Application for Development Consent
Application Reference Number: WWO10001

Tunnel and Bridge Assessments
Central Zone
UK Power Networks Bankside Cable Tunnel
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Dear Mr. Milner

Subject  Non-objection to Interfaces

Further to your e-mail dated 3rd January and following a review of your reports I am pleased to confirm that UK Power Networks have no objection in principle to the works and monitoring interfaces detailed to date provided that:

1) Method statements are submitted before implementation of the Thames Tunnel crossing beneath the UKPN assets.
2) Proposals for instrumentation and monitoring are agreed before implementation of the Thames Tunnel crossing beneath the UKPN assets.
3) Pre and Post condition surveys of the tunnel are undertaken and agreed to record the final condition of the tunnel.
4) An appropriate Asset Protection Agreement is entered into between us to document the above arrangements and ensure protection of UK Power Networks assets to our satisfaction.

Please do not hesitate to contact me if you require any further information.

Yours sincerely

Mark Dunk

Name:  Mark Dunk
Title:  Civil Standards Manager
Email:  Mark.dunk@ukpowernetworks.co.uk
1 Executive summary

Thames Water is currently progressing with its planned Tideway improvements. The improvement works consists of the construction of two new tunnels, the Thames Tunnel and the Lee Tunnel, together with a programme of sewer upgrades. Construction of the proposed Thames Tunnel (TT), an 8.1m – 8.8m excavated diameter tunnel, stretching approximately 23km for much of its route under the River Thames from West London to Abbey Mills is due to commence in 2016.

This report assesses the likely ground movements that may arise from construction of the Thames Tunnel works and the impacts on the UK Power Networks (UKPN) Bankside Cable Tunnel. The Thames Tunnel will pass directly beneath the Bankside cable tunnel with a vertical clearance of approximately 20m. The interface is located below the River Thames near the north bank in the borough of Westminster.

Using conservative estimates of the likely ground movements that may arise from construction of the Thames Tunnel works, the impact on the Bankside Cable Tunnel has been assessed. The calculations indicate that the tunnel will settle by a maximum of 16.7mm and be subjected to a minimum radius of curvature of approximately 12.8km.

The assessment has been based on a number of assumptions regarding the tunnel lining material, properties and geometry. Additional information on the tunnel lining geometry was obtained during a visual inspection carried out on the 1st December 2011. The visual inspection indicated that the concrete tunnel segments are in a very good condition. The tunnel was dry at the time of the inspection and there were only limited signs of previous water ingress. A number of the expanded segments show cracks which are likely to have developed during construction. However all cracks have been repaired and it is not believed that the cracks will impact adversely on the structural capacity of the lining.

The current assessment indicates that the impact on the Bankside Cable Tunnel in both transverse and longitudinal direction is within the existing lining capacity. The radial deformations have been assessed using standardised methods and the resulting bending moments and hoop thrusts have been assessed to be within acceptable limits. In the longitudinal direction, the imposed distortions will result in the potential for opening up of tunnel joints. Conservative estimates indicate that a gap of no more than 0.6mm could potentially open up between the rings. Since the UKPN tunnel is founded in the relatively impermeable London Clay, it is not anticipated that opening up of these joints will result in a significant change in the amount of water ingress that is currently taking place into the tunnel.
2 Introduction

2.1 Site Description

The interface of the proposed Thames Tunnel and the Bankside cable tunnel is located below the River Thames near the north bank, close to Blackfriars Station. The interface of the Thames Tunnel with the Bankside cable tunnel is at approximate Thames Tunnel chainage 16620m and UKPN chainage 575m (assuming 0m chainage starts at the Bankside shaft).

The river bed level at the interface is at approximately 92mATD (ATD = Above Tunnel Datum: 0mATD = -100 Ordnance Datum OD).

At the Thames Tunnel interface, the proposed 8.8m diameter Thames Tunnel will pass directly beneath the Bankside cable tunnel with a vertical clearance of approximately 20m. The Thames Tunnel crosses the UKPN tunnel at an angle of approximately 78° with 90° being a perpendicular interface.

Drawings obtained from the Thames Tunnel project team indicates that the Bankside tunnel consists of a 2.59m internal diameter segmental concrete lined tunnel. Photographic evidence suggests that the lining is unbolted at this location and this was confirmed during the visual inspection, however, bolted segments were also observed where the UKPN alignment is curved.

The site location and position of the Thames Tunnel interface is shown in Figure 1 and Figure 2.

![Figure 1: Plan of the Thames Tunnel (blue) and the crossing with the UKPN Bankside Cable Tunnel.](image-url)
Figure 2: Section on interface of UKPN Bankside Cable Tunnel and Thames Tunnel
3 Structure Details

3.1 Asset Details

The Bankside cable tunnel is owned and operated by UKPN. The tunnel runs from the Bankside shaft, south of the river, to a shaft near Farringdon north of the river.

Limited information about the asset has been obtained from archive drawings and Thames Tunnel alignment drawings received from the Thames Tunnel project team. Further information was also gathered from a visual inspection undertaken on the 1st December 2011. The information is summarised below in Table 1.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asset Name</td>
<td>Bankside Cable Tunnel</td>
</tr>
<tr>
<td>Asset Owner</td>
<td>UKPN</td>
</tr>
<tr>
<td>Built</td>
<td>2003-2005</td>
</tr>
<tr>
<td>UKPN Chainage at interface</td>
<td>Approximately 575m</td>
</tr>
<tr>
<td>Dimensions</td>
<td>2.59m ID</td>
</tr>
<tr>
<td>Type</td>
<td>Segmental concrete lining (expanded and bolted)</td>
</tr>
<tr>
<td></td>
<td>8 segments/ring (7 + 1 Key)</td>
</tr>
<tr>
<td>River Bed Level</td>
<td>92.00m ATD</td>
</tr>
<tr>
<td>Crown Level</td>
<td>81.7m ATD</td>
</tr>
<tr>
<td>Invert Level</td>
<td>79.1m ATD</td>
</tr>
<tr>
<td>Available/received Surveys</td>
<td>Visual inspection carried out by Arup on the 1st December 2011.</td>
</tr>
</tbody>
</table>

The material properties of the lining and whether the lining is reinforced or not, cannot be determined based on the available information. This additional information has been requested from UKPN but has not been received at the time of writing. In order to undertake the structural assessment, parameters are based on data for standard precast segmental linings of the same diameter as specified in Section 4.

A risk register included in Appendix C outlines assumed lining assumptions.

3.2 Asset Condition

The visual inspection indicated that the precast concrete segments are in very good condition and the tunnel was dry at the time of the inspection. A number of the expanded segments, predominantly key and shoulder segments, show signs of hairline cracks which are likely to have developed during construction. However, the cracks have been repaired and it is not believed that the cracks will impact adversely on the structural capacity of the lining. Findings from the inspection have been summarised in the inspection report in Appendix D.
3.3 Thames Tunnel Details

3.3.1 Construction programme

A detailed construction programme for the bored tunnel is yet to be confirmed, however, it is understood that construction work is due to start in 2016.

3.3.2 Thames Tunnel main tunnel

The main Thames Tunnel at the Bankside cable tunnel interface is currently planned to be 7.2m internal diameter with a primary and secondary lining giving an effective 8.5m external diameter and an excavated cut diameter of 8.8m.

The Thames Tunnel in this location is anticipated to be constructed using an Earth Pressure Balance (EPB) style or Slurry style Tunnel Boring Machine (TBM), using a precast segmental lining. The tunnel axis is at approximately 54.6m ATD and the TBM is anticipated to encounter only the Lambeth Group stratum at the interface with the UKPN tunnel.
4 Material Properties

4.1 Lining Details

Since no as-built information has been provided at the time of the assessment, certain key parameters are based on typical material properties for standard pre-cast segmental tunnel linings. The assumed parameters will have to be confirmed by the asset owner. Available data from drawings and from the visual inspection are summarised in Table 2 below.

Table 2: Tunnel lining geometry and assumed key parameters

<table>
<thead>
<tr>
<th>Dimensions/properties</th>
<th>Value</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tunnel internal diameter</td>
<td>2590mm</td>
<td>1,2</td>
</tr>
<tr>
<td>No segments</td>
<td>8 (7 + 1 Key)</td>
<td>1,2</td>
</tr>
<tr>
<td>Segment type</td>
<td>Pre-cast concrete (expanded and bolted segments)</td>
<td>2</td>
</tr>
<tr>
<td>Segment width</td>
<td>1000mm</td>
<td>2</td>
</tr>
<tr>
<td>Lining Thickness (measured through exposed lifting hole pocket)</td>
<td>180mm</td>
<td>2</td>
</tr>
<tr>
<td>Characteristic strength of the concrete</td>
<td>40 N/mm²</td>
<td>3</td>
</tr>
<tr>
<td>Short term Young's modulus of concrete</td>
<td>3522.0 MN/m²</td>
<td>3</td>
</tr>
<tr>
<td>Dependent on the number of joints between segments, the ring lining stiffness will be reduced (Muir Wood effective second moment of area)</td>
<td>7 joints</td>
<td></td>
</tr>
<tr>
<td>Steel reinforcement</td>
<td>0 % (unreinforced)</td>
<td>3</td>
</tr>
</tbody>
</table>

Notes:
1. Drawings received from UKPN.
2. Visual inspection carried out on the 1st December 2011 as part of the Thames Tunnel project.
3. Assumed parameters based on typical material properties for standard pre-cast segmental tunnel linings.

4.2 Ground Conditions

A review of available borehole logs has been undertaken in order to establish ground conditions at the Thames Tunnel interface. The review has also assessed whether geological features such as scour hollows are likely to be present that may affect the tunnel construction. It is important to establish whether geological anomalies are present since it can impact on tunnelling construction and the volume loss which can be achieved.

The geological sequence at the proposed main Thames Tunnel / Bankside cable tunnel crossing is based on borehole SR2045 and SR2047 located in the River Thames, about 250m either side of the crossing. These boreholes were drilled by Fugro in June/August 2010 as part of the Thames Tunnel – Phase 2 Project.
A summary of the borehole log indicates that the geological sequence comprises River Terrace Deposits, London Clay Formation, Harwich Formation, Lambeth Group Formation, Thanet Sand Formation and Seaford Chalk Formation.

The Bankside cable tunnel, with a crown level at 81.7m ATD and an invert level at 79.1m ATD lies entirely within the London Clay stratum. The Thames Tunnel, with an axis level at approximately 54.6m ATD lies entirely within the Lambeth Group stratum. The borehole shows no indications of geological anomalies such as gravel infilled deposits extending in to the London Clay.

The geological cross-section is shown in Figure 2 and the stratigraphy is summarised in Table 3.

Table 3: Summary of Ground Conditions

<table>
<thead>
<tr>
<th>Geological formation and stratigraphy</th>
<th>SR2045 approximate level (mATD)</th>
<th>SR2047 approximate level (mATD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Made Ground</td>
<td>93.9 – 89.9</td>
<td>93.8 – 93.3</td>
</tr>
<tr>
<td>Quaternary</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Palaeogene</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eocene</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thames Group</td>
<td></td>
<td></td>
</tr>
<tr>
<td>River Terrace Deposits</td>
<td>89.9 – 70.9</td>
<td>93.3 – 67.4</td>
</tr>
<tr>
<td>London Clay Formation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Harwich Formation</td>
<td>67.4 – 67.2</td>
<td></td>
</tr>
<tr>
<td>Palaeocene</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lambeth Group</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reading Formation</td>
<td>70.9 – 63.8</td>
<td>67.2 – 65.1</td>
</tr>
<tr>
<td>Upper Mottled Beds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Woolwich Formation</td>
<td>63.8 – 62.7</td>
<td>65.1 – 57.7</td>
</tr>
<tr>
<td>Laminated beds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reading Formation</td>
<td>62.7 – 54.7</td>
<td>57.7 – 50.6</td>
</tr>
<tr>
<td>Lower Mottled Beds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thanet Sand Formation</td>
<td>54.7 – 51.5</td>
<td>50.6 – 48.1</td>
</tr>
<tr>
<td>Upnor Formation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thanet Sand</td>
<td>51.5 – 43.7</td>
<td>48.1 – 38.4</td>
</tr>
<tr>
<td>Formation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bullhead Beds</td>
<td>43.7 – 43.1</td>
<td>38.4 – 38.1</td>
</tr>
<tr>
<td>Cretaceous</td>
<td></td>
<td></td>
</tr>
<tr>
<td>White Chalk Subgroup</td>
<td>43.1 – 28.2 (END)</td>
<td>38.1 – 18.6 (END)</td>
</tr>
<tr>
<td>Seaford Chalk Formation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>White Chalk Subgroup</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5  Assessment Criteria

5.1  Ground Movement Assessments

The ground movement assessment of the UKPN tunnel has assessed end of construction displacements caused by construction of the Thames Tunnel. The magnitude and distribution of these ground movements are a function of many factors such as geotechnical properties of the ground, construction sequence and program, and the overall standard of workmanship.

The assessment of ground movement assumes that a ‘high standard of workmanship’ is adopted by the Contractor. This is assured by review and approval by all relevant parties of the contractors’ method statements. Nonetheless, a conservative approach has been adopted in the selection of input parameters, with the result that this assessment represents a ‘moderately conservative’ estimate of ground movement effects.

5.2  Analytical method

Sub-surface Greenfield ground movements are calculated using empirical methods (Mair et al., 1993 and Taylor, 1995) where a settlement trough perpendicular to the new tunnel can be estimated using an inverted normal probability curve (Gaussian curve). The three dimensional form of movement is calculated using the Attewell & Woodman (1982) methodology.

Unless otherwise stated ground movements discussed in this report represent “Greenfield” values – that is, it is assumed that overlying or adjacent structures have no influence on the magnitude or distribution of the estimated movements at foundation level. This is a conservative, simplifying assumption and the stiffness of individual structures and their depth of embedment may reduce structural deformations.

The estimated ground movements at the asset location are derived from the Oasys software Xdisp.

5.3  Assessment assumptions

The borehole review, described in Section 4.2, confirms that the UKPN cable tunnel is located within the London Clay. The Thames Tunnel is located within the Lambeth Group stratum. Since there is no evidence from the borehole review that scour hollows or other geological anomalies are present, the “moderately conservative” volume loss parameter as specified by the Thames Tunnel project team is deemed appropriate for the ground movement assessment.

<table>
<thead>
<tr>
<th>Assessment parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume Loss (Thames Tunnel main tunnel)</td>
<td>1.0%</td>
</tr>
<tr>
<td>Trough width parameter (K) at ground surface</td>
<td>0.5</td>
</tr>
</tbody>
</table>
5.4 Ground movement estimates for structural assessment

In order to determine the imposed deformation of the UKPN cable tunnel for the structural assessment in Section 6, ‘Greenfield’ vertical ground movements have been calculated along the tunnel at levels corresponding to the crown and invert. These levels are intrados positions of the tunnel. The estimated settlement along the UKPN tunnel is presented graphically in Figure 3.

The estimated ground movements have been used to assess the following tunnel deformations, assuming the tunnel moves freely with the ground:

- Maximum tunnel squat/elongation in the transverse direction; and
- Worst case radius of curvature imposed on the tunnel in the hogging and sagging zones in the longitudinal direction.

5.4.1 Maximum tunnel squat/elongation

The diametrical distortion, i.e. the change in diameter divided by the original tunnel diameter, of a tunnel lining due to ground loading will result in either an increase of the vertical diameter and a decrease of the horizontal diameter (elongation) or an increase of the horizontal diameter and a decrease of the vertical diameter (squat).
The maximum vertical displacement at levels corresponding to the tunnel crown and invert are summarised in Table 5. The distortion of the UKPN tunnel is calculated by dividing the maximum differential ground movement (i.e. the difference between crown and invert settlement) by the diameter of the tunnel.

<table>
<thead>
<tr>
<th>Maximum vertical displacement</th>
<th>Invert</th>
<th>Crown</th>
<th>Max. differential</th>
<th>Diametrical distortion</th>
</tr>
</thead>
<tbody>
<tr>
<td>16.7mm</td>
<td>15.8mm</td>
<td>0.9mm</td>
<td></td>
<td>0.03%</td>
</tr>
</tbody>
</table>

The effect of elongation/squat is a potential change in bending moment of the segmental lining that may cause rotation of the joints. The calculated value will form part of the structural assessment (see Section 6.3.4).

5.4.2 Tunnel imposed radius of curvature

The worst case imposed radius of curvature in the longitudinal direction, $R'_{imposed}$, has been calculated based on the ‘Greenfield’ settlement profile along the tunnel invert level.

The critical mode of longitudinal deformation is where the tunnel deforms (bends) within a sagging or a hogging zone. The radius of curvature has been calculated considering incremental radii of curvature between the points of inflection. The tightest imposed radius of curvature, $R'_{imposed}$ has been calculated as the minimum of these values, as illustrated in Figure 4 below.

$L$ is the cumulative distance between the incremental intervals and $\delta$ is the magnitude of displacement between the points.

Figure 4: Imposed incremental radius of curvature
Table 6: Calculated imposed radius of curvature

<table>
<thead>
<tr>
<th>Minimum imposed radius of curvature, $R'_{\text{imposed}}$ due to vertical movement</th>
<th>Sagging</th>
</tr>
</thead>
<tbody>
<tr>
<td>UKPN Bankside Cable Tunnel</td>
<td>12.8km</td>
</tr>
</tbody>
</table>

The radius of curvature will be used to assess the structural impact on the UKPN tunnel in the longitudinal direction (see Section 6.3.6). This will include assessing the size of the gap which may open up between two segments.
6 Structural Assessment

6.1 General

The structural assessment of the pre-cast concrete lined UKPN tunnel considers existing conditions and additional conditions due to construction of the Thames Tunnel.

The estimated vertical distortion (difference between crown and invert maximum vertical movements) is considered when assessing the change in lining stresses while the imposed radius of curvature is considered when assessing the potential for opening up of tunnel joints and bolts.

6.2 Concrete lining details

The structural assessment is based on assumed material properties and tunnel geometry since no as-built information has been provided at the time of writing of this assessment. The assumed parameters are summarised in Section 4.1.

6.3 Analytical method

6.3.1 Change in lining stresses due to squat/elongation of tunnel section

An outline of the assessment procedure is presented below in Figure 5. Calculations are included in Appendix B.

Figure 5: Assessment procedure – transverse direction
6.3.2 Permissible tunnel lining capacity envelope

The lining capacity envelope is determined by plotting an interaction diagram. The interaction diagram is be plotted, by computing the bending moment and hoop force values. This gives a parabolic curve, which defines the limit of the concrete lining capacity. Lining thickness, concrete grade and segment reinforcement details are all parameters that impact on the capacity envelope. The interaction diagram for the UKPN tunnel is based on the following assumed parameters:

Table 7: Assumed segmental lining parameters

<table>
<thead>
<tr>
<th>Assumed input data</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete grade</td>
<td>C40/50</td>
</tr>
<tr>
<td>Lining thickness</td>
<td>180mm (confirmed during visual inspection)</td>
</tr>
<tr>
<td>Reinforcement</td>
<td>Unreinforced (0%)</td>
</tr>
</tbody>
</table>

6.3.3 Determine existing lining stresses

The existing stresses, which do not include the effect of the Thames Tunnel works, are calculated using Duddeck and Erdmann (1985). Tunnel stresses using Duddeck and Erdmann are assumed to be in a continuous elastic environment and therefore, it does not take into account any volume lost or relaxation of the ground. However, the number of assumptions made in this report, collectively produce a conservative assessment of the stresses in the tunnel lining.

The existing stresses are calculated in accordance with a number of assumed parameters. These are presented in Table 8.

Table 8: Assumed key parameters

<table>
<thead>
<tr>
<th>Assumed key parameters</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth pressure coefficient at tunnel location</td>
<td>( K_0 = 0.7 )</td>
</tr>
<tr>
<td>Surface surcharge</td>
<td>No additional surcharge since interface is located below the River Thames</td>
</tr>
<tr>
<td>Existing diametrical distortion of the tunnel</td>
<td>See below</td>
</tr>
</tbody>
</table>

For the calculations presented in this report it is assumed that a hydrostatic ground water pressure profile exists. Calculations considering zero pore water pressure at the UKPN tunnel axis has also been undertaken but are considered unrealistic since the existing hoop force and bending moment would fall outside the interaction diagram. A pore water pressure at axis level is also considered unrealistic since there are no other known tunnels in close proximity to the UKPN tunnel that could impact on the ground water level drawdown.

Changes in horizontal stress and a reduction of \( K_0 \) following tunnel construction are likely to have resulted in the UKPN cable tunnel having a “squatted” tunnel profile. Since no dimensional survey records have been obtained, the existing distortion is calculated from the maximum radial displacement derived from the Duddeck and Erdmann equations. Based on a maximum radial displacement of 0.54mm, the existing diametrical distortion equates to 0.04% using the Duddeck and Erdmann equations. The Thames Tunnel will then impose 0.03% ovalisation (elongation, i.e. crown to invert distance increases) as discussed in Section 5.4.1.

The maximum bending moment, and hoop force derived from the Duddeck and Erdmann equations are 12.8kNm/m and 709kN/m respectively and these are plotted in the interaction
diagram to confirm that design assumptions are reasonable as the plotted values should fall inside the diagram, see Figure 6.

**Figure 6: Interaction diagram of existing conditions**

6.3.4 Determine change in bending moment in lining due to Thames Tunnel construction

The tunnel cross-sectional distortion calculated from vertical ‘Greenfield’ ground movements equates to a maximum of 0.03% ovalisation as specified in Table 5. Since the existing UKPN tunnel is likely to have a “non-perfect” build lining, i.e. the ring may have “squatted” during/since construction; the calculated ovalisation will potentially counterbalance the squat and will therefore not superpose any additional adverse effect on the lining structural capacity.

This is assessed by using the calculated ovalisation as an input to determine the change in bending moment in the UKPN tunnel. The calculated ovalisation of 0.03% is subtracted from the existing diametrical distortion of 0.04%. Using Morgan’s equations (1961), the final maximum factored bending moment in the tunnel lining will be 6.4kNm/m. For the purpose of the structural assessment the ovalisation due to the Thames Tunnel works is considered to occur in any plane of the concrete tunnel.
6.3.5 Check that the axial force/bending moment remains within the capacity envelope

The factored hoop force calculated by Duddeck and Erdmann and the factored bending moment described in section 6.3.3 are plotted together in the interaction diagram. If the moment / hoop thrust plots inside the capacity envelope, this indicates that the lining is within the section capacity while a moment / hoop thrust outside the capacity envelope indicates that the tunnel lining will not meet the safety requirements for the code of practice specified for the calculations.

As shown in Figure 7, the calculated ovalisation will counterbalance the squatted tunnel profile and the existing bending moment will effectively reduce i.e. move to the left in the interaction diagram. This is indicated in the interaction diagram below where the plots which represents the existing condition have a greater bending moment than the plots which represents the UKPN tunnel after construction of the Thames Tunnel works. It should also be noted that even if the lining distortion would be added to the existing bending moment and hoop force, the lining is still within but close to the structural capacity. This covers the scenario in the hogging region where the crown to invert dimension will reduce as a consequence of ground movement (ref Figure 3).

**Figure 7: Interaction diagram including Thames Tunnel works**
6.3.6 Longitudinal deformation of the tunnel lining

In the longitudinal direction, the UKPN tunnel lining is assessed based on the procedure presented in Figure 8, assuming no bolts (expanded lining).

**Figure 8: Assessment procedure – Longitudinal direction**

The tunnel lining is assessed by examining the maximum gap that can occur between two rings. The imposed radius of curvature is used to calculate the gap which opens up between rings due to bending.

\[
\text{Gap} = \frac{b \times R}{R - \Phi} - b
\]

Where \( b \) = overall width of section  
\( R \) = imposed radius of curvature  
\( \Phi \) = External diameter

The maximum gap from bending at the UKPN interface is 0.23mm. However, the maximum gap from bending as explained above together with maximum imposed gap due to horizontal displacement gives a maximum combined gap of 0.6mm. This gap is considered small and since the UKPN tunnel is founded in the relatively impermeable London Clay, there is no significant risk associated with opening up of the tunnel joints.

6.3.7 Bolt assessment

It was confirmed during the visual inspection that part of the tunnel lining consists of bolted segments. The bolt diameter was measured during the inspection, however no other information is available and therefore the bolt grade, bolt length and embedment length are based on assumed parameters for similar types of bolted segments.

The size of the opening over the assumed bolt length is used to calculate the bolt strain, which is subsequently compared against the yield strain. Assuming a triangular strain distribution across the bolts, with a neutral axis at the tunnel centreline, some bolts at the crown and
shoulder of the tunnel may yield as strain calculated in the bolts exceeds the permissible yield strain (i.e. the force demand on the bolts is equal to the plastic bolt capacity). However, the bolts do not reach the ultimate strain i.e. failure.

Pullout resistance of the concrete has been calculated based on Eurocodes and British Standards. The maximum bolt force is less than the concrete pullout resistance. Therefore, it is not expected that there will be failure between the bolt and concrete interface.

In order to ensure that there are no adverse impacts on the bolted segments during excavation of the Thames Tunnel, it is suggested that maintenance checks of the Bankside tunnel are undertaken. If required, loosening of the circumferential bolts may be appropriate to reduce the risk of localised shear of the concrete at the bolt pockets.

6.3.8 In-Tunnel structures

The Bankside Cable tunnel houses in tunnel structures such as brackets and power cables. The current structures include communications cables, high voltage electricity cables and fibre optic cables. Based on the calculated ground movement, the impact on any in tunnel structures is considered likely to be negligible.
7 Conclusion

The assessment described in this report is based on PBA/Arup’s understanding of the proposed Thames Tunnel project. Any recommendations should be considered holistically by the Thames Tunnel project team within the detailed context of the proposed works onsite.

The UKPN Bankside cable tunnel is located directly above the Thames Tunnel with a vertical clearance of approximately 20m. Results from the ground movement assessment in the longitudinal and transverse direction have been used to calculate the resulting stresses imposed on the tunnel lining. The assessment is based on a number of conservative assumptions regarding lining material properties and geometry.

The current assessment indicates that the impact on the UKPN cable tunnel in both transverse and longitudinal direction is within the lining capacity. The maximum gap of 0.6mm which may open up between two segments is considered to present low risk to the integrity of the tunnel structure since the tunnel is located within the relatively impermeable London Clay strata. The impact on the bolted segments is also considered to be low.

A visual inspection was carried out on the 1st December 2011 in order to validate assumptions relating to this assessment report and to confirm the likely behaviour of the tunnel. The visual inspection indicates that the concrete tunnel segments are in very good condition. A number of the expanded segments show cracks which are likely to have developed during construction. However all cracks have been repaired and it is not believed that the cracks will impact adversely on the structural capacity of the lining.

Maintenance checks of the bolted segments during excavation of the Thames Tunnel may be appropriate and it is also recommended that a condition survey is carried out after the proposed construction of the Thames Tunnel. This will confirm whether any adverse changes in the condition of the tunnel have occurred as a result of the Thames Tunnel construction.
Appendices

Appendix A - Drawings
THAMES TUNNEL

NOTE:
1. DO NOT SCALE FROM DRAWING

DATE ISSUED: 01.08.2011

SUPERFICIAL DEPOSITS
AND MADE GROUND
LONDON CLAY
FORMATION
LAMBETH GROUP
THANET SAND FORMATION
CHALK GROUP

GEOTECHNICAL KEY:

UKPN BANKSIDE CABLE TUNNEL "GREENFIELD"
GROUND SETTLEMENT
1% VL

307-SK1-TPI-TU07T-810000-AA

ARUP

DATE ISSUED: 01.08.2011
NOTE:
1. VERTICAL SETTLEMENT IS SHOWN EXAGGERATED BY A FACTOR OF 250.
2. DO NOT SCALE FROM DRAWING.

DATE ISSUED: 01.08.2011

TUNNEL CURVE KEY:
- TUNNEL SETTLEMENT CURVE 1% VL

GEOTECHNICAL KEY:
- SUPERFICIAL DEPOSITS AND MADE GROUND
- LONDON CLAY FORMATION
- LAMBETH GROUP
- THANET SAND FORMATION
- CHALK GROUP

SECTION A-A UKPN BANKSIDE CABLE TUNNEL

UKPN BANKSIDE CABLE TUNNEL "GREENFIELD"
GROUND SETTLEMENT 1% VL

307-SK2-TPI-TU057-840000-AA
Appendix B – Calculations
1.0 Input Data

Materials

- Young's Modulus of concrete (secant), $E_{cm} = 35220$ MPa
- Long term Young's Modulus of concrete, $E_{long} = 17610$ MPa
- Characteristic strength of concrete (cylinder test), $f_{ck} = 40$ N/mm²
- Partial safety factor for strength of concrete, $\gamma_c = 1.5$
- Young's Modulus of reinforcement, $E_s = 2E+05$ MPa
- Characteristic strength of reinforcement, $f_{y;k} = 500$ N/mm²
- Partial safety factor for reinforcement, $\gamma_s = 1.15$
- Elastic Modulus of ground, $E_c = 50$ MPa
- Poisson's ratio of ground, $\nu = 0.50$

Lining

Select lining type:

1. Rectangular, expanded, (2) Rectangular, bolted

- Internal diameter, $D = 2590$ mm
- Angle subtended by segment (exclude key), $\beta = 51$°
- Lining thickness, $t = 180.0$ mm
- Section Width $b = 1000$ mm
- Number of segments (exclude key) = 7
- Angle subtended by key, $\beta_{key} = 0$°
- Reinforcement % (total steel area (both faces)/total concrete area) = 0.00%
- Cover to reinforcement = 0 mm
- Diameter of main reinforcement = 0 mm
- Width of caulking groove on internal face, $l_{caul} = 0$ mm
- Width of gasket groove on external face, $l_{gat} = 0$ mm
- External radius, $r = 1475$ mm
- Density of concrete, $\rho = 2500$ kg/m³

Steel Fibre

- Steel fibre length, $l = 0$ mm
- Dramix steel fibre type = 65/35
- Dosage of steel fibres, $W_{sf} = 20$ kg/m³

DBV recommendation

- Characteristic flexural strength, $f_{yk} = 4.76$ N/mm²
- Mean equivalent flexural strength at ($\delta_2 = \delta_u + 0.65$mm), $\beta_{LZ2,m,g} = 3.7$ N/mm²
- Mean equivalent flexural strength at ($\delta_3 = \delta_u + 3.15$mm), $\beta_{LZ3,m,g} = 3.3$ N/mm²

Loading

- Consider arching of ground around tunnel? Y
- Vertical Pressure on the tunnel (factored) $P_{vf} = 490.0$ kN/m²
- Horizontal Pressure on the tunnel (factored) $P_{vh} = 442.1$ kN/m²
- Vertical Pressure on the tunnel (unfactored) $P_{uv} = 350.0$ kN/m²
- Horizontal Pressure on the tunnel (unfactored) $P_{uh} = 315.8$ kN/m²

Duddeck and Erdmann analysis

The continuum model derived by Duddeck and Erdmann is used to derive the forces and moments in the lining. This model gives different equations for (a) full bond between the lining and the ground, and (b) tangential slip. Select the type of analysis in the box below. If full bond is to be used type F, if not type T for tangential slip

- Build quality
  - Ring build tolerance over tunnel diameter = 10.0 mm
- Ovalisation due to long term movements
  - Maximum "squat", % of internal radius = 0.000 %
  - Maximum radial displacement, $u_2 = 0$ mm

Grout loads

The check on the lining when primary grouting is being carried out assumes no ground loading and a uniform loading around the ring. For secondary grouting, the grout pressure only acts on the lining in the vertical direction, in addition to the unfactored ground loading

- Primary grouting pressure = 0 kN/m²
- Load factor, $\gamma_{mg} = 0$
- Secondary grouting pressure = 0 kN/m²

Tunnel Boring Machine Characteristics

- Ram load per shoe, $F = 0$ kN
- Ram shoe length = 0 mm
- Ram and width = 0 mm
- Offset of ram Cc from extrados, $f = 0$ mm

Stacking and handling loads

- Dynamic Factor to be applied to lifting loads, $D_0 = 0.0$
- Factor of safety on stacking loads = 0.0

Input data
Loading cases for lining design (full overburden)

Load combinations & load factors for ultimate limit state (UK National Annex to BS EN 1990:2002)

<table>
<thead>
<tr>
<th>Load combination</th>
<th>Load type</th>
<th>Load factors used</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Perm + Var (DA1-1)</td>
<td>Permanent Variable</td>
<td>( \gamma_{DL} ) 1.40 ( \gamma_{IL} ) 1.50 ( \gamma_{EP} ) 1.40 ( \gamma_{WT} ) 1.40</td>
</tr>
<tr>
<td>2. Perm only (DA1-1)</td>
<td>Permanent</td>
<td>-</td>
</tr>
<tr>
<td>3. Perm + Var (DA1-2)</td>
<td>Permanent Variable</td>
<td>-</td>
</tr>
</tbody>
</table>

Selected load combination 1

Slide scroll bar left to right to vary load combination from 1 to 3

Slide scroll bar left to right to vary Elastic Modulus of ground (\( E_c \)) from 10 to 250 MPa

\( E_c = 10 \) 250 MPa

Slide scroll bar left to right to vary number of joints from 0 to 20

0 20

Concrete Grade

\( C40/50 \)

PF for water pressure

Yes

SF to characteristic WL

No

SF = 1.1

Summary of results -

\( M_{\text{max}} = 12.8 \) kNm/m

\( N_{\text{max}} = 709 \) kN/m

\( N_{\text{min}} = 656 \) kN/m

\( M_{\text{max}} = 0.0 \) kNm/m

\( N_{\text{min}} = 468 \) kN/m

\( u_{\text{max}} = 0.54 \) mm
4.0 Duddeck and Erdmann analysis

Input parameters:

Ground:
- Elastic Modulus $E_c = 50 \text{ MPa}$
- Poisson's Ratio $\nu = 0.50$

Lining:
- External Radius $r = 1.475 \text{ m}$
- Elastic Modulus $E = 35220.5 \text{ MPa}$
- Effective Moment of Inertia $I_e = 4.86E-04 \text{ m}^4/m$
- Sectional Area $A = 0.18 \text{ m}^2/m$

Loading:
- Vertical Pressure at the Crown $P_{nv} = 490.04 \text{ kPa}$
- Horizontal Pressure at the Axis $P_{nh} = 315.82 \text{ kPa}$

Theory:
The loading on the lining is calculated using the Duddeck and Erdmann analysis. These equations allow either full bond between the lining and the ground, or tangential slip. This is selected below based on an appreciation of the behaviour of the ground.

Duddeck and Erdmann Formulae

<table>
<thead>
<tr>
<th></th>
<th>Full Bond</th>
<th>Tangential Slip</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum bending moment, $M$</td>
<td>$\sigma_s (1-K_s) R^2 \frac{3-2\nu}{4(1+\nu)(1-\nu)} \frac{E_c R^2}{E J}$</td>
<td>$\sigma_s (1-K_s) R^2 \frac{10-12\nu}{3(1+\nu)(3-4\nu)} \frac{E_c R^2}{E J}$</td>
</tr>
<tr>
<td>Average hoop thrust, $N_{av}$</td>
<td>$\sigma_s (1-K_s) R^2 \frac{2}{1+\nu} \frac{E_c R}{E A}$</td>
<td>$\sigma_s (1-K_s) R^2 \frac{10-12\nu}{3(1+\nu)(3-4\nu)} \frac{E_c R^2}{E J}$</td>
</tr>
<tr>
<td>Variable hoop thrust, $N_{var}$</td>
<td>$\sigma_s (1-K_s) R^2 \frac{1}{2} \frac{E_c R^2}{E J}$</td>
<td>$\sigma_s (1-K_s) R^2 \frac{10-12\nu}{3(1+\nu)(3-4\nu)} \frac{E_c R^2}{E J}$</td>
</tr>
<tr>
<td>Constant radial displacement, $U_0$</td>
<td>$0.5 \frac{r^2}{E A}$</td>
<td>$\frac{r^2}{E A}$</td>
</tr>
<tr>
<td>Maximum radial displacement, $U_{2\nu}$</td>
<td>$\sigma_s (1-K_s) \frac{R^2}{12(1-\nu)(1+\nu)(1+\nu)} \frac{E_c R^3}{E J}$</td>
<td>$\sigma_s (1-K_s) \frac{5(5-6\nu)}{3(1-\nu)(1+\nu)(1+\nu)} \frac{E_c R^3}{E J}$</td>
</tr>
</tbody>
</table>

Results

<table>
<thead>
<tr>
<th></th>
<th>Factored</th>
<th>Unfactored</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bending Moment +/-</td>
<td>$M = 12.76 \text{ kNm/m}$</td>
<td>$M = 9.11 \text{ kNm/m}$</td>
</tr>
<tr>
<td>Average Hoop Thrust</td>
<td>$N_{av} = 682.19 \text{ kNm}$</td>
<td>$N_{av} = 487.28 \text{ kNm}$</td>
</tr>
<tr>
<td>Variable Hoop Thrust +/-</td>
<td>$N_{var} = 26.31 \text{ kNm}$</td>
<td>$N_{var} = 18.79 \text{ kNm}$</td>
</tr>
<tr>
<td>Constant Radial Displacement</td>
<td>$U_0 = 0.16 \text{ mm}$</td>
<td>$U_0 = 0.11 \text{ mm}$</td>
</tr>
<tr>
<td>Max. Radial Displacement</td>
<td>$U_{max} = 0.54 \text{ mm}$</td>
<td>$U_{max} = 0.39 \text{ mm}$</td>
</tr>
<tr>
<td>Relative Flexibility Factor</td>
<td>$Q_2 = 0.52$</td>
<td>$Q_2 = 0.52$</td>
</tr>
<tr>
<td>Design Shear (Lining/ground)</td>
<td>$T = 23.95 \text{ kPa}$</td>
<td>$T = 17.10 \text{ kPa}$</td>
</tr>
</tbody>
</table>

Moments and Hoop Stresses Induced in the Lining

- Factored maximum design hoop load, $N_{max} = 709 \text{ kN/m}$
- Factored minimum design hoop load, $N_{min} = 656 \text{ kN/m}$
- Factored maximum design moment, $M_{max} = 12.8 \text{ kNm/m}$
- Unfactored maximum design moment, $M_{u_max} = 9.1 \text{ kNm/m}$

Duddeck and Erdmann
2.0 Summary of results

Section properties
- Area: 0.18 m²/m
- Second moment of area: 4.86E-04 m⁴/m
- Segment weight: 5.44 kN

Displacements
- Duddeck and Erdmann assessment: 0.5 mm
- Radial displacement: 0 mm

Lining: Axial load and moment capacity
Moments and axial forces as calculated in the following sections are plotted on the capacity graph below:
- 4.0: Duddeck and Erdmann assessment
- 5.0: Imposed radial displacement
- 6.0: Moments induced by poor build

FIGURE 8

Summary of results
1.0 Input Data

Materials

Young's Modulus of concrete (secant), \( E_{cm} = 35 \, 220 \, \text{MPa} \)
Long term Young's Modulus of concrete, \( E_{long \, cm} = 17 \, 610 \, \text{MPa} \)
characteristic strength of concrete (cylinder test) \( f_{ck} = 40 \, \text{N/mm}^2 \)
partial safety factor for strength of concrete, \( \gamma_s = 1.5 \)
Young's Modulus of reinforcement, \( E_s = 2E+05 \, \text{MPa} \)
characteristic strength of reinforcement, \( f_{yk} = 500 \, \text{N/mm}^2 \)
partial safety factor for reinforcement, \( \gamma_s = 1.15 \)
Elastic Modulus of ground, \( E_c = 50 \, \text{MPa} \)

Lining

Select lining type:
1. Rectangular, expanded, 2. Rectangular, bolted

internal diameter, \( D = 2 \, 590 \, \text{mm} \)
age subtended by segment (exclude key), \( \beta = 51 \, ^\circ \)
lining thickness, \( t = 180.0 \, \text{mm} \)
Section Width, \( b = 1000 \, \text{mm} \)
Number of segments (exclude key) = 7
angle subtended by key, \( \beta_{key} = 0 \, ^\circ \)
reinforcement % (total steel area (both faces)/total concrete area) = 0.00 %
cover to reinforcement = 0 mm
diameter of main reinforcement = 0 mm
width of caulking groove on internal face, \( i_{int} = 0 \, \text{mm} \)
width of gasket groove on external face, \( i_{ext} = 0 \, \text{mm} \)
external radius, \( r = 1 \, 475 \, \text{mm} \)
Density of concrete, \( \rho = 2500 \, \text{kg/m}^3 \)

Steel Fibre

steel fibre length, \( l = 0 \, \text{mm} \)
Dramix steel fibre type = 65/35

dosage of steel fibres, \( W_{sf} = 20 \, \text{kg/m}^3 \)

DBV recommendation

characteristic flexural strength, \( \beta_{BZ} = 4.76 \, \text{N/mm}^2 \)
mean equivalent flexural strength at \( \delta = \delta_{u} + 0.65 \, \text{mm} \), \( \beta_{BZ2,m,g} = 3.7 \, \text{N/mm}^2 \)
mean equivalent flexural strength at \( \delta = \delta_{u} + 3.15 \, \text{mm} \), \( \beta_{BZ3,m,g} = 3.3 \, \text{N/mm}^2 \)
\( \delta_{u} \) : deflection at the peak flexural strength

Loading

Consider arching of ground around tunnel? Y  N  1
Vertical Pressure on the tunnel (factored) \( P_v = 490.0 \, \text{kN/m}^2 \)
Horizontal Pressure on the tunnel (factored) \( P_h = 442.1 \, \text{kN/m}^2 \)
Vertical Pressure on the tunnel (unfactored) \( P_{uv} = 350.0 \, \text{kN/m}^2 \)
Horizontal Pressure on the tunnel (unfactored) \( P_{uh} = 315.8 \, \text{kN/m}^2 \)

Duddeck and Erdmann analysis

The continuum model derived by Duddeck and Erdmann is used to derive the forces and moments in the lining. This model gives different equations for (a) full bond between the lining and the ground, and (b) tangential slip. Select the type of analysis in the box below. If full bond is to be used type F, if not type T for tangential slip

Build quality

ring build tolerance over tunnel diameter = 10.0 mm

Ovalisation due to long term movements

maximum "squat", % of internal radius = 0.030 %
maximum radial displacement, \( u_{o} = 0.3885 \, \text{mm} \)

Grout loads

The check on the lining when primary grouting is being carried out assumes no ground loading and a uniform loading around the ring. For secondary grouting, the grout pressure only acts on the lining in the vertical direction, in addition to the unfactored ground loading

Primary grouting pressure = 0 kN/m²
Load factor, \( \gamma_{mg} = 0 \)
Secondary grouting pressure = 0 kN/m²

Tunnel Boring Machine Characteristics

ram load per shoe, \( F = 0 \, \text{kN} \)
ram shoe length = 0 mm
and width = 0 mm
offset of ram from extrados, \( f = 0 \, \text{mm} \)

Stacking and handling loads

Dynamic Factor to be applied to lifting loads, \( D_f = 0.0 \)
Factor of safety on stacking loads = 0.0

Input data
Loading cases for lining design (full overburden)

GL = 103.97 mPD

\( h_1 = 12.0 \) m

\( h_2 = 0.0 \) m \text{ int S1/S2} \ 92.00 mPD

\( h_3 = 11.6 \) m \text{ int S2/S3} \ 92.00 mPD

\( h_w = 0.0 \) m \text{ tun axis} \ 80.36 mPD

\( H = 23.6 \) GWL \ 103.97 mPD

\( \gamma_s = 9.8 \) kN/m³ \( K_{0s1} = 0.7 \)

\( \gamma_{s2} = 20.0 \) kN/m³ \( K_{0s2} = 0.7 \)

\( \gamma_{s3} = 20.0 \) kN/m³ \( K_{0s3} = 0.70 \)

surcharge = 0 kPa

Load combinations & load factors for ultimate limit state (UK National Annex to BS EN 1990:2002)

<table>
<thead>
<tr>
<th>Load combination</th>
<th>Load type</th>
<th>Load factors used</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.Perm + Var (DA1-1)</td>
<td>1.4</td>
<td>1.40</td>
</tr>
<tr>
<td>2.Perm only (DA1-1)</td>
<td>1.4</td>
<td>1.50</td>
</tr>
<tr>
<td>3.Perm + Var (DA1-2)</td>
<td>1.4</td>
<td>1.40</td>
</tr>
</tbody>
</table>

Selected load combination 1

Load combination

Load type

Permanent

Variable

Earth & water pressure

Load factors used

1. Perm + Var (DA1-1) - 1.4

Concrete Grade

C40/50

PF for water pressure

Yes

SF for characteristic WL

No

SF = 1.1

Concrete Grade

C40/50

PF for water pressure

Yes

Summary of results -

\( M_{\text{max}} = 12.8 \) kNm/m

\( N_{\text{max}} = 709 \) kNm

\( N_{\text{min}} = 656 \) kNm

\( M_{\text{max}} = 4.6 \) kNm/m

\( N_{\text{min}} = 468 \) kNm

\( U_{\text{max}} = 0.54 \) mm
4.0 Duddeck and Erdmann analysis

Input parameters:

Ground:  
- Elastic Modulus, \( E_c = 50 \text{ MPa} \)
- Poisson's Ratio, \( v = 0.50 \)

Lining:  
- External Radius, \( r = 1.475 \text{ m} \)
- Elastic Modulus, \( E = 35220.5 \text{ MPa} \)
- Effective Moment of Inertia, \( I_e = 4.866 \times 10^{-4} \text{ m}^4/\text{m} \)
- Sectional Area, \( A = 0.18 \text{ m}^2/\text{m} \)

Loading:  
- Vertical Pressure at the Crown, \( P_v = 490.04 \text{ kPa} \)
- Horizontal Pressure at the Axis, \( P_h = 442.15 \text{ kPa} \)

Theory:

The loading on the lining is calculated using the Duddeck and Erdmann analysis. These equations allow either full bond between the lining and the ground, or tangential slip. This is selected below based on an appreciation of the behaviour of the ground.

Full bond specified

Duddeck and Erdmann Formulae

<table>
<thead>
<tr>
<th></th>
<th>Full Bond</th>
<th>Tangential Slip</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma_v (1-K_v) R^2 )</td>
<td>( \frac{1}{4} \cdot \frac{3 - 2v}{3(1+v)(3-4v)} \cdot \frac{E_c R^2}{E} )</td>
<td>( \frac{1}{2} \cdot \frac{3 - 2v}{3(1+v)(3-4v)} \cdot \frac{E_c R^2}{E} )</td>
</tr>
<tr>
<td>( \sigma_v (1-K_v) R^2 )</td>
<td>( \frac{1}{2} \cdot \frac{3 - 2v}{3(1+v)(3-4v)} \cdot \frac{E_c R^2}{E} )</td>
<td>( \frac{1}{2} \cdot \frac{3 - 2v}{3(1+v)(3-4v)} \cdot \frac{E_c R^2}{E} )</td>
</tr>
<tr>
<td>( \sigma_v (1-K_v) R )</td>
<td>( \frac{e}{1+v} \cdot \frac{E_c R}{E A} )</td>
<td>( \frac{e}{1+v} \cdot \frac{E_c R}{E A} )</td>
</tr>
<tr>
<td>( \sigma_v (1-K_v) R )</td>
<td>( \frac{e}{1+v} \cdot \frac{E_c R}{E A} )</td>
<td>( \frac{e}{1+v} \cdot \frac{E_c R}{E A} )</td>
</tr>
<tr>
<td>( \sigma_v (1-K_v) )</td>
<td>( \frac{e}{1+v} \cdot \frac{E_c R}{E A} )</td>
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</table>

Results

<table>
<thead>
<tr>
<th></th>
<th>Factored</th>
<th>Unfactored</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bending Moment +/-</td>
<td>( M = 12.76 \text{ kNm/m} )</td>
<td>( M = 9.11 \text{ kNm/m} )</td>
</tr>
<tr>
<td>Average Hoop Thrust</td>
<td>( N_{av} = 682.19 \text{ kN/m} )</td>
<td>( N_{av} = 487.28 \text{ kN/m} )</td>
</tr>
<tr>
<td>Variable Hoop Thrust</td>
<td>( N_{var} = 26.31 \text{ kN/m} )</td>
<td>( N_{var} = 18.79 \text{ kN/m} )</td>
</tr>
<tr>
<td>Constant Radial Displacement</td>
<td>( U_0 = 0.16 \text{ mm} )</td>
<td>( U_0 = 0.11 \text{ mm} )</td>
</tr>
<tr>
<td>Max. Radial Displacement</td>
<td>( U_{max} = 0.54 \text{ mm} )</td>
<td>( U_{max} = 0.39 \text{ mm} )</td>
</tr>
<tr>
<td>Relative Flexibility Factor</td>
<td>( Q_2 = 0.52 )</td>
<td>( Q_2 = 0.52 )</td>
</tr>
<tr>
<td>Design Shear(Lining/Ground)</td>
<td>( T = 23.95 \text{ kPa} )</td>
<td>( T = 17.10 \text{ kPa} )</td>
</tr>
</tbody>
</table>

Moments and Hoop Stresses Induced in the Lining

- factored maximum design hoop load, \( N_{max} = 709 \text{ kN/m} \)
- factored minimum design hoop load, \( N_{min} = 656 \text{ kN/m} \)
- factored maximum design moment, \( M_{max} = 12.8 \text{ kNm/m} \)
- unfactored maximum design moment, \( M_{umax} = 9.1 \text{ kNm/m} \)
The drawings below show the typical deflected shapes and the envelopes of shear force and bending moment:

**Typical displacements for** $P_v > P_h, K_o < 1$

- $U_{max}$
- Deflected shape

**Variable displacement**

**Constant displacement**

**Hoop Thrusts and Bending Moment envelopes for** $P_v > P_h, K_o < 1$

**Maximum hoop thrust**

**Maximum bending moments**

### 5.0 Moments due to radial displacement

H.D. Morgan has shown ["A contribution to the analysis of stress in a circular tunnel" Géotechnique 11, pages 37-46, 1961] that, from consideration of the change in curvature around the tunnel, the maximum bending moment due to working loads, $M_{omax}$, induced by a "squat" of $u_{max}$ is given by:

$$M_{omax} = \frac{3 \cdot u_{max} \cdot E_{long} \cdot I_{eff}}{r^2}$$

This moment $M_{omax}$, combined with $N_u$, should fall within the interaction diagram for the lining selected.

### Ovalisation due to long term movements

Maximum radial displacement, $u_{max}$, is **0.3885 mm** from page 2

i.e. $M_{omax} = 4.6 \text{ kNm/m}$
2.0 Summary of results

Section properties

- Area: 0.18 m²/m
- Second moment of area: 4.86E-04 m⁴/m
- Segment weight: 5.44 kN

Displacements

- Duddeck and Erdmann assessment: 0.5 mm
- Radial displacement: 0.3885 mm

Lining: Axial load and moment capacity

Moments and axial forces as calculated in the following sections are plotted on the capacity graph below:

- 4.0: Duddeck and Erdmann assessment
- 5.0: Imposed radial displacement
- 6.0: Moments induced by poor build

FIGURE 8
Bolt & Concrete Pullout Capacity of Damage Assessed Tunnel

- **Lining ID**: 2590 mm
- **fck**: 40 N/mm²
- **Lining Thickness**: 180 mm
- **Opening, δ**: 0.6 mm
- **Bolt Type**: M16
- **d**: 16 mm
- **Bolt Length, L**: 360 mm
- **Nu min**: 468 kN/m
- **As**: 157 mm²
- **Bolt Grade**: 4.6
- **fub**: 400 N/mm²
- **fy**: 240 N/mm²
- **E**: 210000 N/mm²
- **γm2**: 1.25
- **k2**: 0.9

Assumed neutral axis of tunnel is at tunnel axis
Strain from settlement assessment is imposed on joint opening
Section is assumed to contain no shear reinforcement

\[ \text{Force} = \epsilon E A \]
Assuming triangular strain distribution:

<table>
<thead>
<tr>
<th>Bolt Row</th>
<th>No of bolts</th>
<th>Lever Arm</th>
<th>Strain</th>
<th>Force (kN)</th>
<th>Moment (kNm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>1</td>
<td>1.385</td>
<td>0.00167</td>
<td>55.0</td>
<td>76.1</td>
</tr>
<tr>
<td>R2</td>
<td>2</td>
<td>1.265</td>
<td>0.00152</td>
<td>100.4</td>
<td>127.0</td>
</tr>
<tr>
<td>R3</td>
<td>2</td>
<td>0.927</td>
<td>0.00112</td>
<td>73.5</td>
<td>68.1</td>
</tr>
<tr>
<td>R4</td>
<td>2</td>
<td>0.428</td>
<td>0.00052</td>
<td>34.0</td>
<td>14.5</td>
</tr>
</tbody>
</table>

Σ 262.8 285.8

Bolt Tension Capacity

Eurocode : BS EN 1993-1-8: 2005

\[ Ft, ed = k_2 f_{ub} A_s / \gamma_{m2} \]

\[ = 45.2 \text{ kN} \]

British Standard: BS 5950-1:2000

6.3.4.2

\[ P_{nom} = 0.8 p_t A_t \]

\[ = 30.1 \text{ kN} \]

Yield strain, \( \varepsilon_y = f_y / E \)

\[ = 0.00114 \]

SOME BOLTS MAY YIELD

3.2.2 EC3

ultimate strain, \( \varepsilon_u = 0.01714 \)

No bolts fail

If bolts yield, force demand on bolts is equal to plastic bolt capacity

<table>
<thead>
<tr>
<th>Bolt Row</th>
<th>No of bolts</th>
<th>Lever Arm</th>
<th>Strain</th>
<th>EC3 Force (kN)</th>
<th>BS Force (kN)</th>
<th>EC3 Moment</th>
<th>BS Moment (kNm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>1</td>
<td>1.385</td>
<td>0.00167</td>
<td>45.2</td>
<td>30.1</td>
<td>62.6</td>
<td>41.7</td>
</tr>
<tr>
<td>R2</td>
<td>2</td>
<td>1.265</td>
<td>0.00152</td>
<td>90.4</td>
<td>60.3</td>
<td>114.4</td>
<td>76.3</td>
</tr>
<tr>
<td>R3</td>
<td>2</td>
<td>0.927</td>
<td>0.00112</td>
<td>73.5</td>
<td>73.5</td>
<td>68.1</td>
<td>68.1</td>
</tr>
<tr>
<td>R4</td>
<td>2</td>
<td>0.428</td>
<td>0.00052</td>
<td>34.0</td>
<td>34.0</td>
<td>14.5</td>
<td>14.5</td>
</tr>
</tbody>
</table>

Σ 243.1 197.9 259.7 200.7
Concrete Pullout Check

Shear area of failure plane in concrete, Asc = 95147 mm²

Eurocode : BS EN 1993-1-8: 2005

As the reinforcement details are not known, the section will be assumed to contain no reinforcement against shearing

\[ v_{\text{min}} = 0.035 k^{3/2} f_{\text{ck}}^{1/2} \]

\[ f_{\text{ck}} = 40 \text{ N/mm}^2 \]

\[ k = 1 + \sqrt{200/d} \quad < 2.0 \]

\[ k = 2.05 \quad = 2.00 \]

\[ v_{\text{min}} = 0.63 \text{ N/mm}^2 \]

\[ \sigma_{\text{cp}} = \frac{N_{\text{ed}}}{A_{\text{c}}} \]

\[ N_{\text{ed}} = 468 \text{ kN} \]

\[ A_{\text{c}} = 180000 \text{ mm}^2 \]

\[ \sigma_{\text{cp}} = 2.60 \text{ N/mm}^2 \]

(6.2b) Pullout Resistance

\[ V_{\text{rd,c}} = (v_{\text{min}} + k_1 \sigma_{\text{cp}}) A_{\text{c}} \]

\[ k_1 = 0.15 \]

Pullout Resistance = 96.7 kN

Bolt Force = 45.2 kN

CONCRETE PULLOUT RESISTANCE OK

British Standard: BS 8110-1:1997

\[ d = 180 \text{ mm} \]

\[ v_c = 0.4 \text{ N/mm}^2 \]

Pullout Resistance = \( v_c A_{\text{c}} \)

Pullout Resistance = 38.1 kN

Bolt Force = 30.1 kN

CONCRETE PULLOUT RESISTANCE OK
Appendix C - Risk Register
## Hazard Risk Register

### Register reference

<table>
<thead>
<tr>
<th>Project</th>
<th>Thames Tunnel Detailed Assessment package 2b</th>
</tr>
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<tbody>
<tr>
<td>Job number</td>
<td>215748-10</td>
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### Package/Topic
TU057 – UKPN Bankside Cable Tunnel

### Design stage

Remember: Avoid – Reduce – Control and communicate relevant information to others (CDM Regulation 11)

<table>
<thead>
<tr>
<th>Date (+ initials)</th>
<th>Area/Location of Risk Exposure</th>
<th>Description of Hazard and Risk Exposure</th>
<th>Mitigation of Risk (Potential or Achieved)</th>
<th>A</th>
<th>R</th>
<th>C</th>
<th>Further Action</th>
<th>by</th>
<th>Status</th>
</tr>
</thead>
</table>
|                  | Thames Tunnel (TT) excavation below UKPN Bankside Cable Tunnel | Unidentified geological anomalies may cause water ingress during tunnel excavation and the risk of ground movement at the above UKPN tunnel increases. | • TT has carried out a desk study to identify geological anomalies  
• Arup has reviewed existing borehole data to confirm strata at TT face and TT/UKPN interface. | ✓ |   |   | TT to drill additional borehole at TT/UKPN interface. |    | Active/closed |
|                  | Thames Tunnel (TT) excavation below UKPN Bankside Cable Tunnel | The London Clay strata is more permeable than anticipated and water ingress could occur through the gap which may open up between segments. | • Boreholes at tunnel interface to identify sand lenses in the London Clay strata. | ✓ |   |   | TT to drill additional borehole at TT/UKPN interface. |    | Active/closed |
|                  | Thames Tunnel (TT) excavation below UKPN | The assumed lining thickness is incorrect and the structural capacity is | • Lining thickness was confirmed during the TT (UKPN) to issue as-built drawings. | ✓ |   |   |                              |    | Active/closed |

©Arup | F18.2a | Rev 14.2 | 14 February 2011
## Hazard Risk Register

<table>
<thead>
<tr>
<th>Date (+ initials)</th>
<th>Area/Location of Risk Exposure</th>
<th>Description of Hazard and Risk Exposure</th>
<th>Mitigation of Risk (Potential or Achieved)</th>
<th>A</th>
<th>R</th>
<th>C</th>
<th>Further Action</th>
<th>by</th>
<th>Status</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Bankside Cable Tunnel</td>
<td>overestimated. The induced impact on the UKPN tunnel may exceed the lining capacity.</td>
<td>inspection. • Base detailed assessment on as-built drawings</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thames Tunnel (TT) excavation below UKPN Bankside Cable Tunnel</td>
<td>The assumed concrete grade is incorrect and the structural capacity is overestimated. The induced impact on the UKPN tunnel may exceed the lining capacity.</td>
<td>• Use a conservative concrete grade for the detailed assessment. • Base detailed assessment on as-built drawings</td>
<td>✓</td>
<td></td>
<td></td>
<td>TT (UKPN) to issue drawings and/or confirm lining concrete grade.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thames Tunnel (TT) excavation below UKPN Bankside Cable Tunnel</td>
<td>The assumed reinforcement is incorrect and the structural capacity is overestimated. The induced impact on the UKPN tunnel may exceed the lining capacity.</td>
<td>• Base detailed assessment on conservative assumptions (assume unreinforced). • Base detailed assessment on as-built drawings</td>
<td>✓</td>
<td></td>
<td></td>
<td>TT (UKPN) to issue drawings and/or confirm if the lining is unreinforced or reinforced.</td>
<td></td>
<td></td>
</tr>
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</table>
## Hazard Risk Register

### Register reference

<table>
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<td>TU057 – UKPN Bankside Cable Tunnel</td>
<td>Design stage</td>
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Remember: Avoid – Reduce – Control and communicate relevant information to others (CDM Regulation 11)

<table>
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<th>Area/Location of Risk Exposure</th>
<th>Description of Hazard and Risk Exposure</th>
<th>Mitigation of Risk (Potential or Achieved)</th>
<th>A</th>
<th>R</th>
<th>C</th>
<th>Further Action</th>
<th>by</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Thames Tunnel (TT) excavation below UKPN Bankside Cable Tunnel</td>
<td>It is assumed that changes in horizontal stresses and a reduction in K₀ during construction have resulted in a “squatted” tunnel profile. If K₀ is in fact greater than 1, the tunnel may have an elongated profile and the impact from TT would be greater.</td>
<td>• Use dimensional survey records to establish existing tunnel profile.</td>
<td>✓</td>
<td></td>
<td></td>
<td>Carry out condition survey or use existing survey records if available.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thames Tunnel (TT) excavation below UKPN Bankside Cable Tunnel</td>
<td>In tunnel structures may be damage due to the imposed ground movement.</td>
<td>• Condition of in-tunnel structures were confirmed during visual inspection.</td>
<td></td>
<td></td>
<td></td>
<td>Confirm in tunnel structures and their condition during visual inspection</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thames Tunnel (TT) excavation below UKPN Bankside Cable Tunnel</td>
<td>Bolts at the circumferential joints may be overstressed as a result of longitudinal distortion.</td>
<td>• Use as-built records to confirm bolt grade and length. • Bolt diameter confirmed during inspection.</td>
<td>✓</td>
<td></td>
<td></td>
<td>TT (UKPN) to issue as-built drawings.</td>
<td></td>
</tr>
</tbody>
</table>
Appendix D – Inspection Report
UK Power Networks
Bankside Cable Tunnel

Inspection report
Thames Tunnel

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<tr>
<td>WBS</td>
<td></td>
</tr>
<tr>
<td>Authors</td>
<td>L Nordstrom</td>
</tr>
<tr>
<td>Keywords</td>
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Contents amendment record

This document has been issued and amended as follows:

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<td>AA</td>
<td>14/12/2011</td>
<td>For Information</td>
<td>LN</td>
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Required approvals

Mark Gaby – Project Manager  
Date  
14 December 2011

Matt Sykes– Project Director  
Date  
14 December 2011
# Table of contents

<table>
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</tr>
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</tr>
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<tr>
<td>4</td>
</tr>
<tr>
<td>4.1</td>
</tr>
<tr>
<td>4.2</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>5.1</td>
</tr>
<tr>
<td>5.2</td>
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<td>Appendices</td>
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</table>
| Appendix D1 – Figures ...................................................................................................
| Appendix D2 - Ring observations ....................................................................................
| Appendix D3 – Photographs .............................................................................................

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Inspection Report for UKPN Bankside
Cable Tunnel

Printed 14/12/2011
# List of tables

<table>
<thead>
<tr>
<th>Table</th>
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<tbody>
<tr>
<td>Table 1 - Inspection team</td>
<td>6</td>
</tr>
<tr>
<td>Table 2 - Tunnel geometry</td>
<td>8</td>
</tr>
</tbody>
</table>
1 Executive summary

Thames Water is currently progressing with its planned Tideway improvements. The improvement works consists of the construction of two new tunnels, the Thames Tunnel and the Lee Tunnel, together with a programme of sewer upgrades. Construction of the proposed Thames Tunnel (TT), an 8.1m – 8.8m excavated diameter tunnel, stretching approximately 23km for much of its route under the River Thames from West London to Abbey Mills is due to commence in 2016.

The proposed interface between the Thames Tunnel and the UKPN Bankside cable tunnel is located below the River Thames near the north bank in the borough of Westminster. The Thames Tunnel will be constructed below Bankside tunnel with a clear distance of approximately 21m.

To date, an interim detailed assessment report has been issued to the Thames Tunnel team to assess the likely impact on the Bankside cable tunnel due to the construction of the Thames Tunnel works. The interim report is based on a number of assumptions regarding the tunnel lining geometry and tunnel condition. In order to confirm these assumptions and to record the condition of the tunnel, a visual inspection of the Bankside cable tunnel was undertaken on Thursday 01st December 2011.

The inspections indicated that the concrete segments are in a very good condition. Segments are both bolted and expanded non-bolted with wedged in key segments. There are no signs of water ingress except at some bolts pockets. A large number of the expanded segments show signs of hairline cracks particularly at the key. Almost all cracks have been repaired and it is not believed that the cracks will impact adversely on the structural capacity of the lining. The bolted segments show very little signs of defects with only a few missing bolts. The bolts are generally in a very good condition with limited signs of rust/corrosion.
2 Introduction

The Bankside cable tunnel runs from the Bankside shaft south of the river to the Farringdon Road shaft north of the river. The interface of the Thames Tunnel with the Bankside Cable Tunnel is located below the River Thames near the north bank, close to Blackfriars Station at approximate Thames Tunnel chainage 16620m.

The Bankside cable tunnel is owned by UKPN and is used for carrying communications cables, high voltage electricity cables and fibre optic cables.

As part of the assessment of the Bankside cable tunnel, a visual inspection has been undertaken to confirm assumptions made in the detailed analysis and to record the general condition of the tunnel lining. The tunnel inspection was limited to a zone, extending approximately 70m on either side of the tunnel interface. This zone represents the length of the Wimbledon to Pimlico cable tunnel which is subject to ground movement greater than 1mm. An additional 30m was added to either side to ensure that a sufficient length of the tunnel was inspected, see Sketch 1 in Appendix D1.
3 Tunnel construction

The Bankside Cable tunnel was constructed between 2003 and 2005 and the project formed part of EDF Energy’s phased programme to upgrade the City of London primary distribution network.

The Bankside project involved the construction of a 2.59m dia main cable tunnel, 1.1km in length and it was constructed from Bankside working towards an existing shaft located in Farringdon Street. It crosses under the Tate Modern and the River Thames, passing close to the Blackfriars Bridge support piers adjacent to the north bank of the river. It also crosses beneath LUL’s Waterloo & City Line and District Line.

The main 2.59m internal diameter tunnel comprised a mix of expanded and bolted precast wedgeblock concrete segments and was constructed using a full face Tunnel Boring Machine (TBM). Each ring is composed of 7 segments and 1 key segment.
4 Tunnel inspection

The inspection of the Bankside tunnel was carried out on Thursday 01st December 2011 between 8.30am and 1.00pm. The inspection team consisted of Arup Tunnel Engineers and personnel from ABA Engineering Limited. ABA Engineering Ltd was appointed by UKPN to assist and manage the confined space procedures.

<table>
<thead>
<tr>
<th>Table 1 - Inspection team</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
</tr>
<tr>
<td>Linn Nordstrom</td>
</tr>
<tr>
<td>Agnieszka Mazurkiewicz</td>
</tr>
<tr>
<td>6x ABA Engineering Ltd Personnel</td>
</tr>
</tbody>
</table>

A method statement had been prepared for the tunnel entry protocol and safety, and this was fully complied with by all parties.

The weather on the morning of the inspection was overcast and there had been limited rain fall in the days prior to the inspection.

The inspection was undertaken from a north to south direction along the tunnel. However, the inspection team only used the south shaft at Bankside, located behind the Tate Modern gallery, for access and egress.

4.1 Scope of inspection

The scope of the inspection was to undertake a visual observation of the tunnel lining to confirm the lining geometry and to determine the presence of any signs of distress or damage that may compromise the structural capacity of the tunnel. Such features include but are not limited to: cracking / spalling of tunnel segments; corrosion of tunnel segments; water ingress; and birds mouthing of segments.

The visual inspection consisted of a walkthrough with notes and photographs taken where necessary to flag up any potential areas of concern.

It should be noted that the inspection was not intended to be a full structural survey or an intrusive investigation. The following information was recorded as a minimum:

Tunnel details including;
- Location
- Lining Type

Tunnel Lining
- Segment and key position
- Segment dimensions
- Identify defects, major (cracked segments, spalled concrete joints) and minor (seepage and corrosion)
4.2 Access and limitations

It should be noted that the visual inspection did not include the shafts. The area of inspection was limited to:

- Approximately 200 rings of the segmental lined concrete tunnel centred on the interface with the Thames Tunnel works.

As discussed in Section 3, the tunnel contains high voltage electricity cables, fibre optic cables and communication cables. Aside from the cabling which obscured portions of the right and left hand axis segments, visibility of segments were generally good.
5 Observations

The findings of the inspections are summarised below. Recorded observations for each ring are included in Appendix D2 whilst Appendix D3 contains photographs of some of the defects observed.

5.1 General condition

The survey started approximately 700m north from the Bankside shaft. The tunnel was inspected back towards this shaft in a southerly direction. For ease of reference the location of the first ring coincides with the location of the signage board indicating: Farringdon 395m to the north along the tunnel, Bankside 700m to the south along the tunnel. It should be noted that the tunnel was naturally ventilated during the inspection.

The concrete segments were generally in a very good condition. Physical damage to segments, such as spalling and significant cracking, was not encountered however, hairline cracks were visible (particularly at the key and shoulder segments) at several expanded segments.

The tunnel was dry with no signs of active seepage and only limited evidence of water ingress. A few of the bolted segments showed damp patches around the bolt pockets but the bolts very generally in a very good condition with only some showing signs of rust.

A description of observations is presented in Appendix D2, Photographs of observations are presented in Appendix D3.

5.2 Tunnel geometry

The following measurements and observations in regards to the tunnel geometry were made during the inspection.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>No segments</td>
<td>8 (7 + 1Key)</td>
</tr>
<tr>
<td>Segment type</td>
<td>Expanded pre-cast concrete (wedge block key segment) Bolted pre-cast concrete</td>
</tr>
<tr>
<td>Segment width</td>
<td>1000mm</td>
</tr>
<tr>
<td>Segment length</td>
<td>1100mm</td>
</tr>
<tr>
<td>Internal Diameter</td>
<td>2590mm</td>
</tr>
<tr>
<td>Lining Thickness (measured through exposed lifting hole pocket)</td>
<td>180mm</td>
</tr>
<tr>
<td>Bolt diameter</td>
<td>16mm</td>
</tr>
<tr>
<td>No of circumferential bolts (per ring)</td>
<td>22</td>
</tr>
<tr>
<td>No of radial bolts (per ring)</td>
<td>12</td>
</tr>
</tbody>
</table>
Appendix D1 – Figures
NOTE:
1. VERTICAL SETTLEMENT IS SHOWN EXAGGERATED BY A FACTOR OF 250.
2. DO NOT SCALE FROM DRAWING.

TUNNEL CURVE KEY:
- TUNNEL SETTLEMENT CURVE 1% VL

GEOTECHNICAL KEY:
- SUPERFICIAL DEPOSITS AND MADE GROUND
- LONDON CLAY FORMATION
- LAMBETH GROUP
- THANET SAND FORMATION
- CHALK GROUP

SECTION A-A UKPN BANKSIDE CABLE TUNNEL

UKPN BANKSIDE CABLE TUNNEL "GREENFIELD" GROUND SETTLEMENT 1% VL

DATE ISSUED: 01.08.2011
INSPECTION STARTED AT CHAINAGE 700 WHICH COINCIDES WITH EXIT SIGN F15 - BANKSIDE 700M, FARRINGDON 395M

NOTE: LIGHT BLUE ALIGNMENT INDICATES EXPANDED SEGMENTS WHILE DARK BLUE ALIGNMENT INDICATES BOLTED SEGMENTS
Appendix D2 - Ring observations
UKPN Bankside Cable Tunnel
Condition survey results

Legend:
1 = cracking 2 = corrosion 3 = active seepage
4 = calcite buildup 5 = staining 6 = damage at bolt holes
7 = Stalactite 8 = displacement of segment 9 = missing caulking
10 = open joints 11 = seepage at joints 12 = seepage at bolt holes
13 = damage around lifting socket/ grout 14 = corrosion 15 = damp
16 = missing nut 17 = missing bolt 18 = repaired
r = repaired

Date: 01st December 2011
Surveyor: LN/AM

It should be noted that the inspection was carried out from north to the south. Ring 1 coincides with the exit sign marking 700m to Bankside and 395m to Farringdon

<table>
<thead>
<tr>
<th>Ring Number</th>
<th>LK</th>
<th>LA</th>
<th>LS</th>
<th>K</th>
<th>RS</th>
<th>RA</th>
<th>RK</th>
<th>I</th>
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<tbody>
<tr>
<td>1</td>
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## TU057 - UKPN Bankside Cable Tunnel

### Legend:
- 1 = cracking
- 2 = corrosion
- 3 = active seepage
- 4 = calcite buildup
- 5 = staining
- 6 = damage at bolt holes
- 7 = Stalactite
- 8 = displacement of segment
- 9 = missing caulking
- 10 = open joints
- 11 = seepage at joints
- 12 = seepage at bolt holes
- 13 = damage around lifting socket/grout
- 14 = corrosion
- 15 = damp
- 16 = missing nut
- 17 = missing bolt
- r = repaired

### Date:
01st December 2011

### Surveyor:
LN/AM

It should be noted that the inspection was carried out from north to the south. Ring 1 coincides with the exit sign marking 700m to Bankside and 395m to Farringdon.

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*Note: The table details the condition survey results for the UKPN Bankside Cable Tunnel, including various defect types and locations.*
### TU057 - UKPN Bankside Cable Tunnel

**Legend:**
- 1 = cracking
- 2 = corrosion
- 3 = active seepage
- 4 = calcite buildup
- 5 = staining
- 6 = damage at bolt hole
- 7 = Stalactite
- 8 = displacement of segment
- 9 = missing caulking
- 10 = open joint
- 11 = seepage at joint
- 12 = seepage at bolt hole
- 13 = damage around lifting socket/ grout
- 14 = corrosion
- 15 = damp
- 16 = missing nut
- 17 = missing bolt
- r = repaired

**Date:** 01st December 2011

**Surveyor:** LN/AM

It should be noted that the inspection was carried out from north to the south. Ring 1 coincides with the exit sign marking 700m to Bankside and 395m to Farringdon.

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Appendix D3 – Photographs
Appendices

Photo 1 - Start of survey. Ring 1 coincides with the following exit sign.

Photo 2 - Southwards view down tunnel taken at Ring 1
Appendices

Photo 3 - Calcite build up at key segment of Ring 2

Photo 4 - Repaired crack at left axis of Ring 8
Appendices

Photo 5: Repaired crack at right axis of Ring 12

Photo 6 - Evidence of water ingress at right shoulder of Ring 18
Appendices

Photo 7 – Repaired crack at right shoulder of Ring 19

Photo 8 - Southwards view down tunnel taken at Ring 20
Photo 9 – Calcite build up around lifting socket at left shoulder of Ring 31

Photo 10 - Southwards view down tunnel taken at Ring 40
Photo 11 – Calcite build up at key of Ring 50

Photo 12 – Stain/calcite build up at left shoulder of Ring 57
Photo 13 – Stain/calcite build up at left shoulder of Ring 57 (zoom in)

Photo 14 – Southwards view down tunnel taken at Ring 60
Appendices

Photo 15 – Repaired segment at right shoulder of Ring 68

Photo 16 – Southwards view down tunnel taken at Ring 80
Photo 17 – Hairline crack at left knee taken of Ring 87

Photo 18 Repaired crack at right shoulder of Ring 87
Photo 19 – Exit sign at Ring 100

Photo 20 – Southwards view down tunnel taken at Ring 100
Photo 21 – Repaired crack at right axis of Ring 115

Photo 22 – Southwards view down tunnel taken at Ring 120
Photo 23 - Crack at right axis of Ring 121

Photo 24 – Evidence of water ingress at bolt pocket of Ring 135
Appendices

Photo 25 - Southwards view down tunnel taken at Ring 140

Photo 26 – Calcite build up at bolt pocket at right shoulder of Ring 142
Photo 27 – Calcite build up lifting socket at left axis of Ring 152

Photo 28 – Southwards view down tunnel taken at Ring 160
Photo 29 – Missing caulking at right shoulder of Ring 168

Photo 30 – Damp around bolt pocket at right knee of Ring 178
Photo 31 – Southwards view down tunnel taken at Ring 180

Photo 32 – Damp invert joints of Ring 190
Photo 33 – Damp patches in the invert and left knee joint of Ring 197 to Ring 199

Photo 34 – Southwards view down tunnel taken at Ring 200
Photo 35 – End of survey. Ring 200 coincides with the following exit sign.

Photo 36 – Photo of bolted segment (axis)
Appendices

Photo 37 – Photo of bolted segment (shoulder)

Photo 38 – Photo of bolted segment (knee)
Photo 39 – Photo of bolted segment (key)

Photo 40 – Cable and brackets along the left hand side of the tunnel
Photo 41 – Cable and brackets along the right hand side of the tunnel