actual movement is anticipated. The building includes a circular stone "cantilever" stair case extending from basement level one to basement level four. The staircase relies on the treads being soundly locked into the supporting wall to resist torsion, while transmitting vertical load down from tread to tread onto the landings below The balustrade is of timber and is therefore not capable of providing temporary restraint to the individual treads in the event of movement or stone failure (as is the case in most traditional stairs which utilise iron balustrades). There is an existing vertical crack in the supporting wall, extending over more than one storey. The presence of this crack puts the overall stability of the stair at risk, should further movement take place.
Score: 1 - The stone "cantilever" stair is vulnerable to any movement which may affect the fixity of the treads.
SENSITIVITY OF THE HERITAGE
Externally the channelled masonry ground level accurately reflects the solidity of the institution, now fittingly used as the City of London Magistrates Court. The stone used is sandstone and very resistant to weathering. Less well acknowledged is the technological value displayed in the surviving vaults; and the surviving internal decoration which is almost exclusively found below ground level. Evidently the majority of the above ground areas were reserved for administrative offices whilst patrons were invited to descend to the banking hall in the basement where they would access their deposits. The above ground areas have been modernised and no heritage features survive except for some windows, glazing and internal doors on three levels at the magistrate's stair on west corner of the building, away from the potential settlement.

Score: 0 - The predicted settlement to the far eastern area of the building is extremely limited and given the massively strong construction of both the deep basements and technologically significant vaults, the heritage fixtures and finishes are not considered sensitive to this predicted settlement.
SENSITIVITY OF THE CONDITION
Externally the building is in very good condition with no evidence of any structural movement. There are some limited areas that display evidence of surface discolouration due to water washing or vegetation growth, for example on low level cornices. Internally the building has been renovated for use as a magistrate's court. The above ground areas are in an adequate condition. Below ground level the basements are now utilised for storage of court records and disused equipment. The lower basements are subject to regular flooding, with the fifth basement level completely underwater at the time of the site visit, and there is much damage as a result. Heritage features have been damaged by water or the insertion of modern services. The crack in the supporting wall of the stone "cantilever" stair is of concern, due to the sensitivity of this type of stair to movement.
Score: 1 - Below ground the building is in poor condition with much evidence of water ingress and a general lack of maintenance. Surviving heritage finishes below ground have been damaged and there is evidence of structural movement that affects the cantilevered staircase at the east of where any potential settlement will be concentrated.

Table 10: Heritage and structural assessment

5.3 Total Score

The total score is the summation of the damage category, structural sensitivity, heritage sensitivity and condition sensitivity scores:

The damage category is 0

The structural sensitivity score is 1

The heritage sensitivity score is 0

The condition sensitivity score is 1

The total score for this building is 2

6 Conclusion

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0 for 1 Queen Victoria Street. Specific heritage and structural assessment taking into account the location and extent of settlement and tensile strains indicates that though there are sensitivities inherent to the building, the level of settlement predicted will not result in damage to the building. This assessment has determined that the building has a total score of 2.

1 Queen Victoria Street is located to the west of the Bank Station Capacity Upgrade tunnelling works. These will result in extremely limited settlement at the most eastern point of the building.

It is recommended that the building does not require a Stage 3 assessment.

7 References

[1] LU Works Information WI 2300 Ground Movement version 3, 19-07-13.

[2] LU Category 1 Standard: S1050 Civil Engineering - Common Requirements, Issue No. A7, Nov. 2013.

[3] Mair R J, Taylor R N and Bracegirdle A (1993). Subsurface settlement profiles above tunnels in clays. Géotechnique 43, No. 2, pp. 315-320.

[4] Mair R J, Taylor R N and Burland J B (1996). Prediction of ground movements and assessment of risk of building damage due to bored tunnelling. (In: International Conference of Geotechnical Aspects of Underground Construction in Soft Ground, London, pp. 713–718.

[5] LU Guidance Document G0058 Civil Engineering Technical Advice Notes, Issue No. A17, Feb. 2013.

[6] Burland J B (1995). Assessment of risk of damage to buildings due to tunnelling and excavation. Proceedings: 1st International Conference of Earthquake Geotechnical Engineering, IS Tokyo, 1995.

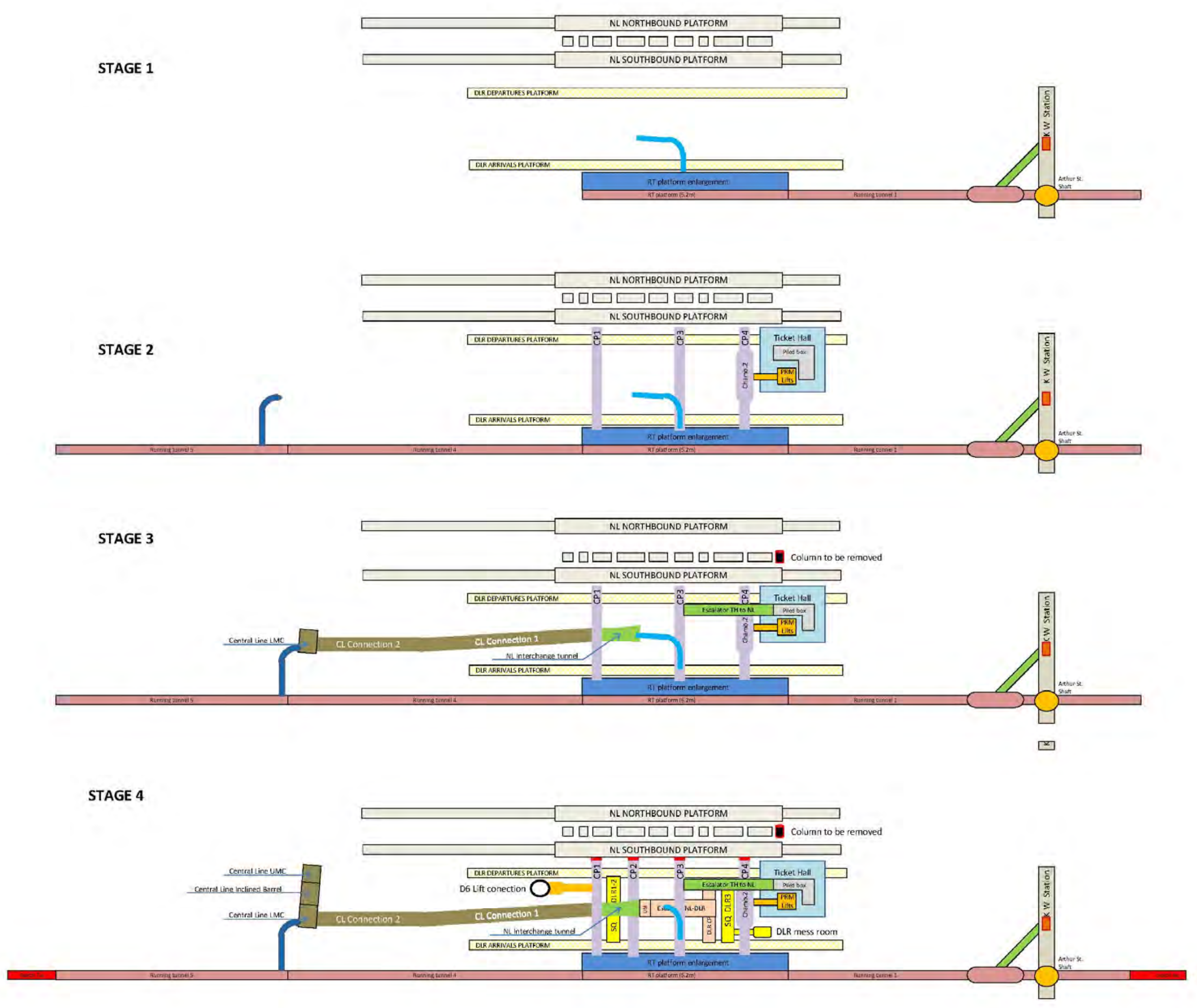

Figure 1: Construction Stage model

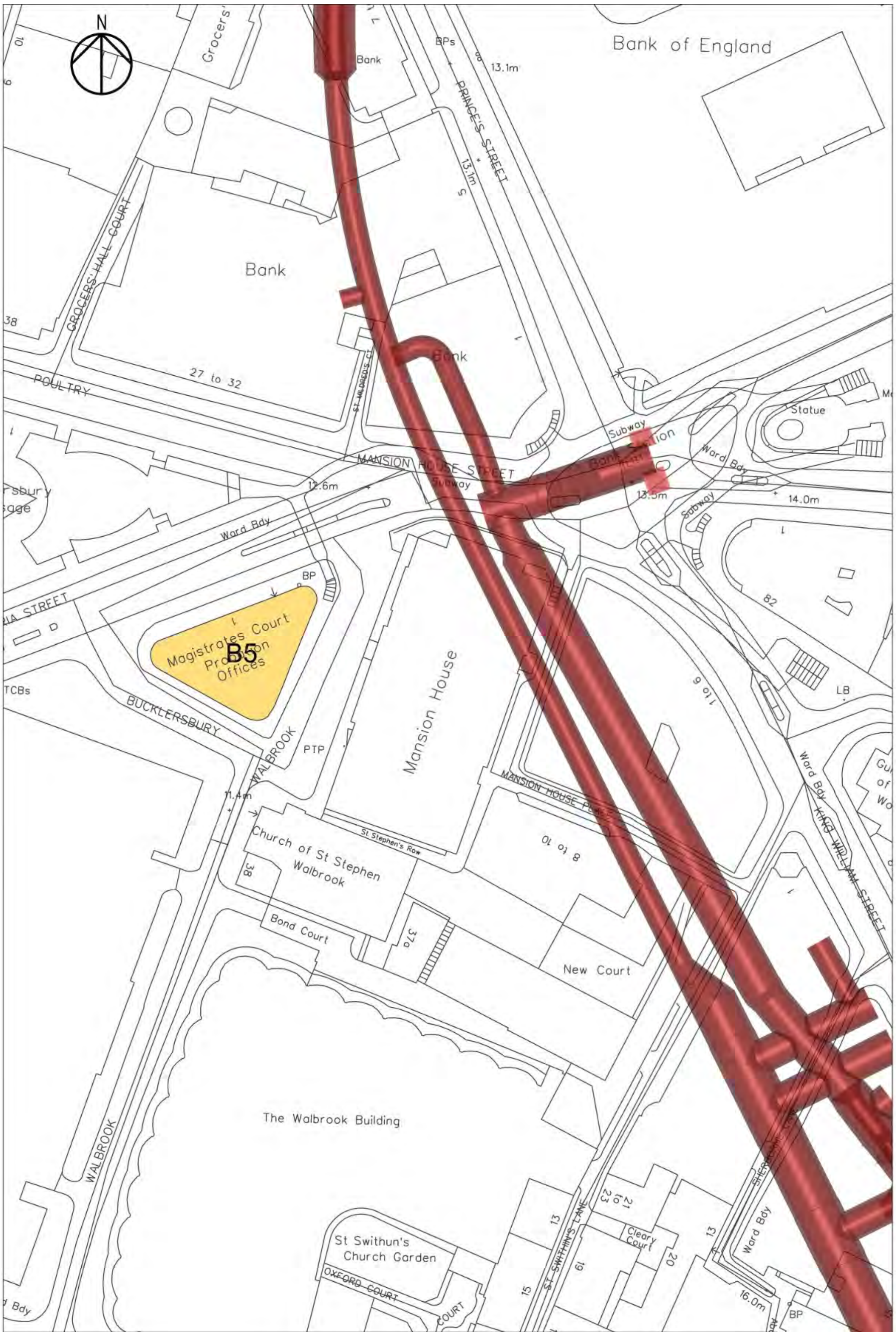

Figure 2: Location plan showing building location in relation to BSCU works

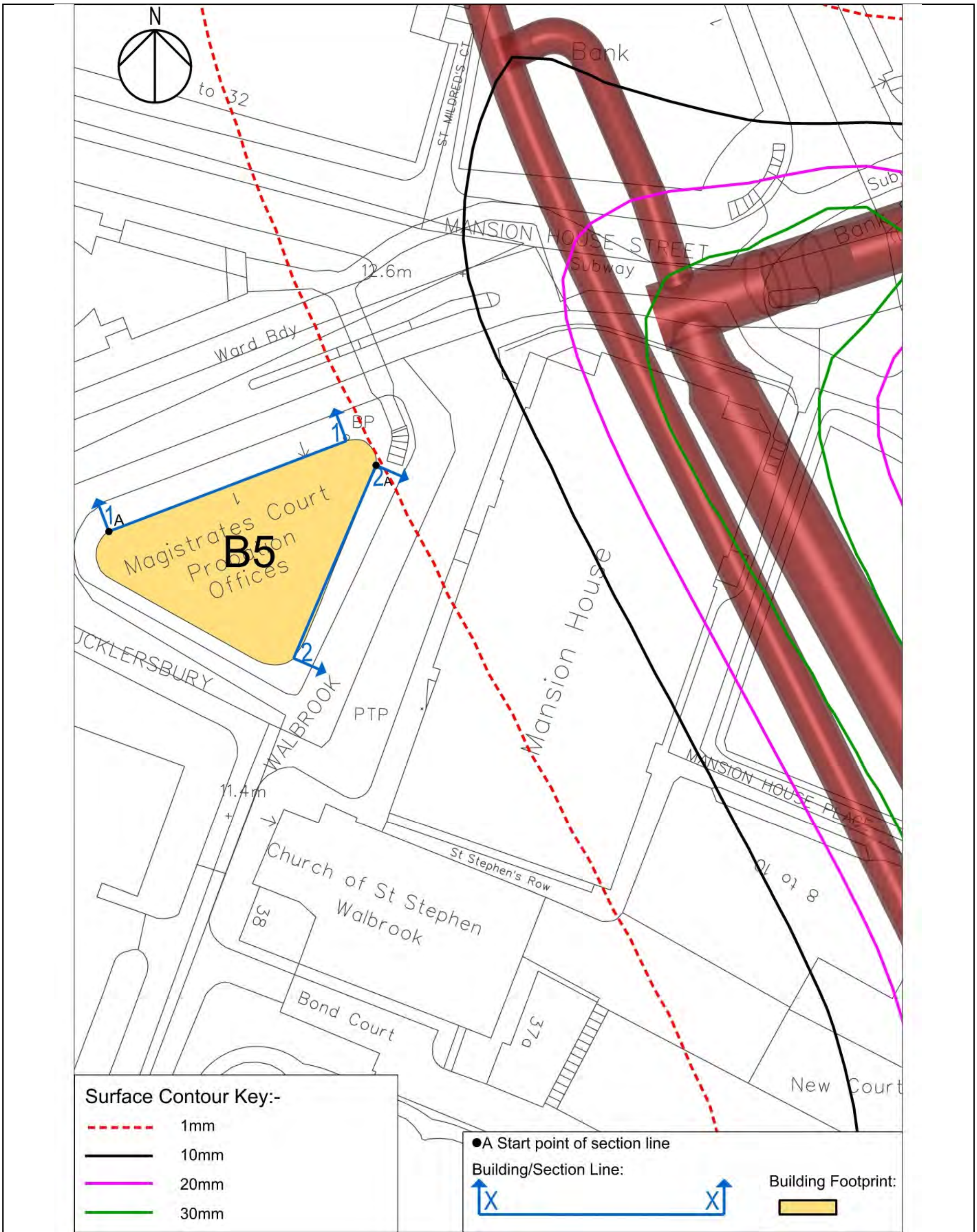

Figure 3: Building location, sections analysed and Settlement Contours at stage of worst case for tensile strains

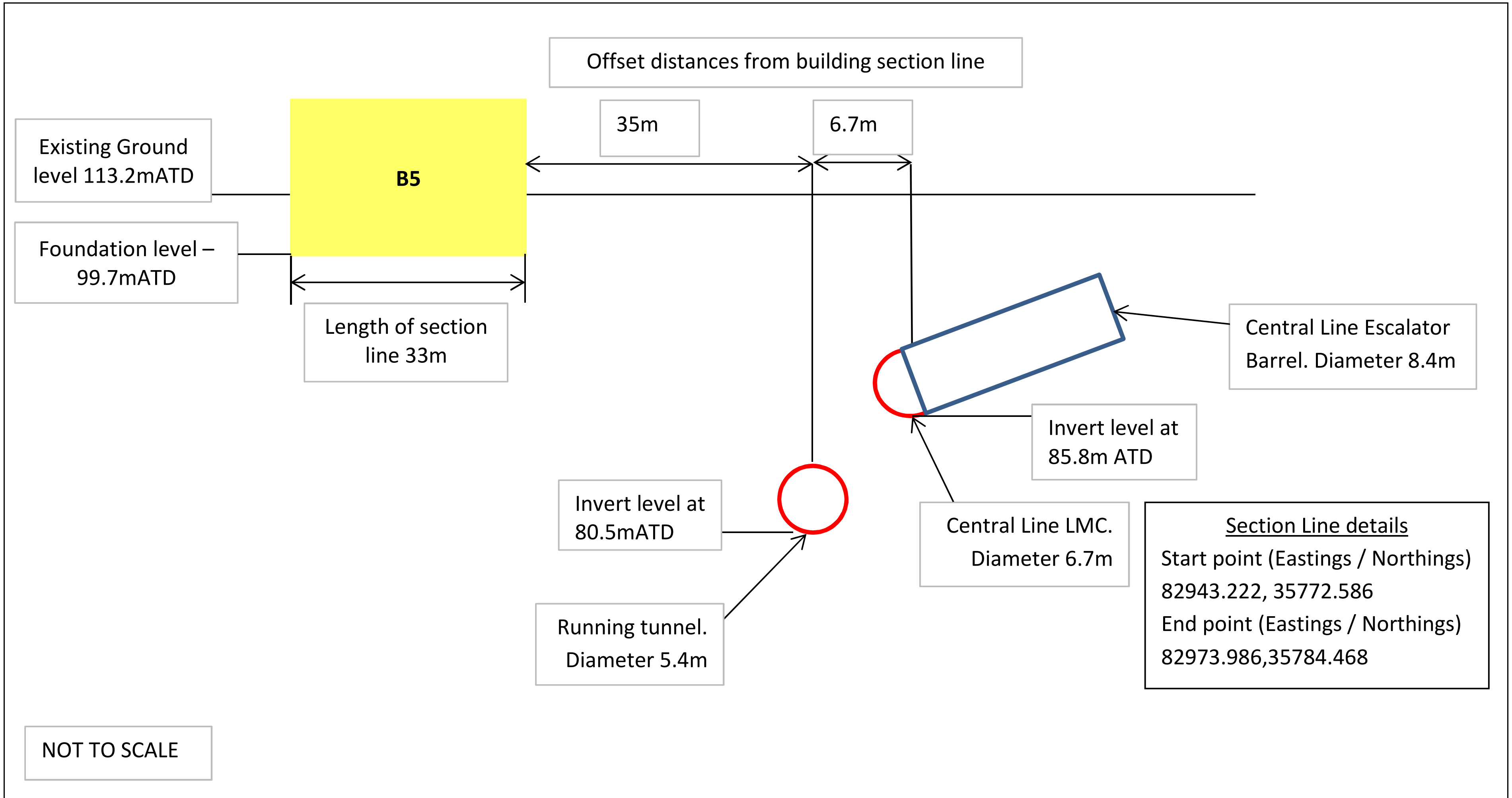

Figure 4: Diagrammatic cross-section of section (line 1) relative to tunnel position

LUL Bank Project Office
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Bank Station Capacity Upgrade

Building Damage Assessment Report

Building B18

Fishmongers' Hall

URS-8798-RPT-G-001210

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1.0	March 2014	Issue for Heritage
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3.0	July 2014	TWAO Issue

For the status of this document, please refer to the Building Damage Assessment Report Register (URS-8798-RGT-001229)

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• Keith Bowers/Neil Moss/Paul Dryden	London Underground
• Olly Newman	Dragados

Contents

FIGURES

TABLES

1 Introduction

This report summarises the results of a Stage 2 damage assessment for Fishmongers' Hall.

Stage 2 damage assessments are undertaken for all buildings within the Stage 1 Greenfield ground surface 1mm settlement contour induced by the construction of the Bank Station Capacity Upgrade (BSCU).).

The purpose of the assessment is to determine the potential effect the works will have on the building. This report describes the engineering and heritage assessments undertaken for the building and concludes whether mitigation is likely to be needed and if a further (Stage 3) assessment is recommended in order to verify this.

2 The Building

2.1 General Information

The building information used has been assembled from a site walk over and web based inspection upon which conservative assumptions were made. This information is presented in Table 1.

Category	Building Information
BSCU Reference	B18
Location	Fishmongers' Hall
Address	Fishmongers' Hall, King William Street
Building Type	Load bearing masonry (assumed)
Construction Age	Varied
No. of Storeys	7
Basements	2
Eaves Level (mATD)	124.9
Foundation Type	Raft constructed over pre-existing timber piles(
Ground Level (mATD)	106.9 (Upper Thames St)
Listed Grade	Grade II* and Scheduled Monument
Note: Levels given are in metres above Tunnel Datum, mATD. Tunnel Datum is 100m below Ordnance Survey Datum at Newlyn	

Table 1: General building information

A general view of the building exterior is shown in Plate 1. A location plan showing the building in relation to the proposed BSCU works is presented in Figure 2.

Plate 1: General view

2.2 Building Description

Fishmongers' Hall is a substantial 19th century building in the Greek revival style constructed adjacent to the River Thames north foreshore and London Bridge. It is designed to be accessed both from London Bridge and the river, two floors below. The building has five stories including two basement levels.

The present building was constructed between 1831 and 1835 as the result of a competition which attracted 87 entrants. The exterior survives largely unaltered. The building was designed at the same time as London Bridge was being built and so it responds neatly to the variety of levels that that building had to address: river, Thames Street and London Bridge. A large coat of arms is located above the central pediment on the east elevation, overlooking London Bridge.

Documentary evidence records that the building was constructed on a lime concrete raft with the shell completed in 1833. The remainder of the building was completed in 1835 and decorations added in 1840. In September 1940 the Hall was gutted by bombing although the structure survived largely intact. After a comprehensive restoration the building reopened in 1951. The interiors have been repeatedly redecorated as changing tastes dictated.

Internally Fishmongers' Hall contains grand reception rooms, a number of offices overlooking the Thames and the company Court room, accessed from the central hall and double-winding principal stair. The grandest of the reception rooms are the Banquet Hall and Court Dining Room. These rooms and circulation spaces are richly decorated with paintings and other treasures collected during the Fishmongers' history. Also on the 1st and 2nd floors, but generally located in the northern areas of the building are a number of service facilities such as kitchens. In addition there are a number of residential rooms to accommodate visiting members of the Company.

3 Methodology

This building damage assessment is undertaken in accordance with LU Works Information WI2300[1] and LU Civil Engineering - Common Requirements S1050[2].

The analysis methodology applies to ground-bearing buildings which will be affected by ground movements resulting from the construction of the BSCU. The engineering assessment calculates the potential impact of ground movements and assigns a damage category to the building based on a numeric scale. Additionally, for listed buildings, a heritage assessment is carried out which considers the sensitivity of the structure and the sensitivity of its particular features; a heritage sensitivity score is assigned. The heritage sensitivity score is added to the damage category to obtain the total score. If the total score is 3 or more, a more detailed Stage 3 assessment is triggered.

Since the building is piled the movement assessment is based on a combination of assumptions. This is in accordance with Selemetas.D et al (2005) [7]. In the region above the tunnel alignment piles with a toe level within 20% of the depth of the tunnel are assumed to move the same amount as the soil at the toe level using the method given by New & Bowers [8].Piles to either side are assumed to move the same amount as the greenfield settlement prediction at the base of building level using the methods of Mair et al [3, 4]. The deflected shape is assessed from these two approaches and the tensile strains calculated using the method given by Burland et al [6]. It is assumed that the substructure is sufficiently robust to prevent horizontal strains.

It is not certain if the timber piles give support to the building. Also, since they are to the side of the tunnel this assessment is carried out using the methods of Mair to obtain ground movements at substructure level to predict the movements of the building. Oasys Xdisp is used to analyse the Greenfield ground movement in terms of settlement and horizontal displacement. Subsurface tunnelling induced ground movement profiles are determined in accordance with the methodology described by Mair et al[3 & 4].

Movements resulting from the Whole Block Scheme (WBS) and shaft excavations have been calculated using LU Guidance Document G0058[5].

The building is modelled as a simple elastic beam which is conservatively assumed to follow the Greenfield ground displacements. The beam is divided into hogging and sagging segments. The tensile strains within each segment are calculated based on the distortion associated with differential settlement (which is characterised by deflection ratio) and the distortion associated with differential horizontal displacement (characterised by horizontal strain).

Xdisp provides a method for calculating the maximum tensile strain within the building superstructure associated with these movements, in accordance with the assessment methodology described by Mair et al [4]. This strain is used to determine the damage category based on the classification system proposed by Burland[6] and in accordance with LU Civil Engineering - Common Requirements S1050[2]. The categories are presented in Table 2.

Damage Category	Description of Degree of Damage	Description of Typical Damage and likely forms of Repair for Typical Masonry Buildings.	Approx. Crack Width (mm)	Max. Tensile Strain %
0	Negligible	Hairline cracks.		< 0.05
1	Very slight	Fine cracks easily treated during normal redecoration. Perhaps isolated slight fracture in building. Cracks in exterior visible upon close inspection.	0.1 to 1.0	0.05 to 0.075
2	Slight	Cracks easily filled. Redecoration probably required. Several slight fractures inside building. Exterior cracks visible; some repainting may be required for weather-tightness. Doors and windows may stick slightly.	1 to 5	0.075 to 0.15
3	Moderate	Cracks may require cutting out and patching. Recurrent cracks can be masked by suitable linings. Tuck pointing and possible replacement of a small amount of exterior brickwork may be required. Doors and windows sticking. Utility services may be interrupted. Weather tightness often impaired.	5 to 15 or a number of cracks > 3	0.15 to 0.3
4	Severe	Extensive repair required involving removal and replacement of walls especially over doors and windows. Window and door frames distorted. Floor slopes noticeably. Walls lean or bulge noticeably. Some loss of bearing in beams. Utility services disrupted.	15 to 25 but also depends on number of cracks	> 0.3
5	Very severe	Major repair required involving partial or complete reconstruction. Beams lose bearing, walls lean badly and require shoring. Windows broken by distortion. Danger of instability.	Usually > 25 but depends on number of cracks	
Note: Please refer LU Civil Engineering - Common Requirements S1050[2].				

Table 2: Building damage classification

4 Input Data

The magnitude and distribution of ground movements and degree of building damage is calculated based on the following input data:

- The Xdisp model coordinates and levels are based on the 3D model (20130212DSPITT Scheme R09);
- Four construction stages are considered in accordance with the proposed programme (November 2013) as illustrated in Figure 1
- Trough width parameter constant, K=0.5 is used in accordance with WI2300[1]

The input data for the building, tunnels and shaft excavation are summarised in Table 3, Table 4 and Table 5 respectively.

Location	Foundation level (mATD)	Building Height above foundation level (m)	E/G
Fishmongers' Hall	99.4*	25.5	2.6
Note: Where E / G is the ratio of Young's modulus to shear modulus of the deep beam representing the building. * Assumed level, 1.5m thick slab beneath basement floor level.			

Table 3: Building data

Tunnel Item	Level of axis (mATD)	External diameter (m)	Volume Loss (%)
Running tunnel Southbound tie in	83.4	5.4	1.5
Square works adits	75.8 to 95.3	4.1 to 7.8	2.5
Platform enlargement	85.6	7.4 to 11.2	1.5
Escalator barrels	Inclined	8.3 to 8.4	1.5
Central Line Connection	Inclined (87.6 to 89.2)	8.6	1.5

Table 4: Tunnel data

Excavation	Excavation Base Level (mATD)
Grout Shaft at King William Street	97
Whole Block Scheme Box excavation	73
Arthur Street Shaft	81

Table 5: Excavation data

The distance of building Fishmongers' Hall (B18) relative to the excavation elements listed in Table 5 is sufficiently large that the building should not be affected by their construction.

The Xdisp models filename used to undertake this assessment are:

- B18 - Stage 4
- B18 - Stage 3
- B18 - Stage 2
- B18 - Stage 1

5 Results

5.1 Engineering Assessment

The sections through the building which have been analysed are shown on plan in Figure 3.

Assessment has been undertaken at three intermediate construction stages and at the end of construction when all major elements of the works including shaft and tunnels have been completed. The damage category assigned to the building is based on the construction stage at which the potential impact on the building is most severe.

The maximum settlement and tensile strain calculated for each of the analysis sections at the most onerous intermediate construction stage and at the end of construction are presented in Table 6 and Table 7.

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
B18 (line 1)	<1	<0.001
B18 (line 2)	<1	<0.001

Table 6: Building response at most onerous intermediate stage - Construction Stage 1

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
B18 (line 1)	<1	0.004
B18 (line 2)	<1	0.002

Table 7: Building response at end of construction stage

The results of the assessment show construction Stage 4 is the critical stage for this building with B18 (line 1) showing the maximum calculated tensile strain. The line orientation is shown in Figure 3. The vertical and horizontal Greenfield ground movements along the section of the building are shown in Figure 4. The relative positions of the building and tunnel along Section (line 1) are shown in Figure 5. The calculated strains are summarised in Table 8.

Line No	Strains in section (Curvature)	Position from start (m)	Length (m)	Average* Horizontal Strain (%)	Maximum Tensile Strains (%)	Damage Category
(line 1)	Hogging	5,0	20.1	0.003	0.004	Negligible
Note: * Tensile horizontal strains are +ve. Compressive horizontal strains are –ve.						

Table 8: Section analysed, results for worst case tensile strain

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0. This corresponds to Negligible damage rating in accordance with Table 2.

The maximum settlement of the building at foundation level at the end of construction is less than 1mm.

5.2 Heritage and Structural Assessment

Following site inspection, assessment has been made using the following scoring methodology as set out in Table 9.

Score	STRUCTURE Sensitivity of the structure to ground movements and interaction with adjacent buildings	HERITAGE FEATURES Sensitivity to calculated movement of particular features within the building	CONDITION Factors which may affect the sensitivity of structural or heritage features
0	Masonry buildings with lime mortar and regular openings, not abutted by other buildings, and therefore similar to the buildings on which the original Burland assessment was based.	No particular sensitive features	Good/Fair - not affecting the sensitivity of structural or heritage features
1	Buildings not complying with categories 0 or 2, but still with some sensitive structural features in the zone of settlement e.g.: cantilever stone staircases, long walls without joints or openings, existing cracks where further movements are likely to concentrate, mixed foundations	Brittle finishes, e.g. faience or tight-jointed stonework, which are susceptible to small structural movements and difficult to repair invisibly.	Poor - may change the behaviour of a building in cases of movement. Poor condition of heritage features and finishes. Evidence of previous movement.
2	Buildings which, by their structural form, will tend to concentrate all their movements in one location (e.g.: a long wall without joints and with a single opening).	Finishes which if damaged will have a significant effect on the heritage value of the building, e.g. Delicate frescos, ornate plasterwork ceilings.	Very poor – parlous condition of heritage features and finishes, severe existing damage to structure including evidence of ongoing movement. Essentially buildings where even very small movements could lead to significant damage.

Table 9: Heritage and structural scoring methodology

The results of the heritage assessment carried out for the building are summarised in Table 10.

SENSITIVITY OF THE STRUCTURE
Fishmongers' Hall is constructed from a mix of load-bearing masonry and external granite facings, with internal cast iron columns and beams creating the large open function rooms. The upper floors are timber joisted spanning between the masonry walls and internal cast iron beams, while the ground floor and two lower warehouse levels below are formed as a combination of brick vaults or concrete filler joist floors, with overlain timber battened and boarded finishes. All wall foundations and bases beneath the cast iron columns or brick piers are stepped spread brickwork, which sits on a common level raft foundation just below the lower warehouse level. The raft was constructed in 1832 from mass fill lime concrete up to eleven feet thick, overlaying a peat layer and oak timber piles reportedly in perfect condition, laid down in the Tudor period as foundations for former buildings on the site. The raft shares a common foundation level with that of the London Bridge (not the same bridge as stands today) which was completed shortly before, and encapsulated drainage for the current building. Internal structural elements include an impressive stone cantilevered staircase and landings between the ground and first floors, vaulted brickwork and cast iron columns in the lower warehouse level, The external elevations are generally clad in granite but with fairfaced brickwork elevations forming the internal courtyard.
Score: 0 - The building is robustly constructed on a sound and robust ground replacement lime concrete raft, and displays no serious structural movement or damage. It is considered that the small predicted settlements will cause little or no movement to the building as a whole, nor to individual elements, therefore requiring no mitigation methods to be considered.
SENSITIVITY OF THE HERITAGE
Fishmongers' Hall was designated as a Grade II* listed building by English Heritage due to the current building's association with Henry Roberts and George Gilbert Scott, its architectural quality and prominent location on the River Thames on a site that has little changed for 700 years and its function as the home of the Fishmongers' Livery Company. These attributes have a national and international significance. The building also contains several layers of archaeology from the Tudor period onwards resulting in its further designation as a Scheduled Monument. Internally the building retains many sensitive heritage finishes which contribute to the building's use and the perceived health of the institution of the Fishmongers' Company, such as decorative plaster ceilings, fine-jointed marble panelling and stone floors.

Score: 0 - Despite the potential sensitivity of external form and decoration and the sensitivity of the internal heritage finishes, the predicted settlement and associated structural movement is not considered sufficient to cause damage to these features.
SENSITIVITY OF THE CONDITION
The building is in excellent condition with very little sign of structural movement although the east elevation at ground level and above (Portland stone section) has a number of cracked window cills and one area of minor deformation near the south east corner of the building that indicate that some movement has occurred in the past, possibly due to rust jacking of iron cramps. The decorative condition of the interior is significant in its own right as it is a key means by which the Company displays its wealth and heritage within the City. The Hall and its interiors represent the cumulated treasure of the Company and validate its role within commercial society.
Score: 0 - Fishmongers' Hall is in excellent condition throughout, both structurally and in the highly decorative internal finishes and external stonework. The property is very highly maintained and repairs are carried out without delay whenever any problems arise.

Table 10: Heritage and structural assessment

5.3 Total Score

The total score is the summation of the damage category, structural sensitivity, heritage sensitivity and condition sensitivity scores:

The damage category is 0

The structural sensitivity score is 0

The heritage sensitivity score is 0

The condition sensitivity score is 0

The total score for this building is 0

6 Conclusion

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0 for Fishmongers' Hall. Specific heritage and structural assessment taking into account the location and extent of settlement and tensile strains highlights the buildings low level of structural and heritage sensitivity to movement. This assessment has determined that the building has a total score of 0.

Fishmongers' Hall is located sufficient distance from the BSCU tunnelling work that any settlement and associated structural movement will be negligible, especially considering the substantial nature of the building and its foundation on a limecrete raft of considerable mass.

It is recommended that the building does not require a Stage 3 assessment.

7 References

[1] LU Works Information WI 2300 Ground Movement version 3, 19-07-13.

[2] LU Category 1 Standard: S1050 Civil Engineering - Common Requirements, Issue No. A7, Nov. 2013.

[3] Mair R J, Taylor R N and Bracegirdle A (1993). Subsurface settlement profiles above tunnels in clays. Géotechnique 43, No. 2, pp. 315-320.

[4] Mair R J, Taylor R N and Burland J B (1996). Prediction of ground movements and assessment of risk of building damage due to bored tunnelling. (In: International Conference of Geotechnical Aspects of Underground Construction in Soft Ground, London, pp. 713–718.

[5] LU Guidance Document G0058 Civil Engineering Technical Advice Notes, Issue No. A17, Feb. 2013.

[6] Burland J B (1995). Assessment of risk of damage to buildings due to tunnelling and excavation. Proceedings: 1st International Conference of Earthquake Geotechnical Engineering, IS Tokyo, 1995.

[7] Selemetas.D et al (2005). The response of full scale piles to tunnelling. Geotechnical aspects of underground construction in soft ground (Bakker et al (eds)) pp.763-769.

[8] New B M and Bowers K H (1994). Ground movement model validation at the Heathrow Express trial tunnel. Proc. Tunnelling 1994. IMM, London, pp 301-327.

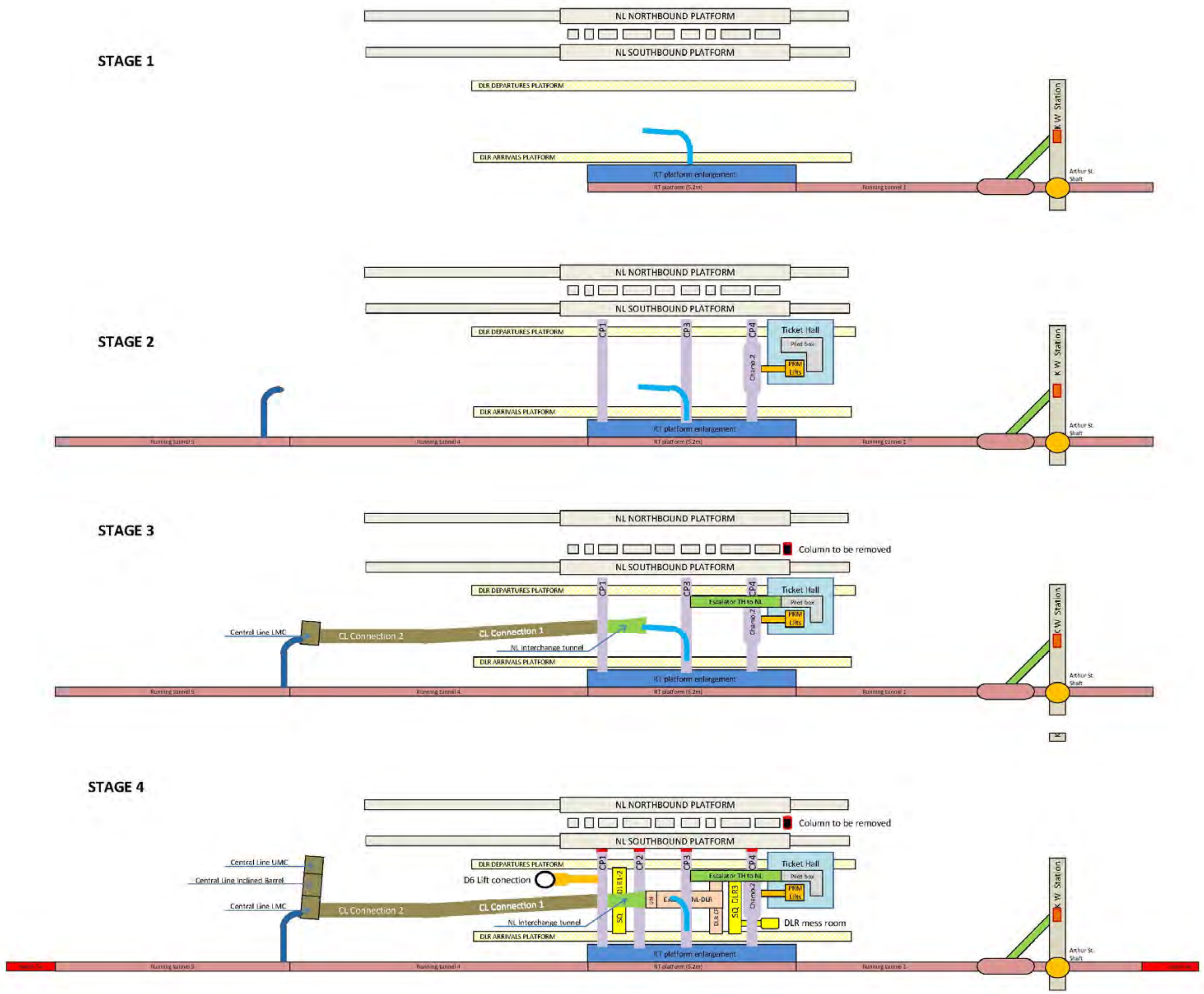

Figure 1: Construction Stage model

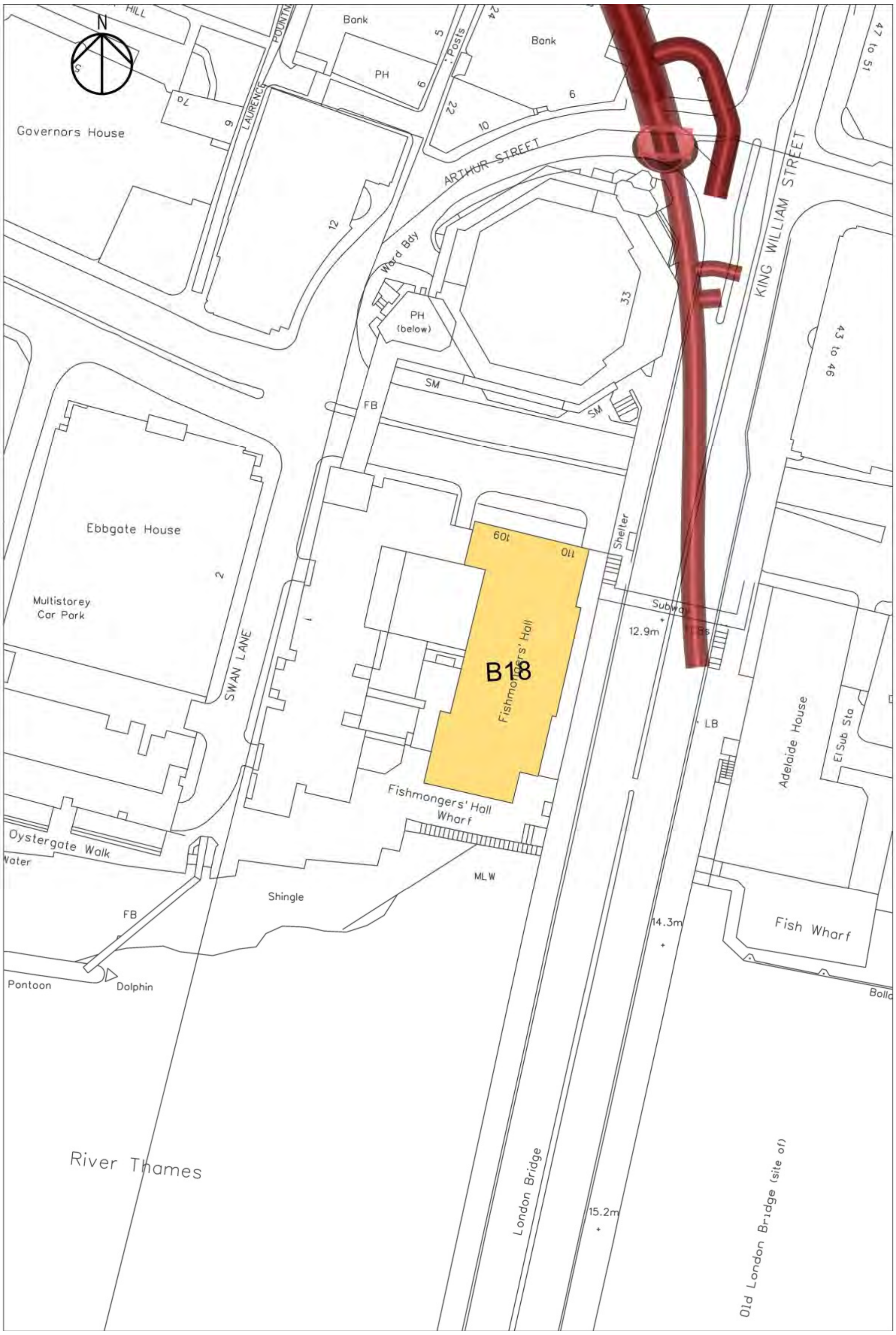

Figure 2: Location plan showing building location in relation to BSCU works

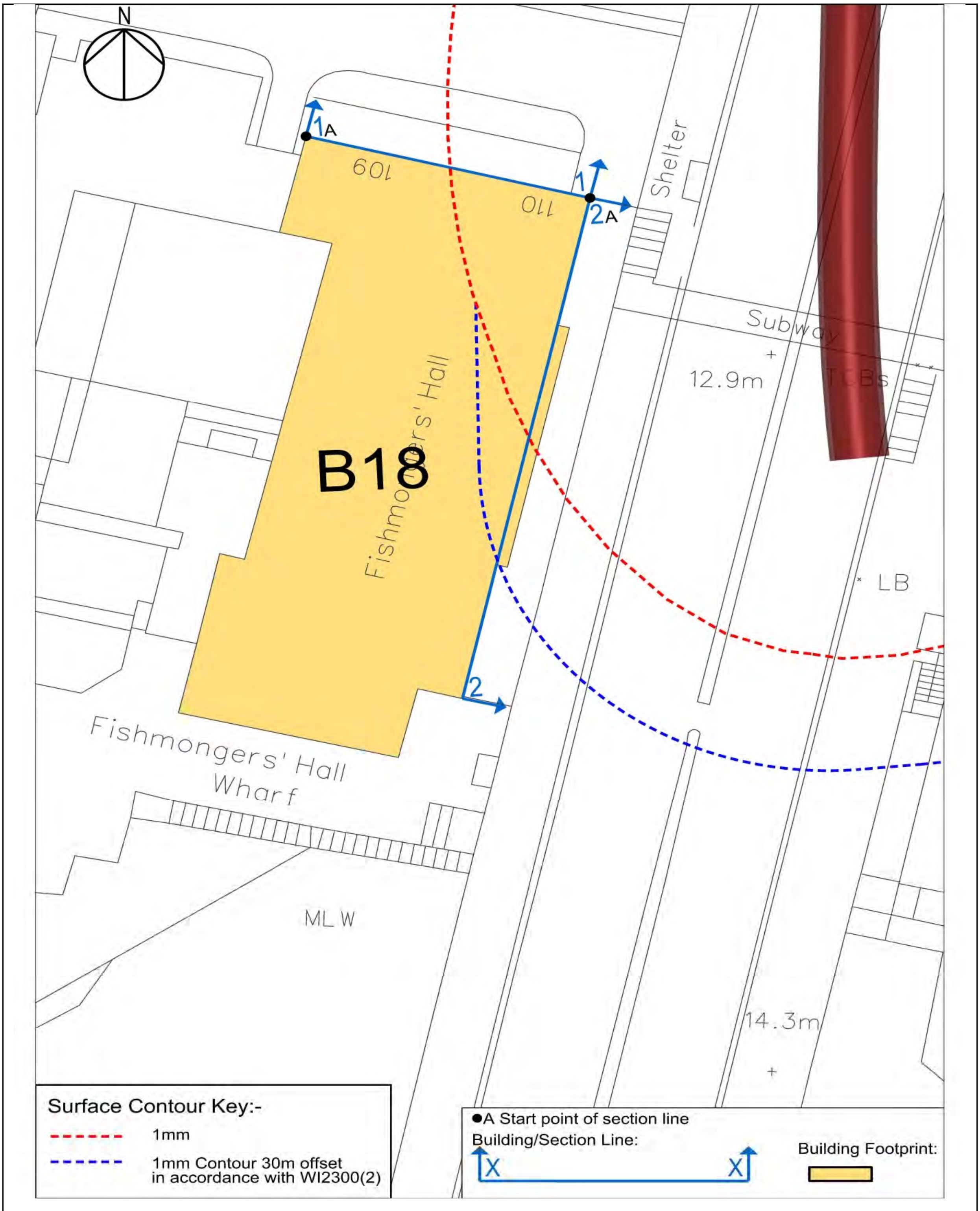

Figure 3: Building location, sections analysed and Settlement Contours at stage of worst case for tensile strains

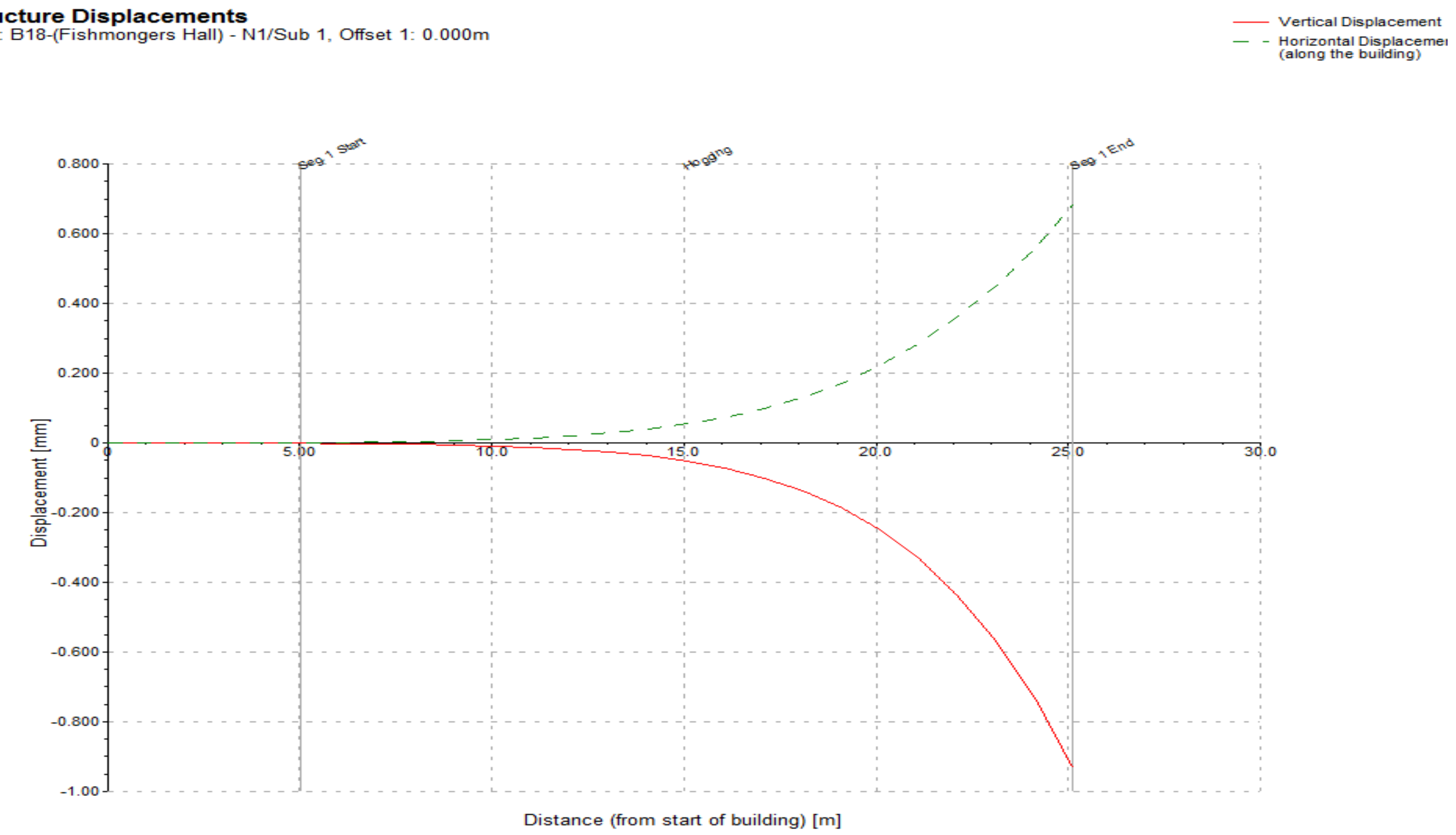

Figure 4: Building displacement at founding level at stage 4 (line 1) of worst case for tensile strains

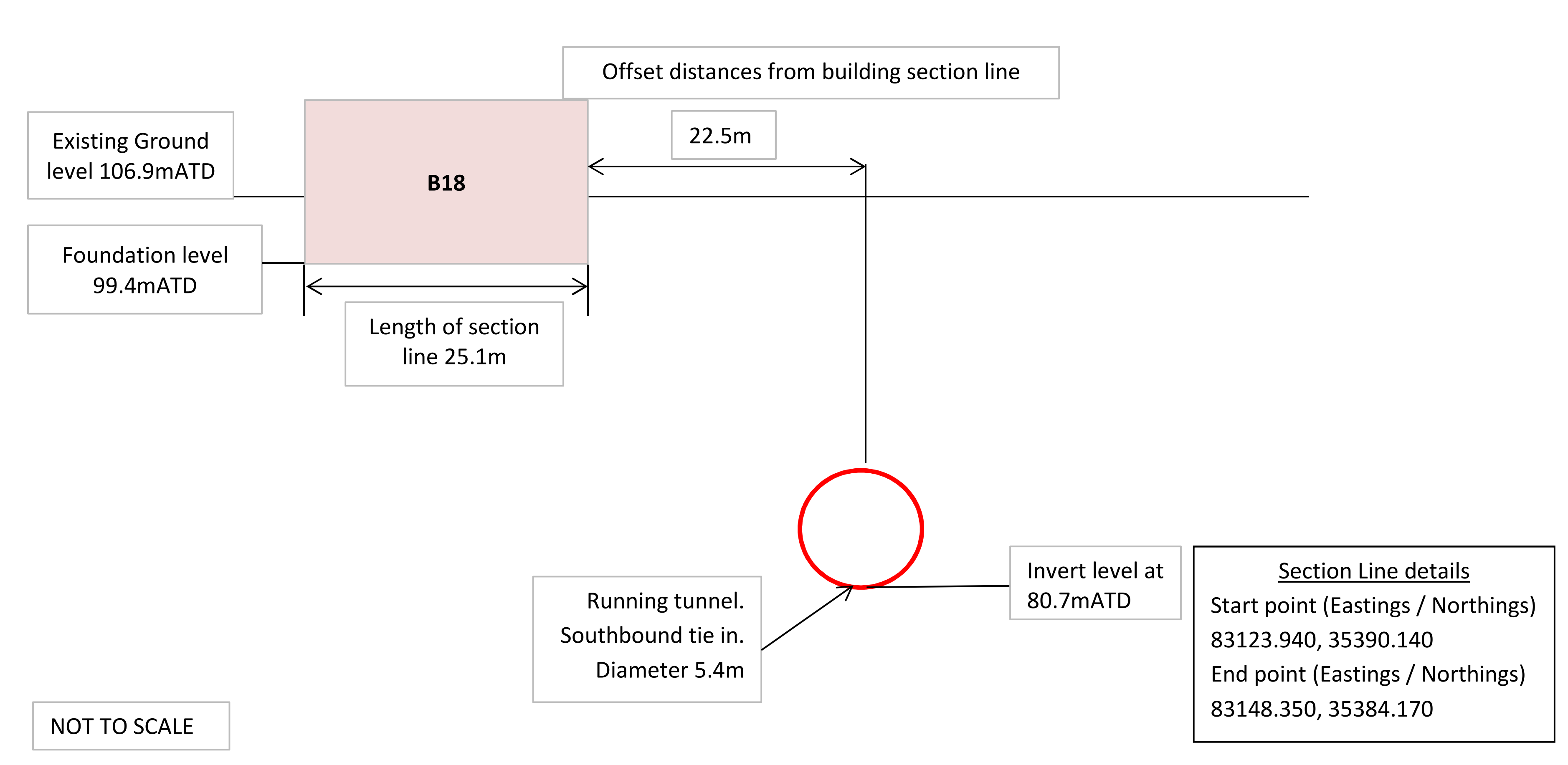

Figure 5: Diagrammatic cross-section of section (line 1) relative to tunnel position

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Bank Station Capacity Upgrade

Building Damage Assessment Report

Building B21

St. Clement's Church

URS-8798-RPT-G-001213

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Revision	Date	Summary of changes
1.0	March 2014	Issue for Heritage
2.0	May 2014	For Approval
3.0	July 2014	TWAO Issue

For the status of this document, please refer to the Building Damage Assessment Report Register (URS-8798-RGT-001229)

Consultation:

• Ela Palmer	URS Heritage
• Brian Lyons	Dr.Sauer
• Keith Bowers/Neil Moss/Paul Dryden	London Underground
• Olly Newman	Dragados

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1 Introduction

This report summarises the results of a Stage 2 damage assessment for St. Clement's Church.

Stage 2 damage assessments are undertaken for all buildings within the Stage 1 Greenfield ground surface 1mm settlement contour induced by the construction of the Bank Station Capacity Upgrade (BSCU).

The purpose of the assessment is to determine the potential effect the works will have on the building. This report describes the engineering and heritage assessments undertaken for the building and concludes whether mitigation is likely to be needed and if a further (Stage 3) assessment is recommended in order to verify this.

2 The Building

2.1 General Information

General building information used in the assessment has been acquired as part of the structural desktop appraisal. Where data was not available, conservative assumptions were made instead. This information is presented in Table 1.

Category	Building Information
BSCU Reference	B21
Location	St. Clement's Church
Address	St. Clement's Church
Building Type	Load bearing masonry (assumed)
Construction Age	1683 - 1687
No. of Storeys	3
Basements	1 (assumed)
Eaves Level (mATD)	125.3
Foundation Type	Shallow (assumed)
Ground Level (mATD)	115.3
Listed Grade	I
Note: Levels given are in metres above Tunnel Datum, mATD. Tunnel Datum is 100m below Ordnance Survey Datum at Newlyn.	

Table 1: General building information

A general view of the building exterior is shown in Plate 1. A location plan showing the building in relation to the proposed BSCU works is presented in Figure 2.

Plate 1: General view

2.2 Building Description & Heritage

Grade I listed building, erected 1683 to 1687, by Sir Christopher Wren shows brick masonry with stone quoins and dressings. Today it has a stuccoed exterior. The tower is located in the south west corner and is built upon the foundations of the former medieval church meaning it is aligned to the street as opposed to the nave. There is a storage room to first floor of bell tower with stone spiral stair. Large room with timber trusses to second floor, trusses run along whole extent of church tower. St Clements's does not have a steeple or a cupola. A potential crypt may exist underneath the rear of the main building but no access currently is provided. Refurbishment works are being carried out to interiors, of church and servicing rooms except for the bell tower. The ceilings of the central nave are not touched by the refurbishment works. Timber panelled room to rear is currently being refurbished to be converted into office. All timber panelling, pilasters, decorative features, original doors and furniture have been fully preserved. The original church cemetery extends to rear elevation, with its tomb stones still preserved. The roof to the nave has been replaced with steel trusses and new roof structure

3 Methodology

This assessment is undertaken in accordance with LU Works Information WI2300[1] and LU Civil Engineering - Common Requirements S1050[2].

The analysis methodology applies to ground-bearing buildings which will be affected by ground movements resulting from the construction of the BSCU. The engineering assessment calculates the potential impact of ground movements and assigns a damage category to the building based on a numeric scale. Additionally, for listed buildings, a heritage assessment is carried out which considers the sensitivity of the structure and the sensitivity of its particular features; a heritage sensitivity score is assigned. The heritage sensitivity score is added to the damage category to obtain the total score. If the total score is 3 or more, a more detailed Stage 3 assessment is triggered.

Oasys Xdisp is used to analyse the Greenfield ground movement in terms of settlement and horizontal displacement. Subsurface tunnelling induced ground movement profiles are determined in accordance with the methodology described by Mair et al[3 & 4].

Movements resulting from the Whole Block Scheme (WBS) and shaft excavations have been calculated using LU Guidance Document G0058[5].

The building is modelled as a simple elastic beam which is conservatively assumed to follow the Greenfield ground displacements. The beam is divided into hogging and sagging segments. The tensile strains within each segment are calculated based on the distortion associated with differential settlement (which is characterised by deflection ratio) and the distortion associated with differential horizontal displacement (characterised by horizontal strain).

Xdisp provides a method for calculating the maximum tensile strain within the building superstructure associated with these movements, in accordance with the assessment methodology described by Mair et al [4]. This strain is used to determine the damage category based on the classification system proposed by Burland[6] and in accordance with LU Civil Engineering - Common Requirements S1050[2]. The categories are presented in Table 2.

Damage Category	Description of Degree of Damage	Description of Typical Damage and likely forms of Repair for Typical Masonry Buildings.	Approx. Crack Width (mm)	Max. Tensile Strain %
0	Negligible	Hairline cracks.		< 0.05
1	Very slight	Fine cracks easily treated during normal redecoration. Perhaps isolated slight fracture in building. Cracks in exterior visible upon close inspection.	0.1 to 1.0	0.05 to 0.075
2	Slight	Cracks easily filled. Redecoration probably required. Several slight fractures inside building. Exterior cracks visible; some repainting may be required for weather-tightness. Doors and windows may stick slightly.	1 to 5	0.075 to 0.15
3	Moderate	Cracks may require cutting out and patching. Recurrent cracks can be masked by suitable linings. Tuck pointing and possible replacement of a small amount of exterior brickwork may be required. Doors and windows sticking. Utility services may be interrupted. Weather tightness often impaired.	5 to 15 or a number of cracks > 3	0.15 to 0.3
4	Severe	Extensive repair required involving removal and replacement of walls especially over doors and windows. Window and door frames distorted. Floor slopes noticeably. Walls lean or bulge noticeably. Some loss of bearing in beams. Utility services disrupted.	15 to 25 but also depends on number of cracks	> 0.3
5	Very severe	Major repair required involving partial or complete reconstruction. Beams lose bearing; walls lean badly and require shoring. Windows broken by distortion. Danger of instability.	Usually > 25 but depends on number of cracks	
Note: Please refer LU Civil Engineering - Common Requirements S1050[2].				

Table 2: Building damage classification

4 Input Data

The magnitude and distribution of ground movements and degree of building damage is calculated based on the following input data:

- The Xdisp model coordinates and levels are based on the 3D model (20130212DSPITT Scheme R09);
- Four construction stages are considered in accordance with the proposed programme (November 2013) as illustrated in Figure 1;
- Trough width parameter constant, K=0.5 is used in accordance with WI2300[1]

The input data for the building, tunnels and shaft excavation are summarised in Table 3, Table 4 and Table 5 respectively.

Location	Foundation level (mATD)	Building Height above foundation level (m)	E/G
St. Clement's church	110.8*	14.5	2.6
Note: Where E / G is the ratio of Young's modulus to shear modulus of the deep beam that is to represent the building. * Assumed level, 1.5m thick slab beneath floor level.			

Table 3: Building data

Tunnel Item	Level of axis (mATD)	External diameter (m)	Volume Loss (%)
Running tunnels	83.5	5.4	1.5
Square works adits	75.8 to 95.3	4.1 to 7.8	2.5
Platform enlargement	85.6	7.4 to 11.2	1.5
Escalator barrels	Inclined	8.3 to 8.4	1.5
Central Line Connection	Inclined (87.6 to 89.2)	8.6	1.5

Table 4: Tunnel data

Excavation	Excavation Base Level (mATD)
Grout Shaft at King William Street	97
Whole Block Scheme Box excavation	73
Arthur Street Shaft	81

Table 5: Excavation data

The Xdisp model filenames used to undertake this assessment are:

- B21 - Stage 4
- B21 - Stage 3
- B21 - Stage 2
- B21 - Stage 1

5 Results

5.1 Engineering Assessment

The sections through the building which have been analysed are shown on plan in **Error! Reference source not found.**.

Assessment has been undertaken at three intermediate construction stages and at the end of construction when all major elements of the works including shaft and tunnels have been completed. The damage category assigned to the building is based on the construction stage at which the potential impact on the building is most severe.

The maximum settlement and tensile strain calculated for each of the analysis sections at the most onerous intermediate construction stage and at the end of construction are presented in Table 6 and Table 7.

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
B21 (line 1)	<1	<0.001
B21 (line 2)	<1	<0.001

Table 6: Building response at most onerous intermediate stage - Construction Stage 1

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
B21 (line 1)	<1	<0.001
B21 (line 2)	<1	<0.001

Table 7: Building response at end of construction stage

The results of the assessment show construction Stage 1 is the critical stage for this building due to construction of running tunnel and Arthur Street shaft. Section B21 (line 1) experiences the most onerous combined tensile strain. The orientation of this building is shown in Figure 2. The relative position of the building and tunnels along section B21 (line 1) is shown in Figure 4. The calculated strains are summarised in Table 8.

Strains in section (Curvature)	Position from start (m)	Length (m)	Average* Horizontal Strain (%)	Maximum Tensile Strains (%)	Damage Category
Sagging	18.8	1.0	<0.001	<0.001	Negligible
Note: * Tensile horizontal strains are +ve. Compressive horizontal strains are –ve.					

Table 8: Section analysed, results for worst case tensile strain

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0. This corresponds to Negligible damage in accordance with Table 2.

The maximum settlement of the building at foundation level at construction stage 1 is less than 1mm.

5.2 Heritage and Structural Assessment

Following site inspection, assessment has been made using the following scoring methodology as set out in Table 9.

Score	STRUCTURE Sensitivity of the structure to ground movements and interaction with adjacent buildings	HERITAGE FEATURES Sensitivity to calculated movement of particular features within the building	CONDITION Factors which may affect the sensitivity of structural or heritage features
0	Masonry buildings with lime mortar and regular openings, not abutted by other buildings, and therefore similar to the buildings on which the original Burland assessment was based.	No particular sensitive features	Good/Fair - not affecting the sensitivity of structural or heritage features
1	Buildings not complying with categories 0 or 2, but still with some sensitive structural features in the zone of settlement e.g.: cantilever stone staircases, long walls without joints or openings, existing cracks where further movements are likely to concentrate, mixed foundations	Brittle finishes, e.g. faience or tight-jointed stonework, which are susceptible to small structural movements and difficult to repair invisibly.	Poor - may change the behaviour of a building in cases of movement. Poor condition of heritage features and finishes. Evidence of previous movement.
2	Buildings which, by their structural form, will tend to concentrate all their movements in one location (e.g.: a long wall without joints and with a single opening).	Finishes which if damaged will have a significant effect on the heritage value of the building, e.g. Delicate frescos, ornate plasterwork ceilings.	Very poor – parlous condition of heritage features and finishes, severe existing damage to structure including evidence of ongoing movement. Essentially buildings where even very small movements could lead to significant damage.

Table 9: Heritage and structural scoring methodology

The results of the heritage assessment carried out for the building are summarised in Table 10.

SENSITIVITY OF THE STRUCTURE
The external walls in both the church and the tower display some cracking, the main church building has a concentration of cracking to the North West elevation particularly in locations weakened by window and door locations. While the movement appears not particularly recent, additional movement could be aggravated in the event of further ground settlement and disturbance The foundations of the building are unknown but are likely to be spread brick corbels or simply formed directly onto a compacted soil base. Levels of the foundations are thought to be variable, and while the main body of the church and bell tower would probably have originally been consistent with one another, the church only appears to have a small basement to the rear. Construction of the adjoining building included the formation of a deep double basement, and although having an apparent shared wall, this would probably have initiated a form of underpinning to the south east wall of the church and possibly the return walls, locally extending these foundations to a much deeper level than the remaining church. The building was going through an internal refurbishment at the time of the site survey and it is possible that this internal work may have covered over other building defects. The roof to the nave has been replaced with steel trusses and new roof structure.
Score: 1 - The assumed deep underpinning to part of the building results in mixed foundation conditions
SENSITIVITY OF THE HERITAGE
This Grade I Listed Building is the result of work from three renowned ecclesiastical architects; Sir Christopher Wren, William Butterfield and Sir Ninian Comper. Its external classical simplicity and the unifying use of pilasters around the interior wall, St Clement's still significantly represents Wren's style. Historically it was the first church to be destroyed during the Great Fire of London and was one of the many brick and stone churches to be rebuilt by Wren according to the Rebuilding Act of 1667 further to the Great Fire This church bears high historical, architectural and artistic significance because of its design, decorative apparatus and furniture. Its prominent designers, the intactness of the original facades and of the historically layered interiors all contribute to its high significance. Important features such as decorative plasterwork and decorated ceilings, historic timber panelling preserved from the south gallery woodwork and reused and reused in 1872 in the stalls, original woodwork including a large Norwegian oak pulpit, would be sensitive to settlement
Score:1 – The interior finishes of the church are considered to be brittle and sensitive to small settlements, particularly the decorative plasterwork
SENSITIVITY OF THE CONDITION
The façades are in overall good condition despite showing fine vertical cracks crossing the side elevation in various areas, but a general lack of maintenance to exterior is noted. The interiors are in good condition, and the original features have been fully preserved and repaired.
Score: 0 the interiors are in good condition and are currently being improved; the minor condition issues to the façade would not be sensitive to the predicted settlement

Table 10: Heritage and structural assessment

5.3 Total Score

The total score is the summation of the damage category, structural sensitivity, heritage sensitivity and condition sensitivity scores:

The damage category is 0

The structural sensitivity score is 1

The heritage sensitivity score is 1

The condition sensitivity score is 0

The total score for this building is 2

6 Conclusion

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0 for St Clement's Church. Specific heritage and structural assessment taking into account the location and extent of settlement and tensile strains concludes that although the building has a potentially high sensitivity to movement, the predicted levels of settlement will not be detrimental to the structure or finishes. This assessment has determined that the building has a total score of 2.

It is recommended that the building does not require a Stage 3 assessment.

7 References

[1] LU Works Information WI 2300 Ground Movement version 3, 19-07-13.

[2] LU Category 1 Standard: S1050 Civil Engineering - Common Requirements, Issue No. A7, Nov. 2013.

[3] Mair R J, Taylor R N and Bracegirdle A (1993). Subsurface settlement profiles above tunnels in clays. Géotechnique 43, No. 2, pp. 315-320.

[4] Mair R J, Taylor R N and Burland J B (1996). Prediction of ground movements and assessment of risk of building damage due to bored tunnelling. (In: International Conference of Geotechnical Aspects of Underground Construction in Soft Ground, London, pp. 713–718.

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[6] Burland J B (1995). Assessment of risk of damage to buildings due to tunnelling and excavation. Proceedings: 1st International Conference of Earthquake Geotechnical Engineering, IS Tokyo, 1995.

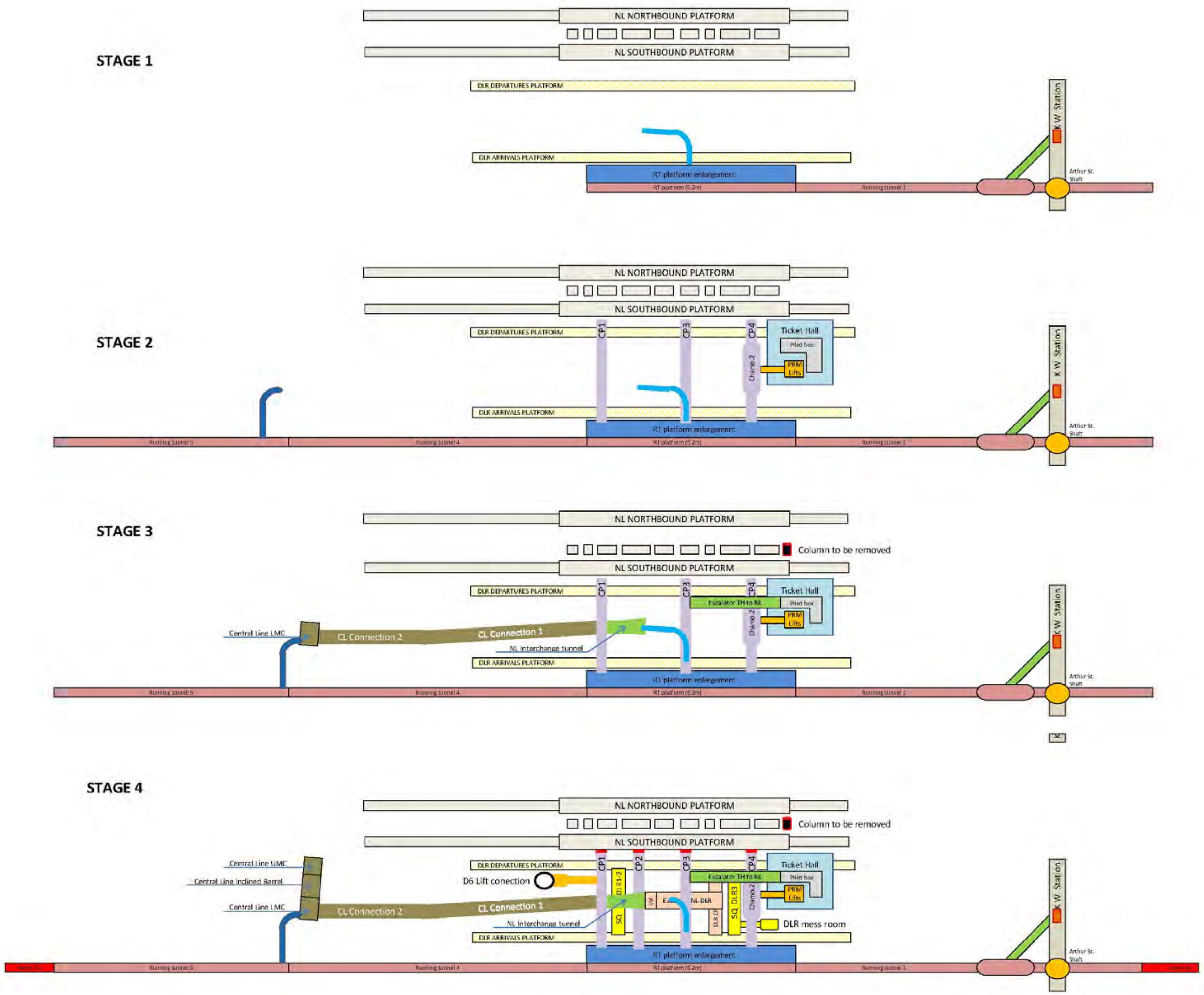

Figure 1: Construction Stage model

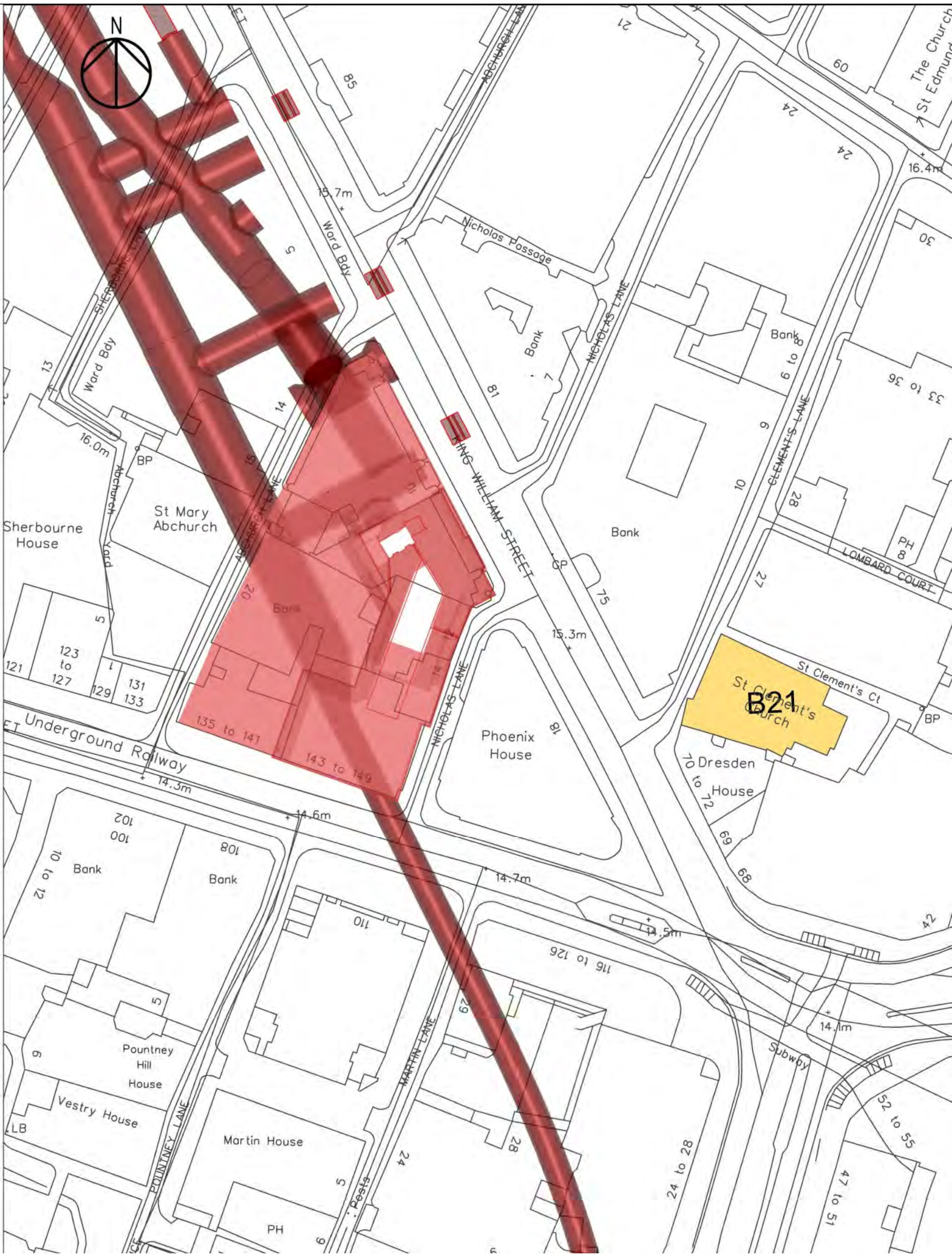

Figure 2: Location plan showing building location in relation to BSCU works

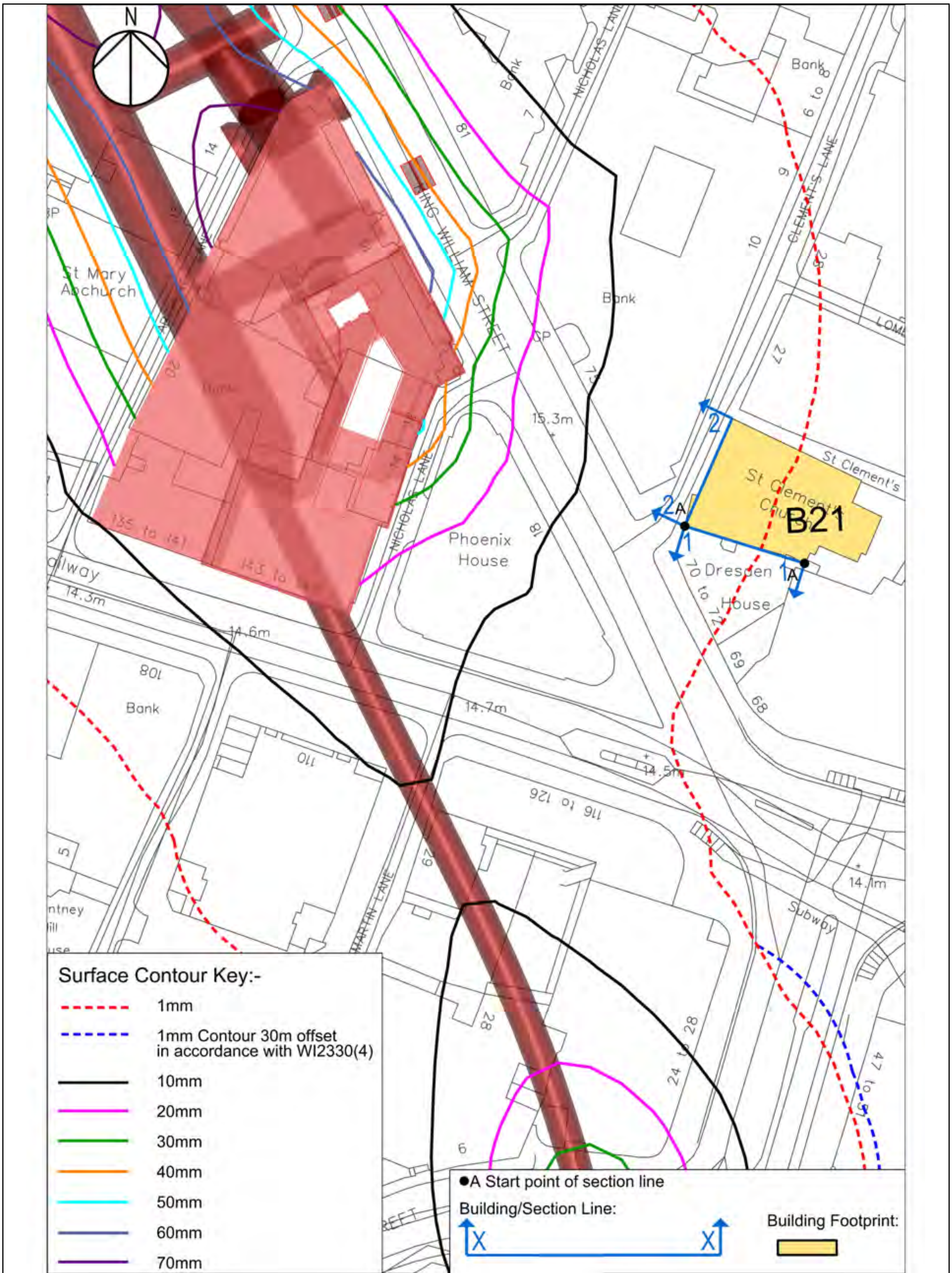

Figure 3: Building location, sections analysed and Settlement Contours at end of construction.

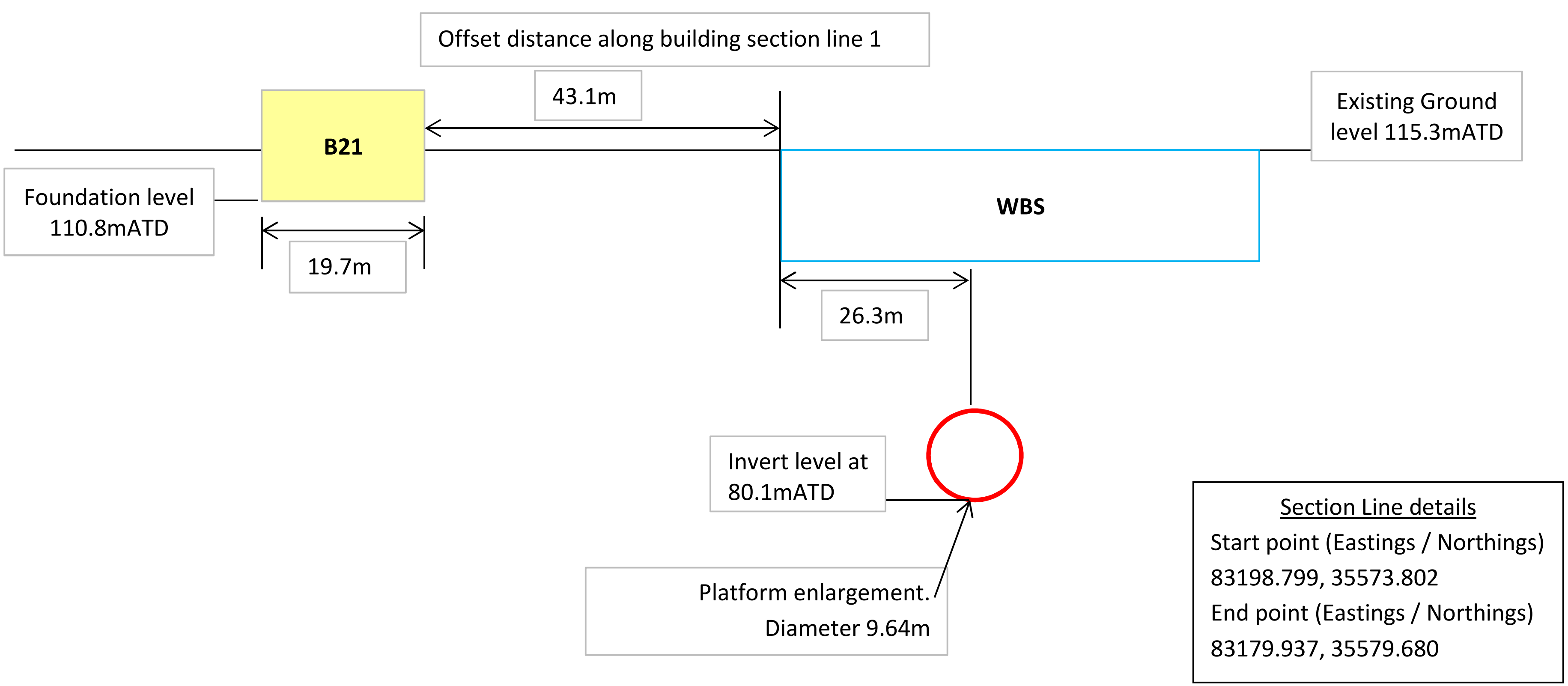

Figure 4: Diagrammatic cross-section of section (line 1) relative to tunnel position

Safely Together

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Bank Station Capacity Upgrade

Building Damage Assessment Report

Building B22

27 Clements Lane

URS-8798-RPT-G-001214

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1.0	March 2014	Issue for Heritage
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Consultation:

- Ela Palmer — URS Heritage
- Brian Lyons — Dr.Sauer
- Keith Bowers/Neil Moss/Paul Dryden — London Underground
- Olly Newman — Dragados

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FIGURES

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1 Introduction

This report summarises the results of a Stage 2 damage assessment for 27 Clements Lane.

Stage 2 damage assessments are undertaken for all buildings within the Stage 1 Greenfield ground surface 1mm settlement contour induced by the construction of the Bank Station Capacity Upgrade (BSCU).

The purpose of the assessment is to determine the potential effect the works will have on the building. This report describes the engineering and heritage assessments undertaken for the building and concludes whether mitigation is likely to be needed and if a further (Stage 3) assessment is recommended in order to verify this.

2 The Building

2.1 General Information

General building information used in the assessment has been acquired as part of the structural desktop appraisal. Where data was not available, conservative assumptions were made instead. This information is presented in Table 1.

Category	Building Information
BSCU Reference	B22
Location	Clements Lane
Address	27 Clements Lane
Building Type	Load bearing masonry (assumed)
Construction Age	During 19th Century
No. of Storeys	4
Basements	1
Eaves Level (mATD)	127.5
Foundation Type	Shallow (assumed)
Ground Level (mATD)	115.5
Listed Grade	II
Note: Levels given are in metres above Tunnel Datum, mATD. Tunnel Datum is 100m below Ordnance Survey Datum at Newlyn	

Table 1: General building information

A general view of the building exterior is shown in Plate 1. A location plan showing the building in relation to the proposed BSCU works is presented in Figure 2.

Plate 1: General view

2.2 Building Description & Heritage

27 Clements Lane, St. Clements House, has been formed by the consolidation of several smaller properties by the City Offices Company during the 19th century.

The building consists of a principal façade along St Clements Lane, with the façade spanning the entrance to Lombard Court. This principal facade is constructed of load bearing architectural masonry, a combination of Portland stone plinth and marble polychrome masonry at ground floor level, with brick masonry and stone dressings and cornices forming floors two and three. The building is supported above the passageway into Lombard Court by shallow brick arches springing from flanged iron beams. The secondary facades onto Lombard Court and Church Passage are constructed of gault brick with a combination of Portland stone segmental window heads and gauged brick arches. The basement and sub-basement consist of a series of brick arched spaces and reinforced concrete corridors.

The building has been extended during the 20th century. According to planning records held by the City of London, number 27 was “reinstated” after WWII bomb damage in 1951 and in 1957 further demolition and rebuilding was recorded relating to both number 27 and 28. In 1964 the fourth floor was altered and in 1970 a fifth floor was added. Finally, internal alterations and refurbishment to the ground and 3rd floor were completed in 1993. The original pitched slate roofs and lead covered dormer windows survive at fourth floor level with the modern additions stepped back from this to render them less conspicuous from the street.

Internally the building has been completely remodelled for use as an office. There is apparently little original fabric surviving other than the cast iron column structure and the stone cantilevered staircase from ground to third floor levels.

3 Methodology

This building damage assessment is undertaken in accordance with LU Works Information WI2300[1] and LU Civil Engineering - Common Requirements S1050[2].

The analysis methodology applies to ground-bearing buildings which will be affected by ground movements resulting from the construction of the BSCU. The engineering assessment calculates the potential impact of ground movements and assigns a damage category to the building based on a numeric scale. Additionally, for listed buildings, a heritage assessment is carried out which considers the sensitivity of the structure and the sensitivity of its particular features; a heritage sensitivity score is assigned. The heritage sensitivity score is added to the damage category to obtain the total score. If the total score is 3 or more, a more detailed Stage 3 assessment is triggered.

Oasys Xdisp is used to analyse the Greenfield ground movement in terms of settlement and horizontal displacement. Subsurface tunnelling induced ground movement profiles are determined in accordance with the methodology described by Mair et al[3 & 4].

Movements resulting from the Whole Block Scheme (WBS) and shaft excavations have been calculated using LU Guidance Document G0058[5].

The building is modelled as a simple elastic beam which is conservatively assumed to follow the Greenfield ground displacements. The beam is divided into hogging and sagging segments. The tensile strains within each segment are calculated based on the distortion associated with differential settlement (which is characterised by deflection ratio) and the distortion associated with differential horizontal displacement (characterised by horizontal strain).

Xdisp provides a method for calculating the maximum tensile strain within the building superstructure associated with these movements, in accordance with the assessment methodology described by Mair et al [4]. This strain is used to determine the damage category based on the classification system proposed by Burland[6] and in accordance with LU Civil Engineering - Common Requirements S1050[2]. The categories are presented in Table 2.

Damage Category	Description of Degree of Damage	Description of Typical Damage and likely forms of Repair for Typical Masonry Buildings.	Approx. Crack Width (mm)	Max. Tensile Strain %
0	Negligible	Hairline cracks.		< 0.05
1	Very slight	Fine cracks easily treated during normal redecoration. Perhaps isolated slight fracture in building. Cracks in exterior visible upon close inspection.	0.1 to 1.0	0.05 to 0.075
2	Slight	Cracks easily filled. Redecoration probably required. Several slight fractures inside building. Exterior cracks visible; some repainting may be required for weather-tightness. Doors and windows may stick slightly.	1 to 5	0.075 to 0.15
3	Moderate	Cracks may require cutting out and patching. Recurrent cracks can be masked by suitable linings. Tuck pointing and possible replacement of a small amount of exterior brickwork may be required. Doors and windows sticking. Utility services may be interrupted. Weather tightness often impaired.	5 to 15 or a number of cracks > 3	0.15 to 0.3
4	Severe	Extensive repair required involving removal and replacement of walls especially over doors and windows. Window and door frames distorted. Floor slopes noticeably. Walls lean or bulge noticeably. Some loss of bearing in beams. Utility services disrupted.	15 to 25 but also depends on number of cracks	> 0.3
5	Very severe	Major repair required involving partial or complete reconstruction. Beams lose bearing, walls lean badly and require shoring. Windows broken by distortion. Danger of instability.	Usually > 25 but depends on number of cracks	
Note: Please refer LU Civil Engineering - Common Requirements S1050[2].				

Table 2: Building damage classification

4 Input Data

The magnitude and distribution of ground movements and degree of building damage is calculated based on the following input data:

- The Xdisp model coordinates and levels are based on the 3D model (20130212DSPITT Scheme R09);
- Four construction stages are considered in accordance with the proposed programme (November 2013) as illustrated in Figure 1;
- Trough width parameter constant, K=0.5 is used in accordance with WI2300.

The input data for the building, tunnels and shaft excavation are summarised in Table 3, Table 4 and Table 5 respectively.

Location	Foundation level (mATD)	Building Height above foundation level (m)	E/G
27 Clements Lane	111.0*	16.5	2.6
Note: Where E / G is the ratio of Young's modulus to shear modulus of the deep beam that is to represent the building. * Assumed level, 1.5m thick slab beneath floor level.			

Table 3: Building data

Tunnel Item	Level of axis (mATD)	External diameter (m)	Volume Loss (%)
Running tunnels	83.5	5.4	1.5
Square works adits	75.8 to 95.3	4.1 to 7.8	2.5
Platform enlargement	85.5	7.4 to 11.2	1.5
Escalator barrels	Inclined	8.3 to 8.4	1.5
Cross passage CP4	86.2	7.8	1.5
Central Line Connection	Inclined (87.6 to 89.2)	8.6	1.5

Table 4: Tunnel data

Excavation	Excavation Base Level (mATD)
Grout Shaft at King William Street	97
Whole Block Scheme Box excavation	73
Arthur Street Shaft	81

Table 5: Excavation data

The distance of building 27 Clements Lane (B22) relative to the excavation elements listed in Table 5 is sufficiently large that this building should not be affected by their construction.

The Xdisp model filenames used to undertake this assessment are:

- B22 - Stage 4
- B22 - Stage 3
- B22 - Stage 2
- B22 - Stage 1

5 Results

5.1 Engineering Assessment

The sections through the building which have been analysed are shown on plan in Figure 3.

Assessment has been undertaken at three intermediate construction stages and at the end of construction when all major elements of the works including shaft and tunnels have been completed. The damage category assigned to the building is based on the construction stage at which the potential impact on the building is most severe.

The maximum settlement and tensile strain calculated for each of the analysis sections at the most onerous intermediate construction stage and at the end of construction are presented in Table 6 and Table 7.

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
B22 (line 1)	<1	<0.001
B22 (line 2)	<1	<0.001

Table 6: Building response at most onerous intermediate stage - Construction Stage 1

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
B22 (line 1)	<1	<0.001
B22 (line 2)	<1	<0.001

Table 7: Building response at end of construction stage

The results of the assessment show construction Stage 4 is the critical stage for this building, with the results close to the intermediate construction stages. At this stage, section B22 (line 1) experiences the most onerous combined tensile strain. The orientation of this building is shown in Figure 3. The relative position of the building and tunnels along section (line 1) is shown in Figure 4. The calculated strains are summarised in Table 8.

Line No (stage)	Strains in section (Curvature)	Position from start (m)	Length (m)	Average* Horizontal Strain (%)	Maximum Tensile Strains (%)	Damage Category
(Line 1)	Hogging	21.1	19.1	<0.001	<0.001	Negligible
Note: * Tensile horizontal strains are +ve. Compressive horizontal strains are –ve.						

Table 8: Section analysed, results for worst case tensile strain

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0. This corresponds to negligible damage in accordance with Table 2.

The maximum settlement of the building at foundation level at end of construction is less than 1mm.

5.2 Heritage and Structural Assessment

Following site inspection, assessment has been made using the following scoring methodology set out in Table 9.

Score	STRUCTURE Sensitivity of the structure to ground movements and interaction with adjacent buildings	HERITAGE FEATURES Sensitivity to calculated movement of particular features within the building	CONDITION Factors which may affect the sensitivity of structural or heritage features
0	Masonry buildings with lime mortar and regular openings, not abutted by other buildings, and therefore similar to the buildings on which the original Burland assessment was based.	No particular sensitive features	Good/Fair - not affecting the sensitivity of structural or heritage features
1	Buildings not complying with categories 0 or 2, but still with some sensitive structural features in the zone of settlement e.g.: cantilever stone staircases, long walls without joints or openings, existing cracks where further movements are likely to concentrate, mixed foundations	Brittle finishes, e.g. faience or tight-jointed stonework, which are susceptible to small structural movements and difficult to repair invisibly.	Poor - may change the behaviour of a building in cases of movement. Poor condition of heritage features and finishes. Evidence of previous movement.
2	Buildings which, by their structural form, will tend to concentrate all their movements in one location (e.g.: a long wall without joints and with a single opening).	Finishes which if damaged will have a significant effect on the heritage value of the building, e.g. Delicate frescos, ornate plasterwork ceilings.	Very poor – parlous condition of heritage features and finishes, severe existing damage to structure including evidence of ongoing movement. Essentially buildings where even very small movements could lead to significant damage.

Table 9: Heritage and structural scoring methodology

The results of the heritage assessment carried out for the building are summarised in Table 10.

SENSITIVITY OF THE STRUCTURE
The building contains a stone cantilever staircase extending for much of the height of the building. Stairs of this type are vulnerable to movement due to the reliance on solid and robust restraint provided by the masonry wall into which they are built. Any movement in the supporting wall which affects the restraint of the treads to twisting in the wall could lead to significant distortion or failure of the stair. At the front of the building the beams supporting the masonry vaults under the first level of basement are propped off the floor slab of the lower level of basement. This is thought to be due to the presence of water filled exercise machines at basement level. Since the props are not tied to the beams above movement of the building may cause them to become displaced, resulting in the overloading of the original floor beams. The presence of cracks due to previous movement points to existing weaknesses in the structure and suggests that any movement in these areas will manifest its self in an opening up of these cracks.
Score: 1 - The building includes some sensitive features, specifically the stone cantilever staircase and the existing cracks in the external wall
SENSITIVITY OF THE HERITAGE
The English Heritage designation indicates that of primary significance is the high quality of the architectural masonry and decoration to Clements Lane façade which complements the neighbouring St. Clements Church. The architectural masonry includes Green Man keystones and segmented arched window surrounds decorated with foliate carving. Damage to the exterior form and decoration of this façade will therefore undermine the historical significance of the building. There is some evidence of cracking at the south-west corner of the building and several joggled voussoirs in the marble segmental arches along Clements Lane.
Score: 1 Due to the evidence of previous damage and movement in the principle façade, heritage features may be sensitive to the predicted settlement
SENSITIVITY OF THE CONDITION
The condition of the building in general and heritage finishes specifically is good with little evidence of serious issues requiring attention such as ongoing structural movement or water ingress in the basements. The asphalt roof appears to be nearing the end of its useful life and is splitting and delaminating in some areas. There are some cracks in areas to previous movement to the facades, however these have not damaged heritage features.
Score: 0 - The condition of the building is not considered likely to alter the response of the building to the predicted movement.

Table 10: Heritage and structural assessment

5.3 Total Score

The total score is the summation of the damage category, structural sensitivity, heritage sensitivity and condition sensitivity scores:

The damage category is 0

The structural sensitivity score is 1

The heritage sensitivity score is 1

The condition sensitivity score is 0

The total score for this building is 2

6 Conclusion

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0 for St Clement House. Specific heritage and structural assessment taking into account the location and extent of settlement and tensile strains indicated that the building would have a low level of structural and heritage sensitivity to the predicted movements. This assessment has determined that the building has a total score of 2.

It is recommended that the building does not require a Stage 3 assessment.

7 References

[1] LU Works Information WI 2300 Ground Movement version 3, 19-07-13.

[2] LU Category 1 Standard: S1050 Civil Engineering - Common Requirements, Issue No. A7, Nov. 2013.

[3] Mair R J, Taylor R N and Bracegirdle A (1993). Subsurface settlement profiles above tunnels in clays. Géotechnique 43, No. 2, pp. 315-320.

[4] Mair R J, Taylor R N and Burland J B (1996). Prediction of ground movements and assessment of risk of building damage due to bored tunnelling. (In: International Conference of Geotechnical Aspects of Underground Construction in Soft Ground, London, pp. 713–718.

[5] LU Guidance Document G0058 Civil Engineering Technical Advice Notes, Issue No. A17, Feb. 2013.

[6] Burland J B (1995). Assessment of risk of damage to buildings due to tunnelling and excavation. Proceedings: 1st International Conference of Earthquake Geotechnical Engineering, IS Tokyo, 1995.

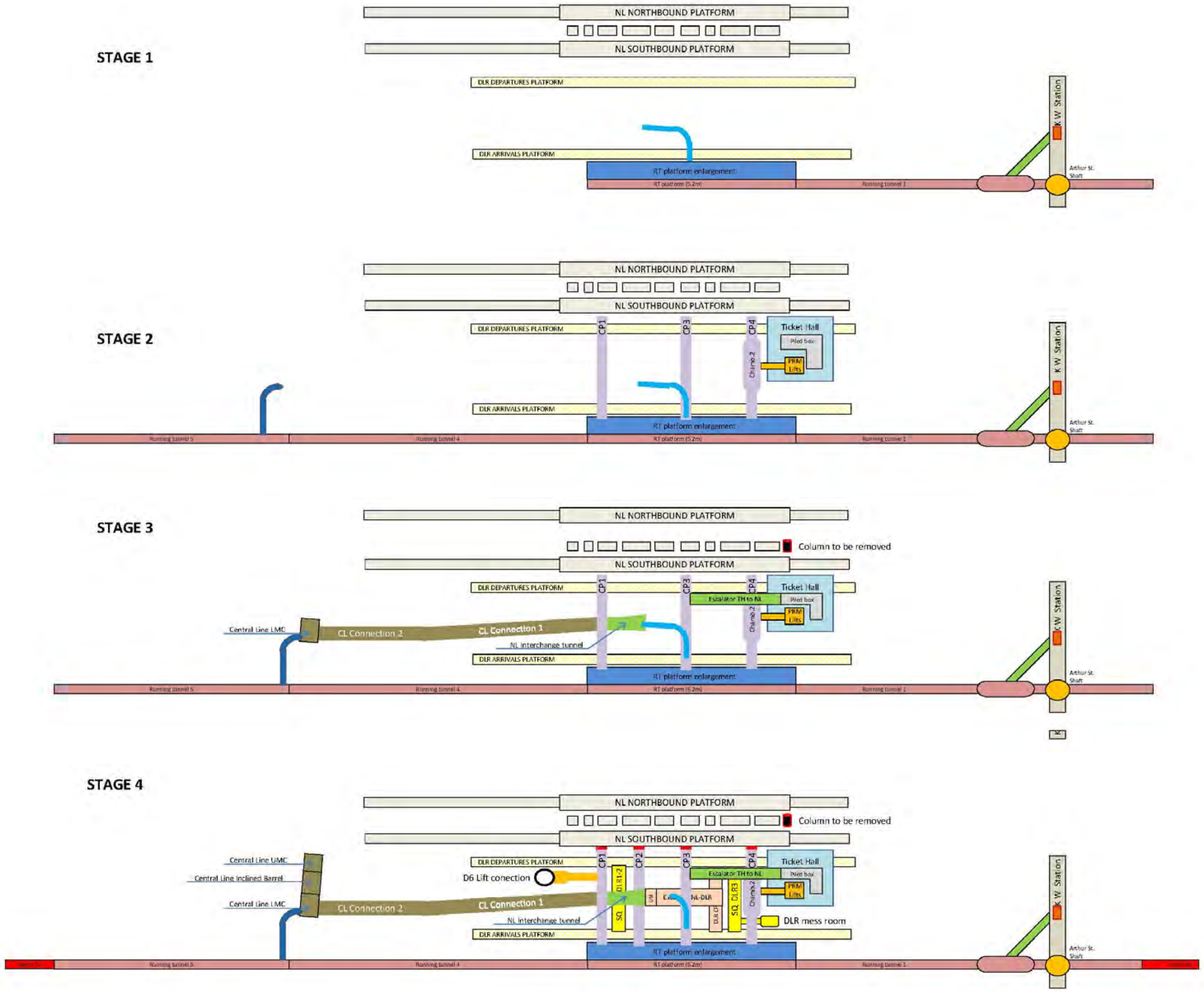

Figure 1: Construction Stage model

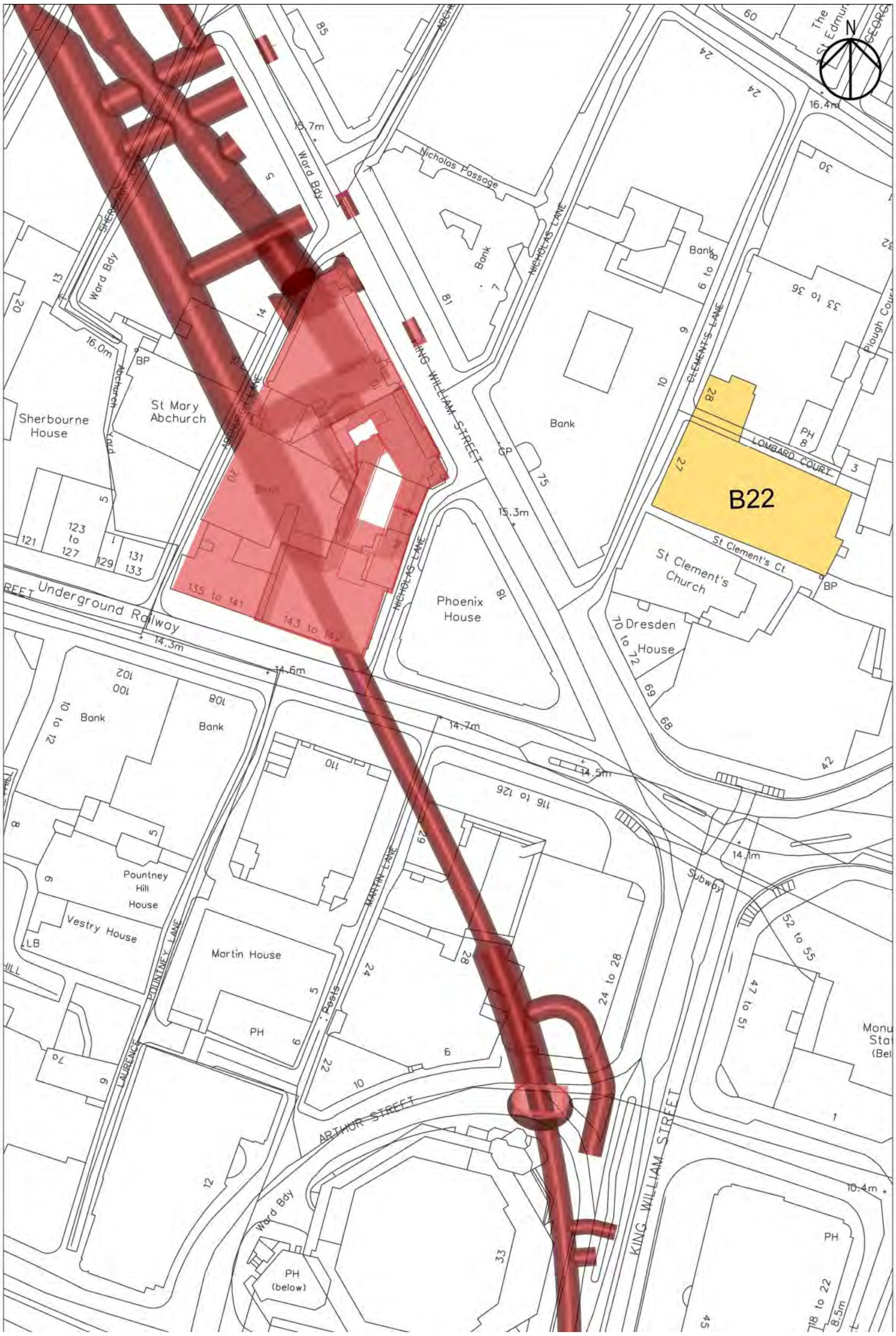

Figure 2: Location plan showing building location in relation to BSCU works

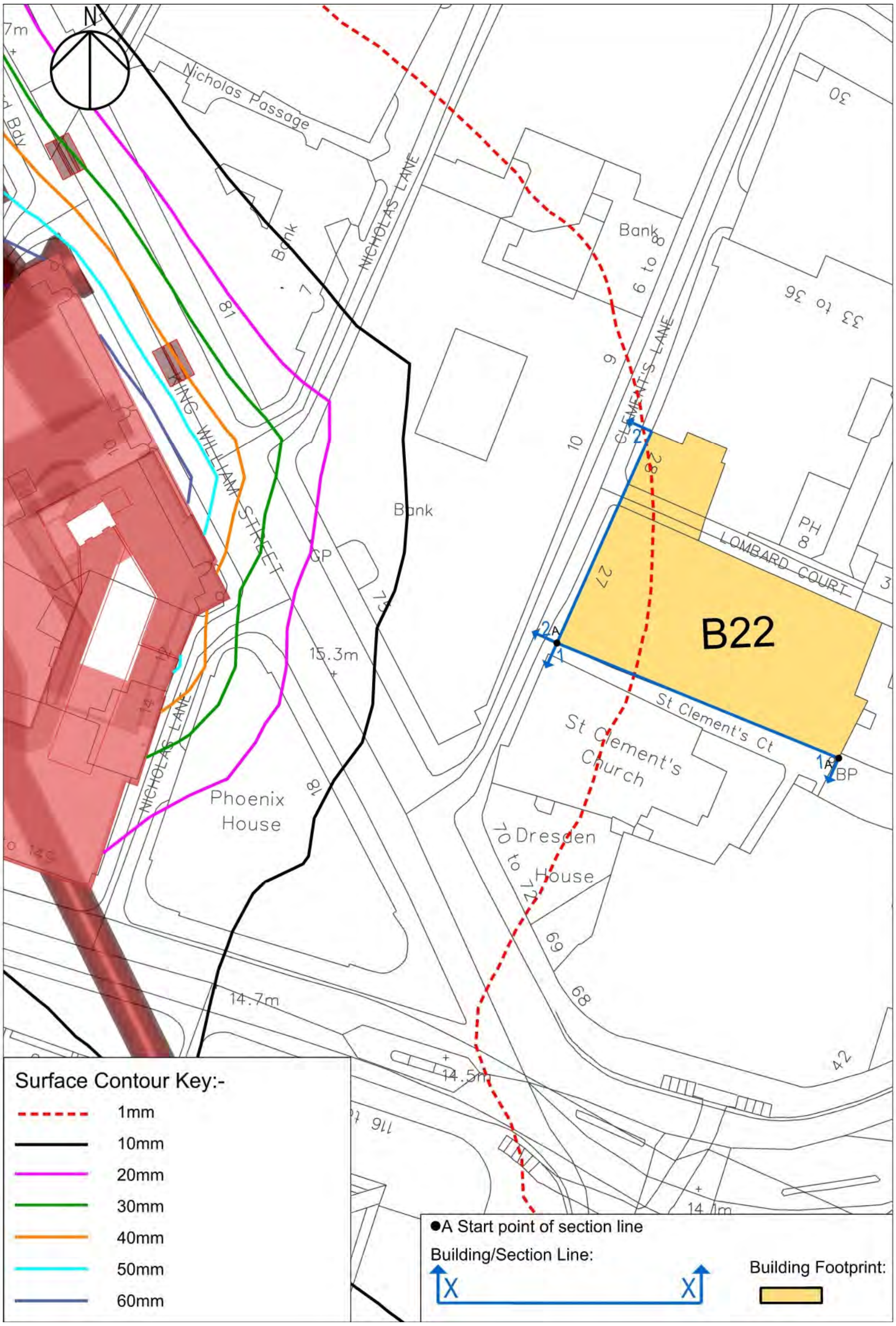

Figure 3: Building location, sections analysed and Settlement Contours at stage of worst case for tensile strains

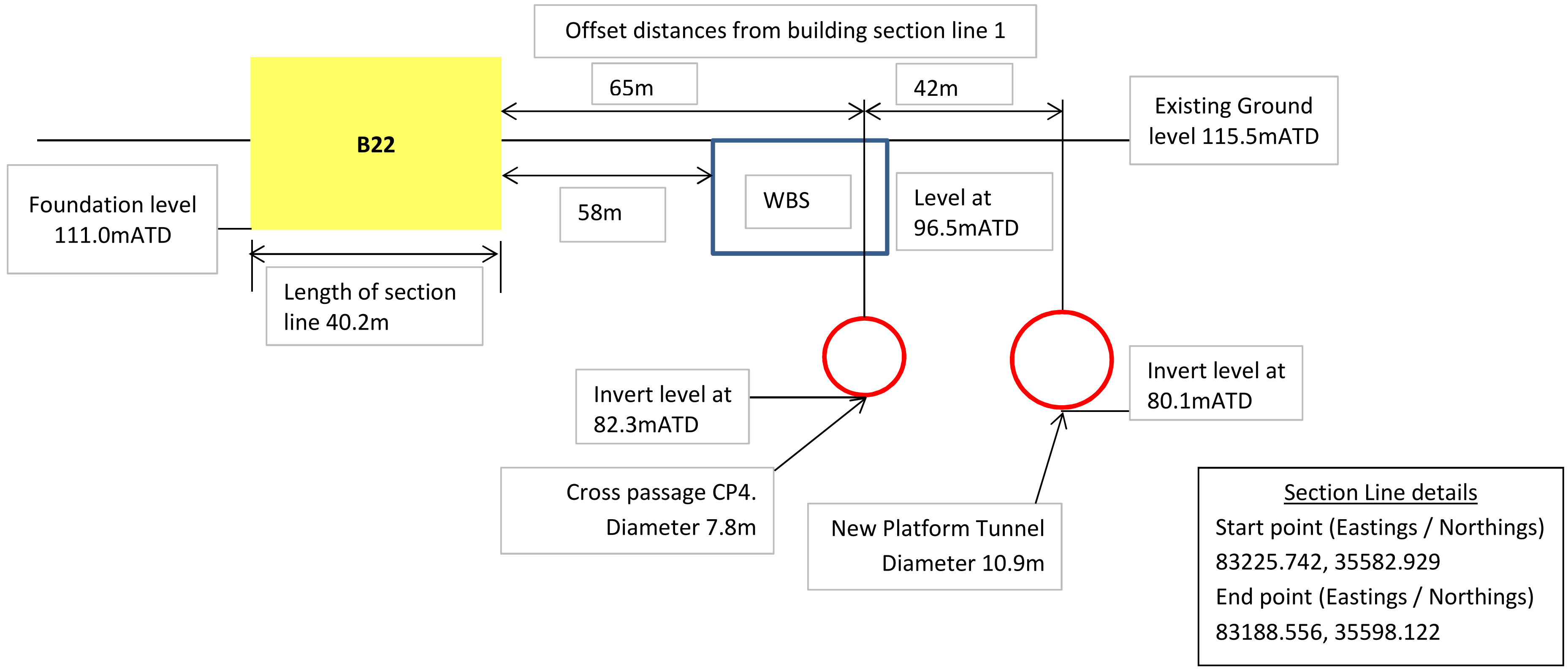

Figure 4: Diagrammatic cross-section of section line (1) relative to tunnel position

LUL Bank Project Office
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Bank Station Capacity Upgrade

Building Damage Assessment Report

Building B23

6-8 Clements Lane

URS-8798-RPT-G-001215

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Document Owner	
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Role:	Designer

Document History

Revision	Date	Summary of changes
1.0	March 2014	Issue to Heritage
2.0	May 2014	For Approval
3.0	July 2014	TWAO Issue

For the status of this document, please refer to the Building Damage Assessment Report Register (URS-8798-RGT-001229)

<u>Consultation:</u>

• Ela Palmer	URS Heritage
• Brian Lyons	Dr.Sauer
• Keith Bowers/Neil Moss/Paul Dryden	London Underground
• Olly Newman	Dragados

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FIGURES

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1 Introduction

This report summarises the results of a Stage 2 damage assessment for 6 - 8 Clements Lane.

Stage 2 damage assessments are undertaken for all buildings within the Stage 1 Greenfield ground surface 1mm settlement contour induced by the construction of the Bank Station Capacity Upgrade (BSCU).

The purpose of the assessment is to determine the potential effect the works will have on the building. This report describes the updated engineering assessments undertaken for the building and concludes whether mitigation is likely to be needed and if a further (Stage 3) assessment is recommended in order to verify this.

2 The Building

2.1 General Information

General building information used in the assessment has been acquired as part of the structural desktop appraisal. Where data was not available, conservative assumptions were made instead. This information is presented in Table 1.

Category	Building Information
BSCU Reference	B23
Location	Clements Lane
Address	6-8 Clements Lane
Building Type	Load bearing masonry (assumed)
Construction Age	Late 19th century
No. of Storeys	3
Basements	1 (assumed)
Eaves Level (mATD)	127.8
Foundation Type	Shallow (assumed)
Ground Level (mATD)	115.8
Listed Grade	II
Note: Levels given are in metres above Tunnel Datum, mATD. Tunnel Datum is 100m below Ordnance Survey Datum at Newlyn.	

Table 1: General building information

A general view of the building exterior is shown in Plate 1. A location plan showing the building in relation to the proposed BSCU works is presented in Figure 2.

Plate 1: General view

2.2 Building Description

6-8 Clement's Lane dates from the late 19th century, and is constructed of stone with a granite plinth. The building is three storeys high with two attic storeys within a mansard, one level of basement. A masonry type structure on shallow foundation such as strip footing is considered as the most conservative when assessing strains for the building facades.

The windows to the historic façade are tall and narrow, round headed to the ground and second floors and square to the first floor. The façade has some decorative motifs in the Renaissance style, with scroll keystones to the ground and second floor windows, and slim egg and dart detailing to the window surrounds.

Internally, the building has lost all of its heritage features, and is decorated with modern materials. The windows have been replaced.

3 Methodology

This building damage assessment is undertaken in accordance with LU Works Information WI2300[1] and LU Civil Engineering - Common Requirements S1050[2].

The analysis methodology applies to ground-bearing buildings which will be affected by ground movements resulting from the construction of the BSCU. The engineering assessment calculates the potential impact of ground movements and assigns a damage category to the building based on a numeric scale. Additionally, for listed buildings, a heritage assessment is carried out which considers the sensitivity of the structure and the sensitivity of its particular features; a heritage sensitivity score is assigned. The heritage sensitivity score is added to the damage category to obtain the total score. If the total score is 3 or more, a more detailed Stage 3 assessment is triggered.

Oasys Xdisp is used to analyse the Greenfield ground movement in terms of settlement and horizontal displacement. Subsurface tunnelling induced ground movement profiles are determined in accordance with the methodology described by Mair et al[3 & 4].

Movements resulting from the Whole Block Scheme (WBS) and shaft excavations have been calculated using LU Guidance Document G0058[5].

The building is modelled as a simple elastic beam which is conservatively assumed to follow the Greenfield ground displacements. The beam is divided into hogging and sagging segments. The tensile strains within each segment are calculated based on the distortion associated with differential settlement (which is characterised by deflection ratio) and the distortion associated with differential horizontal displacement (characterised by horizontal strain).

Xdisp provides a method for calculating the maximum tensile strain within the building superstructure associated with these movements, in accordance with the assessment methodology described by Mair et al [4]. This strain is used to determine the damage category based on the classification system proposed by Burland[6] and in accordance with LU Civil Engineering - Common Requirements S1050[2]. The categories are presented in Table 2.

Damage Category	Description of Degree of Damage	Description of Typical Damage and likely forms of Repair for Typical Masonry Buildings.	Approx. Crack Width (mm)	Max. Tensile Strain %
0	Negligible	Hairline cracks.		< 0.05
1	Very slight	Fine cracks easily treated during normal redecoration. Perhaps isolated slight fracture in building. Cracks in exterior visible upon close inspection.	0.1 to 1.0	0.05 to 0.075
2	Slight	Cracks easily filled. Redecoration probably required. Several slight fractures inside building. Exterior cracks visible; some repainting may be required for weather-tightness. Doors and windows may stick slightly.	1 to 5	0.075 to 0.15
3	Moderate	Cracks may require cutting out and patching. Recurrent cracks can be masked by suitable linings. Tuck pointing and possible replacement of a small amount of exterior brickwork may be required. Doors and windows sticking. Utility services may be interrupted. Weather tightness often impaired.	5 to 15 or a number of cracks > 3	0.15 to 0.3
4	Severe	Extensive repair required involving removal and replacement of walls especially over doors and windows. Window and door frames distorted. Floor slopes noticeably. Walls lean or bulge noticeably. Some loss of bearing in beams. Utility services disrupted.	15 to 25 but also depends on number of cracks	> 0.3
5	Very severe	Major repair required involving partial or complete reconstruction. Beams lose bearing, walls lean badly and require shoring. Windows broken by distortion. Danger of instability.	Usually > 25 but depends on number of cracks	
Note: Please refer LU Civil Engineering - Common Requirements S1050[2].				

Table 2: Building damage classification

4 Input Data

The magnitude and distribution of ground movements and degree of building damage is calculated based on the following input data:

- The Xdisp model coordinates and levels are based on the 3D model (20130212DSPITT Scheme R09);
- Four construction stages are considered in accordance with the proposed programme (November 2013), as illustrated in Figure 1;
- Trough width parameter constant, K=0.5 is used in accordance with WI2300[1].

The input data for the building, tunnels and shaft excavation are summarised in Table 3, Table 4 and Table 5 respectively.

Location	Foundation level (mATD)	Building Height above foundation level (m)	E/G
6-8 Clements Lane	111.3*	16.5	2.6
Note: Where E / G is the ratio of Young's modulus to shear modulus of the deep beam representing the building. * Assumed level, 1.5m thick slab beneath floor level.			

Table 3: Building data

Tunnel Item	Level of axis (mATD)	External diameter (m)	Volume Loss (%)
Running tunnels	83.5	5.4	1.5
NL interchange tunnel	84.8	9.75	1.5
Square works adits	75.8 to 95.3	4.1 to 7.8	2.5
Platform enlargement	85.5	10.9	1.5
Escalator barrels	Inclined	8.3 to 8.4	1.5
Central Line Connection	Inclined (87.6 to 89.2)	8.6	1.5

Table 4: Tunnel data

Excavation	Excavation Base Level (mATD)
Grout Shaft at King William Street	97
Whole Block Scheme Box excavation	73
Arthur Street Shaft	81

Table 5: Excavation data

The distance of building 6-8 Clements Lane (B23) relative to the excavation elements at Arthur Street listed in Table 5 is sufficiently large that this building should not be affected by these works.

The Xdisp model filenames used to undertake this assessment are:

- B23 - Stage 4
- B23 - Stage 3
- B23 - Stage 2
- B23 - Stage 1

5 Results

5.1 Engineering Assessment

The sections through the building which have been analysed are shown on plan in Figure 3.

Assessment has been undertaken at three intermediate construction stages and at the end of construction when all major elements of the works including shaft and tunnels have been completed. The damage category assigned to the building is based on the construction stage at which the potential impact on the building is most severe.

The maximum settlement and tensile strain calculated for each of the analysis sections at the most onerous intermediate construction stage and at the end of construction are presented in Table 6 and Table 7.

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
B23 (Line 1)	<1	<0.001
B23 (Line 2)	<1	<0.001

Table 6: Building response at most onerous intermediate stage - Construction Stage 2

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
B23 Line (1)	<1	<0.001
B23 (Line 2)	<1	<0.001

Table 7: Building response at end of construction stage

The results of the assessment show that construction stage 2 is the critical stage for this building with results very similar to end of construction stage. At this stage, B23 (line 1) experiences the most onerous combined tensile strain. The building orientation is shown in Figure 3. The relative position of the building and tunnels along section (line 1) is shown Figure 4. The calculated strains are summarised in Table 8.

Strains in section (Curvature)	Position from start (m))	Length (m)	Average* Horizontal Strain (%)	Maximum Tensile Strains (%)	Damage Category
Hogging	0.0	9.4	<0.001	<0.001	Negligible
Note: * Tensile horizontal strains are +ve. Compressive horizontal strains are –ve.					

Table 8: Section analysed, results for worst case tensile strain

The Stage 4 engineering assessment has predicted that the maximum tensile strain falls within damage category 0. This corresponds to negligible damage in accordance with Table 2.

The maximum settlement of the building at foundation level at construction stage 2 is less than 1mm.

5.2 Heritage and Structural Assessment

Following site inspection, assessment has been made using the scoring methodology set out in Table 9.

Score	Structure (Sensitivity of the structure to ground movements and interaction with adjacent buildings)	Heritage features (Sensitivity to calculated movement of particular features within the building)	Condition (Factors which may affect the sensitivity of structural or heritage features)
0	Masonry buildings with lime mortar and regular openings, not abutted by other buildings, and therefore similar to the buildings on which the original Burland assessment was based.	No particular sensitive features	Good/Fair - not affecting the sensitivity of structural or heritage features
1	Buildings not complying with categories 0 or 2, but still with some sensitive structural features in the zone of settlement e.g.: cantilever stone staircases, long walls without joints or openings, existing cracks where further movements are likely to concentrate, mixed foundations	Brittle finishes, e.g. faience or tight-jointed stonework, which are susceptible to small structural movements and difficult to repair invisibly.	Poor - may change the behaviour of a building in cases of movement. Poor condition of heritage features and finishes. Evidence of previous movement.
2	Buildings which, by their structural form, will tend to concentrate all their movements in one location (e.g.: a long wall without joints and with a single opening).	Finishes which if damaged will have a significant effect on the heritage value of the building, e.g. Delicate frescos, ornate plasterwork ceilings.	Very poor – parlous condition of heritage features and finishes, severe existing damage to structure including evidence of ongoing movement. Essentially buildings where even very small movements could lead to significant damage.

Table 9: Heritage and structural scoring methodology

The results of the heritage assessment carried out for the building are summarised in Table 10.

SENSITIVITY OF THE STRUCTURE
Very little of the structure of this building was visible at the time of the survey, however there are no obvious features that would be sensitive to ground movements. The predicted settlements under this building are very small and are very unlikely to cause any significant damage to the primary structure.
Score: 0 - The structure is not sensitive to the levels of settlement predicted.
SENSITIVITY OF THE HERITAGE
The façade of 6-8 Clement's Lane is the only remaining sensitive heritage feature of the building. However, due to the very low predicted settlement in this area of less than 1mm, the façade is unlikely to suffer damage or change.
Score: 0 - The heritage features of the building will not be sensitive to the predicted settlement.
SENSITIVITY OF THE CONDITION
The condition of the building is generally good, with localised areas of damp and leaking in the basement.
Score: 0 - The condition of the building will not exacerbate any structural or heritage sensitivities.

Table 10: Heritage and structural assessment

5.3 Total Score

The total score is the summation of the damage category, structural sensitivity, heritage sensitivity and condition sensitivity scores:

The damage category is 0

The structural sensitivity score is 0

The heritage sensitivity score is 0

The condition sensitivity score is 0

The total score for this building is 0

6 Conclusion

The Stage 2 Assessment for the BSCU works has determined that the building has a total score of 0. This total score indicates that the building does not require a Stage 3 Assessment.

7 References

[1] LU Works Information WI 2300 Ground Movement version 3, 19-07-13.

[2] LU Category 1 Standard: S1050 Civil Engineering - Common Requirements, Issue No. A7, Nov. 2013.

[3] Mair R J, Taylor R N and Bracegirdle A (1993). Subsurface settlement profiles above tunnels in clays. Géotechnique 43, No. 2, pp. 315-320.

[4] Mair R J, Taylor R N and Burland J B (1996). Prediction of ground movements and assessment of risk of building damage due to bored tunnelling. (In: International Conference of Geotechnical Aspects of Underground Construction in Soft Ground, London, pp. 713–718.

[5] LU Guidance Document G0058 Civil Engineering Technical Advice Notes, Issue No. A17, Feb. 2013.

[6] Burland J B (1995). Assessment of risk of damage to buildings due to tunnelling and excavation. Proceedings: 1st International Conference of Earthquake Geotechnical Engineering, IS Tokyo, 1995.

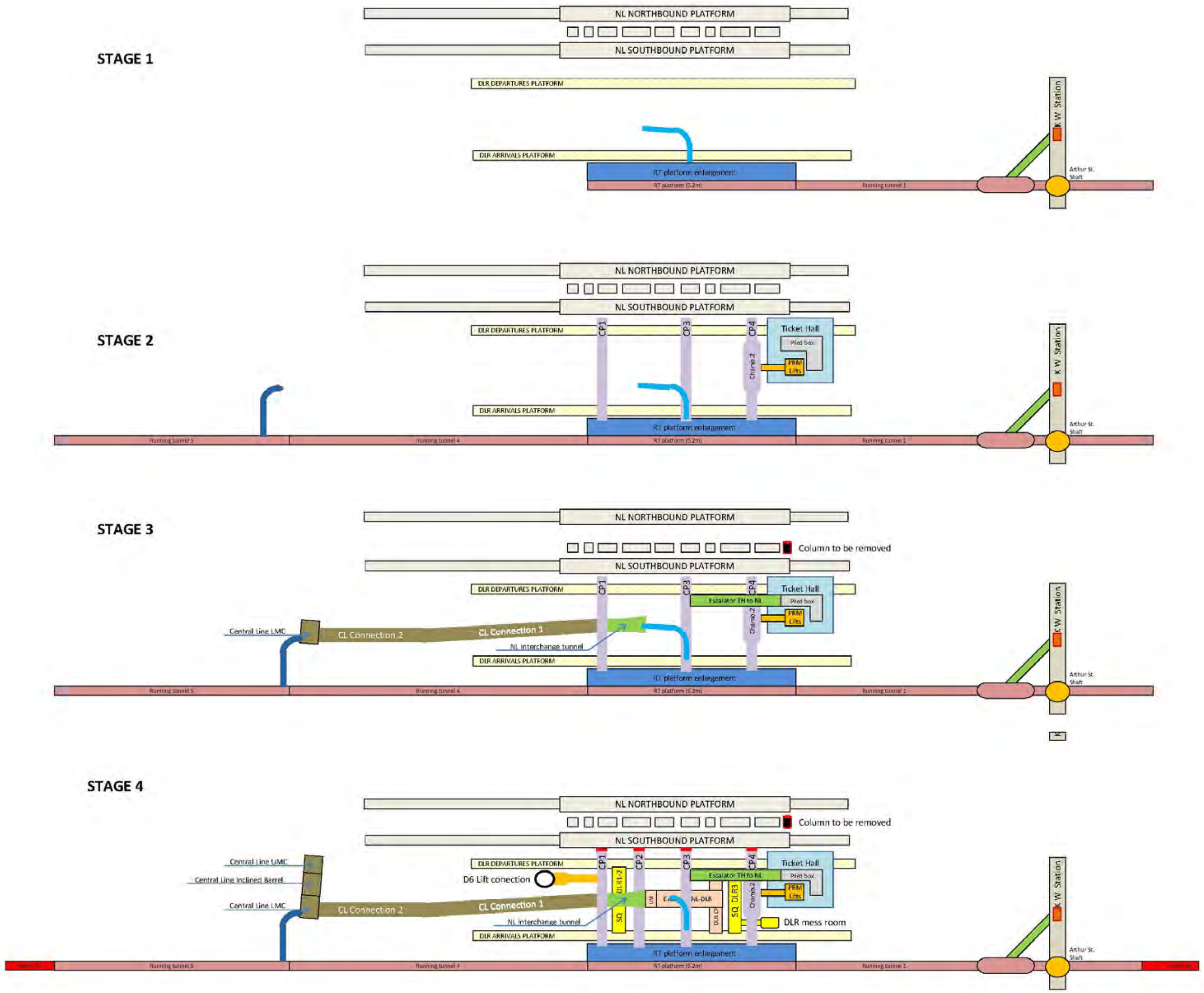

Figure 1: Construction Stage model

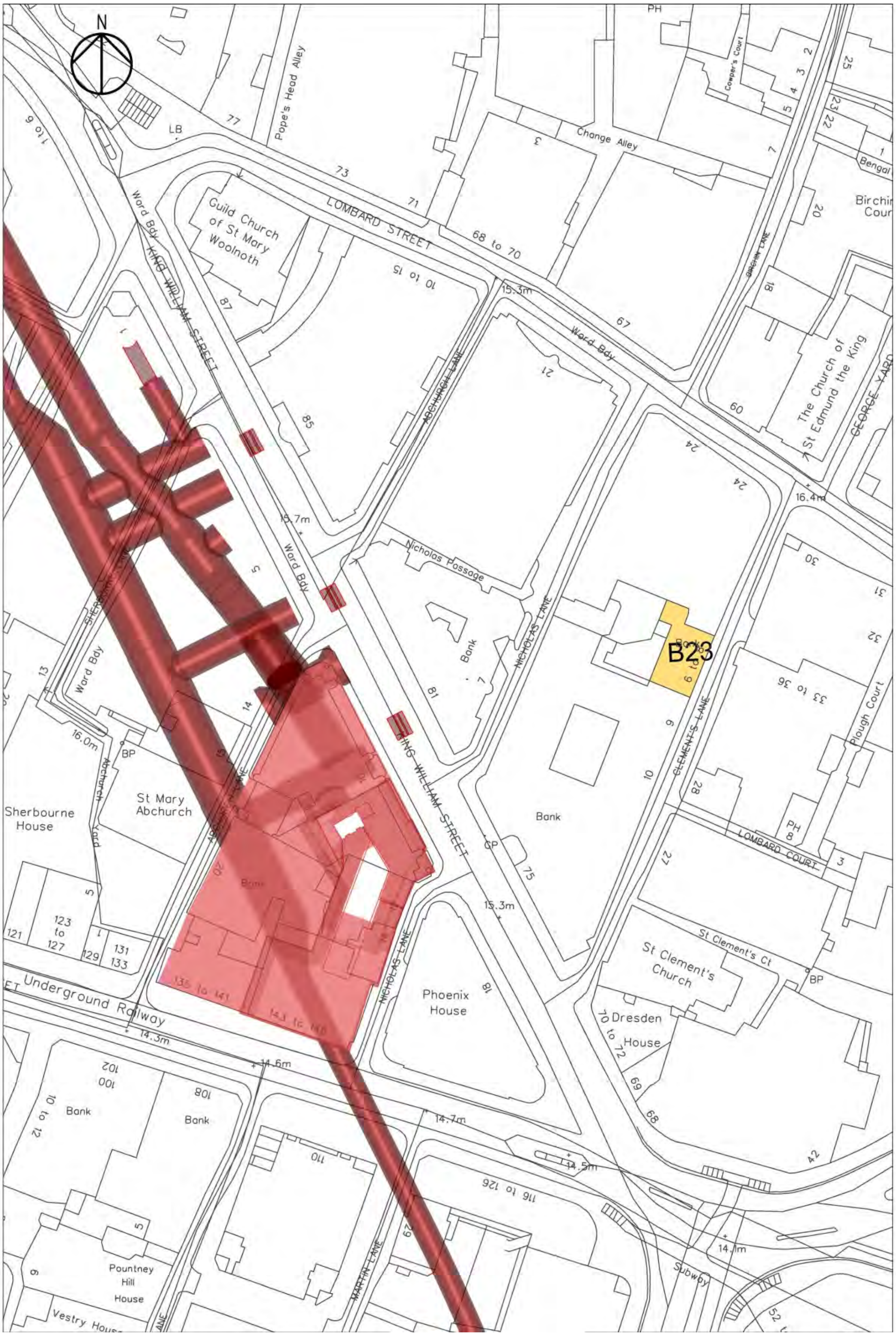

Figure 2: Location plan showing building location in relation to BSCU works

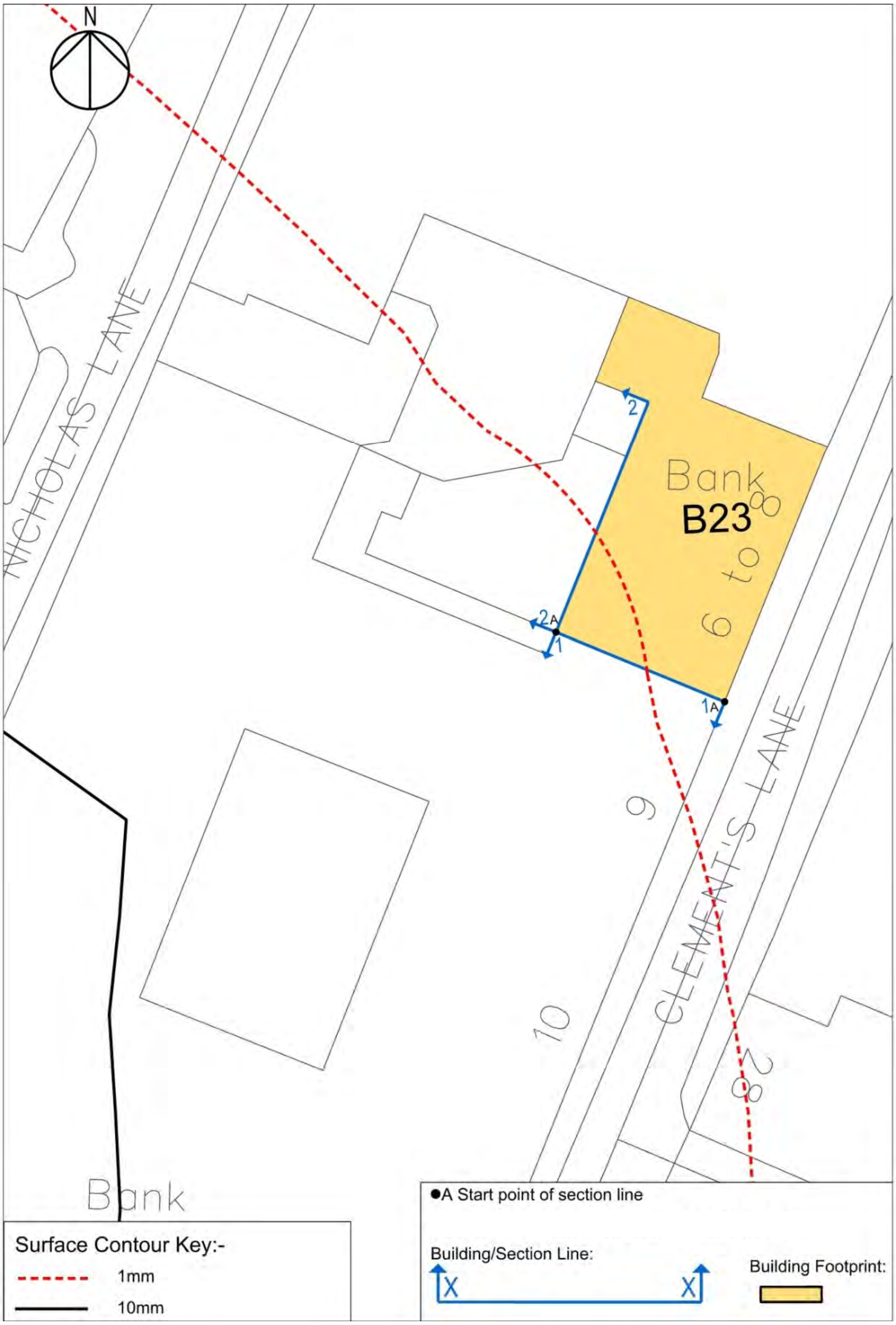

Figure 3: Building location, sections analysed and Settlement Contours at stage of worst case for tensile strains

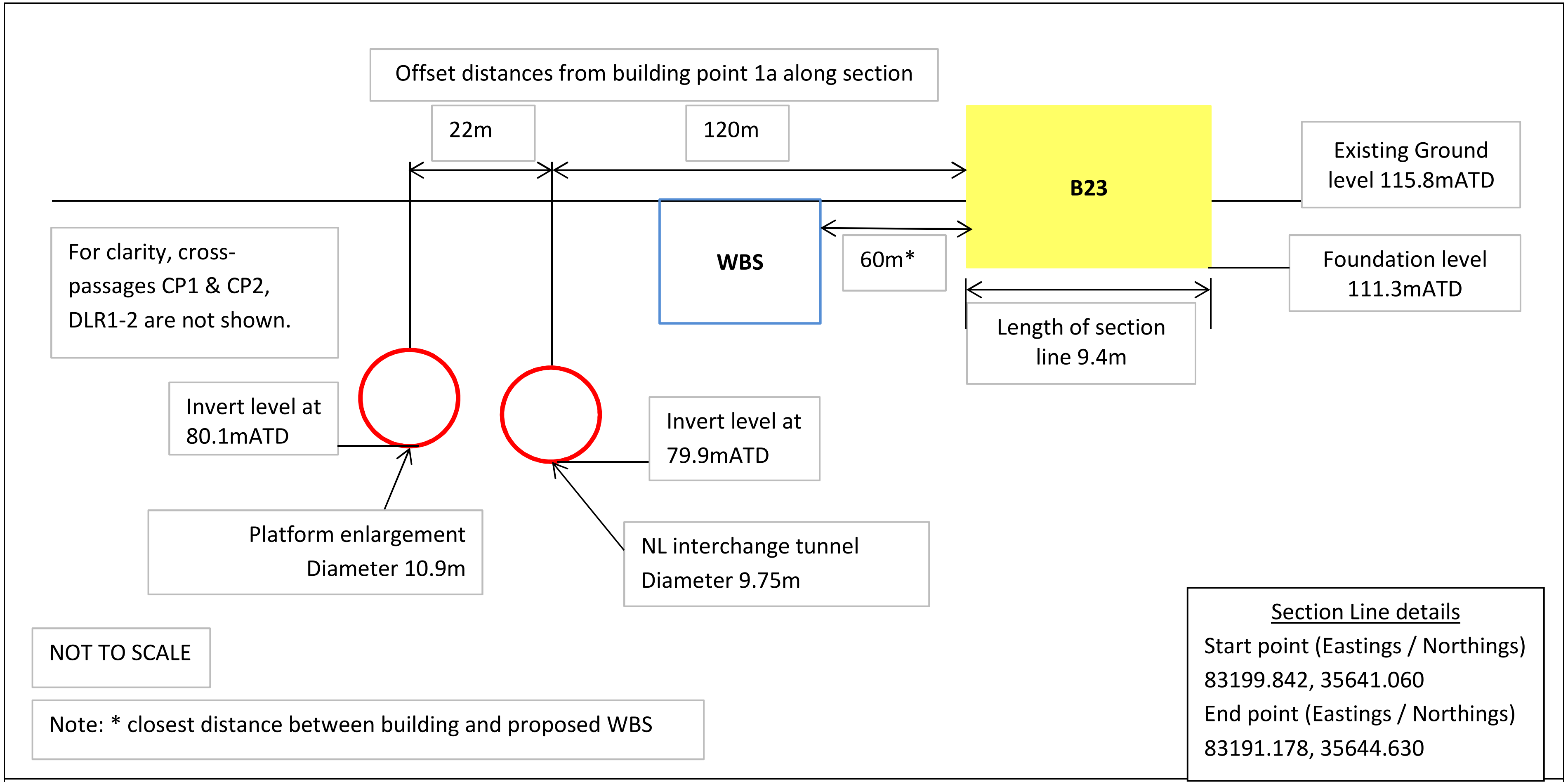

Figure 4: Diagrammatic cross-section of section (line 1) relative to tunnel position

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Bank Station Capacity Upgrade

Building Damage Assessment Report

Building B24

24 Lombard Street

URS-8798-RPT-G-001216

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Document Owner	
Company:	URS
Role:	Designer

Document History

Revision	Date	Summary of changes
1.0	March 2014	Issue for Heritage
2.0	May 2014	For Approval
3.0	July 2014	TWAO Issue

Consultation:

- Ela Palmer — URS Heritage
- Brian Lyons — Dr.Sauer
- Keith Bowers/Neil Moss/Paul Dryden — London Underground
- Olly Newman — Dragados

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FIGURES

TABLES

1 Introduction

This report summarises the results of a Stage 2 damage assessment for 24 Lombard Street, (building ref. B24).

Stage 2 damage assessments are undertaken for all buildings within the Stage 1 Greenfield ground surface 1mm settlement contour induced by the construction of the Bank Station Capacity Upgrade (BSCU).

The purpose of the assessment is to determine the potential effect the works will have on the building. This report describes the engineering and heritage assessments undertaken for the building and concludes whether mitigation is likely to be needed and if a further (Stage 3) assessment is recommended in order to verify this.

2 The Building

2.1 General Information

General building information used in the assessment has been acquired as part of the structural desktop appraisal and walk over surveys. Where data was not available, conservative assumptions were made instead. This information is presented in Table 1.

Category	Building Information
BSCU Reference	B24
Location	Lombard Street
Address	24 Lombard Street
Building Type	Framed building with retained façade (assumed)
Construction Age	1910s
No. of Storeys	6
Basements	2
Eaves Level (mATD)	146.4
Foundation Type	Bored piles
Ground Level (mATD)	116.4
Listed Grade	II
Note: Levels given are in metres above Tunnel Datum, mATD. Tunnel Datum is 100m below Ordnance Survey Datum at Newlyn	

Table 1: General building information

A general view of the building exterior is shown in Plate 1. A location plan showing the building in relation to the proposed BSCU works is presented in Figure 2.

Plate 1: General view

2.2 Building Description & Heritage

Attributed to Gunton and Gunton Architects and constructed in 1910, 24-28 Lombard Street is a commercial building that is currently owned by Mitsubishi Bank. In 1981 the majority of the building was demolished and rebuilt retaining the facades. The Nicholas Lane elevation incorporates the façade of 34-37 Nicholas Lane which is a separate Grade II designated listed building.

The structure above ground is constructed of steel frame and brick masonry with independent Portland stone and brick masonry facades. Below ground the basement level and sub-basement is constructed of reinforced concrete and brick masonry.

The consolidated building is an irregular rectangle in plan with a small courtyard in its southern half accessed from Nicholas Lane. There are 4 principal stories with two additional stories above and a basement and sub-basement below. The ground and first floor are rusticated with large double height semi-circular arched window with metal frames. The 2nd, 3rd and 4th floors are decorated with an Ionic order; the corner to Clements Lane is constructed with a full height domed oriel window. The 34-37 Nicholas Lane façade is a 19th century classical frontage also in Portland stone. It consists of a rusticated ground storey with segmentally arched windows and carved keystones. The first floor windows with columns of polished pink granite.

The main entrance on Lombard Street is a highly attractive and unusual treatment of flanking Ionic columns with a wrought iron fanlight and oculus with an oversized carved lion's head, set under large segmental pediment on brackets, above which is an oversized group of figures in bronze.

Internally the building functions as a financial institution and the entire building has been renovated to offer a series of large open plan office spaces and smaller meeting rooms. However, at the entrance the original marble lined vestibule survives, Corinthian pilasters support a dentiled entablature, balustrade and circular dome, also in marble.

3 Methodology

This building damage assessment is undertaken in accordance with LU Works Information WI2300[1] and LU Civil Engineering - Common Requirements S1050[2].

The analysis methodology applies to ground-bearing / piled buildings which will be affected by ground movements resulting from the construction of the BSCU. The engineering assessment calculates the potential impact of ground movements and assigns a damage category to the building based on a numeric scale. Additionally, for listed buildings, a heritage assessment is carried out which considers the sensitivity of the structure and the sensitivity of its particular features; a heritage sensitivity score is assigned. The heritage sensitivity score is added to the damage category to obtain the total score. If the total score is 3 or more, a more detailed Stage 3 assessment is triggered.

Since the building is piled the movement assessment is based on a combination of assumptions. This is in accordance with Selemetas.D et al (2005)[7]. In the region above the tunnel alignment piles with a toe level within 20% of the depth of the tunnel are assumed to move the same amount as the soil at the toe level using the method given by New & Bowers[8].Piles to either side are assumed to move the same amount as the greenfield settlement prediction at the base of building level using the methods of Mair et al[3, 4]. The deflected shape is assessed from these two approaches and the tensile strains calculated using the method given by Burland et al[6]. It is assumed that the substructure is sufficiently robust to prevent horizontal strains. Since this building is relatively remote from the tunnel the movement assessment is carried out at pile cap level assumed to be 1.5m below basement level, i.e.108mATD.

Oasys Xdisp is used to analyse the Greenfield ground movement in terms of settlement and horizontal displacement. Subsurface tunnelling induced ground movement profiles are determined in accordance with the methodology described by Mair et al[3 & 4].

Movements resulting from the Whole Block Scheme (WBS) and shaft excavations have been calculated using LU Guidance Document G0058[5].

The building is modelled as a simple elastic beam which is conservatively assumed to follow the Greenfield ground displacements. The beam is divided into hogging and sagging segments. The tensile strains within each segment are calculated based on the distortion associated with differential settlement (which is characterised by deflection ratio) and the distortion associated with differential horizontal displacement (characterised by horizontal strain).

Xdisp provides a method for calculating the maximum tensile strain within the building superstructure associated with these movements, in accordance with the assessment methodology described by Mair et al [4]. This strain is used to determine the damage category based on the classification system proposed by Burland[6] and in accordance with LU Civil Engineering - Common Requirements S1050[2]. The categories are presented in Table 2.

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Damage Category	Description of Degree of Damage	Description of Typical Damage and likely forms of Repair for Typical Masonry Buildings.	Approx. Crack Width (mm)	Max. Tensile Strain %
0	Negligible	Hairline cracks.		< 0.05
1	Very slight	Fine cracks easily treated during normal redecoration. Perhaps isolated slight fracture in building. Cracks in exterior visible upon close inspection.	0.1 to 1.0	0.05 to 0.075
2	Slight	Cracks easily filled. Redecoration probably required. Several slight fractures inside building. Exterior cracks visible; some repainting may be required for weather-tightness. Doors and windows may stick slightly.	1 to 5	0.075 to 0.15
3	Moderate	Cracks may require cutting out and patching. Recurrent cracks can be masked by suitable linings. Tuck pointing and possible replacement of a small amount of exterior brickwork may be required. Doors and windows sticking. Utility services may be interrupted. Weather tightness often impaired.	5 to 15 or a number of cracks > 3	0.15 to 0.3
4	Severe	Extensive repair required involving removal and replacement of walls especially over doors and windows. Window and door frames distorted. Floor slopes noticeably. Walls lean or bulge noticeably. Some loss of bearing in beams. Utility services disrupted.	15 to 25 but also depends on number of cracks	> 0.3
5	Very severe	Major repair required involving partial or complete reconstruction. Beams lose bearing, walls lean badly and require shoring. Windows broken by distortion. Danger of instability.	Usually > 25 but depends on number of cracks	
Note: Please refer LU Civil Engineering - Common Requirements S1050[2].				

Table 2: Building damage classification

4 Input Data

The magnitude and distribution of ground movements and degree of building damage is calculated based on the following input data:

- The Xdisp model coordinates and levels are based on the 3D model (20130212DSPITT Scheme R09)
- Four construction stages are considered in accordance with the proposed programme (November 2013) as illustrated in Figure 1;
- Trough width parameter constant, K=0.5 is used in accordance with WI2300[1].

The input data for the building, tunnels and shaft excavation are summarised in Table 3, Table 4 and Table 5 respectively.

Location	Foundation level (mATD)	Building Height above foundation level (m)	E/G
24 Lombard	108*	38.4	12.5
Note: Where E / G is the ratio of Young's modulus to shear modulus of the deep beam that is to represent the building. *Known level. See reference [9].			

Table 3: Building data

Tunnel Item	Level of axis (mATD)	External diameter (m)	Volume Loss (%)
Running tunnels	83.5	5.4	1.5
Square works adits	75.8 to 95.3	4.1 to 7.8	2.5
Platform enlargement	85.6	7.4 to 11.2	1.5
Escalator barrels	Inclined	8.3 to 8.4	1.5
NL Interchange tunnel	86.2	9.75	1.5
Central Line Connection	Inclined (87.6 to 89.2)	8.6	1.5

Table 4: Tunnel data

Excavation	Excavation Base Level (mATD)
Grout Shaft at King William Street	97
Whole Block Scheme Box excavation	73
Arthur Street Shaft	81

Table 5: Excavation data

The distance of building 24 Lombard Street (B24) relative to Arthur Street Shaft is sufficiently large that this building should not be affected by its construction.

The Xdisp model filenames used to undertake this assessment are:

- B24 - Stage 4
- B24 - Stage 3
- B24 - Stage 2
- B24 - Stage 1

5 Results

5.1 Engineering Assessment

The sections through the building which have been analysed are shown on plan in Figure 3.

Assessment has been undertaken at three intermediate construction stages and at the end of construction when all major elements of the works including shaft and tunnels have been completed. The damage category assigned to the building is based on the construction stage at which the potential impact on the building is most severe.

The maximum settlement and tensile strain calculated for each of the analysis sections at the most onerous intermediate construction stage and at the end of construction are presented in Table 6 and Table 7.

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
B24 (line 1)	<1	<0.001
B24 (line 2)	<1	<0.001

Table 6: Building response at most onerous intermediate stage - Construction Stage 1

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
B24 (line 1)	<1	<0.001
B24 (line 2)	<1	<0.001

Table 7: Building response at end of construction stage

The results of the assessment show that construction Stage 4 is the critical stage for this building where (line 1) experiences the most onerous combined tensile strain. The orientation is shown in Figure 3. The relative position of the building and tunnels along section (line 2) is shown in Figure 4 and (line 1) is shown in Figure 5. The calculated strains are summarised in Table 8.

Line No	Strains in section (Curvature)	Position from start (m)	Length (m)	Average* Horizontal Strain (%)	Maximum Tensile Strains (%)	Damage Category
(line 1)	Hogging	0.0	9.7	<0.001	<0.001	Negligible
Note: * Tensile horizontal strains are +ve. Compressive horizontal strains are –ve.						

Table 8: Section analysed, results for worst case tensile strain

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0. This corresponds to negligible damage in accordance with Table 2.

The maximum settlement of the building at foundation level occurs at end of construction stage 4 which is less than 1mm.

5.2 Heritage and Structural Assessment

Following site inspection, assessment has been made using the scoring methodology set out in Table 9.

Score	Structure (Sensitivity of the structure to ground movements and interaction with adjacent buildings)	Heritage features (Sensitivity to calculated movement of particular features within the building)	Condition (Factors which may affect the sensitivity of structural or heritage features)
0	Masonry buildings with lime mortar and regular openings, not abutted by other buildings, and therefore similar to the buildings on which the original Burland assessment was based.	No particular sensitive features	Good/Fair - not affecting the sensitivity of structural or heritage features
1	Buildings not complying with categories 0 or 2, but still with some sensitive structural features in the zone of settlement e.g.: cantilever stone staircases, long walls without joints or openings, existing cracks where further movements are likely to concentrate, mixed foundations	Brittle finishes, e.g. faience or tight-jointed stonework, which are susceptible to small structural movements and difficult to repair invisibly.	Poor - may change the behaviour of a building in cases of movement. Poor condition of heritage features and finishes. Evidence of previous movement.
2	Buildings which, by their structural form, will tend to concentrate all their movements in one location (e.g.: a long wall without joints and with a single opening).	Finishes which if damaged will have a significant effect on the heritage value of the building, e.g. Delicate frescos, ornate plasterwork ceilings.	Very poor – parlous condition of heritage features and finishes, severe existing damage to structure including evidence of ongoing movement. Essentially buildings where even very small movements could lead to significant damage.

Table 9: Heritage and structural scoring methodology

The results of the heritage assessment carried out for the building are summarised in Table 10.

Sensitivity of the structure
Much of the structure of the building is of new reinforced concrete construction, with only the façade retained from the earlier phases of construction. The available archive drawings from the 1979 works suggest that (at least at basement and ground level) a bay of original beams were retained from the façade to the first column line. The original beams were encased in concrete as part of the new floor slabs. This indicates that no movement joint was provided, so the façade and frame will act together. It is believed that the existing façade sits on its original strip footings, while the new sub-basement was set back from the building perimeter behind a new piled retaining wall.
Score: 0 –The building is robust and the predicted settlement is very small.
Sensitivity of the heritage
24-28 Lombard Street is a Grade II Listed Building, one of a number of large commercial buildings on the same street. Of greatest significance and sensitivity are the masonry facades that contribute most to the character of the surrounding area. The Nicholas Lane elevation is notable for being made up of three different building frontages, two constructed of Portland stone and one of brick. The design quality of the Lombard Street façade, especially the unusual entrance decorated with bronze sculptures and marble lined vestibule is an important element of the aesthetic and architectural significance of the building. The earlier façade of 34-37 Nicholas Lane which is now incorporated into the larger building is highly attractive and contributes to the richness of the architectural ensemble. The masonry joints are between 3mm and 5mm and therefore relatively susceptible to damage resulting from structural movement. The marble lined entrance vestibule is highly decorative and being constructed of thin marble panels with very fine joints would be susceptible to damage resulting from structural movement. Other than this there are no sensitive internal heritage finishes that may be affected.
Score: 0 - Damage to the exterior form and decoration therefore would denigrate the significance of the building. However, the predicted settlement due to tunnelling works is so slight as to render the risk of this negligible.
Sensitivity of the condition
The building as is now appears to be in very good condition. During the site walkover it was not possible to identify any defects that might be exacerbated by settlement. There was no evidence of cracked, deformed or newly repaired masonry.
Score: 0 - The condition of the building in general and the exterior in particular was found to be excellent, with no signs of active movement or unusual disrepair.

Table 10: Heritage and structural assessment

5.3 Total Score

The total score is the summation of the damage category, structural sensitivity, heritage sensitivity and condition sensitivity scores:

The damage category is	0
The structural sensitivity score is	0
The heritage sensitivity score is	0
The condition sensitivity score is	0
The total score for this building is	**0**

6 Conclusion

24-28 Lombard Street is located to the east of the core of the Bank Station Capacity Upgrade tunnelling works, however only the very southern portion of the building, itself of little heritage value, is within the 1mm settlement contour. It is not predicted that the building will suffer any significant ground movement that will damage the heritage finishes and features of the building. Furthermore, the most sensitive area of the building is outside the 1mm settlement contour.

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0 for 24-28 Lombard Street. Specific heritage and structural assessment taking into account the location and extent of settlement and tensile strains highlights the buildings low level of structural and heritage sensitivity to movement. This assessment has determined that the building has a total score of 0.

It is recommended that the building does not require a Stage 3 assessment.

7 References

[1] LU Works Information WI 2300 Ground Movement version 3, 19-07-13.

[2] LU Category 1 Standard: S1050 Civil Engineering - Common Requirements, Issue No. A7, Nov. 2013.

[3] Mair R J, Taylor R N and Bracegirdle A (1993). Subsurface settlement profiles above tunnels in clays. Géotechnique 43, No. 2, pp. 315-320.

[4] Mair R J, Taylor R N and Burland J B (1996). Prediction of ground movements and assessment of risk of building damage due to bored tunnelling. (In: International Conference of Geotechnical Aspects of Underground Construction in Soft Ground, London, pp. 713–718.

[5] LU Guidance Document G0058 Civil Engineering Technical Advice Notes, Issue No. A17, Feb. 2013.

[6] Burland J B (1995). Assessment of risk of damage to buildings due to tunnelling and excavation. Proceedings: 1st International Conference of Earthquake Geotechnical Engineering, IS Tokyo, 1995.

[7] Selemetas.D et al (2005). The response of full scale piles to tunnelling. Geotechnical aspects of underground construction in soft ground (Bakker et al (eds)) pp.763-769.

[8] New B M and Bowers K H (1994). Ground movement model validation at the Heathrow Express trial tunnel. Proc. Tunnelling 1994. IMM, London, pp 301-327

[9] Crowe Kelsey & Partners, 1980. Drawing number 1829/16A Structural G.A. 24 Lombard Street. The Royal Bank of Scotland.

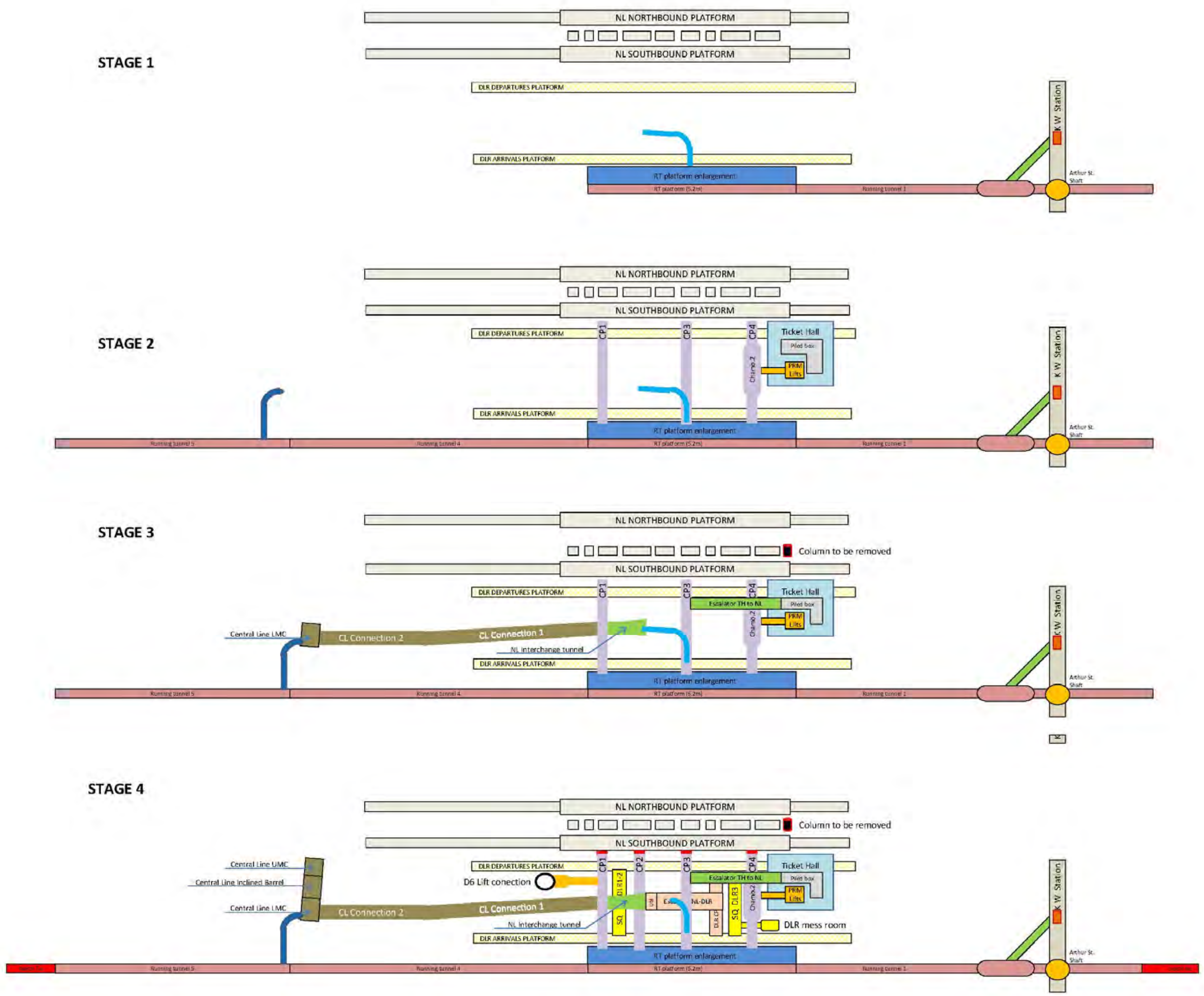

Figure 1: Construction Stage model

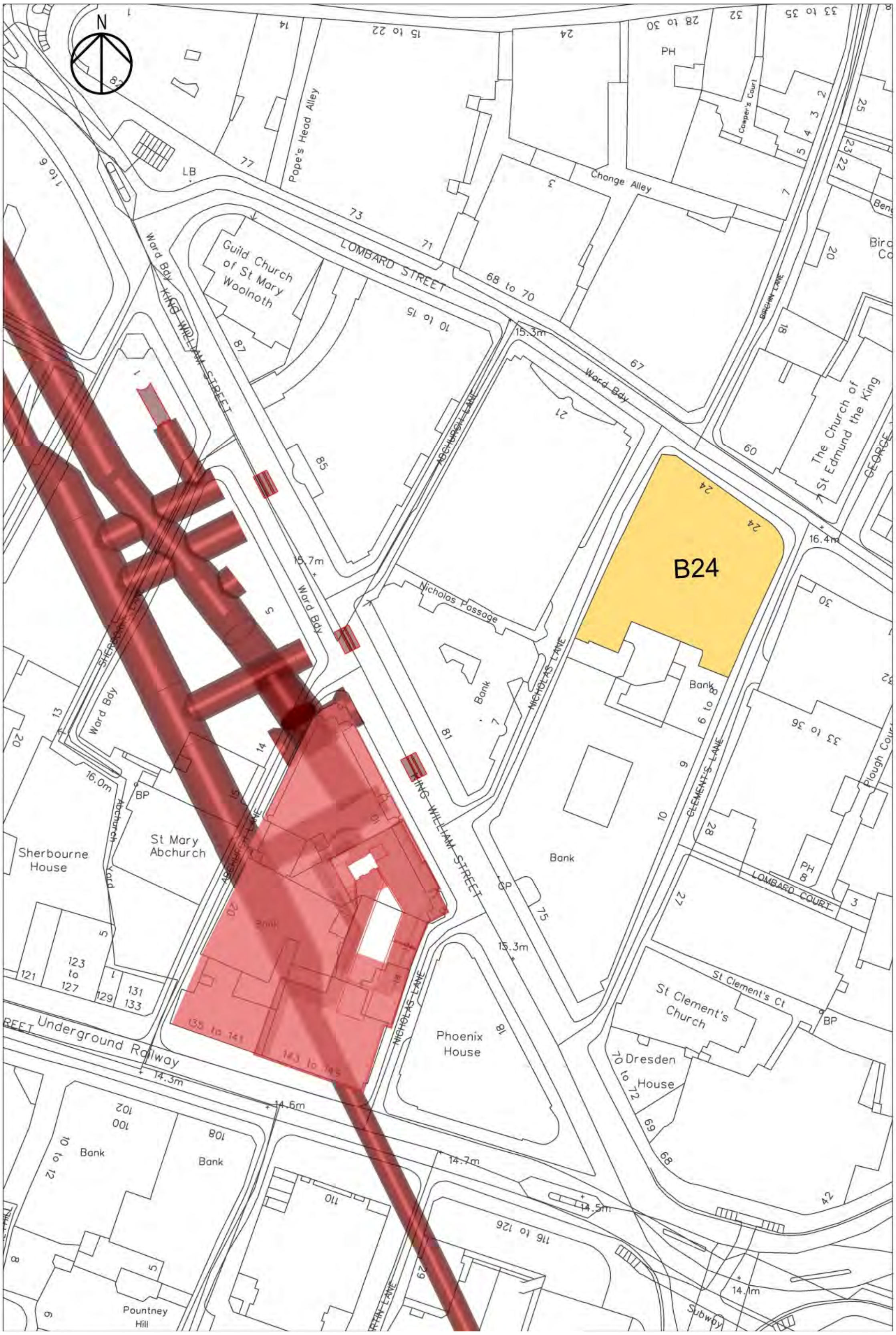

Figure 2: Location plan showing building location in relation to BSCU works

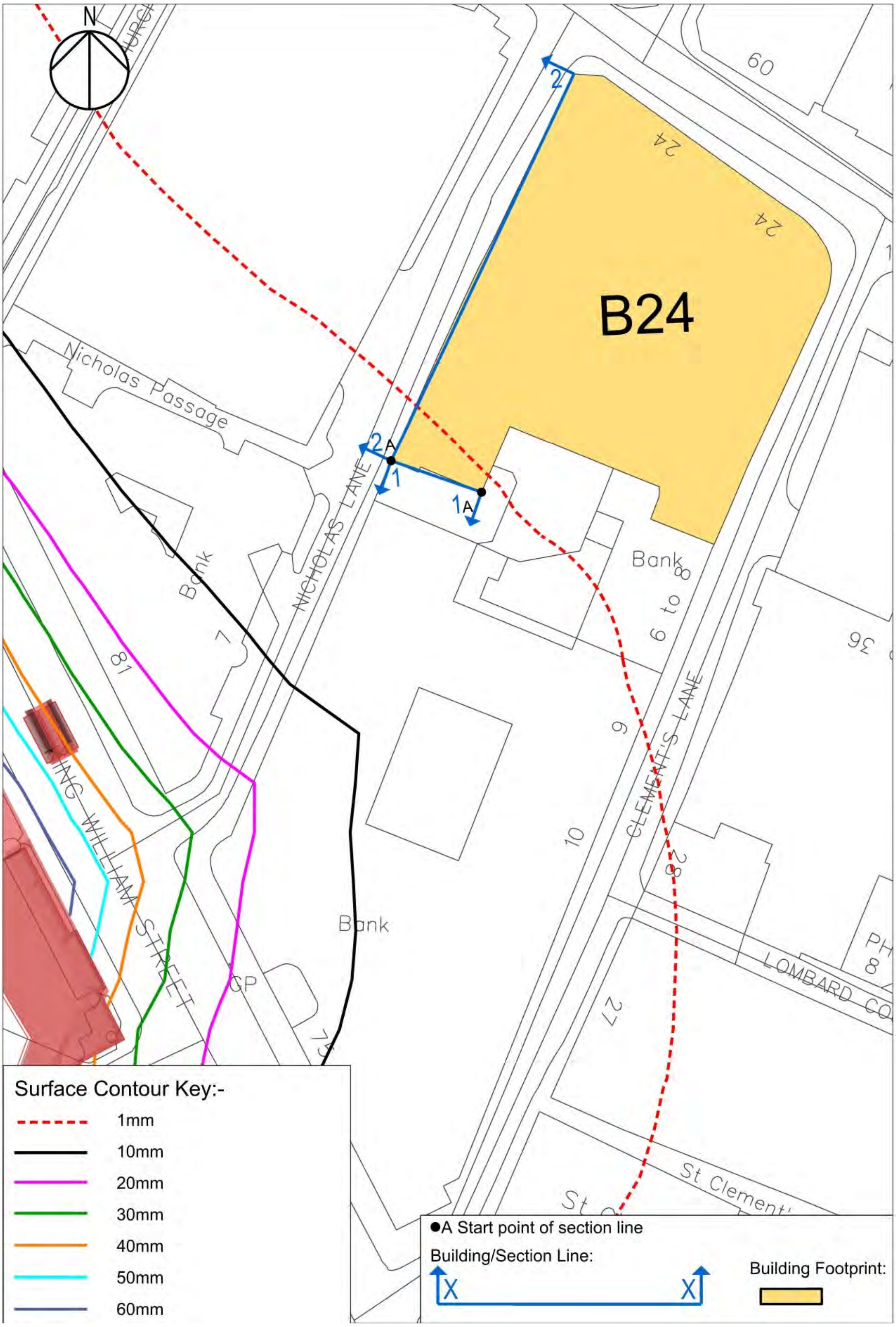

Figure 3: Building location, sections analysed and Settlement Contours at stage of worst case for tensile strains

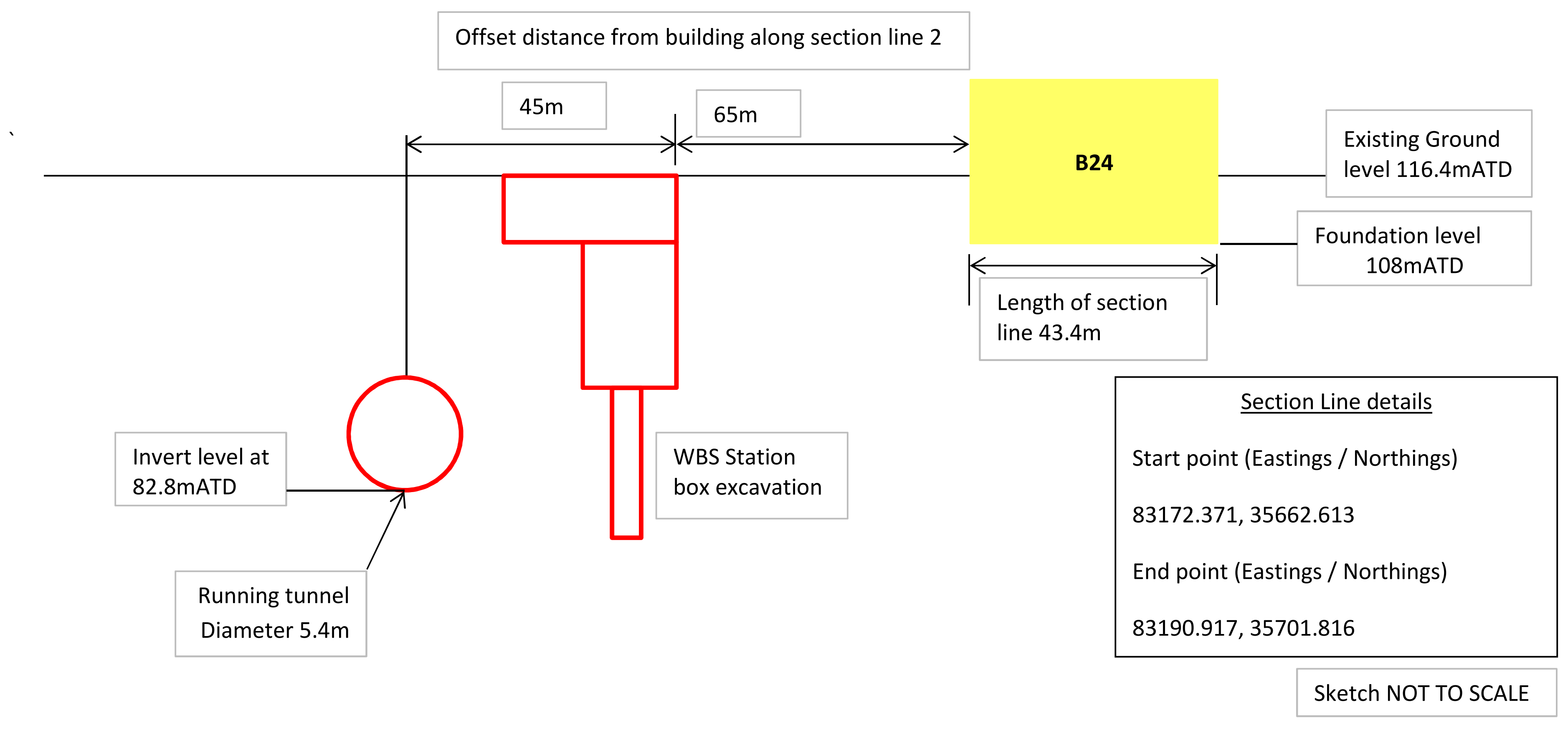

Figure 4: Diagrammatic cross-section of section (line 2) relative to tunnel position

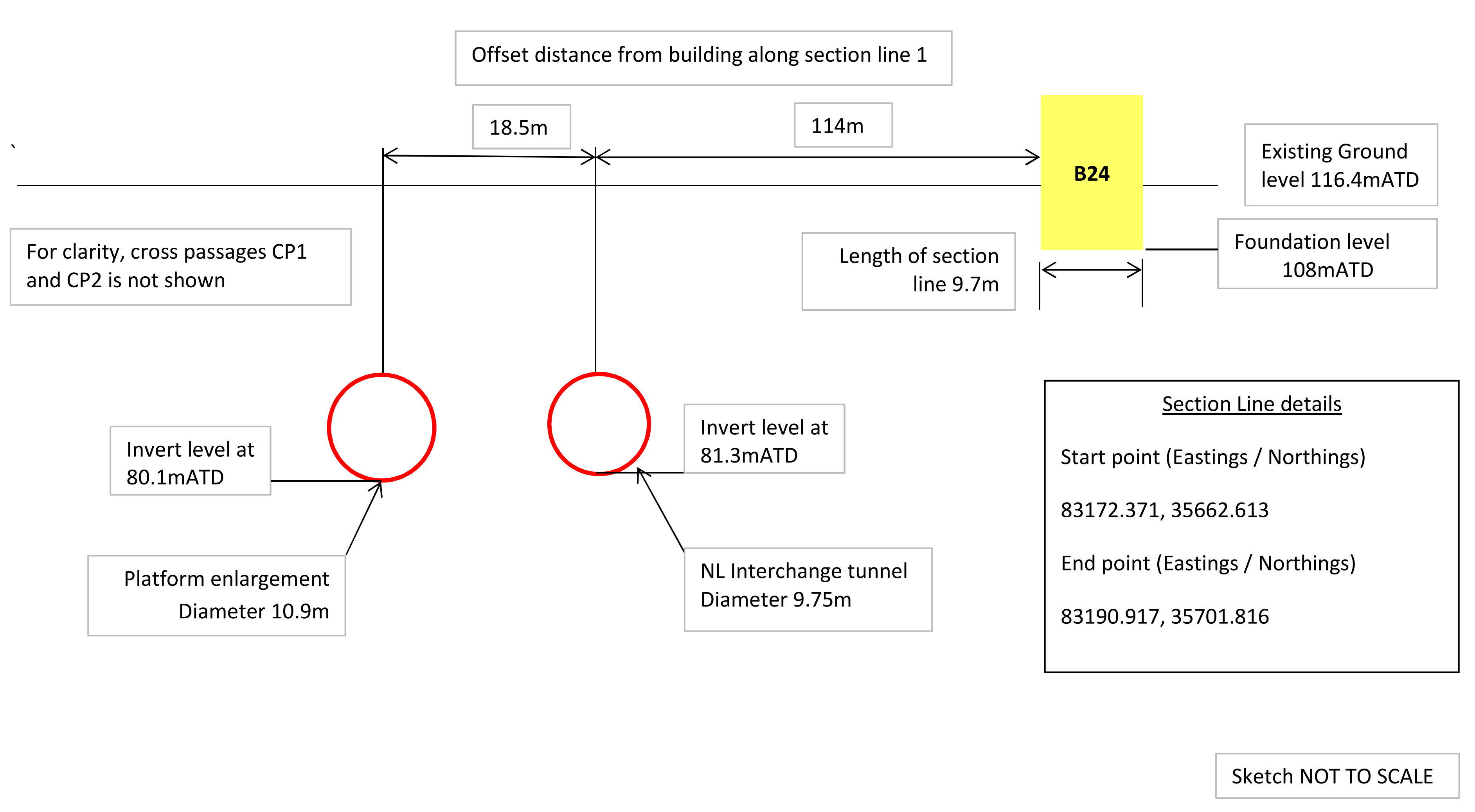

Figure 5: Diagrammatic cross-section of section (line 1) relative to tunnel position

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Bank Station Capacity Upgrade

Building Damage Assessment Report

Building B26

1 Cornhill / 82 Lombard Street

URS-8798-RPT-G-001218

Prepared by:	Lisa Perkins Assistant Geotechnical Engineer	L. Perkins	21/07/14
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Role:	Designer

Document History

Revision	Date	Summary of changes
1.0	March 2014	Issue for Heritage
2.0	April 2014	For Approval
3.0	July 2014	TWAO Issue

For the status of this document, please refer to the Building Damage Assessment Report Register (URS-8798-RGT-001229)

Consultation:

- Ela Palmer — URS Heritage
- Brian Lyons — Dr.Sauer
- Keith Bowers/Neil Moss/Paul Dryden — London Underground
- Olly Newman — Dragados

Contents

FIGURES

TABLES

1 Introduction

This report summarises the results of a Stage 2 damage assessment for 1 Cornhill, 82 Lombard Street.

Stage 2 damage assessments are undertaken for all buildings within the Stage 1 Greenfield ground surface 1mm settlement contour induced by the construction of the Bank Station Capacity Upgrade (BSCU).

The purpose of the assessment is to determine the potential effect the works will have on the building. This report describes the engineering and heritage assessments undertaken for the building and concludes whether mitigation is likely to be needed and if a further (Stage 3) assessment is recommended in order to verify this.

2 The Building

2.1 General Information

General building information used in the assessment has been acquired as part of the structural desktop appraisal. Where data was not available, conservative assumptions were made instead. This information is presented in Table 1.

Category	Building Information
BSCU Reference	B26
Location	Cornhill, Lombard Street
Address	1 Cornhill, 82 Lombard Street
Building Type	Steel framed (assumed)
Construction Age	1905
No. of Storeys	6
Basements	2
Eaves Level (mATD)	130.0
Foundation Type	Steel grillage/concrete raft (assumed)
Ground Level (mATD)	114.0
Listed Grade	II
Note: Levels given are in metres above Tunnel Datum, mATD. Tunnel Datum is 100m below Ordnance Survey Datum at Newlyn.	

Table 1: General building information

A general view of the building exterior is shown in Plate 1. A location plan showing the building in relation to the proposed BSCU works is presented in Figure 2.

Plate 1: General view

2.2 Building Description & Heritage

1 Cornhill is a classical Grade II listed building built in 1905 by Macvicar Anderson as new offices for the Liverpool and London Globe Insurance Company. It is lying on an arrow like plot including No 82 Lombard Street. The exterior is fully cladded with Portland stone with rounded corner supporting a lead-covered dome at the intersection of Cornhill and Lombard Street. Originally built over 5 storeys plus a roof mansard level and 2 basement levels, it was laterally extended in 1978/9 on Cornhill to provide an additional 2 bays in an easterly direction, together with the reconstruction of 79/82 Lombard Street. The buildings have a flat roof with various housings, enclosing plant and lift motor rooms. Where the extended section of façade on Cornhill abuts the original building, there is a vertical joint signifying the different periods, types of construction and foundations used. The street elevations are also

jointed where they meet the adjoining buildings, both of which are of similar appearance and style.

The property is currently in use as serviced offices and meeting rooms which occupy the majority of floor areas throughout the buildings, other than the lower basement level, which houses service areas and plant serving the property. The office areas are fully fitted out in pristine condition with lightweight partitions, false ceilings and carpeted raised pedestal floors. Leading from the ground floor reception in Cornhill is the rotunda, which provides a lounge area with perimeter balcony and high ceiling, marble clad columns, walls and faience ceramics to ceiling. Above this level is a meeting room with fine plaster finishes and the lead covered domed roof. A fine stone torsion staircase leads up from the ground floor lounge to the first floor balcony level above. The central enclosed area houses 2 x lifts, toilets and the main concrete staircase rising fully through the building, with a secondary concrete escape staircase in the south-east corner.

The construction appears to be steel framed with suspended concrete floors, possibly steel filler joist, as appears likely from our inspection of the directly plastered soffits in the lower basement level. The lower basement floor is concrete, with an apparent mix of mass concrete and brickwork retaining walls in both basement levels. The lower basement level has vaulted arrangements along the perimeter of both Cornhill and Lombard Street providing air intakes/exhausts into the boiler room and storage areas. Previously noted, the upper basement level has a mix of brick arched and steel filler joisted vaults along the street perimeters with pavement light. The vaults are generally damp and some Sika rendered and while the brick vaulting is in good condition, those with steel filler joist roofs are showing serious corrosion in the steelwork. Foundation type is unknown, but is likely to be a steel grillage and concrete raft arrangement.

3 Methodology

This assessment is undertaken in accordance with LU Works Information WI2300[1] and LU Civil Engineering - Common Requirements S1050[2].

The analysis methodology applies to ground-bearing buildings which will be affected by ground movements resulting from the construction of the BSCU. The engineering assessment calculates the potential impact of ground movements and assigns a damage category to the building based on a numeric scale. Additionally, for listed buildings, a heritage assessment is carried out which considers the sensitivity of the structure and the sensitivity of its particular features; a heritage sensitivity score is assigned. The heritage sensitivity score is added to the damage category to obtain the total score. If the total score is 3 or more, a more detailed Stage 3 assessment is triggered.

Oasys Xdisp is used to analyse the Greenfield ground movement in terms of settlement and horizontal displacement. Subsurface tunnelling induced ground movement profiles are determined in accordance with the methodology described by Mair et al[3 & 4].

Movements resulting from the Whole Block Scheme (WBS) and shaft excavations have been calculated using LU Guidance Document G0058[5].

The building is modelled as a simple elastic beam which is conservatively assumed to follow the Greenfield ground displacements. The beam is divided into hogging and sagging segments. The tensile strains within each segment are calculated based on the distortion associated with differential settlement (which is characterised by deflection ratio) and the distortion associated with differential horizontal displacement (characterised by horizontal strain).

Xdisp provides a method for calculating the maximum tensile strain within the building superstructure associated with these movements, in accordance with the assessment methodology described by Mair et al [4]. This strain is used to determine the damage category based on the classification system proposed by Burland[6] and in accordance with LU Civil Engineering - Common Requirements S1050[2]. The categories are presented in Table 2.

Damage Category	Description of Degree of Damage	Description of Typical Damage and likely forms of Repair for Typical Masonry Buildings.	Approx. Crack Width (mm)	Max. Tensile Strain %
0	Negligible	Hairline cracks.		< 0.05
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2	Slight	Cracks easily filled. Redecoration probably required. Several slight fractures inside building. Exterior cracks visible; some repainting may be required for weather-tightness. Doors and windows may stick slightly.	1 to 5	0.075 to 0.15
3	Moderate	Cracks may require cutting out and patching. Recurrent cracks can be masked by suitable linings. Tuck pointing and possible replacement of a small amount of exterior brickwork may be required. Doors and windows sticking. Utility services may be interrupted. Weather tightness often impaired.	5 to 15 or a number of cracks > 3	0.15 to 0.3
4	Severe	Extensive repair required involving removal and replacement of walls especially over doors and windows. Window and door frames distorted. Floor slopes noticeably. Walls lean or bulge noticeably. Some loss of bearing in beams. Utility services disrupted.	15 to 25 but also depends on number of cracks	> 0.3
5	Very severe	Major repair required involving partial or complete reconstruction. Beams lose bearing, walls lean badly and require shoring. Windows broken by distortion. Danger of instability.	Usually > 25 but depends on number of cracks	
Note: Please refer LU Civil Engineering - Common Requirements S1050[2].				

Table 2: Building damage classification

4 Input Data

The magnitude and distribution of ground movements and degree of building damage is calculated based on the following input data:

- The Xdisp model coordinates and levels are based on the 3D model (20130212DSPITT Scheme R09);
- Four construction stages are considered in accordance with the proposed programme (November 2013) as illustrated in Figure 1;
- Trough width parameter constant, K=0.5 is used in accordance with WI2300[1].

The input data for the building, tunnels and shaft excavation are summarised in Table 3, Table 4 and Table 5 respectively.

Location	Foundation level (mATD)	Building Height above foundation level (m)	E/G
1 Cornhill, 82 Lombard Street	106.5*	23.5	2.6
Note: Where E / G is the ratio of Young's modulus to shear modulus of the deep beam that is to represent the building. * Assumed level, 1.5m thick slab beneath floor level.			

Table 3: Building data

Tunnel Item	Level of axis (mATD)	External diameter (m)	Volume Loss (%)
Running tunnels	83.5	5.4	1.5
Square works adits	75.8 to 95.3	4.1 to 7.8	2.5
Platform enlargement	85.6	7.4 to 11.2	1.5
Escalator barrels	Inclined	8.3 to 8.4	1.5
Central Line Connection	Inclined (87.6 to 89.2)	8.6	1.5

Table 4: Tunnel data

Excavation	Excavation Base Level (mATD)
Grout Shaft at King William Street	97
Whole Block Scheme Box excavation	73
Arthur Street Shaft	81

Table 5: Excavation data

The Xdisp model filenames used to undertake this assessment are:

- B26 - Stage 4
- B26 - Stage 3
- B26 - Stage 2
- B26 - Stage 1

The distance of building 1 Cornhill, 82 Lombard Street (B26) relative to the excavation elements listed in Table 5 is reasonably large so this building is unlikely to be affected by their construction.

5 Results

5.1 Engineering Assessment

The sections through the building which have been analysed are shown on plan in Figure 3.

Assessment has been undertaken at three intermediate construction stages and at the end of construction when all major elements of the works including shaft and tunnels have been completed. The damage category assigned to the building is based on the construction stage at which the potential impact on the building is most severe.

The maximum settlement and tensile strain calculated for each of the analysis sections at the most onerous intermediate construction stage and at the end of construction are presented in Table 6 and Table 7.

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
B26 (line 1)	<1	<0.001
B26 (line 2)	<1	<0.001
B26 (line 3)	<1	<0.001

Table 6: Building response at most onerous intermediate stage - Construction Stage 2

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
B26 (line 1)	<1	0.001
B26 (line 2)	<1	0.001
B26 (line 3)	<1	<0.001

Table 7: Building response at end of construction stage

The results of the assessment show construction Stage 4 is the critical stage for this building where line 1 experiences the most onerous combined tensile strain. The orientation of this building is shown in Figure 2. The relative position of the building and tunnels along section line 1 is shown in Figure 4. The calculated strains are summarised in Table 8.

Strains in section (Curvature)	Position from start (m)	Length (m)	Average* Horizontal Strain (%)	Maximum Tensile Strains (%)	Damage Category
Hogging	0.0	18.9	0.001	0.001	Negligible
Sagging	18.9	2.5	<0.001	<0.001	Negligible
Hogging	21.3	2.5	<0.001	<0.001	Negligible
Note: * Tensile horizontal strains are +ve. Compressive horizontal strains are –ve.					

Table 8: Section analysed, results for worst case tensile strain

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0. This corresponds to negligible damage in accordance with Table 2.

The maximum settlement of the building at foundation level at the end of construction is less than 1mm.

5.2 Heritage Assessment

Following site inspection, assessment has been made using the following scoring methodology as set out in Table 9.

Score	STRUCTURE Sensitivity of the structure to ground movements and interaction with adjacent buildings	HERITAGE FEATURES Sensitivity to calculated movement of particular features within the building	CONDITION Factors which may affect the sensitivity of structural or heritage features
0	Masonry buildings with lime mortar and regular openings, not abutted by other buildings, and therefore similar to the buildings on which the original Burland assessment was based.	No particular sensitive features	Good/Fair - not affecting the sensitivity of structural or heritage features
1	Buildings not complying with categories 0 or 2, but still with some sensitive structural features in the zone of settlement e.g.: cantilever stone staircases, long walls without joints or openings, existing cracks where further movements are likely to concentrate, mixed foundations	Brittle finishes, e.g. faience or tight-jointed stonework, which are susceptible to small structural movements and difficult to repair invisibly.	Poor - may change the behaviour of a building in cases of movement. Poor condition of heritage features and finishes. Evidence of previous movement.
2	Buildings which, by their structural form, will tend to concentrate all their movements in one location (e.g.: a long wall without joints and with a single opening).	Finishes which if damaged will have a significant effect on the heritage value of the building, e.g. Delicate frescos, ornate plasterwork ceilings.	Very poor – parlous condition of heritage features and finishes, severe existing damage to structure including evidence of ongoing movement. Essentially buildings where even very small movements could lead to significant damage.

Table 9: Heritage and structural scoring methodology

The results of the heritage assessment carried out for the building are summarised in Table 10. The sensitivity score of the structure and that of its particular features and finishes are presented separately.

SENSITIVITY OF THE STRUCTURE
Maximum settlement is predicted to be in the order of 0.3mm and is therefore considered unlikely to cause a significant problem to the structure of this building. While the structure should be unaffected, even small variations in foundation settlement could result in minor damage to the external stonework and internal marble finishes of the rotunda. Of particular note is the fine stone torsion staircase between the ground and first floor balcony levels that leads out into the rotunda. The staircase will be especially sensitive to even small movements in the supporting walls and floor, which could lead to structural damage and destabilisation of the structure. The vertical jointing between the facades of the original building and the later extension could open up through differential foundation movement, due to the likely different forms of foundation. The extensions are most likely to be piled, although possibly a concrete raft.
Score: 1 - The predicted movements would potentially impact the existing stairs and the pavement vaults.
SENSITIVITY OF THE HERITAGE
The grade II listing reflects the building's architectural and historical significance which is mainly surviving through its original elevations, the marble cladded entrance hall, the stair to mezzanine, mezzanine floor, the stair to rear of lift block, and the circular room under the dome on the fourth floor. The most vulnerable features to the exterior appear to be the fine jointed stone work, mouldings and decorations to architraves and parapets, some local cracking that may be consistent with corrosion of steelwork in façades. To interiors are the marble and ceramic finishes of the round hall, in particular marble columns, wall linings, cornices, balustrades and floors, together with faience ceilings and the plasterwork of the dome room to fourth floor. Settlement is predicted to be in the order of 0.3mm and is unlikely to have a noticeable effect on the structure or finishes, although differential settlement between the original and later extension is possible due to likely foundation differences, and could lead to a minor opening of existing joints between the external stone facades.

Score: 0 - The heritage features are not sensitive to the levels of predicted movement
SENSITIVITY OF THE CONDITION
The property has been fully fitted out to a very high standard for the provision of serviced offices, meeting rooms and venues, and it is in immaculate condition throughout. Little of the structure is visible except in the plainly finished and functional lower basement level, and within the upper basement level pavement vaults. The only clear defects observed were in the pavement vaults where general dampness is a problem, in particular causing serious corrosion in the filler joists and supporting steel beams. All the stonework is in generally sound condition, although some fine cracking is evident in a few locations. Externally the glazed brickwork to the light well and the stone facades are in very good condition, although some fine cracking was noted in a small number of locations in the stonework.
Score: 1 - The localised, defective conditions of steel work observed in the basement vaults could be affected by minor differential movement.

Table 10: Heritage assessment

5.3 Total Score

The total score is the summation of the damage category, structural sensitivity, heritage sensitivity and condition sensitivity scores:

The damage category is 0

The structural sensitivity score is 1

The heritage sensitivity score is 0

The condition sensitivity score is 1

The total score for this building is 2

6 Conclusion

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0 for 1 Cornhill. However, specific heritage and structural assessment taking into account the location and extent of settlement and tensile strains highlights the buildings high level of structural and heritage sensitivity to movement. This assessment has determined that the building has a total score of 2.

This Stage 2 assessment highlights the relevant combined level of structural, heritage and condition sensitivity to the predictive movement, but concludes that the predicted settlement is unlikely to have an impact on the structure, heritage features and fine finishes.

It is recommended that the building does not require a Stage 3 assessment.

7 References

[1] LU Works Information WI 2300 Ground Movement version 3, 19-07-13.

[2] LU Category 1 Standard: S1050 Civil Engineering - Common Requirements, Issue No. A7, Nov. 2013.

[3] Mair R J, Taylor R N and Bracegirdle A (1993). Subsurface settlement profiles above tunnels in clays. Géotechnique 43, No. 2, pp. 315-320.

[4] Mair R J, Taylor R N and Burland J B (1996). Prediction of ground movements and assessment of risk of building damage due to bored tunnelling. (In: International Conference of Geotechnical Aspects of Underground Construction in Soft Ground, London, pp. 713–718.

[5] LU Guidance Document G0058 Civil Engineering Technical Advice Notes, Issue No. A17, Feb. 2013.

[6] Burland J B (1995). Assessment of risk of damage to buildings due to tunnelling and excavation. Proceedings: 1st International Conference of Earthquake Geotechnical Engineering, IS Tokyo, 1995.

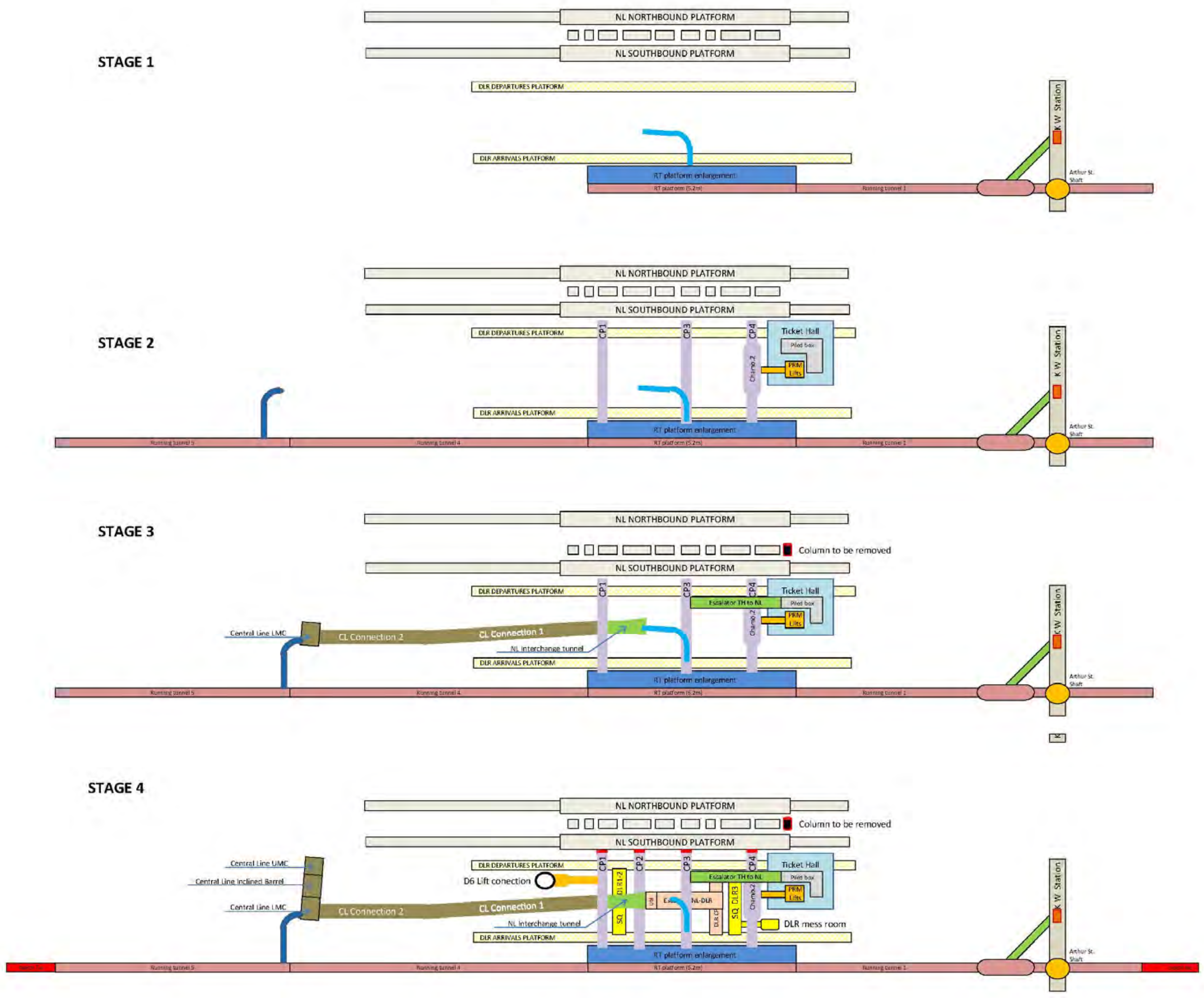

Figure 1: Construction Stage model

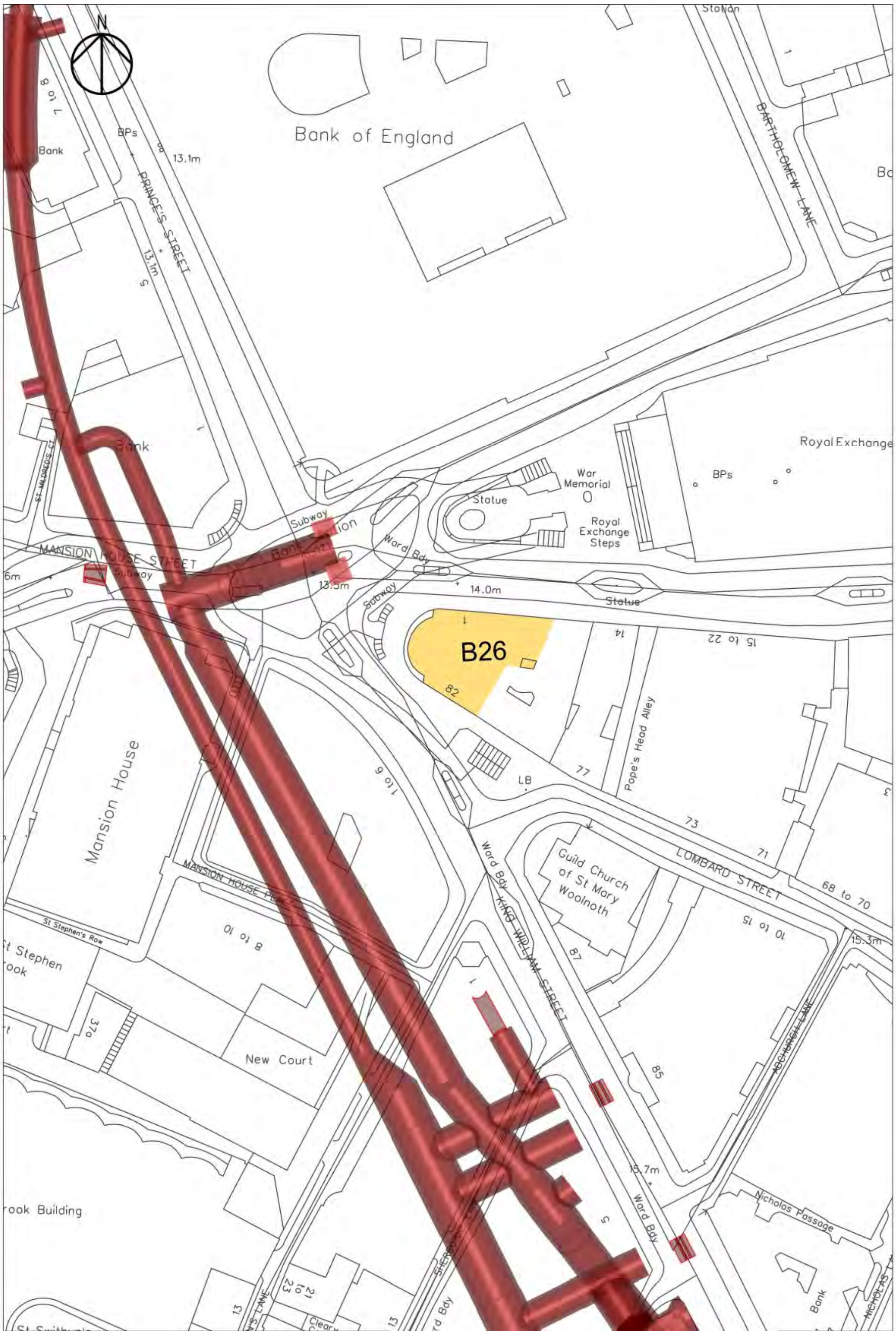

Figure 2: Location plan showing building location in relation to BSCU works

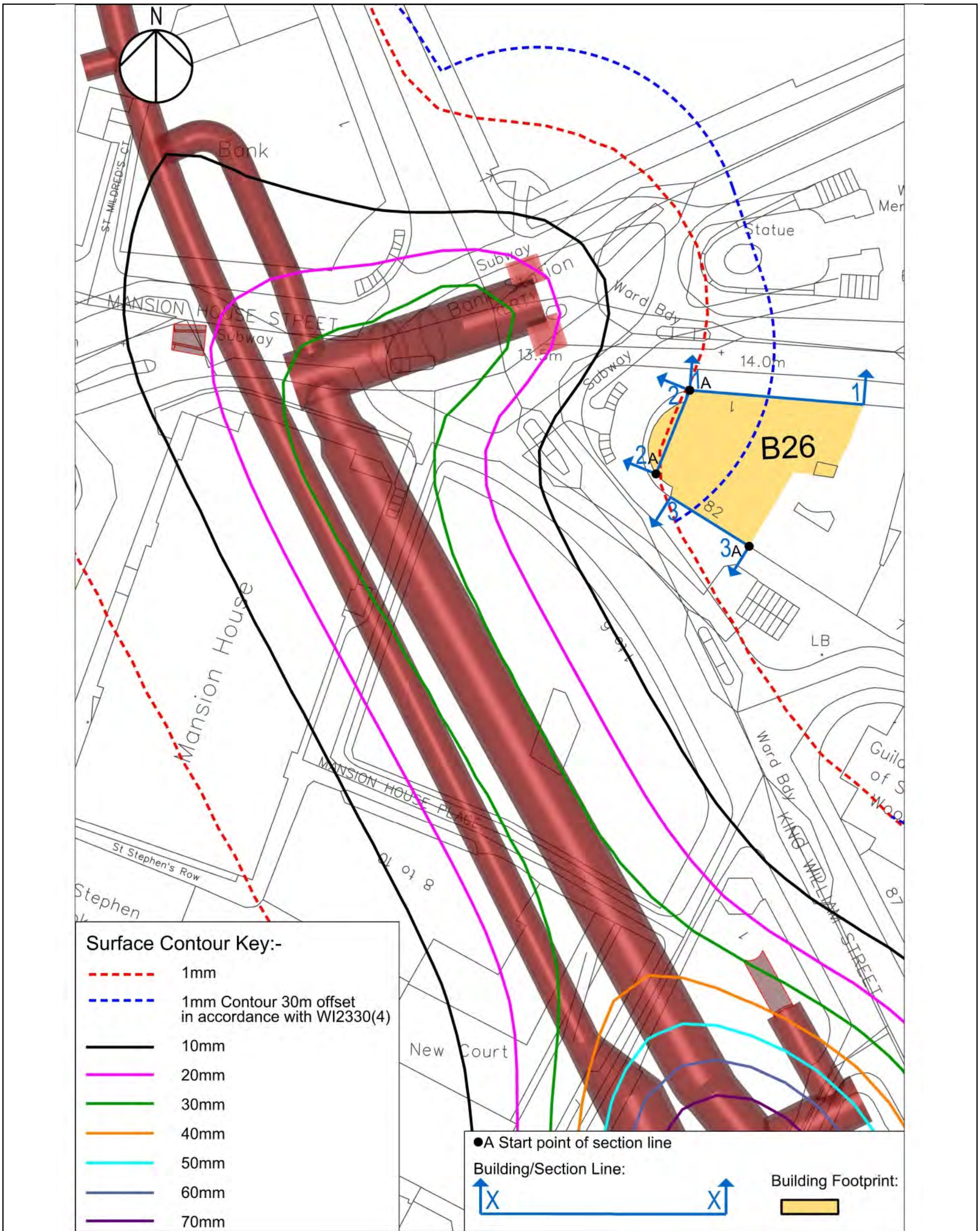

Figure 3: Building location, sections analysed and Settlement Contours at stage of worst case for tensile strains

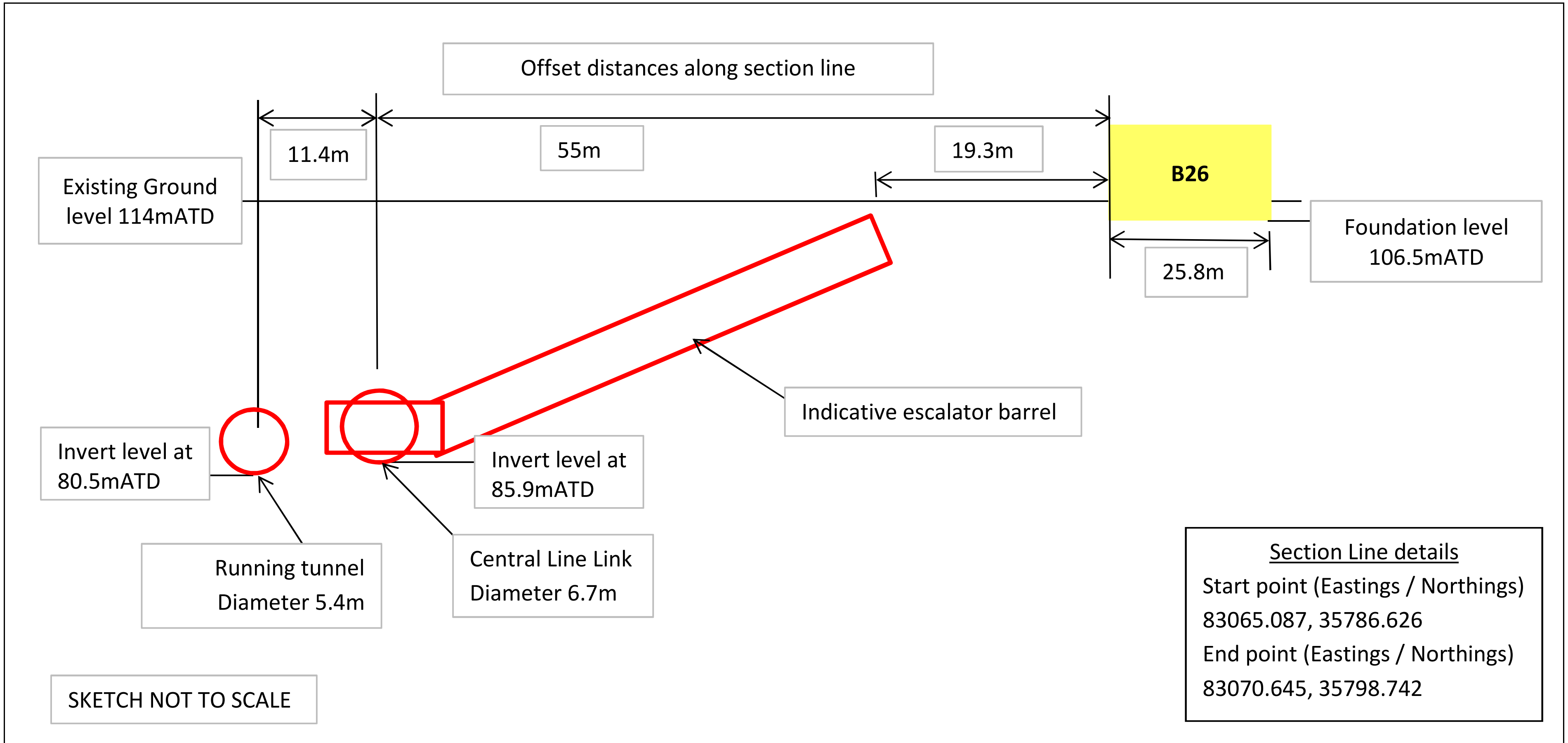

Figure 4: Diagrammatic cross-section of section (line 1) relative to tunnel position

LUL Bank Project Office
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Bank Station Capacity Upgrade

Building Damage Assessment Report

Building B29

Duke of Wellington Statue

URS-8798-RPT-G-001220

Prepared by:	Lisa Perkins Assistant Geotechnical Engineer	[signature]	18/07/14
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Document History

Revision	Date	Summary of changes
1.0	March 2014	Issue for Heritage
2.0	April 2014	For Approval
3.0	July 2014	TWAO Issue

For the status of this document, please refer to the Building Damage Assessment Report Register (URS-8798-RGT-001229)

Consultation:

• Ela Palmer	URS Heritage
• Brian Lyons	Dr.Sauer
• Keith Bowers/Neil Moss/Paul Dryden	London Underground
• Olly Newman	Dragados

Contents

FIGURES

TABLES

1 Introduction

This report summarises the results of a Stage 2 damage assessment for Duke of Wellington Statue.

Stage 2 damage assessment for the statue was undertaken as its location fell within the Greenfield ground surface 1mm settlement contour induced by the construction of the Bank Station Capacity Upgrade (BSCU).

The purpose of the assessment is to determine the potential effect the works will have on the statue. This report describes the updated engineering assessments undertaken for the statue and concludes whether mitigation is likely to be needed and if a further (Stage 3) assessment is recommended in order to verify this.

2 The Building

2.1 General Information

General information used in the assessment has been acquired as part of the structural desktop appraisal. Where data was not available, conservative assumptions were made instead. This information is presented in Table 1.

Category	Building Information
BSCU Reference	B29
Location	Duke of Wellington Statue
Address	Outside front of Royal Exchange building
Building Type	N/A
Construction Age	Unknown
No. of Storeys	N/A
Basements	N/A
Height (m)	Assumed 4m
Foundation Type	Monolithic base
Ground Level (mATD)	114.0
Listed Grade	II
Note: Levels given are in metres above Tunnel Datum, m ATD. Tunnel Datum is 100m below Ordnance Survey Datum at Newlyn	

Table 1: General building information

A general view of the statue is shown in Plate 1. A location plan showing the statue plinth in relation to the proposed BSCU works is presented in Figure 2.

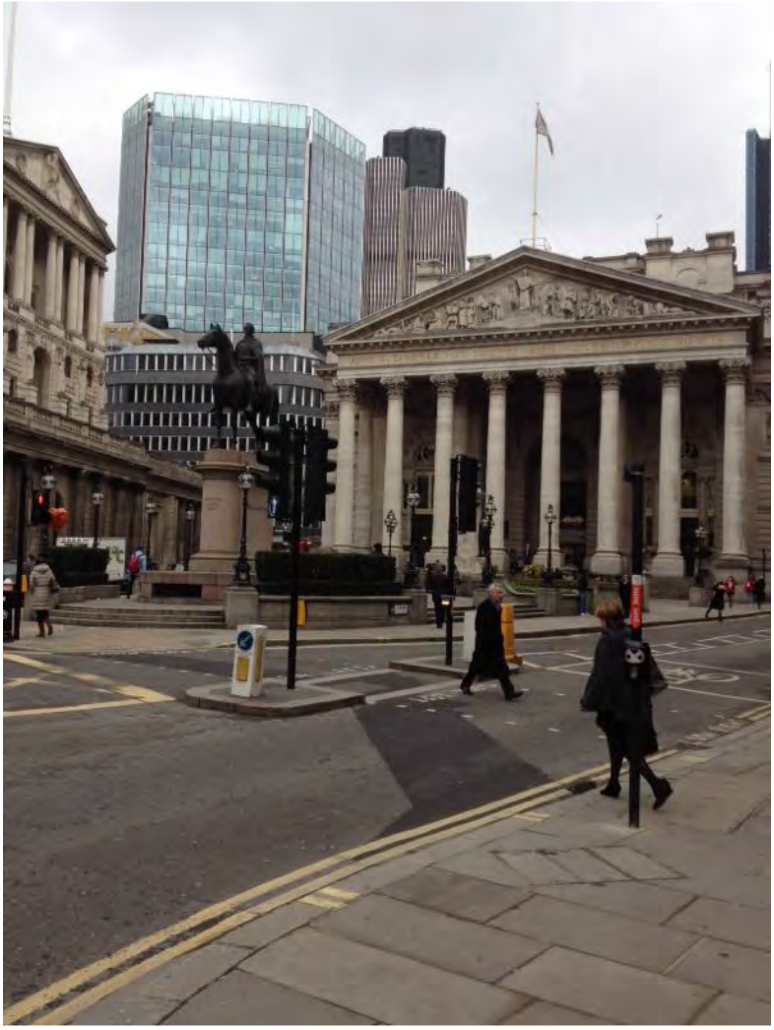

Plate 1: General view

2.2 Building Description & Heritage

The Duke of Wellington Statue is situated in front of Royal Exchange, at the crossing of Threadneedle Street and Cornhill. A shallow foundation for the statue is assumed although in reality it sits on top of the LU Bank Station Bull Ring structure.

3 Methodology

The building damage assessment is undertaken in accordance with LU Works Information WI2300[1] and LU Civil Engineering- Common Requirements S1050[2].

The analysis methodology applies to Duke of Wellington statue which will be affected by ground movements resulting from the construction of the BSCU. The engineering assessment calculates the potential impact of ground movements to the statue based on a numeric scale. Additionally, where applicable, a heritage assessment is carried out which considers the sensitivity of the statue and the sensitivity of its particular features; a heritage sensitivity score is assigned. The heritage sensitivity score is added to the damage category to obtain the total score. If the total score is 3 or more, a more detailed Stage 3 assessment is triggered.

Oasys Xdisp is used to analyse the Greenfield ground movement in terms of settlement and horizontal displacement. Subsurface tunnelling induced ground movement profiles are determined in accordance with the methodology described by Mair et al[3 & 4].

Since this statue is a solid item, most likely founded on a monolithic raft internal strains will, realistically, not be correct. The overall tilt will be assessed instead.

As the statue is idealised as a building, it is modelled as a simple elastic beam which is conservatively assumed to follow the Greenfield ground displacements.

Movements resulting from the Whole Block Scheme (WBS) and shaft excavations have been calculated using LU Guidance Document G0058[5].

4 Input Data

The magnitude and distribution of ground movements and degree of building damage is calculated based on the following input data:

- The Xdisp model coordinates and levels are based on the 3D model (20130212DSPITT Scheme R09);
- Four construction stages are considered in accordance with the proposed programme (November 2013) as illustrated in Figure 1;
- Trough width parameter constant, K=0.5 is used in accordance with WI2300[1].

The input data for the building, tunnels and shaft excavation are summarised in Table 2, Table 3 and Table 4 respectively.

Location	Foundation level (mATD)	Height above foundation level (m)	E/G
Duke of Wellington Statue	114.0*	4	2.6
Note: Where E / G is the ratio of Young's modulus to shear modulus of the deep beam that is to represent the building. * Assumed level			

Table 2: Building data

Tunnel Item	Level of axis (mATD)	External diameter (m)	Volume Loss (%)
Running tunnels	83.5	5.4	1.5
Square works adits	75.8 to 95.3	4.1 to 7.8	2.5
Platform enlargement	85.6	7.4 to 11.2	1.5
Escalator barrels	Inclined	8.3 to 8.4	1.5
Central Line Connection	Inclined (87.6 to 89.2)	8.6	1.5

Table 3: Tunnel data

Excavation	Excavation Base Level (mATD)
Grout Shaft at King William Street	97
Whole Block Scheme Box excavation	73
Arthur Street Shaft	81

Table 4: Excavation data

The distance of the statue relative to the excavation elements listed in Table 4 is sufficiently large that the statue should not be affected by their construction.

The Xdisp model filenames used to undertake this assessment are:

- B29 - Stage 4
- B29 - Stage 3
- B29 - Stage 2
- B29 - Stage 1

5 Results

5.1 Engineering Assessment

The sections through the statue which have been analysed are shown on plan in Figure 3.

Assessment has been undertaken at three intermediate construction stages and at the end of construction when all major elements of the works including shaft and tunnels have been completed. The differential settlement or tilt to the statue is based on the construction stage at which the potential impact on the statue is most severe.

The maximum settlement calculated for the analysis section at the most onerous intermediate construction stage and at the end of construction is presented in Table 5 and Table 6.

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
B29 (line 1)	<1	N/A

Table 5: Building response at most onerous intermediate stage - Construction Stage 2

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
B29 (line 1)	<1	N/A

Table 6: Building response at end of construction stage

The line 1 orientation relative to the statue is shown in Figure 3. The vertical and horizontal ground movements along the section of the statue are shown in Figure 4. The relative position of the statue and tunnels along section line 1 is shown in Figure 5.

The Stage 2 engineering assessment has predicted that the maximum settlement of the statue at the end of construction is less than 1mm. The differential settlement is very small, also less than 1mm and as a result, the tilt is considered insignificant to the statue.

5.2 Heritage Assessment

Following site inspection, assessment has been made using the following scoring methodology as set out in Table 7.

Score	STRUCTURE Sensitivity of the structure to ground movements and interaction with adjacent buildings	HERITAGE FEATURES Sensitivity to calculated movement of particular features within the building	CONDITION Factors which may affect the sensitivity of structural or heritage features
0	Masonry buildings with lime mortar and regular openings, not abutted by other buildings, and therefore similar to the buildings on which the original Burland assessment was based.	No particular sensitive features	Good/Fair - not affecting the sensitivity of structural or heritage features
1	Buildings not complying with categories 0 or 2, but still with some sensitive structural features in the zone of settlement e.g.: cantilever stone staircases, long walls without joints or openings, existing cracks where further movements are likely to concentrate, mixed foundations	Brittle finishes, e.g. faience or tight-jointed stonework, which are susceptible to small structural movements and difficult to repair invisibly.	Poor - may change the behaviour of a building in cases of movement. Poor condition of heritage features and finishes. Evidence of previous movement.
2	Buildings which, by their structural form, will tend to concentrate all their movements in one location (e.g.: a long wall without joints and with a single opening).	Finishes which if damaged will have a significant effect on the heritage value of the building, e.g. Delicate frescos, ornate plasterwork ceilings.	Very poor – parlous condition of heritage features and finishes, severe existing damage to structure including evidence of ongoing movement. Essentially buildings where even very small movements could lead to significant damage.

Table 7: Heritage and structural assessment

The results of the heritage assessment carried out for the building are summarised in Table 8.

SENSITIVITY OF THE STRUCTURE
The statue's plinth incorporates ventilation from the existing underground station below and is supported on the "roof" of the station. It is located on the predicted settlement zone. It is not considered structurally sensitive given the very small predicated movement and the nature of its "foundations".
Score: 0 - No particular structural sensitivities are thought to be present.
SENSITIVITY OF THE HERITAGE
The statue itself is not vulnerable to the levels of predicted movement. Its plinth, more modern, is of heritage interest, but is also not sensitive to the predicted settlements.
Score: 0 – No heritage sensitivities to the predicted settlement
SENSITIVITY OF THE CONDITION
The statue and its plinth are in good condition.
Score: 0 – No sensitivities relating to condition

Table 8: Heritage and structural assessment

5.3 Total Score

The total score is the summation of the damage category, structural sensitivity, heritage sensitivity and condition sensitivity scores:

The damage category is 0

The structural sensitivity score is 0

The heritage sensitivity score is 0

The condition sensitivity score is 0

The total score for this building is 0

6 Conclusion

The use of maximum tensile strain to categorize the damage category of this statue is inappropriate. However, reviewing the potential negligible tilt resulting from differential settlement of the statue's plinth, the damage category is considered to be negligible. Specific heritage and structural assessment has determined a low level of structural and heritage sensitivity to the predicted settlement. This assessment has determined that the building has a total score of 0.

It is recommended that the structure does not require a Stage 3 assessment.

7 References

[1] LU Works Information WI 2300 Ground Movement version 3, 19-07-13.

[2] LU Category 1 Standard: S1050 Civil Engineering - Common Requirements, Issue No. A7, Nov. 2013.

[3] Mair R J, Taylor R N and Bracegirdle A (1993). Subsurface settlement profiles above tunnels in clays. Géotechnique 43, No. 2, pp. 315-320.

[4] Mair R J, Taylor R N and Burland J B (1996). Prediction of ground movements and assessment of risk of building damage due to bored tunnelling. (In: International Conference of Geotechnical Aspects of Underground Construction in Soft Ground, London, pp. 713–718.

[5] LU Guidance Document G0058 Civil Engineering Technical Advice Notes, Issue No. A17, Feb. 2013.

[6] Burland J B (1995). Assessment of risk of damage to buildings due to tunnelling and excavation. Proceedings: 1st International Conference of Earthquake Geotechnical Engineering, IS Tokyo, 1995.

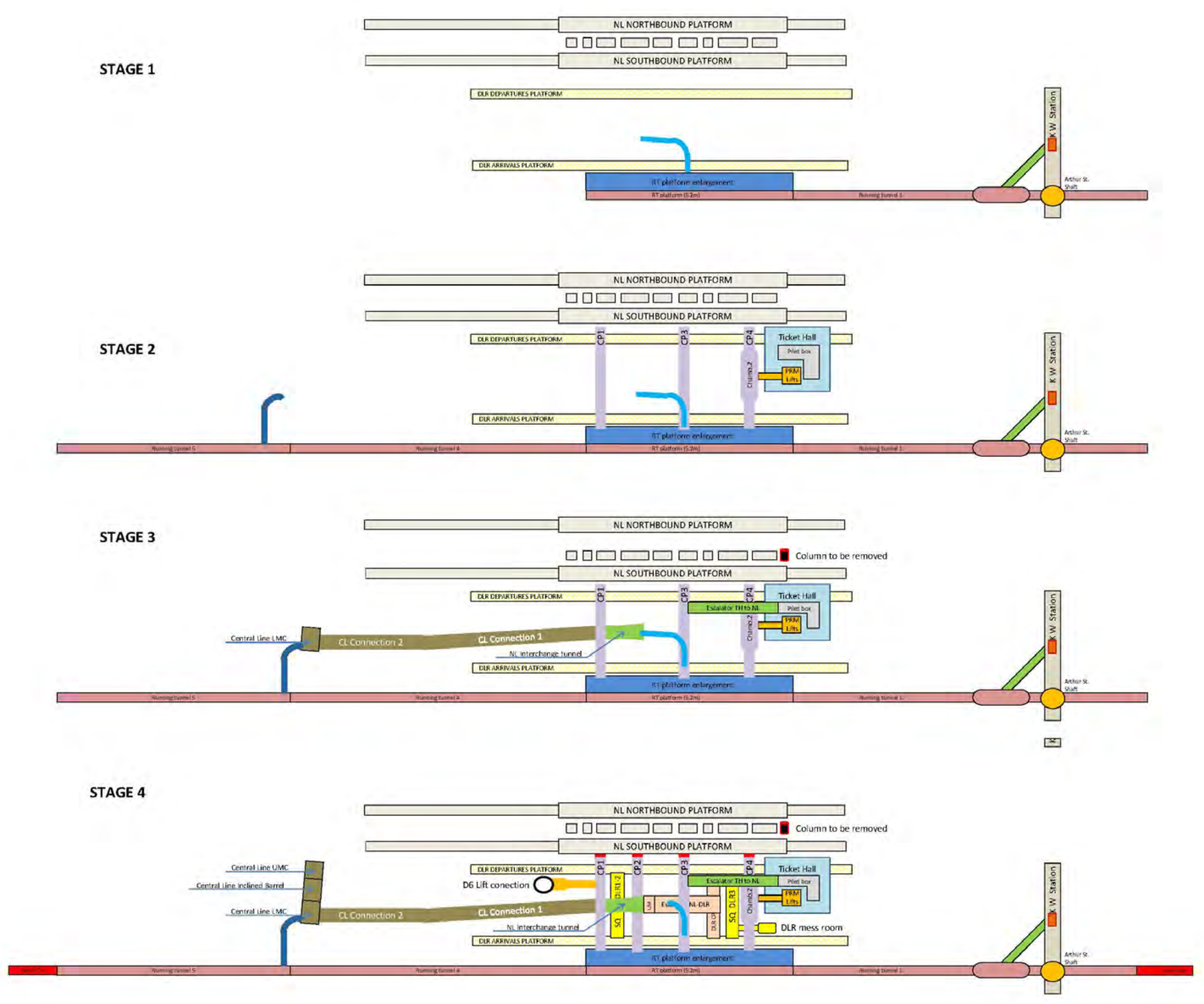

Figure 1: Construction Stage model

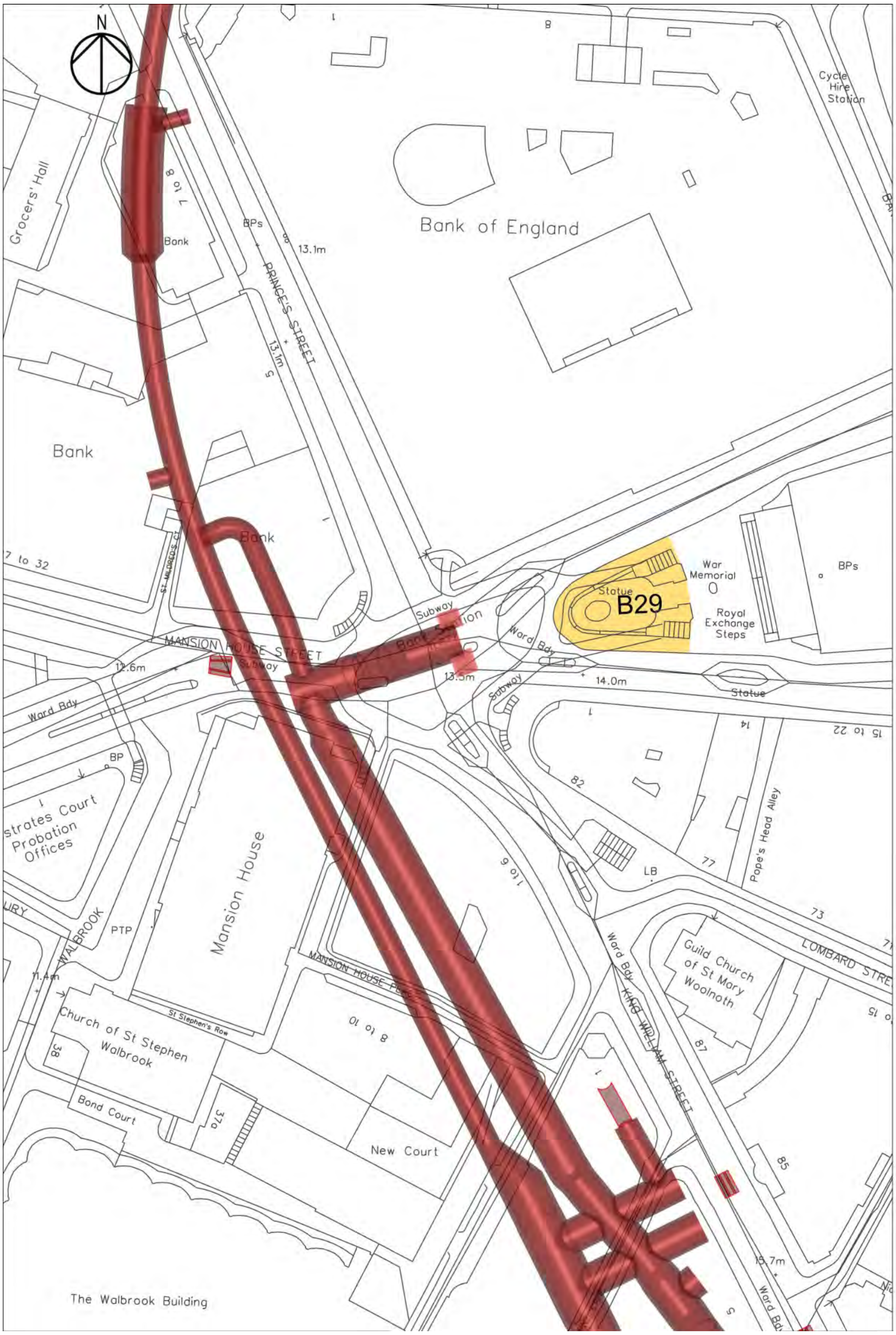

Figure 2: Location plan showing building location in relation to BSCU works

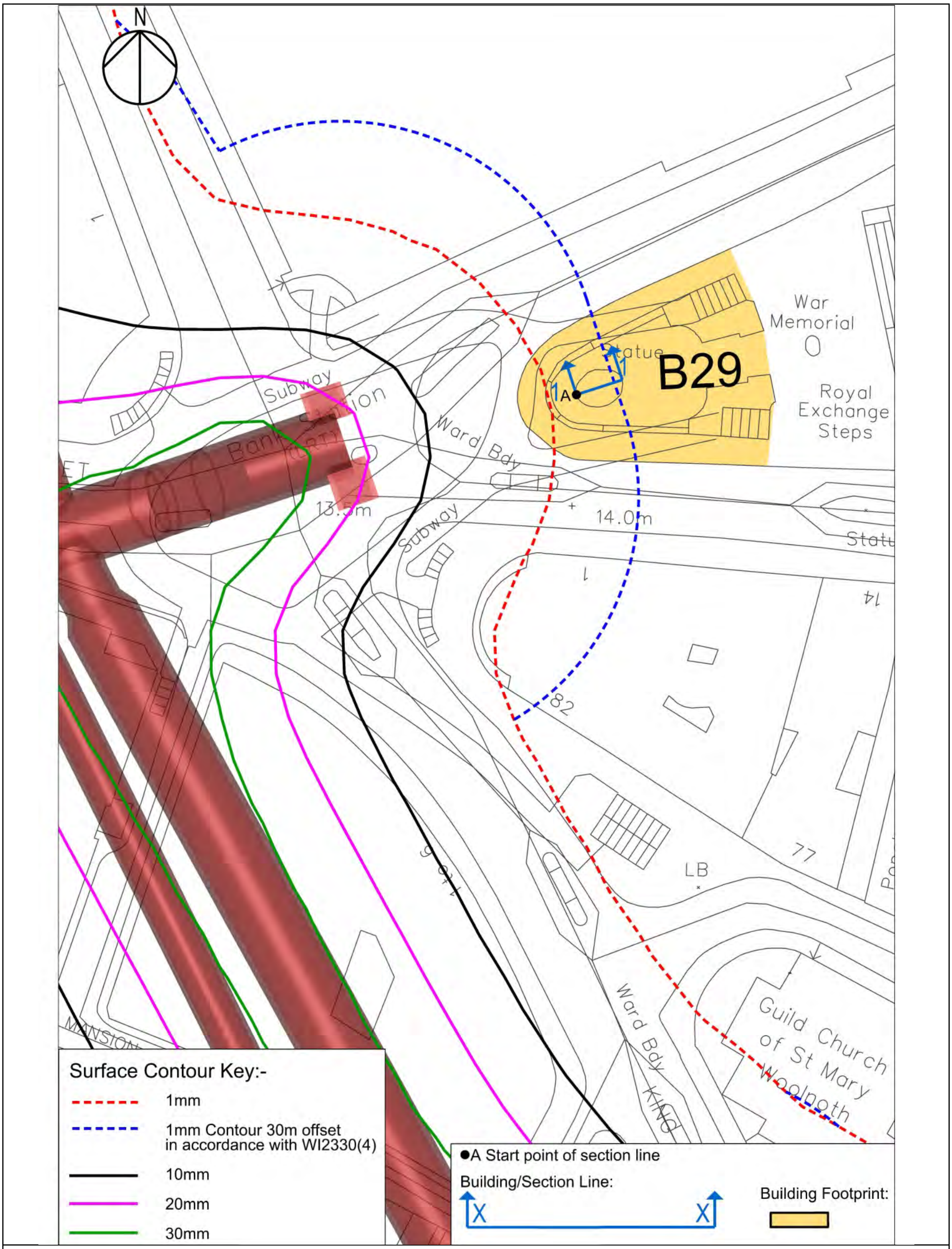

Figure 3: Building location, sections analysed and Settlement Contours at stage of worst case for tensile strains

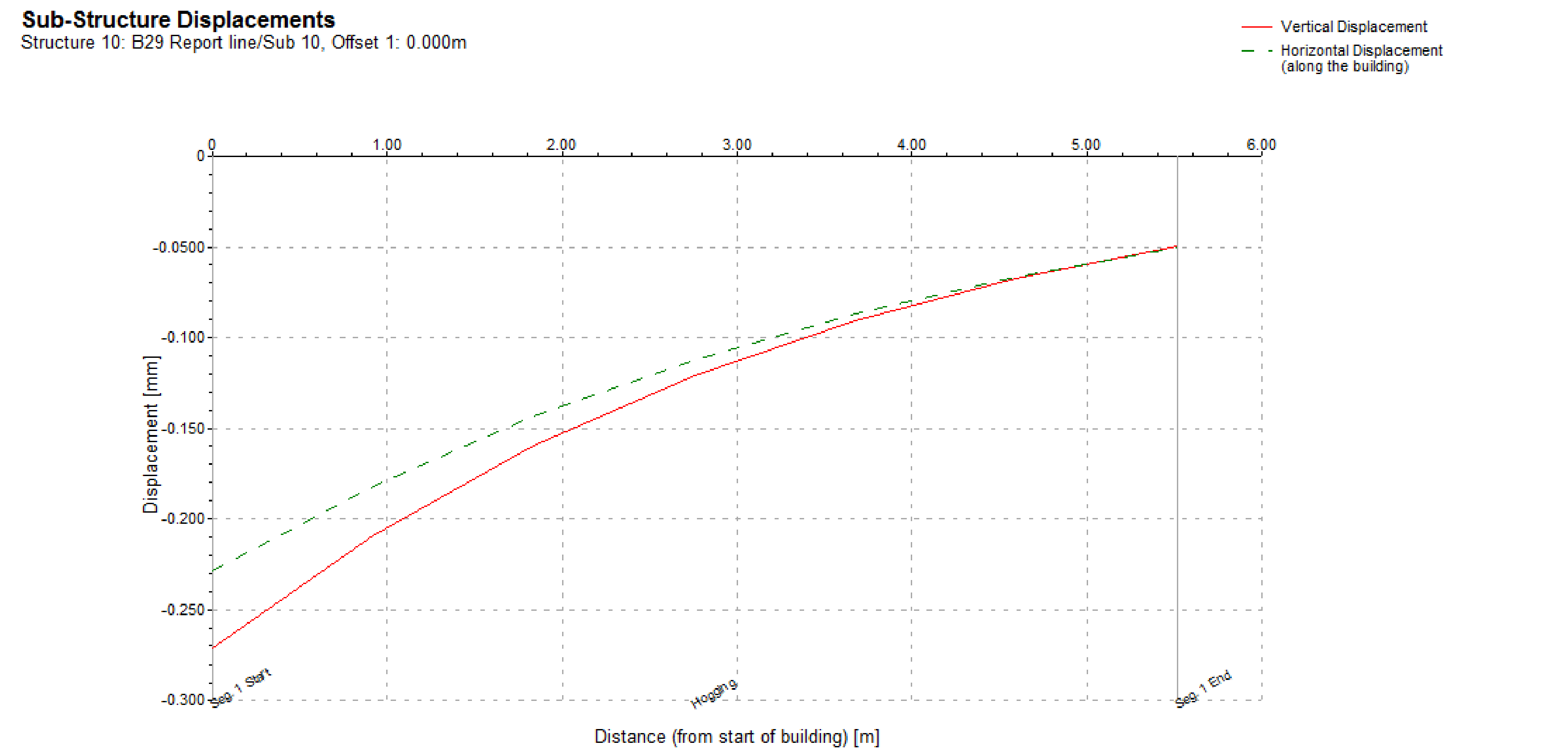

Figure 4: Building displacement at founding level at stage 4 (line 1)

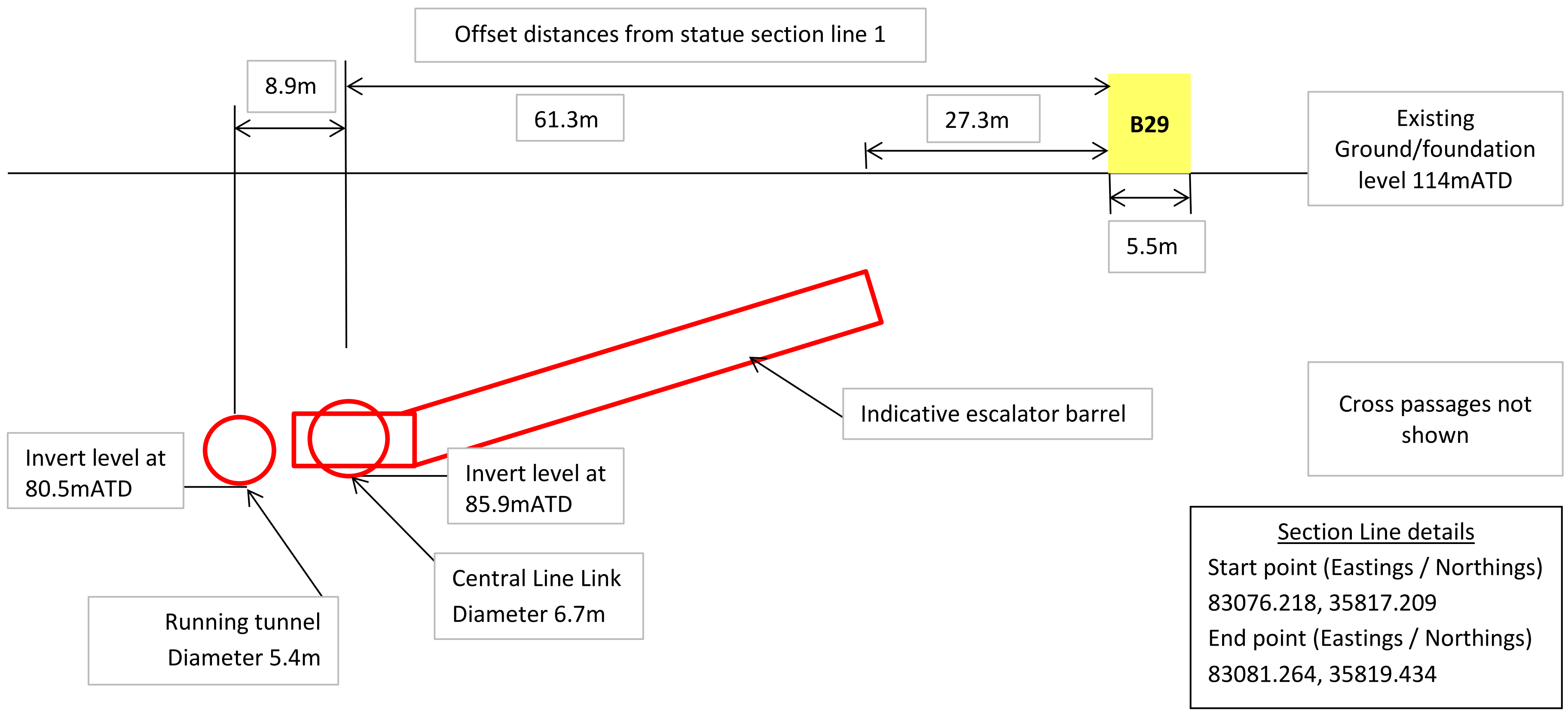

Figure 5: Diagrammatic cross-section of section (line 1) relative to tunnel position

LUL Bank Project Office
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Bank Station Capacity Upgrade

Building Damage Assessment Report

Building B31

6 Lothbury

URS-8798-RPT-G-001221

Prepared by: Lisa Perkins
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Role:	Designer

Document History

Revision	Date	Summary of changes
1.0	March 2014	Issue for Heritage
2.0	April 2014	For Approval
3.0	July 2014	TWAO Issue

For the status of this document, please refer to the Building Damage Assessment Report Register (URS-8798-RGT-001229)

Consultation:

• Ela Palmer	URS Heritage
• Brian Lyons	Dr.Sauer
• Keith Bowers/Neil Moss/Paul Dryden	London Underground
• Olly Newman	Dragados

Contents

FIGURES

TABLES

1 Introduction

This report summarises the results of a Stage 2 damage assessment for 6 Lothbury.

Stage 2 damage assessments are undertaken for all buildings within the Stage 1 Greenfield ground surface 1mm settlement contour induced by the construction of the Bank Station Capacity Upgrade (BSCU).

The purpose of the assessment is to determine the potential effect the works will have on the building. This report describes the engineering and heritage assessments undertaken for the building and concludes whether mitigation is likely to be needed and if a further (Stage 3) assessment is recommended in order to verify this.

2 The Building

2.1 General Information

General building information used in the assessment has been acquired as part of the structural desktop appraisal. Where data was not available, conservative assumptions were made instead. This information is presented in Table 1.

Category	Building Information
BSCU Reference	B31
Location	Lothbury
Address	6 Lothbury
Building Type	Load bearing masonry (assumed)
Construction Age	1932
No. of Storeys	7
Basements	1 (assumed)
Eaves Level (mATD)	143.1
Foundation Type	Pad (assumed)
Ground Level (mATD)	113.1
Listed Grade	II
Note: Levels given are in metres above Tunnel Datum, mATD. Tunnel Datum is 100m below Ordnance Survey Datum at Newlyn.	

Table 1: General building information

A general view of the building exterior is shown in Plate 1. A location plan showing the building in relation to the proposed BSCU works is presented in Figure 2.

Plate 1: General view

2.2 Building Description & Heritage

No. 6 Lothbury is situated at the end Lothbury facing Bank of England. The building is seven storeys high with one (assumed) level of basement.

6 Lothbury dates from 1932 and was designed by Stanley Hall Easton & Robertson. Stanley Hall was known for hospital design and President of the Royal Institute of British Architects at his death in 1940. The building has a paired down classical design of rusticated Portland masonry with six storeys plus a later attic. Above the three semi-circular arched openings with decorative ironwork at ground floor level is an order of stylized Corinthian pilasters with pedimented second floor windows. A heavy cornice bands the building above the fourth floor.

A shallow foundation such as strip footing is considered most conservative is assessing strains for the building facades.

3 Methodology

This assessment is undertaken in accordance with LUL Works Information WI2300[1] and LU Civil Engineering - Common Requirements S1050[2].

The analysis methodology applies to ground-bearing buildings which will be affected by ground movements resulting from the construction of the BSCU. The engineering assessment calculates the potential impact of ground movements and assigns a damage category to the building based on a numeric scale. Additionally, for listed buildings, a heritage assessment is carried out which considers the sensitivity of the structure and the sensitivity of its particular features; a heritage sensitivity score is assigned. The heritage sensitivity score is added to the damage category to obtain the total score. If the total score is 3 or more, a more detailed Stage 3 assessment is triggered.

Oasys Xdisp is used to analyse the Greenfield ground movement in terms of settlement and horizontal displacement. Subsurface tunnelling induced ground movement profiles are determined in accordance with the methodology described by Mair et al[3 & 4].

Movements resulting from the Whole Block Scheme (WBS) and shaft excavations have been calculated using LU Guidance Document G0058[5].

The building is modelled as a simple elastic beam which is conservatively assumed to follow the Greenfield ground displacements. The beam is divided into hogging and sagging segments. The tensile strains within each segment are calculated based on the distortion associated with differential settlement (which is characterised by deflection ratio) and the distortion associated with differential horizontal displacement (characterised by horizontal strain).

Xdisp provides a method for calculating the maximum tensile strain within the building superstructure associated with these movements, in accordance with the assessment methodology described by Mair et al [4]. This strain is used to determine the damage category based on the classification system proposed by Burland[6] and in accordance with LU Civil Engineering - Common Requirements S1050[2]. The categories are presented in Table 2.

Damage Category	Description of Degree of Damage	Description of Typical Damage and likely forms of Repair for Typical Masonry Buildings.	Approx. Crack Width (mm)	Max. Tensile Strain %
0	Negligible	Hairline cracks.		< 0.05
1	Very slight	Fine cracks easily treated during normal redecoration. Perhaps isolated slight fracture in building. Cracks in exterior visible upon close inspection.	0.1 to 1.0	0.05 to 0.075
2	Slight	Cracks easily filled. Redecoration probably required. Several slight fractures inside building. Exterior cracks visible; some repainting may be required for weather-tightness. Doors and windows may stick slightly.	1 to 5	0.075 to 0.15
3	Moderate	Cracks may require cutting out and patching. Recurrent cracks can be masked by suitable linings. Tuck pointing and possible replacement of a small amount of exterior brickwork may be required. Doors and windows sticking. Utility services may be interrupted. Weather tightness often impaired.	5 to 15 or a number of cracks > 3	0.15 to 0.3
4	Severe	Extensive repair required involving removal and replacement of walls especially over doors and windows. Window and door frames distorted. Floor slopes noticeably. Walls lean or bulge noticeably. Some loss of bearing in beams. Utility services disrupted.	15 to 25 but also depends on number of cracks	> 0.3
5	Very severe	Major repair required involving partial or complete reconstruction. Beams lose bearing, walls lean badly and require shoring. Windows broken by distortion. Danger of instability.	Usually > 25 but depends on number of cracks	
Note: Please refer LU Civil Engineering - Common Requirements S1050[2].				

Table 2: Building damage classification

4 Input Data

The magnitude and distribution of ground movements and degree of building damage is calculated based on the following input data:

- The Xdisp model coordinates and levels are based on the 3D model (20130212DSPITT Scheme R09);
- Four construction stages are considered in accordance with the proposed programme (November 2013) as illustrated in Figure 1;
- Trough width parameter constant, K=0.5 is used in accordance with WI2300[1].

The input data for the building, tunnels and shaft excavation are summarised in Table 3, Table 4 and Table 5 respectively.

Location	Foundation level (mATD)	Building Height above foundation level (m)	E/G
6 Lothbury	108.6*	34.5	2.6
Note: Where E / G is the ratio of Young's modulus to shear modulus of the deep beam that is to represent the building. * Assumed level, 1.5m thick slab beneath floor level.			

Table 3: Building data

Tunnel Item	Level of axis (mATD)	External diameter (m)	Volume Loss (%)
Running tunnels	Inclined (82.9 to 85.8)	5.4	1.5
Running tunnel northern tie in	Inclined (83 to 83.6)	4.8	1.5
Square works adits	75.8 to 95.3	4.1 to 7.8	2.5
Platform enlargement	85.6	7.4 to 11.2	1.5
Tunnel enlargement	Inclined (82.9 to 83)	8	1.5
Escalator barrels	Inclined	8.3 to 8.4	1.5
Central Line Connection	Inclined (87.6 to 89.2)	8.6	1.5

Table 4: Tunnel data

Excavation	Excavation Base Level (mATD)
Grout Shaft at King William Street	97
Whole Block Scheme Box excavation	73
Arthur Street Shaft	81

Table 5: Excavation data

The Xdisp model filenames used to undertake this assessment are:

- B31 - Stage 4
- B31 - Stage 3
- B31 - Stage 2
- B31 - Stage 1

The distance of building 6 Lothbury (B31) relative to the excavation elements listed in Table 5 is reasonably large so this building is unlikely to be affected by their construction.

5 Results

5.1 Engineering Assessment

The sections through the building which have been analysed are shown on plan in Figure 3.

Assessment has been undertaken at three intermediate construction stages and at the end of construction when all major elements of the works including shaft and tunnels have been completed. The damage category assigned to the building is based on the construction stage at which the potential impact on the building is most severe.

The maximum settlement and tensile strain calculated for each of the analysis sections at the most onerous intermediate construction stage and at the end of construction are presented in Table 6 and Table 7.

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
B31 (line 1)	<1	<0.001
B31 (line 2)	<1	<0.001

Table 6: Building response at most onerous intermediate stage - Construction Stage 2

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
B31 (line 1)	<1	0.002
B31 (line 2)	<1	<0.001

Table 7: Building response at end of construction stage

The results of the assessment show construction Stage 4 is the critical stage for this building due to the construction of the northern tie-in. At this stage, section B31 line 1 experiences the most onerous combined tensile strain. The orientation of section B31 line 1 is shown in Figure 3. The relative position of the building and tunnels along section line 1 is shown in Figure 4. The calculated strains are summarised in Table 8.

Line No.	Strains in section (Curvature)	Position from start (m)	Length (m)	Average* Horizontal Strain (%)	Maximum Tensile Strains (%)	Damage Category
Line 1	Hogging	0.0	14.3	0.001	0.002	Negligible
Note: * Tensile horizontal strains are +ve. Compressive horizontal strains are –ve.						

Table 8: Section analysed, results for worst case tensile strain

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0. This corresponds to negligible damage in accordance with Table 2.

The maximum settlement of the building at foundation level at the end of construction is <1mm.

5.2 Heritage and Structural Assessment

Following site inspection, assessment has been made using the following scoring methodology as set out in Table 9.

Score	STRUCTURE Sensitivity of the structure to ground movements and interaction with adjacent buildings	HERITAGE FEATURES Sensitivity to calculated movement of particular features within the building	CONDITION Factors which may affect the sensitivity of structural or heritage features
0	Masonry buildings with lime mortar and regular openings, not abutted by other buildings, and therefore similar to the buildings on which the original Burland assessment was based.	No particular sensitive features	Good/Fair - not affecting the sensitivity of structural or heritage features
1	Buildings not complying with categories 0 or 2, but still with some sensitive structural features in the zone of settlement e.g.: cantilever stone staircases, long walls without joints or openings, existing cracks where further movements are likely to concentrate, mixed foundations	Brittle finishes, e.g. faience or tight-jointed stonework, which are susceptible to small structural movements and difficult to repair invisibly.	Poor - may change the behaviour of a building in cases of movement. Poor condition of heritage features and finishes. Evidence of previous movement.
2	Buildings which, by their structural form, will tend to concentrate all their movements in one location (e.g.: a long wall without joints and with a single opening).	Finishes which if damaged will have a significant effect on the heritage value of the building, e.g. Delicate frescos, ornate plasterwork ceilings.	Very poor – parlous condition of heritage features and finishes, severe existing damage to structure including evidence of ongoing movement. Essentially buildings where even very small movements could lead to significant damage.

Table 9: Heritage and structural scoring methodology

The results of the heritage assessment carried out for the building are summarised in Table 10.

SENSITIVITY OF THE STRUCTURE
Since no visit of this property has been possible the assessment below is based on the external appearance of the building and the description contained in the Listing Description. The building is located outside the 1mm contour, but the 30mm off set line crosses the south western corner of the building. Predicted settlements and strains are very low.
Score: 0 - Based on the available information there are no particular structural sensitivities.
SENSITIVITY OF THE HERITAGE
No internal inspection has been made of this property. Externally, there are no heritage features that would be sensitive to the very low predicted settlements. Whilst it must be assumed that there are surviving fine interior finishes, again these would not be sensitive to the predicted settlements.
Score: 0 – heritage features will not be sensitive to the low predicted settlements
SENSITIVITY OF THE CONDITION
External inspection of the building has noted no particular sensitivities due to condition, and the ~~building appear~~building appears to be well maintained.
Score: 0 – no external sensitivities due to condition

Table 10: Heritage and structural assessment

5.3 Total Score

The total score is the summation of the damage category, structural sensitivity, heritage sensitivity and condition sensitivity scores:

The damage category is 0

The structural sensitivity score is 0

The heritage sensitivity score is 0

The condition sensitivity score is 0

The total score for this building is 0

6 Conclusion

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0 for 6 Lothbury. Specific heritage and structural assessment taking into account the location and extent of settlement and tensile strains highlights the buildings low level of structural and heritage sensitivity to movement, based on external inspection of the building only. This assessment has determined that the building has a total score of 0.

It is recommended that the building does not require a Stage 3 assessment.

7 References

[1] LU Works Information WI 2300 Ground Movement version 3, 19-07-13.

[2] LU Category 1 Standard: S1050 Civil Engineering - Common Requirements, Issue No. A7, Nov. 2013.

[3] Mair R J, Taylor R N and Bracegirdle A (1993). Subsurface settlement profiles above tunnels in clays. Géotechnique 43, No. 2, pp. 315-320.

[4] Mair R J, Taylor R N and Burland J B (1996). Prediction of ground movements and assessment of risk of building damage due to bored tunnelling. (In: International Conference of Geotechnical Aspects of Underground Construction in Soft Ground, London, pp. 713–718.

[5] LU Guidance Document G0058 Civil Engineering Technical Advice Notes, Issue No. A17, Feb. 2013.

[6] Burland J B (1995). Assessment of risk of damage to buildings due to tunnelling and excavation. Proceedings: 1st International Conference of Earthquake Geotechnical Engineering, IS Tokyo, 1995.

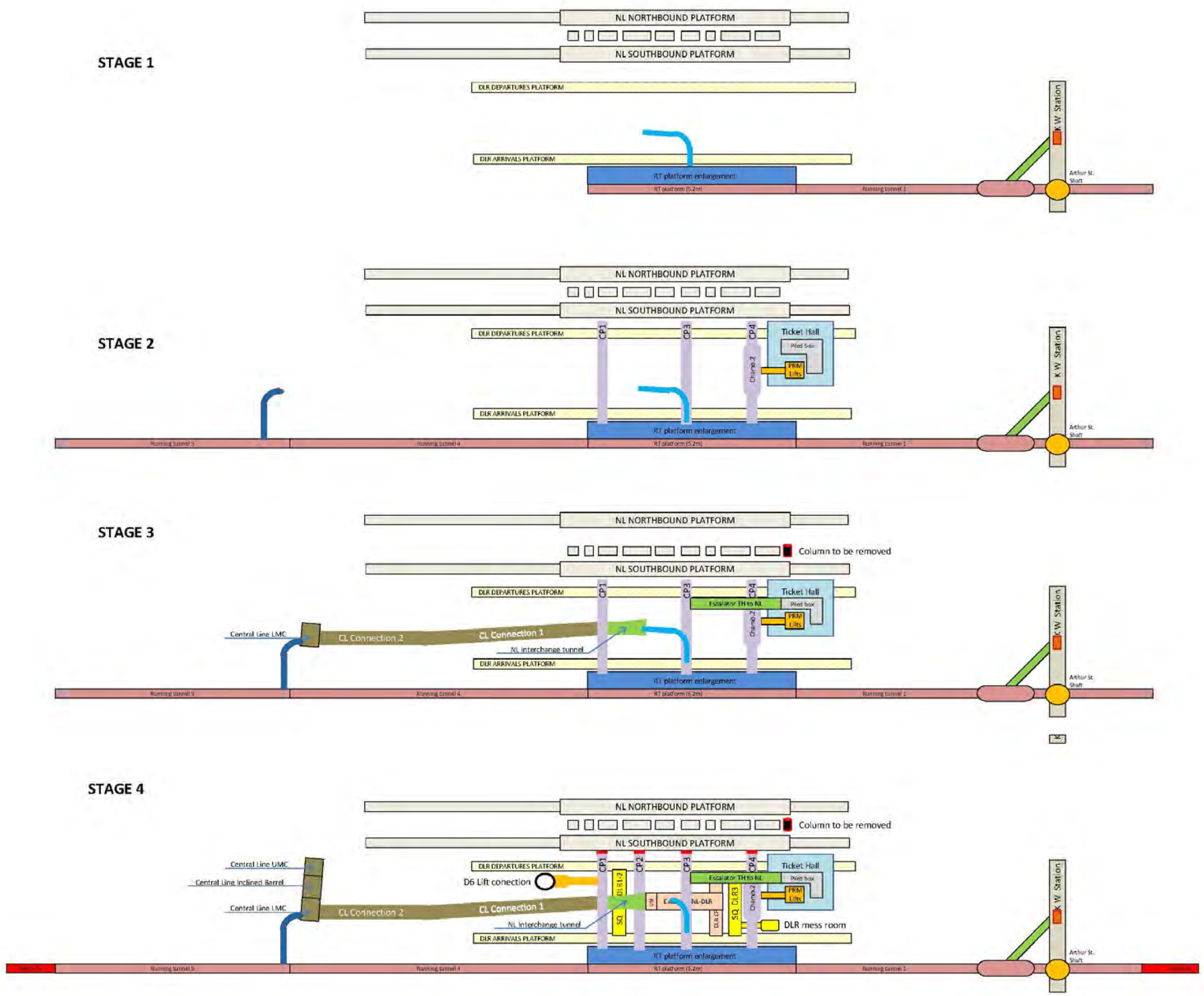

Figure 1: Construction Stage model

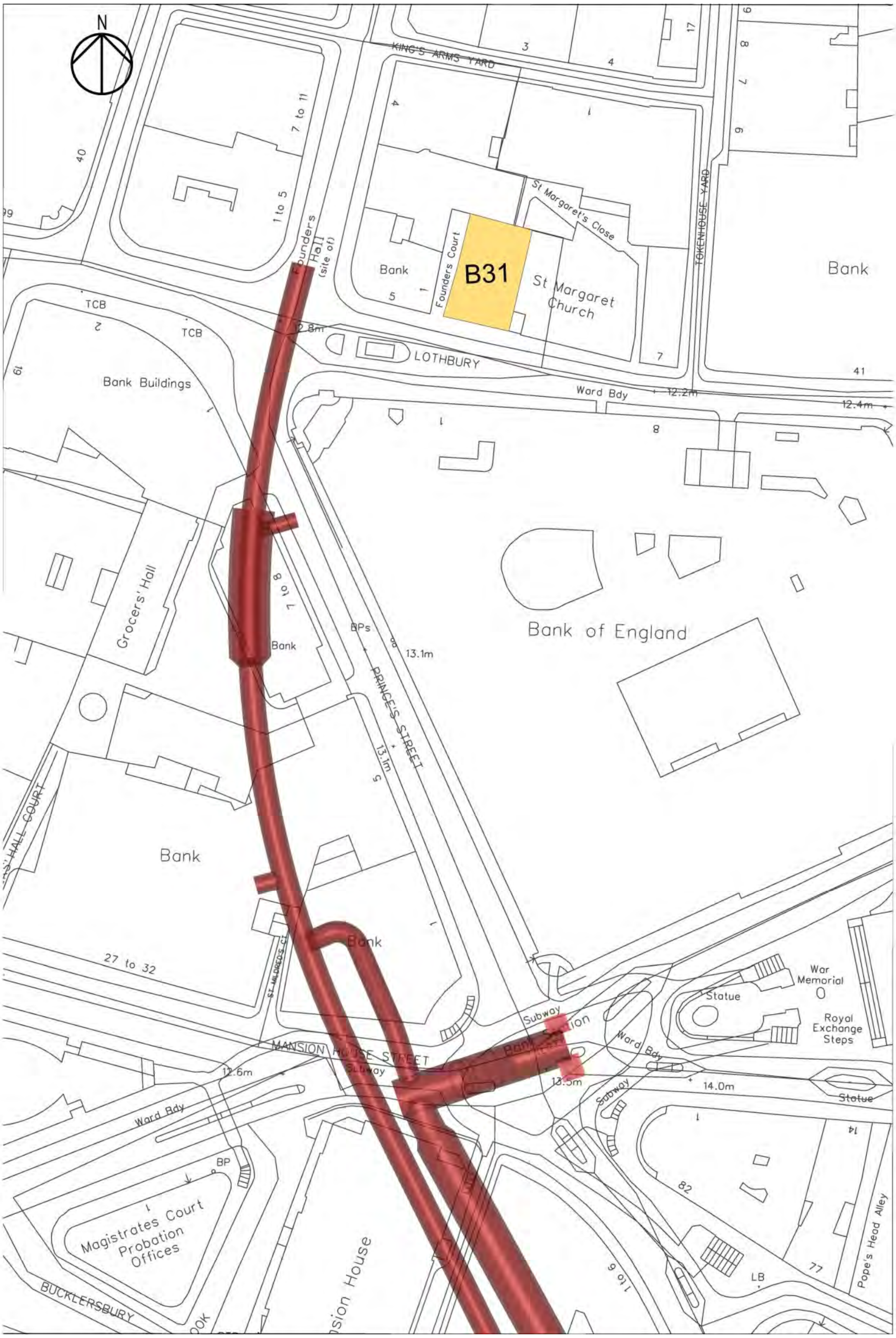

Figure 2: Location plan showing building location in relation to BSCU works

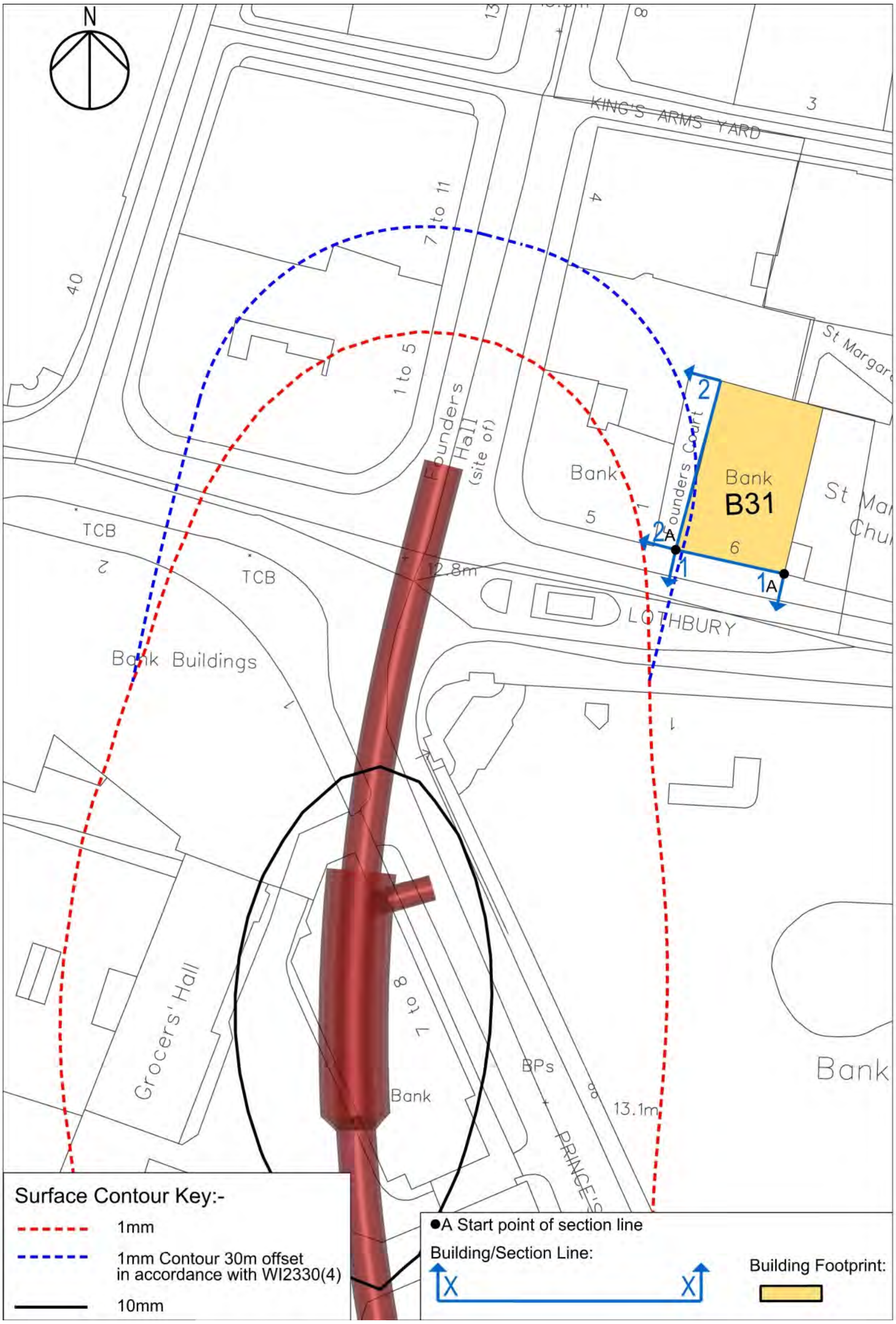

Figure 3: Building location, sections analysed and Settlement Contours at stage of worst case for tensile strains

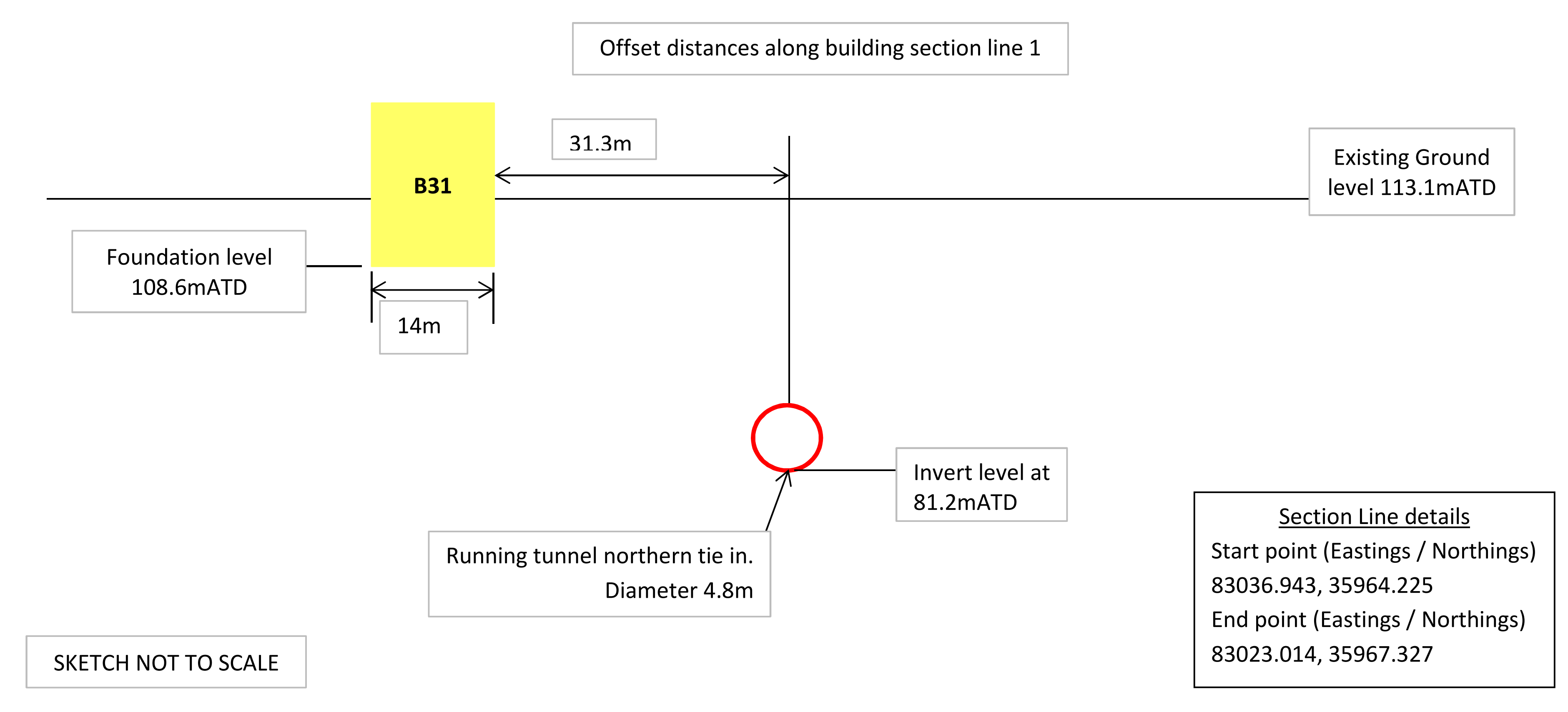

Figure 4: Diagrammatic cross-section of section (line 1) relative to tunnel position

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Bank Station Capacity Upgrade

Building Damage Assessment Report

Building B33

4 Moorgate

URS-8798-RPT-G-001223

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1.0	March 2014	Issue for Heritage
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<u>Consultation:</u>

• Ela Palmer	URS Heritage
• Brian Lyons	Dr.Sauer
• Keith Bowers/Neil Moss/Paul Dryden	London Underground
• Olly Newman	Dragados

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FIGURES

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1 Introduction

This report summarises the results of a Stage 2 damage assessment for 4 Moorgate.

Stage 2 damage assessments are undertaken for all buildings within the Stage 1 Greenfield ground surface 1mm settlement contour induced by the construction of the Bank Station Capacity Upgrade (BSCU).

The purpose of the assessment is to determine the potential effect the works will have on the building. This report describes the engineering and heritage assessments undertaken for the building and concludes whether mitigation is likely to be needed and if a further (Stage 3) assessment is recommended in order to verify this.

2 The Building

2.1 General Information

General building information used in the assessment has been acquired as part of the structural desktop appraisal. Where data was not available, conservative assumptions were made instead. This information is presented in Table 1.

Category	Building Information
BSCU Reference	B33
Location	Moorgate
Address	4 Moorgate
Building Type	Load bearing masonry (assumed)
Construction Age	Unknown (early 20th Century)
No. of Storeys	7
Basements	1
Eaves Level (mATD)	143.0
Foundation Type	Shallow foundation (assumed)
Ground Level (mATD)	113.0
Listed Grade	II
Note: Levels given are in metres above Tunnel Datum, mATD. Tunnel Datum is 100m below Ordnance Survey Datum at Newlyn.	

Table 1: General building information

A general view of the building exterior is shown in Plate 1. A location plan showing the building in relation to the proposed BSCU works is presented in Figure 1.

Plate 1: General view

2.2 Building Description & Heritage

4 Moorgate is an early 20th century commercial building that has been recently redeveloped, only retaining the facades of the original structure and decorative elements of the entrance vestibule. The original designer is not documented. The ground floor and basement are used as a bar and the remaining upper stories used as offices.

The exterior is of three main stories and historic attic storey with a second modern attic and slated modern mansard roof with dormer windows above. The “L” shaped building is five bays wide on the Moorgate elevation and nine bays wide on the Kings Arms Yard elevation. The architectural masonry at ground floor consists of a channelled Portland stone with tuscan pilasters, square headed windows with foliate keystones and a principal semi-circular arched entrance to the bar (the office entrance is to the south corner). The first and second floors are united by giant Corinthian order with alternating triangular and segmental pedimented windows. The attic stories are formed of Portland ashlar with shallow pilasters and square headed windows with moulded surrounds. The exterior has been thoroughly cleaned and repainted.

Internally the building has been completely renovated with large open office spaces constructed to accommodate modern usage. An exception to this are elements of an original entrance vestibule, possibly relocated during the renovation, consisting of carved marble cornice with semi-circular marble panel tympanum and a circular decorative ring of marble with relief carving of fruit and vegetables.

3 Methodology

This assessment is undertaken in accordance with LU Works Information WI2300[1] and LU Civil Engineering - Common Requirements S1050[2].

The analysis methodology applies to ground-bearing buildings which will be affected by ground movements resulting from the construction of the BSCU. The engineering assessment calculates the potential impact of ground movements and assigns a damage category to the building based on a numeric scale. Additionally, for listed buildings, a heritage assessment is carried out which considers the sensitivity of the structure and the sensitivity of its particular features; a heritage sensitivity score is assigned. The heritage sensitivity score is added to the damage category to obtain the total score. If the total score is 3 or more, a more detailed Stage 3 assessment is triggered.

Oasys Xdisp is used to analyse the Greenfield ground movement in terms of settlement and horizontal displacement. Subsurface tunnelling induced ground movement profiles are determined in accordance with the methodology described by Mair et al[3 & 4].

Movements resulting from the Whole Block Scheme (WBS) and shaft excavations have been calculated using LU Guidance Document G0058[5].

The building is modelled as a simple elastic beam which is conservatively assumed to follow the Greenfield ground displacements. The beam is divided into hogging and sagging segments. The tensile strains within each segment are calculated based on the distortion associated with differential settlement (which is characterised by deflection ratio) and the distortion associated with differential horizontal displacement (characterised by horizontal strain).

Xdisp provides a method for calculating the maximum tensile strain within the building superstructure associated with these movements, in accordance with the assessment methodology described by Mair et al [4]. This strain is used to determine the damage category based on the classification system proposed by Burland[6] and in accordance with LU Civil Engineering - Common Requirements S1050[2]. The categories are presented in Table 2.

Damage category	Description of degree of damage	Description of typical damage and likely forms of repair for typical masonry buildings.	Approx. crack width (mm)	Max. tensile strain %
0	Negligible	Hairline cracks.		< 0.05
1	Very slight	Fine cracks easily treated during normal redecoration. Perhaps isolated slight fracture in building. Cracks in exterior visible upon close inspection.	0.1 to 1.0	0.05 to 0.075
2	Slight	Cracks easily filled. Redecoration probably required. Several slight fractures inside building. Exterior cracks visible; some repainting may be required for weather-tightness. Doors and windows may stick slightly.	1 to 5	0.075 to 0.15
3	Moderate	Cracks may require cutting out and patching. Recurrent cracks can be masked by suitable linings. Tuck pointing and possible replacement of a small amount of exterior brickwork may be required. Doors and windows sticking. Utility services may be interrupted. Weather tightness often impaired.	5 to 15 or a number of cracks > 3	0.15 to 0.3
4	Severe	Extensive repair required involving removal and replacement of walls especially over doors and windows. Window and door frames distorted. Floor slopes noticeably. Walls lean or bulge noticeably. Some loss of bearing in beams. Utility services disrupted.	15 to 25 but also depends on number of cracks	> 0.3
5	Very severe	Major repair required involving partial or complete reconstruction. Beams lose bearing, walls lean badly and require shoring. Windows broken by distortion. Danger of instability.	Usually > 25 but depends on number of cracks	
Note: Please refer LU Civil Engineering - Common Requirements S1050[2].				

Table 2: Building damage classification

4 Input Data

The magnitude and distribution of ground movements and degree of building damage is calculated based on the following input data:

- The Xdisp model coordinates and levels are based on the 3D model (20130212DSPITT Scheme R09);
- Four construction stages are considered in accordance with the proposed programme (November 2013) as illustrated in Figure 1;
- Trough width parameter constant, K=0.5 is used in accordance with WI2300[1]

The input data for the building, tunnels and shaft excavation are summarised in Table 3, Table 4 and Table 5 respectively.

Location	Foundation level (mATD)	Building Height above foundation level (m)	E/G
1-5 Moorgate	108.5*	34.5	2.6
Note: Where E / G is the ratio of Young's modulus to shear modulus of the deep beam that is to represent the building. * Assumed level, 1.5m thick slab beneath floor level.			

Table 3: Building data

Tunnel Item	Level of axis (mATD)	External diameter (m)	Volume Loss (%)
Running tunnels	Inclined (82.9 to 85.8)	5.4	1.5
Running tunnel northern tie in	Inclined (83 to 83.6)	4.8	1.5
Square works adits	75.8 to 95.3	4.1 to 7.8	2.5
Platform enlargement	85.6	7.4 to 11.2	1.5
Tunnel enlargement	Inclined (82.9 to 83)	8	1.5
Escalator barrels	Inclined	8.3 to 8.4	1.5
Central Line Connection	Inclined (87.6 to 89.2)	8.6	1.5

Table 4: Tunnel data

Excavation	Excavation Base Level (mATD)
Grout Shaft at King William Street	97
Whole Block Scheme Box excavation	73
Arthur Street Shaft	81

Table 5: Excavation data

The Xdisp model filenames used to undertake this assessment are:

- B33 - Stage 4
- B33 - Stage 3
- B33 - Stage 2
- B33 - Stage 1

The distance of building 4 Moorgate (B33) relative to the excavation elements listed in Table 5 is reasonably large so this building is unlikely to be affected by their construction.

5 Results

5.1 Engineering Assessment

The sections through the building which have been analysed are shown on plan in Figure 3.

Assessment has been undertaken at three intermediate construction stages and at the end of construction when all major elements of the works including shaft and tunnels have been completed. The damage category assigned to the building is based on the construction stage at which the potential impact on the building is most severe.

The maximum settlement and tensile strain calculated for each of the analysis sections at the most onerous intermediate construction stage and at the end of construction are presented in Table 6 and Table 7.

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
B33 (line 1)	<1	<0.001
B33 (line 2)	<1	<0.001

Table 6: Building response at most onerous intermediate stage - Construction Stage 2

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
B33 (line 1)	<1	<0.001
B33 (line 2)	<1	<0.001

Table 7: Building response at end of construction stage

The results of the assessment show construction Stage 4 is the critical stage for this building due to the construction of the northern tie-in. At this stage, section B33 line 1 experiences the most onerous combined tensile strain. The orientation of section B33 line 1 is shown in Figure 3. The relative position of the building and tunnels along section line 1 is shown in Figure 4. The calculated strains are summarised in Table 8.

Line No.	Strains in section (Curvature)	Position from start (m)	Length (m)	Average* Horizontal Strain (%)	Maximum Tensile Strains (%)	Damage Category
line 1	Hogging	0.0	18.2	<0.001	<0.001	Negligible

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Note: * Tensile horizontal strains are +ve. Compressive horizontal strains are –ve.

Table 8: Section analysed, results for worst case tensile strain

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0. This corresponds to negligible damage in accordance with Table 2.

The maximum settlement of the building at foundation level at the end of construction is less than 1mm.

5.2 Heritage and Structural Assessment

Following site inspection, assessment has been made using the following scoring methodology as set out in Table 9.

Score	STRUCTURE Sensitivity of the structure to ground movements and interaction with adjacent buildings	HERITAGE FEATURES Sensitivity to calculated movement of particular features within the building	CONDITION Factors which may affect the sensitivity of structural or heritage features
0	Masonry buildings with lime mortar and regular openings, not abutted by other buildings, and therefore similar to the buildings on which the original Burland assessment was based.	No particular sensitive features	Good/Fair - not affecting the sensitivity of structural or heritage features
1	Buildings not complying with categories 0 or 2, but still with some sensitive structural features in the zone of settlement e.g.: cantilever stone staircases, long walls without joints or openings, existing cracks where further movements are likely to concentrate, mixed foundations	Brittle finishes, e.g. faience or tight-jointed stonework, which are susceptible to small structural movements and difficult to repair invisibly.	Poor - may change the behaviour of a building in cases of movement. Poor condition of heritage features and finishes. Evidence of previous movement.
2	Buildings which, by their structural form, will tend to concentrate all their movements in one location (e.g.: a long wall without joints and with a single opening).	Finishes which if damaged will have a significant effect on the heritage value of the building, e.g. Delicate frescos, ornate plasterwork ceilings.	Very poor – parlous condition of heritage features and finishes, severe existing damage to structure including evidence of ongoing movement. Essentially buildings where even very small movements could lead to significant damage.

Table 9: Heritage and structural assessment

The results of the heritage assessment carried out for the building are summarised in Table 10.

SENSITIVITY OF THE STRUCTURE
The building structure internally appears to be largely modern, behind a retained façade. There are two levels of basement, the lowest level of which appears to be largely original construction with masonry vaults and some reinforced beams over. The floor is generally finished with stone flagstones, although some areas of insitu concrete slab or screed are present. A stone cantilever stair is located to the rear of the property, at the furthest point from the proposed tunnelling works.
Score: 0 Although a stone cantilever staircase is present the building is outside the 1mm contour and largely outside the 30m off set line.
SENSITIVITY OF THE HERITAGE
The English Heritage listing description indicates that the building was designated due to it being a high quality example of commercial building in the City and the contribution this makes to the character of Moorgate and the Bank Conservation Area more generally. The design quality of the Moorgate street façade, despite it being assumed to have been extended upwards by two storeys, is an important element of the aesthetic and architectural significance of the building. The marble lined entrance vestibule is decorative and constructed of thin marble panels with very fine joints would be susceptible to damage resulting from structural movement.
Score: 0 - Damage to the exterior form and decoration would undermine the significance of the building. However, the predicted settlement due to tunnelling works is so slight as to render the risk of this negligible.
SENSITIVITY OF THE CONDITION
The building appears to be in very good condition. During the site walkover it was not possible to identify any defects that might be exacerbated by settlement. There was no evidence of cracked, deformed or newly repaired masonry.
Score: 0 - The condition of the building in general and the exterior in particular was found to be excellent, with no signs of active movement or unusual disrepair.

Table 10: Heritage and structural assessment

5.3 Total Score

The total score is the summation of the damage category, structural sensitivity, heritage sensitivity and condition sensitivity scores:

The damage category is 0

The structural sensitivity score is 0

The heritage sensitivity score is 0

The condition sensitivity score is 0

The total score for this building is 0

6 Conclusion

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0 for 4 Moorgate. Specific heritage and structural assessment taking into account the location and extent of settlement and tensile strains highlights the buildings low level of structural and heritage sensitivity to movement. This assessment has determined that the building has a total score of 0.

4 Moorgate is located to the north of the Bank Station Capacity Upgrade tunnelling works, beyond the 1mm contour but touching the 30m Offset Line. These works are predicted to result in negligible settlement which is not expected to result in ground movement or damage to the heritage finishes and features of the building.

It is recommended that the building does not require a Stage 3 assessment.

7 References

[1] LU Works Information WI 2300 Ground Movement version 3, 19-07-13.

[2] LU Category 1 Standard: S1050 Civil Engineering - Common Requirements, Issue No. A7, Nov. 2013.

[3] Mair R J, Taylor R N and Bracegirdle A (1993). Subsurface settlement profiles above tunnels in clays. Géotechnique 43, No. 2, pp. 315-320.

[4] Mair R J, Taylor R N and Burland J B (1996). Prediction of ground movements and assessment of risk of building damage due to bored tunnelling. (In: International Conference of Geotechnical Aspects of Underground Construction in Soft Ground, London, pp. 713–718.

[5] LU Guidance Document G0058 Civil Engineering Technical Advice Notes, Issue No. A17, Feb. 2013.

[6] Burland J B (1995). Assessment of risk of damage to buildings due to tunnelling and excavation. Proceedings: 1st International Conference of Earthquake Geotechnical Engineering, IS Tokyo, 1995.

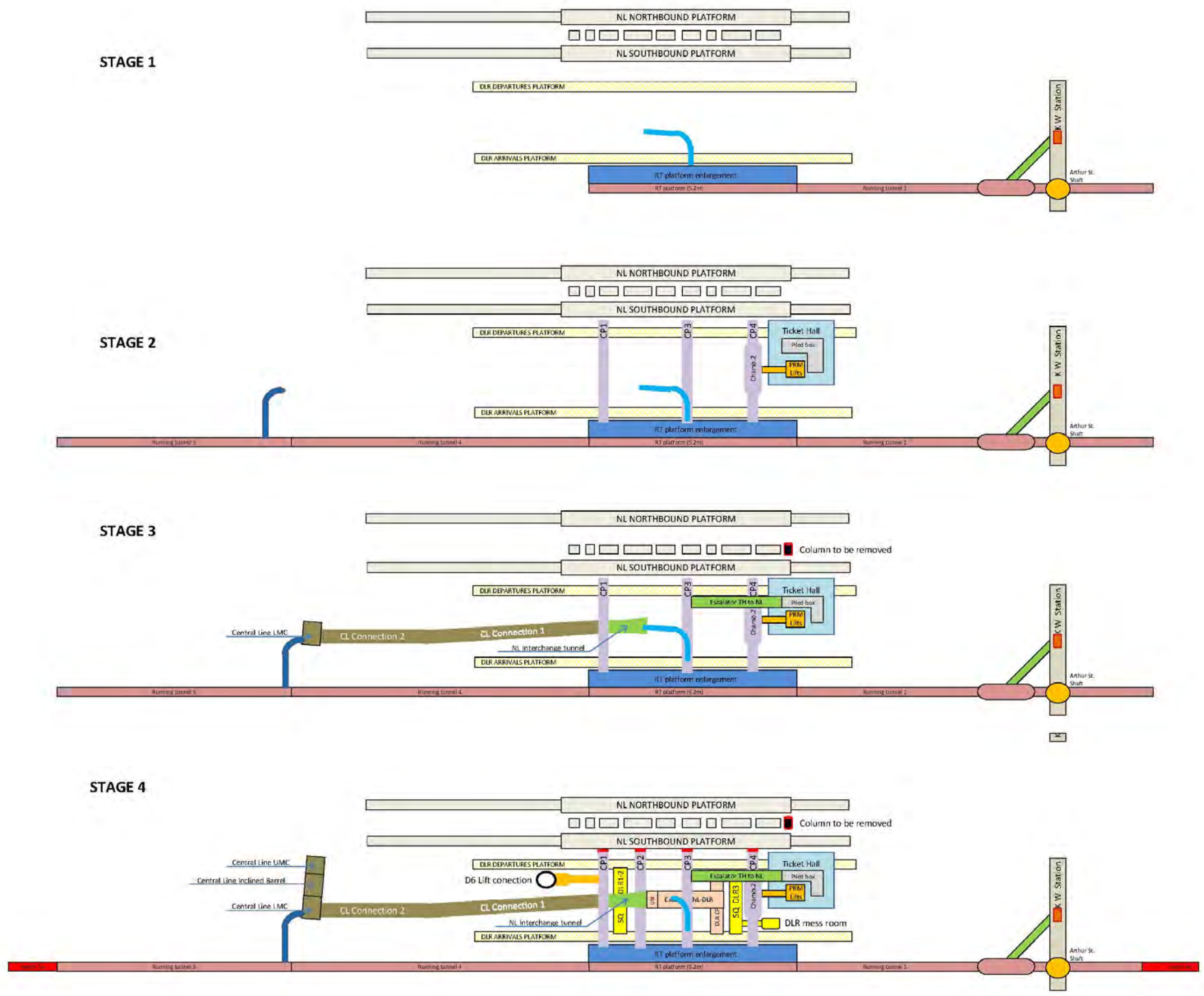

Figure 1: Construction Stage model

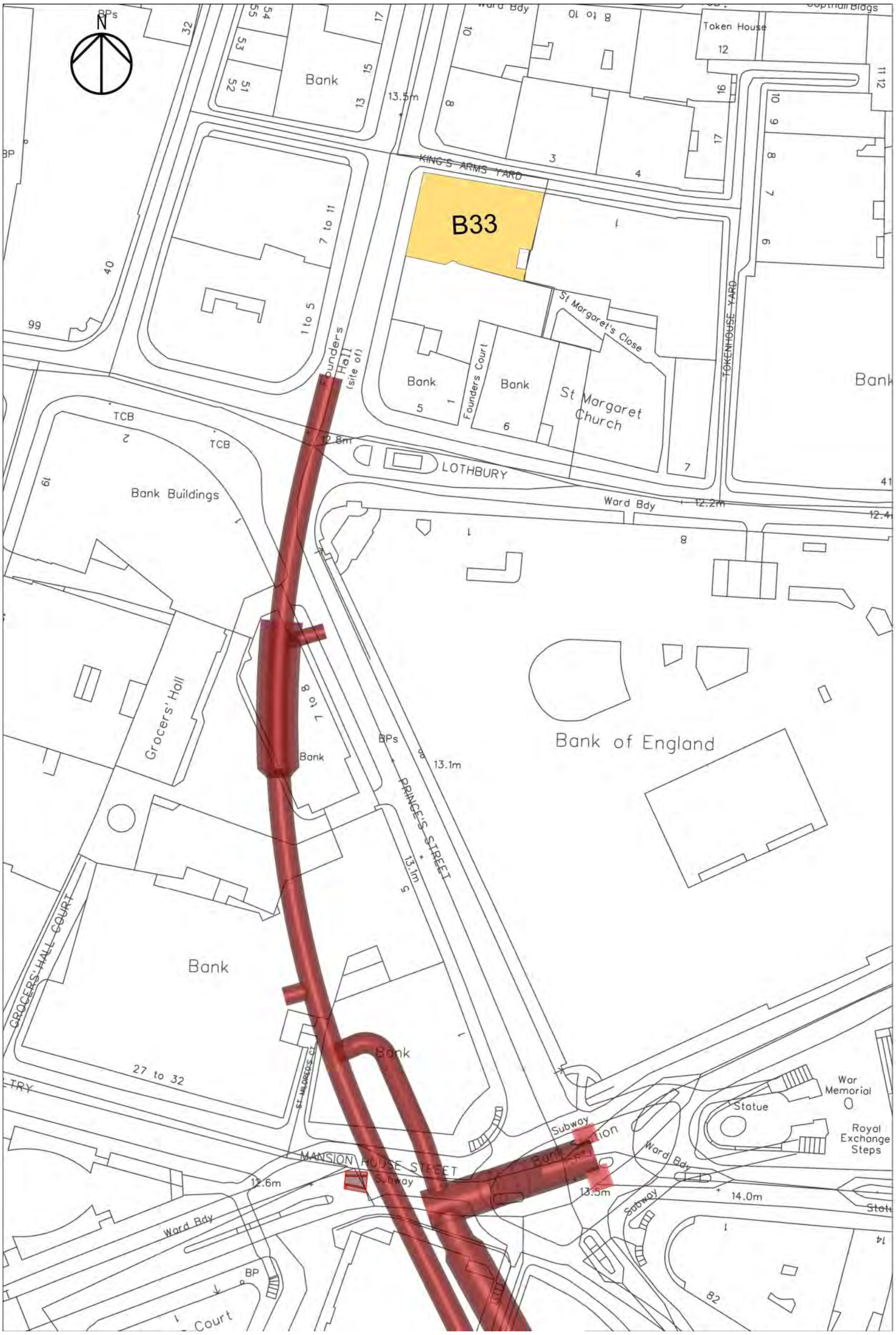

Figure 2: Location plan showing building location in relation to BSCU works

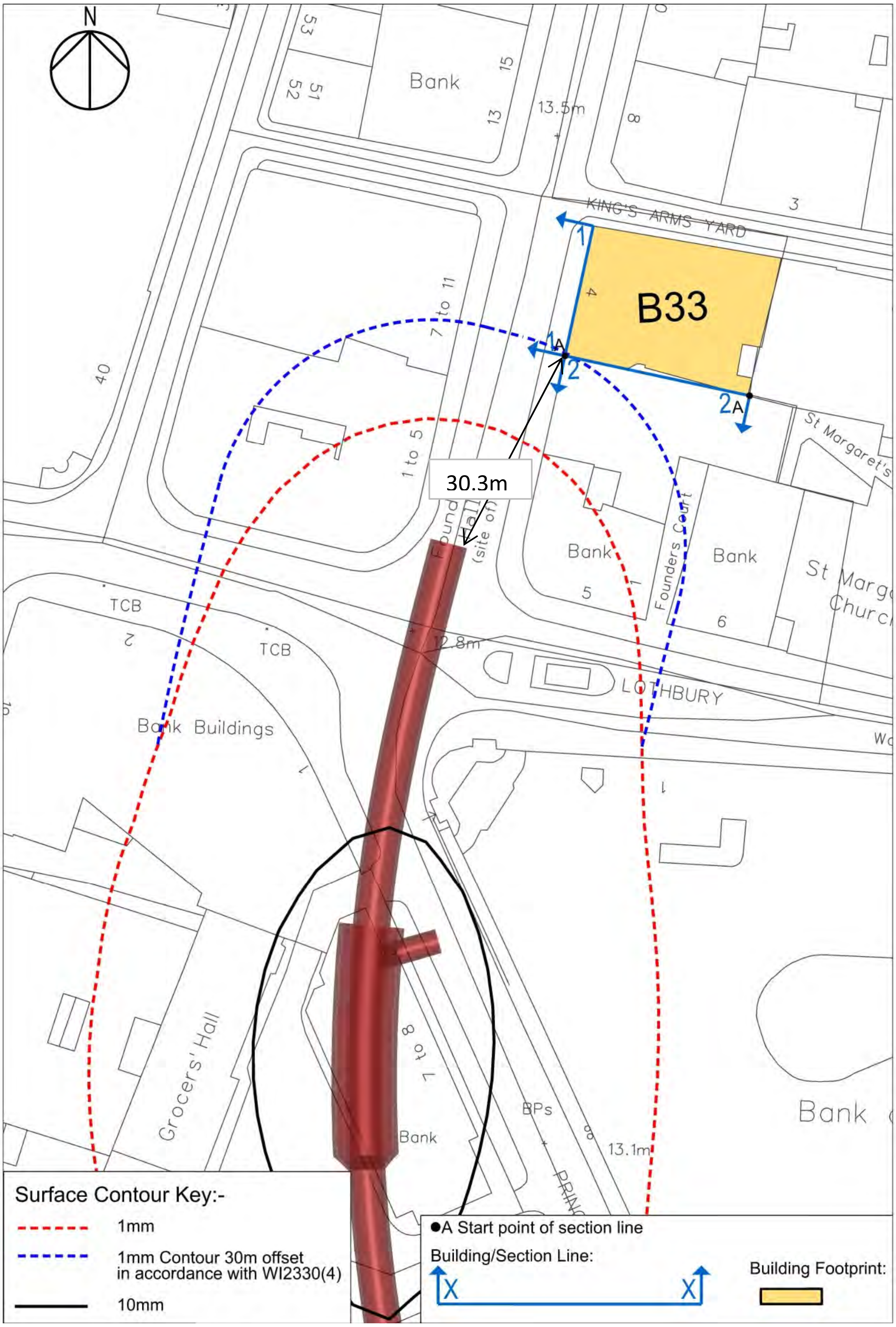

Figure 3: Building location, sections analysed and Settlement Contours at stage of worst case for tensile strains

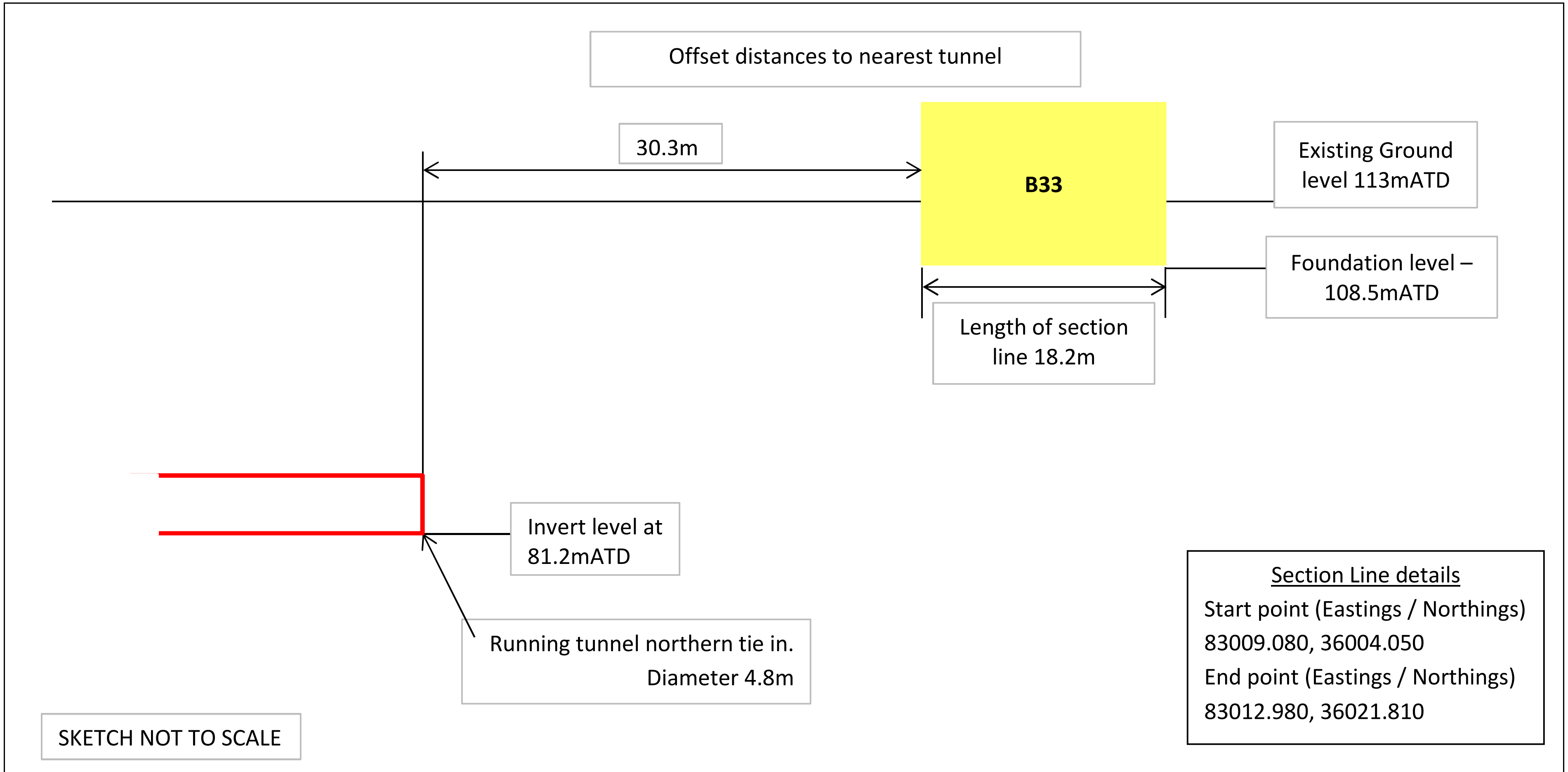

Figure 4: Diagrammatic cross-section of section (line 1) relative to tunnel position

DRAGADOS

Safely Together

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Bank Station Capacity Upgrade

Building Damage Assessment Report

Building B34

7 – 11 Moorgate

URS-8798-RPT-G-001224

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Document History

Revision	Date	Summary of changes
1.0	March 2014	Issue for Heritage
2.0	April 2014	For Approval
3.0	July 2014	TWAO Issue

For the status of this document, please refer to the Building Damage Assessment Report Register (URS-8798-RGT-001229)

Consultation:

• Ela Palmer	URS Heritage
• Brian Lyons	Dr.Sauer
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Contents

FIGURES

TABLES

1 Introduction

This report summarises the results of a Stage 2 damage assessment for Basildon House at 7-11 Moorgate (Building ref: B34).

Stage 2 damage assessments are undertaken for all buildings within the Stage 1 Greenfield ground surface 1mm settlement contour induced by the construction of the Bank Station Capacity Upgrade (BSCU).

The purpose of the assessment is to determine the potential impact that the works will have on the building. This report describes the engineering and heritage assessments undertaken for the building and concludes whether mitigation is likely to be needed and if a further (Stage 3) assessment is recommended in order to verify this.

2 The Building

2.1 General Information

Basildon House at 7-11 Moorgate is a Grade II listed building. The general building information used in the assessment has been acquired as part of the structural desktop appraisal. Where data was not available, conservative assumptions have been made instead. This information is presented in Table 1.

Category	Building Information
BSCU Reference	B34
Location	Moorgate
Address	7-11 Moorgate (Basildon House)
Building Type	Steel Framed (assumed)
Construction Age	1897 - 1899
No. of Storeys	7
Basements	2 (assumed)
Eaves Level (mATD)	148.4
Foundation Type	Shallow foundation (assumed)
Ground Level (mATD)	113.4
Listed Grade	II
Note: Levels given are in metres above Tunnel Datum, mATD. Tunnel Datum is 100m below Ordnance Survey Datum at Newlyn.	

Table 1: General building information

A general view of the building exterior is shown in Plate 1. A location plan showing the building in relation to the proposed BSCU works is presented in Figure 2.

Plate 1: General view

2.2 Building Description

Attributed to Gordon, Lowther & Gunton Architects and constructed circa 1897-9, 7-11 Moorgate used as multi-occupancy commercial building. The building is Grade II listed and it is enclosed by Kings Arms Yard and Coleman Street with its frontage facing Moorgate.

The structure above ground is constructed with a steel frame and brick masonry with independent Portland stone and brick masonry facades. The steel frame is believed to extend below ground level, together with reinforced concrete and brick masonry construction. The building is arranged over 5 storeys with two additional attic storeys set back from the street and two lower ground levels with a part 3rd sub-level (switch room). The façades on Kings Arms Yard and Coleman Street are set back from the roads behind a retaining wall structure.

At ground level the façade is of pink granite, and at first floor this is Portland stone with polished granite columns. Three storeys of large oriel windows exist centrally in each elevation.

Internally the building has been renovated to offer a series of large open plan office spaces and smaller meeting rooms which are arranged around the central staircase and twin lifts.

No information has been provided on the foundations to the building. The likely construction is the existing façade resting on its original mass concrete strip footings shared with the lower ground levels over a raft or a grillage of steel beams under the steel columns.

According to the planning portal information various upper floors were replaced circa 1987, and the central staircase and lift core were replaced in 1990 following a fire.

3 Methodology

This building damage assessment is undertaken in accordance with LU Works Information WI2300[1] and LU Civil Engineering - Common Requirements S1050[2].

The analysis methodology applies to ground-bearing buildings which will be affected by ground movements resulting from the construction of the BSCU. The engineering assessment calculates the potential impact of ground movements and assigns a damage category to the building based on a numeric scale. Additionally, for listed buildings, a heritage assessment is carried out which considers the sensitivity of the structure and the sensitivity of its particular features; a heritage sensitivity score is assigned. The heritage sensitivity score is added to the damage category to obtain the total score. If the total score is 3 or more, a more detailed Stage 3 assessment is triggered.

Oasys Xdisp is used to analyse the Greenfield ground movement in terms of settlement and horizontal displacement. Subsurface tunnelling induced ground movement profiles are determined in accordance with the methodology described by Mair et al[3 & 4].

Movements resulting from the Whole Block Scheme (WBS) and shaft excavations have been calculated using LU Guidance Document G0058[5].

The building is modelled as a simple elastic beam which is conservatively assumed to follow the Greenfield ground displacements. The beam is divided into hogging and sagging segments. The tensile strains within each segment are calculated based on the distortion associated with differential settlement (which is characterised by deflection ratio) and the distortion associated with differential horizontal displacement (characterised by horizontal strain).

Xdisp provides a method for calculating the maximum tensile strain within the building superstructure associated with these movements, in accordance with the assessment methodology described by Mair et al [4]. This strain is used to determine the damage category based on the classification system proposed by Burland[6] and in accordance with LU Civil Engineering - Common Requirements S1050[2]. The categories are presented in Table 2.

Damage Category	Description of Degree of Damage	Description of Typical Damage and likely forms of Repair for Typical Masonry Buildings.	Approx. Crack Width (mm)	Max. Tensile Strain %
0	Negligible	Hairline cracks.		< 0.05
1	Very slight	Fine cracks easily treated during normal redecoration. Perhaps isolated slight fracture in building. Cracks in exterior visible upon close inspection.	0.1 to 1.0	0.05 to 0.075
2	Slight	Cracks easily filled. Redecoration probably required. Several slight fractures inside building. Exterior cracks visible; some repainting may be required for weather-tightness. Doors and windows may stick slightly.	1 to 5	0.075 to 0.15
3	Moderate	Cracks may require cutting out and patching. Recurrent cracks can be masked by suitable linings. Tuck pointing and possible replacement of a small amount of exterior brickwork may be required. Doors and windows sticking. Utility services may be interrupted. Weather tightness often impaired.	5 to 15 or a number of cracks > 3	0.15 to 0.3
4	Severe	Extensive repair required involving removal and replacement of walls especially over doors and windows. Window and door frames distorted. Floor slopes noticeably. Walls lean or bulge noticeably. Some loss of bearing in beams. Utility services disrupted.	15 to 25 but also depends on number of cracks	> 0.3
5	Very severe	Major repair required involving partial or complete reconstruction. Beams lose bearing, walls lean badly and require shoring. Windows broken by distortion. Danger of instability.	Usually > 25 but depends on number of cracks	
Note: Please refer LU Civil Engineering - Common Requirements S1050[2].				

Table 2: Building damage classification

4 Input Data

The magnitude and distribution of ground movements and degree of building damage are calculated based on the following input data:

- The Xdisp model coordinates and levels are based on the 3D model (20130212DSPITT Scheme R09);
- Four construction stages are considered in accordance with the proposed programme (November 2013) as illustrated in Figure 1;
- Trough width parameter constant, K=0.5 is used in accordance with WI2300[1]

The input data for the building, tunnels and shaft excavation are summarised in Table 3, Table 4 and Table 5 respectively.

Location	Foundation level (mATD)	Building Height above foundation level (m)	E/G
7-11 Moorgate Street	105.9*	42.5	12.5
Note: Where E / G is the ratio of Young's modulus to shear modulus of the deep beam representing the building. * Assumed level, 1.5m thick slab beneath floor level.			

Table 3: Building data

Tunnel Item	Level of axis (mATD)	External diameter (m)	Volume Loss (%)
Running tunnel	Inclined (82.9 to 85.8)	5.4	1.5
Running tunnel northern tie in	Inclined (83 to 83.6)	4.8	1.5
Square works adits	75.8 to 95.3	4.1 to 7.8	2.5
Platform enlargement	85.6	7.4 to 11.2	1.5
Tunnel enlargement	Inclined (82.9 to 83)	8	1.5
Escalator barrels	Inclined	8.3 to 8.4	1.5
Central Line Connection	Inclined (87.6 to 89.2)	8.6	1.5

Table 4: Tunnel data

Excavation	Excavation Base Level (mATD)
Grout Shaft at King William Street	97
Whole Block Scheme Box excavation	73
Arthur Street Shaft	81

Table 5: Shaft excavation data

The distance of building 7 – 11 Moorgate (B34) relative to the excavation elements listed in Table 5 is sufficiently large that the building should not be affected by their construction.

The Xdisp model filenames used to undertake this assessment are:

- B34 - Stage 4
- B34 - Stage 3
- B34 - Stage 2
- B34 - Stage 1

5 Results

5.1 Engineering Assessment

The sections through the building which have been analysed are shown on plan in Figure 3.

Assessment has been undertaken at three intermediate construction stages and at the end of construction when all major elements of the works including shaft and tunnels have been completed. The damage category assigned to the building is based on the construction stage at which the potential impact on the building is most severe.

The maximum settlement and tensile strain calculated for each of the analysis sections at the most onerous intermediate construction stage and at the end of construction are presented in Table 6 and Table 7.

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
B34 (line 1)	<1	<0.001
B34 (line 2)	<1	<0.001

Table 6: Building response at most onerous intermediate stage - Construction Stage 2

Section	Maximum Settlement (mm)	Maximum Tensile Strains (%)
B34 (line 1)	<1	0.001
B34 (line 2)	<1	<0.001

Table 7: Building response at end of construction stage

The results of the assessment show that construction Stage 4 is the critical stage for this building due to construction of running tunnel northern tie-in. Section B34 (line 1) experiences the most onerous combined tensile strain. The orientation of the building is shown in Figure 2. The relative position of the building and tunnels along section line 1 is shown in Figure 4. The calculated strains are summarised in Table 8.

Strains in section (Curvature)	Position from start (m)	Length (m)	Average* Horizontal Strain (%)	Maximum Tensile Strains (%)	Damage Category
Hogging	0.0	22.1	<0.001	0.001	Negligible
Note: * Tensile horizontal strains are +ve. Compressive horizontal strains are –ve.					

Table 8: Section analysed, results for worst case tensile strain

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0. This corresponds to negligible damage in accordance with Table 2.

The maximum settlement of the building at foundation level at the end of construction is less than 1mm.

5.2 Heritage and Structural Assessment

Following site inspection, assessment has been made using the following scoring methodology as set out in Table 9.

Score	STRUCTURE Sensitivity of the structure to ground movements and interaction with adjacent buildings	HERITAGE FEATURES Sensitivity to calculated movement of particular features within the building	CONDITION Factors which may affect the sensitivity of structural or heritage features
0	Masonry buildings with lime mortar and regular openings, not abutted by other buildings, and therefore similar to the buildings on which the original Burland assessment was based.	No particular sensitive features	Good/Fair - not affecting the sensitivity of structural or heritage features
1	Buildings not complying with categories 0 or 2, but still with some sensitive structural features in the zone of settlement e.g.: cantilever stone staircases, long walls without joints or openings, existing cracks where further movements are likely to concentrate, mixed foundations	Brittle finishes, e.g. faience or tight-jointed stonework, which are susceptible to small structural movements and difficult to repair invisibly.	Poor - may change the behaviour of a building in cases of movement. Poor condition of heritage features and finishes. Evidence of previous movement.
2	Buildings which, by their structural form, will tend to concentrate all their movements in one location (e.g.: a long wall without joints and with a single opening).	Finishes which if damaged will have a significant effect on the heritage value of the building, e.g. Delicate frescos, ornate plasterwork ceilings.	Very poor – parlous condition of heritage features and finishes, severe existing damage to structure including evidence of ongoing movement. Essentially buildings where even very small movements could lead to significant damage.

Table 9: Heritage and structural scoring methodology

The results of the heritage assessment carried out for the building are summarised in Table 10.

SENSITIVITY OF THE STRUCTURE
The structure of the building is framed with a large number of openings above ground floor level, which can reduce the overall stiffness of the building. The replacement lift cars are enclosed in glass and shared with the central staircase. The lift core does not contribute to the stiffness of the building. Most of the upper floors to the building are believed to be of modern composite concrete construction, with only the façade retained from the earlier phases of construction. Due to the absence of available archive drawings from the 1980's refurbishment works it is not possible to determine how the façade is connected to the perimeter retaining wall structure. It is possible that little or no allowance for differential movement between the façade and the new structure behind was made. At the party wall junction with 3-4 Lothbury there is a tall and slender chimney stack housing seven flues that protrudes out of the mansard roof at 5th floor. This is a vulnerable feature due to the slenderness of the chimney and the unknown degree of connectivity between the adjoining buildings.
Score: 0 - The predicted settlement is very small, and therefore despite the doubt regarding the degree of fixity between the façade and the structure behind it is not considered that the building is structurally sensitive.
SENSITIVITY OF THE HERITAGE
The building has been subject to complete internal renovation, which has left minimal surviving heritage features. Externally, the masonry façade has decorative elements, however they will not be sensitive to the predicted settlement which is very small.
Score: 0 – The surviving heritage features will not be sensitive to the predicted settlements
SENSITIVITY OF THE CONDITION
The building as is now appears to be in very good condition. During the site walkover it was not possible to identify any defects that might be exacerbated by settlement. There was no evidence of cracked, deformed or newly repaired masonry.
Score: 0 - The condition of the building in general and the exterior in particular was found to be in good order, with no signs of active movement or unusual disrepair.

Table 10: Heritage and structural assessment

5.3 Total Score

The total score is the summation of the damage category, structural sensitivity, heritage sensitivity and condition sensitivity scores:

The damage category is 0

The structural sensitivity score is 0

The heritage sensitivity score is 0

The condition sensitivity score is 0

The total score for this building is 0

6 Conclusion

The Stage 2 engineering assessment has predicted that the maximum tensile strain falls within damage category 0 for 7-11 Moorgate. Specific heritage and structural assessment taking into account the location and extent of settlement and tensile strains highlights the buildings very low level of structural and heritage sensitivity to movement. This assessment has determined that the building has a total score of 0.

7-11 Moorgate is located to the north of the Bank Station Capacity Upgrade tunnelling works, beyond the 1mm contour but touching the 30m Offset Line. These works are predicted to result in negligible settlement which is not expected to result in ground movement or damage to the heritage finishes and features of the building.

It is recommended that the building does not require a Stage 3 assessment.

7 References

[1] LU Works Information WI 2300 Ground Movement version 3, 19-07-13.

[2] LU Category 1 Standard: S1050 Civil Engineering - Common Requirements, Issue No. A7, Nov. 2013.

[3] Mair R J, Taylor R N and Bracegirdle A (1993). Subsurface settlement profiles above tunnels in clays. Géotechnique 43, No. 2, pp. 315-320.

[4] Mair R J, Taylor R N and Burland J B (1996). Prediction of ground movements and assessment of risk of building damage due to bored tunnelling. (In: International Conference of Geotechnical Aspects of Underground Construction in Soft Ground, London, pp. 713–718.

[5] LU Guidance Document G0058 Civil Engineering Technical Advice Notes, Issue No. A17, Feb. 2013.

[6] Burland J B (1995). Assessment of risk of damage to buildings due to tunnelling and excavation. Proceedings: 1st International Conference of Earthquake Geotechnical Engineering, IS Tokyo, 1995.

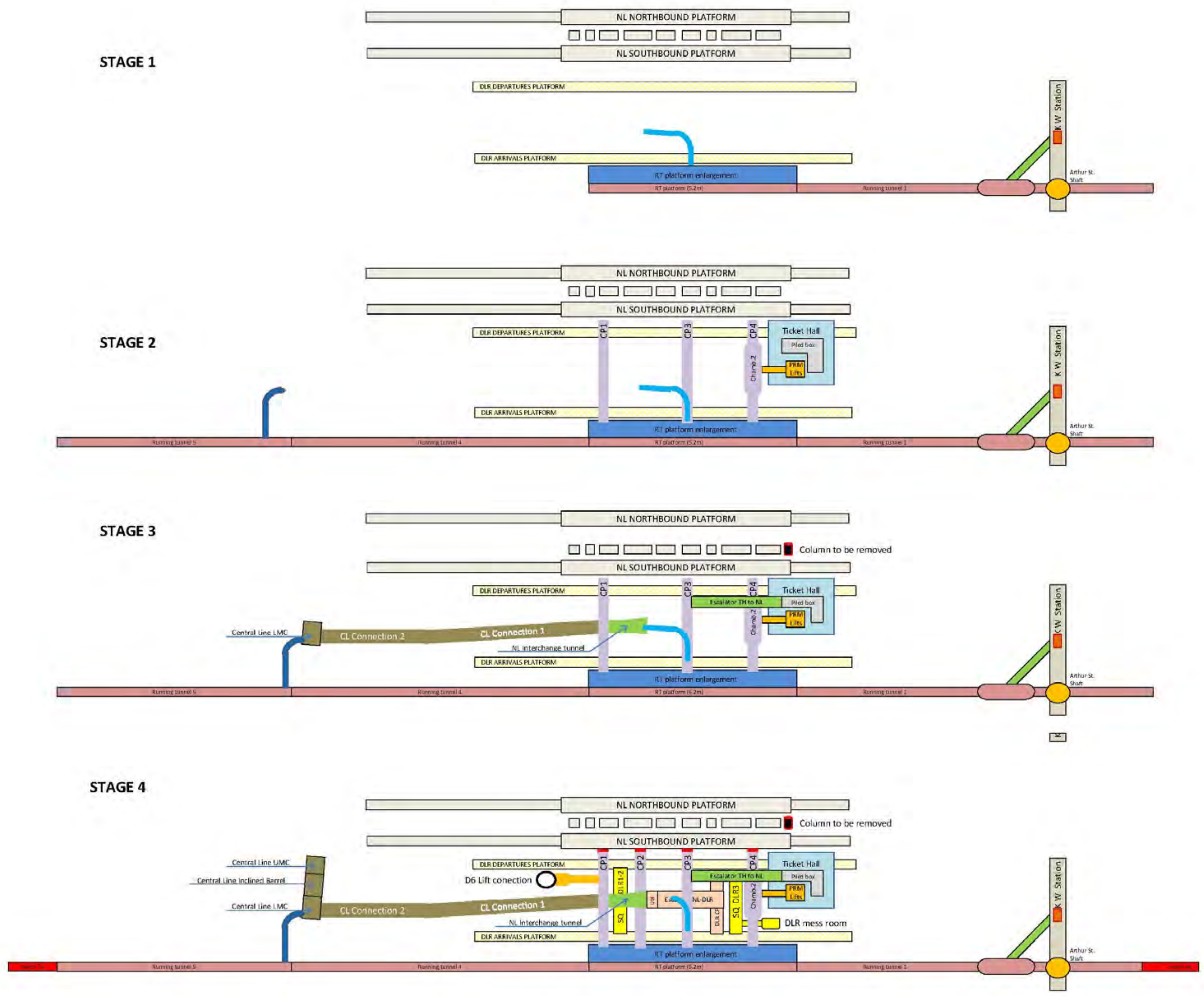

Figure 1: Construction Stage model

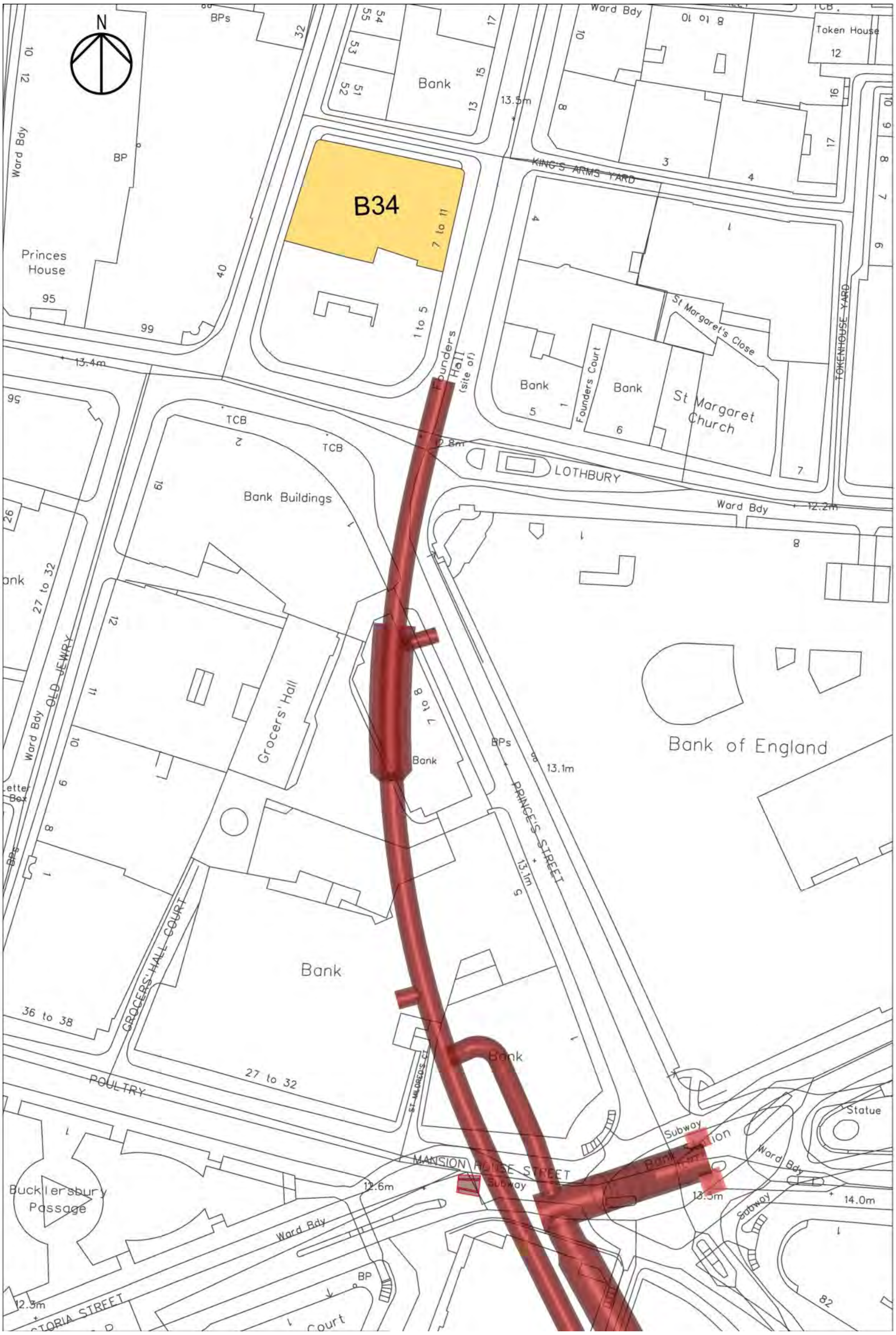

Figure 2: Location plan showing building location in relation to BSCU works

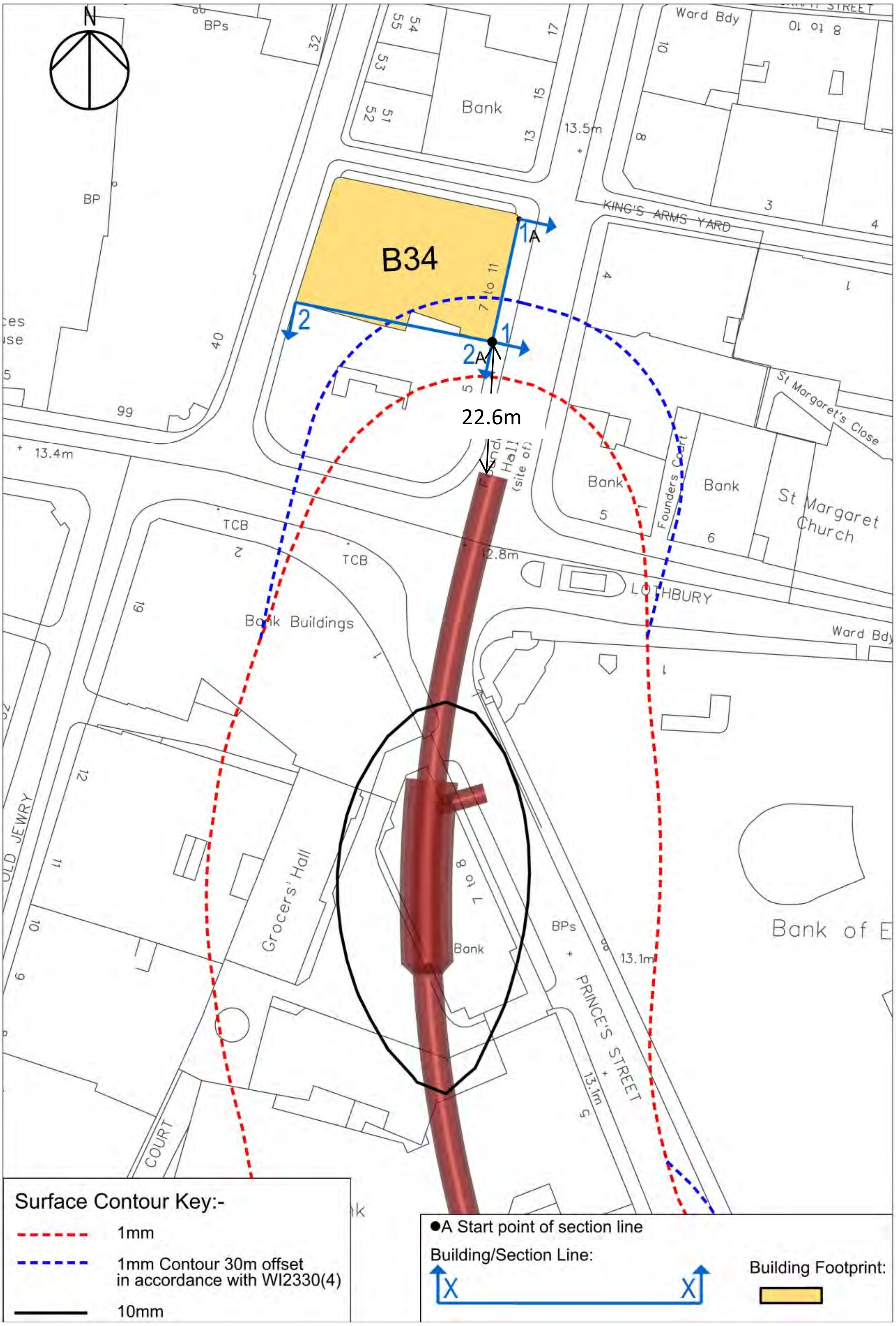

Figure 3: Building location, sections analysed and Settlement Contours at stage of worst case for tensile strains

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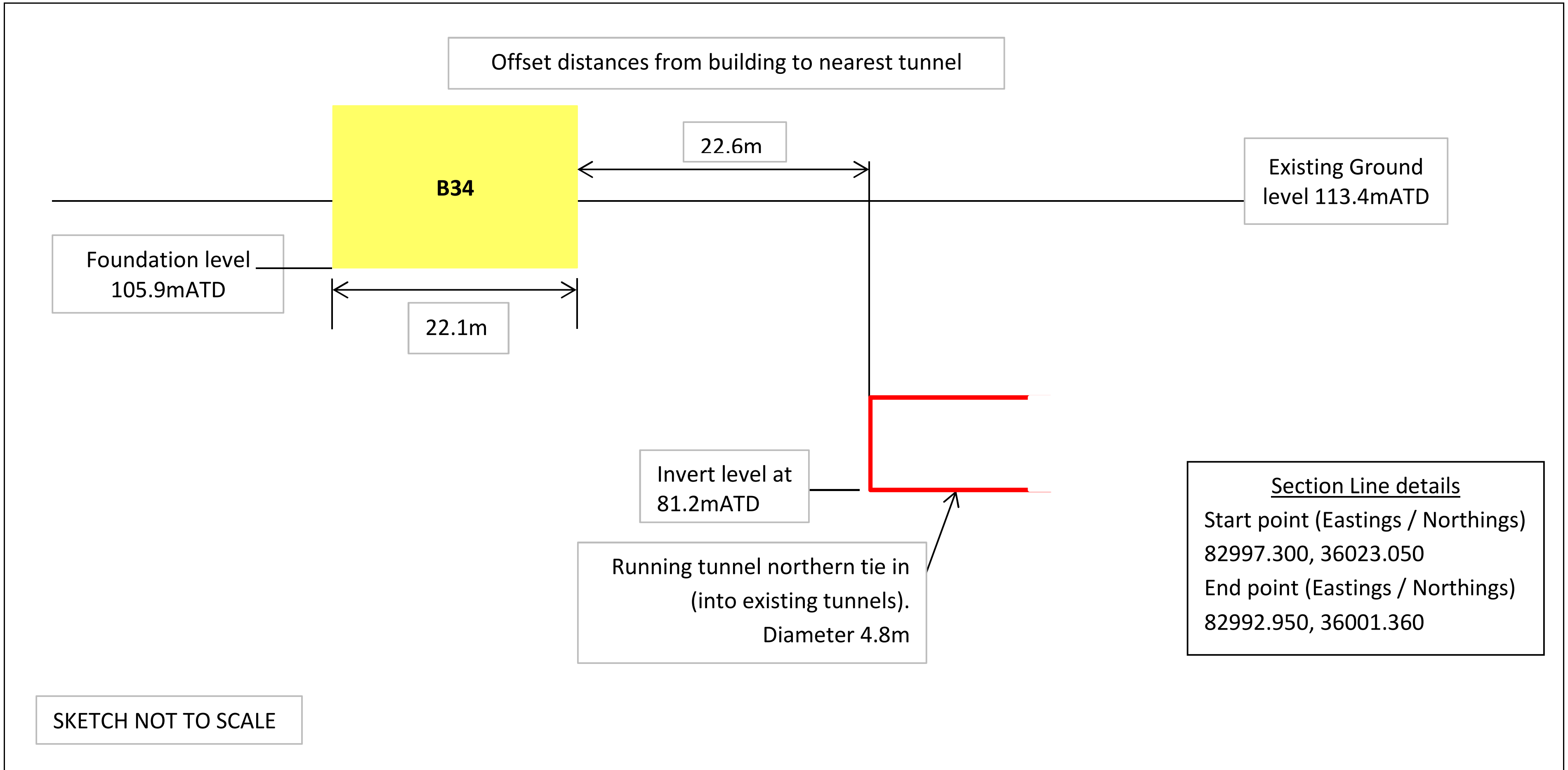

Figure 4: Diagrammatic cross-section of section (line 1) relative to tunnel position