Benprop Drury Limited

8-10 Stukeley Street

Crossrail Vibration Assessment

MLM.

Group

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1 Executive Summary

This study evaluates the vibration and re-radiated noise from the operation of Crossrail trains at the proposed development at 8-10 Stukeley Street. The prevalent vibration levels affecting the proposed basement extension have been assessed using the vibration velocity level information provided in Appendix A of the Crossrail Information for Developers document dated December 2016.

The proposed office development is approximately 17m from the nearest proposed Crossrail tunnel which will be operated by Crossrail trains.

Information supplied by Crossrail, states that the nearest tunnel is 14m to the north of the proposed development, and 13m below ground level; this has used as a basis for the calculations.

The vibration and re-radiated noise calculations indicate that the vibration/re-radiated noise will not have a significant impact on the office space located in the proposed basement. The calculated $L_{Amax,S}$ noise levels are below the operational goundborne noise criteria provided by Crossrail; 40dB $L_{Amax,S}$.

2 Introduction

MLM Acoustics have been commissioned by Benprop Drury Ltd to undertake an assessment of the vibration impacts from a proposed Crossrail tunnel upon the proposed development at 8-10 Stukeley Street, London.

There is a potential for vibration from Crossrail underground trains to have an adverse impact on the development. The possible adverse impact of the vibration, in terms of re-radiated noise within the new office unit, has been considered in assessing the potential requirements for mitigation measures.

The assessment was undertaken using the methodology and the equation described in paragraph 5.2, Appendix A of *'Crossrail: Information for Developers December 2016: A Technical guide for developers'*.

3 Proposed Development and Ground Conditions

The proposed development is a basement extension to an existing three storey office building. The basement will extend approximately 3.7m below ground level. The basement will be underpinned at this level and will include a retaining wall. These will bear onto a very dense granular Lynch Hill Gravel; the surface of the London Clay is 3.3m below this point.

Figure 1 was provided by Crossrail and shows the proposed location of the Crossrail tunnels. Crossrail state that 'the closest tunnel (westbound running tunnel) is approx. 14m to the north and approx. 13m below ground level (very shallow).'

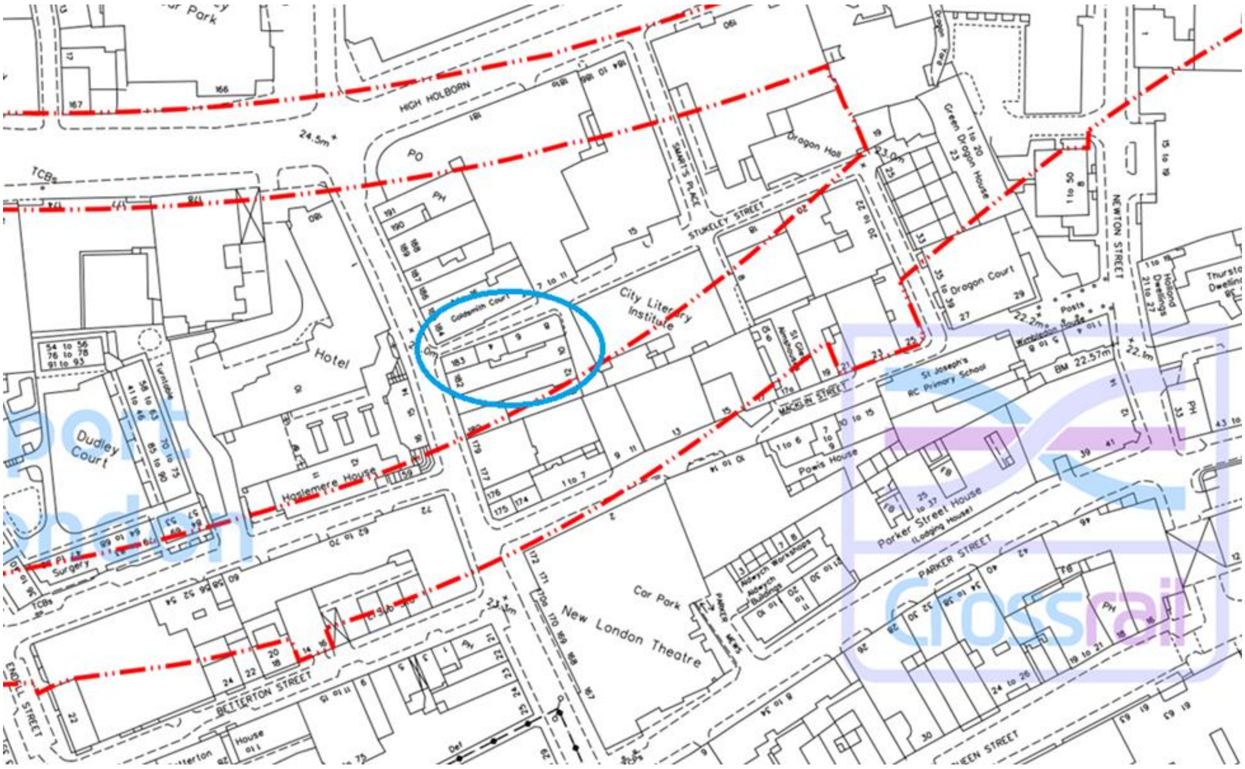


Figure 1: Location of proposed Crossrail tunnels

4 Methodology

This assessment is based on calculation methodologies which are presented in the publication *'Crossrail: Information for Developers December 2016: A Technical guide for developers'.*

There are multiple parameters which influence the emission and transmission of waves. These include distance, soil type, coupling losses and building response.

The tunnel vibration levels provided in Appendix A of the Crossrail information are used in this assessment. Worst case scenarios have been used in the calculations, which are: vibration levels at 55 degrees (nearest to calculated 52 degree angle to development) radiating from the tunnel and with a train with a speed of 100 km/h.

The following equation evaluates vibration transmission (Equation 1) and re-radiated noise (Equation 2).

Equation 1

$$L_r = L_t - 4.34\frac{\omega\eta r}{c_s} - 10\log_{10}\left[\frac{r_0 + r}{r_0}\right]$$

Where L_t is the tunnel wall radial velocity for a tunnel of radius r_0 and L_r is the soil radial velocity at distance r, both in dB re 1 nanometer/second, c_s is the phase speed of compression waves in soil with loss factor η and ω is the angular frequency of each 1/3 octave band in radians per second. The coupling loss factor and building response generally have opposite sign and as a first order approximation they may be assumed to cancel. In the case of piled foundations, if r is taken to be the shortest distance to any part of the nearest pile, a worst-case estimate will be obtained. Any distance units may be used, provided they are consistent throughout.

Figure 2: Crossrail vibration transmission calculation method

Constants:

- Tunnel radius: 3 metres;
- Distance: 16.7 metres (to basement slab) ;
- Loss Factor (London Clay) = 0.1-0.5;

  (Data on the loss factor for London Clay varies significantly depending on the source. References:
  Propagation of Ground Vibration: A review – Gutowski & Dym 1976 states 0.5.
  Crossrail Report No. 1E315-G0E00-00002 - Crossrail Groundborne Noise and Vibration Prediction, Validation on DLR Greenwich, Technical Report states 0.1);
- c_s = 1611 m/s.

The notes below equation 1 state that coupling losses and building response may be assumed to cancel. To ensure an accurate conclusion is reached in this assessment, coupling losses and building response have been included in the assessment. The sources of the information included in the calculation are presented overleaf.

The figure below shows the coupling losses expected for a large masonry building on piles.

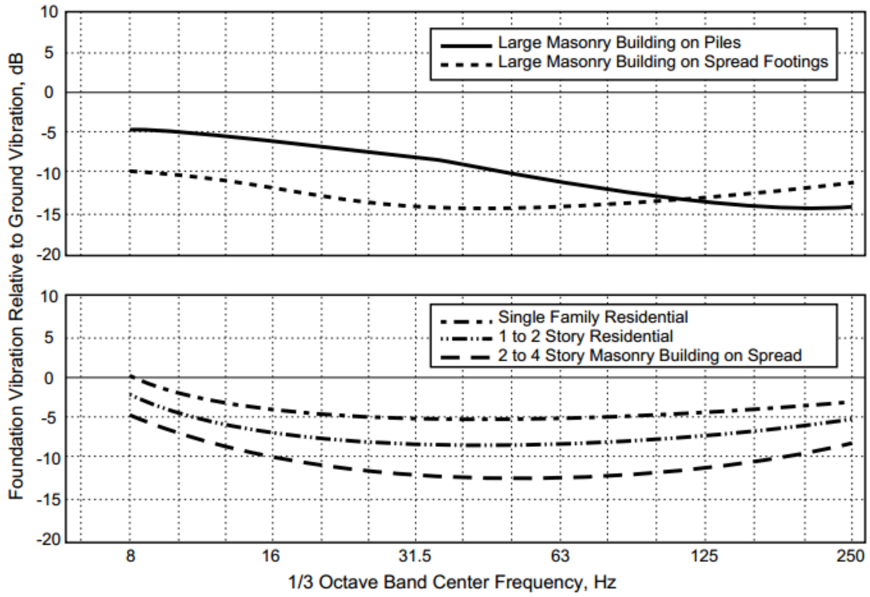


Figure 3 – Coupling losses for various building types taken from the Handbook or Urban Rail Noise and Vibration Control – Saurenman, Nelson, Wilson (1982).

The figure below shows the expected amplification as a result of building response.

Factors Affecting Vibration Receiver

Receiver Factor	Adjustment to Propagation Curve	Comment
Floor-to-floor attenuation	1 to 5 floors above grade: -2 dB/floor 5 to 10 floors above grade: -1 dB/floor	This factor accounts for dispersion and attenuation of the vibration energy as it propagates through a building.
Amplification due to resonances of floors, walls, and ceilings	+6 dB	The actual amplification will vary greatly depending on the type of construction. The amplification is lower near the wall/floor and wall/ceiling intersections.
Radiated Sound	Peak frequency of ground vibration: Low frequency (<30 Hz): -50 dB Typical (peak 30 to 60 Hz): -35 dB High frequency (>60 Hz): -20 dB	Use these adjustments to estimate the A-weighted sound level given the average vibration velocity level of the room surfaces. See text for guidelines for selecting low, typical or high frequency characteristics. Use the high-frequency adjustment for subway tunnels in rock or if the dominant frequencies of the vibration spectrum are known to be 60 Hz or greater.

Figure 4 – Building response information taken from table 10-1 of the Transit Noise and Vibration Impact Assessment prepared for the U.S Department of Transportation (1995).

The document states that 'reinforced-concrete slab floors in modern buildings will have fundamental resonance frequencies in the 20 – 30 Hz range. An amplification resulting in a gain of approximately 6 dB should be used in the frequency range of the fundamental resonance.'

For robustness, 6 dB has been added to each 3rd octave value in this assessment.

Re-radiated noise into the basement level has been calculated according to the following formula, this is presented in Appendix A of the Crossrail Information for Developers document.

Equation 2:

$L_p = L_v$ - 27 dB

Where L_p is the 1/3 octave band sound pressure level

Lv = is the "rms" vibration velocity in dB re 1 nanometre per second.

5 Criteria

The internal groundborne noise criteria presented in the Crossrail Information for Developers document are presented below.

Building	Level/Measure
Residential buildings	40dB $L_{Amax,S}$
Offices[2]	40dB $L_{Amax,S}$
Hotels[2]	40dB $L_{Amax,S}$
Theatres	25dB $L_{Amax,S}$
Large Auditoria/Concert Halls	25dB $L_{Amax,S}$
Sound recording studios	30dB $L_{Amax,S}$
Places of meeting for religious worship[3]	35dB $L_{Amax,S}$
Courts, lecture theatres	35dB $L_{Amax,S}$
Small Auditoria/halls	35dB $L_{Amax,S}$
Hospitals, laboratories	A40dB $L_{Amax,S}$
Libraries	40dB $L_{Amax,S}$

Figure 5 – Crossrail operation groundborne noise criteria

6 Calculated Internal Groundborne Noise Level

The expected groundborne noise level within the proposed basement office has been undertaken based on the methodology set out in section 4 of this report.

Based on information provided by Crossrail, the distance to the tunnel has been calculated as approximately 16.6m. This assumes that the lowest point of the proposed basement will be 4m below ground level (current proposals show 3.7m). There will be a layer of dense Lynch Hill gravel from the basement slab down to a distance of approximately 7m below ground level; the ground type beneath this is London Clay. Distances are represented in Appendix A.

The shortest path for vibration transmission therefore extends approximately 9.8m through London Clay and then 6.8m through the dense gravel; the calculation takes into account two different loss factors.

For a robust assessment, the calculation has been undertaken twice to account for the varying information on the loss factor of London Clay. A range of expected noise levels is provided which representative of loss factors 0.1 – 0.5. The loss factor used for dense gravel is 0.05.

In terms of coupling losses, the values shown graphically in Figure 3 for a 2 to 4 story masonry building on spread footings have been used. This is thought to best represent the proposed four storey building.

The angle between tunnel and development was calculated to be 52 degrees and therefore the vibration velocity data provided for a 100km/h train at this angle (55 degrees nearest data point) was used to demonstrate the highest expected groundborne noise levels.

The expected groundborne noise level within the proposed basement when Crossrail is operating, is between 33-39 dBA L_{smax}. The range is provided to account for the variable data on the loss factor of London Clay. The expected levels are compliant with criteria for offices; 40dBA L_{Smax}. The calculations are set out in Appendix B.

The *Crossrail Report No. 1E315-G0E00-00002 - Crossrail Groundborne Noise and Vibration Prediction, Validation on DLR Greenwich, Technical Report* states that measured levels are unlikely to exceed predicted levels by more than 5 dBA.

The Crossrail Information for Developers states that 'with regard to vibration, it is normally the case that where groundborne noise criteria are satisfied, vibration criteria are also satisfied'. Past experience would indicate that this statement generally holds and therefore vibration is expected to be within the limits set out be Crossrail.

7 Conclusions

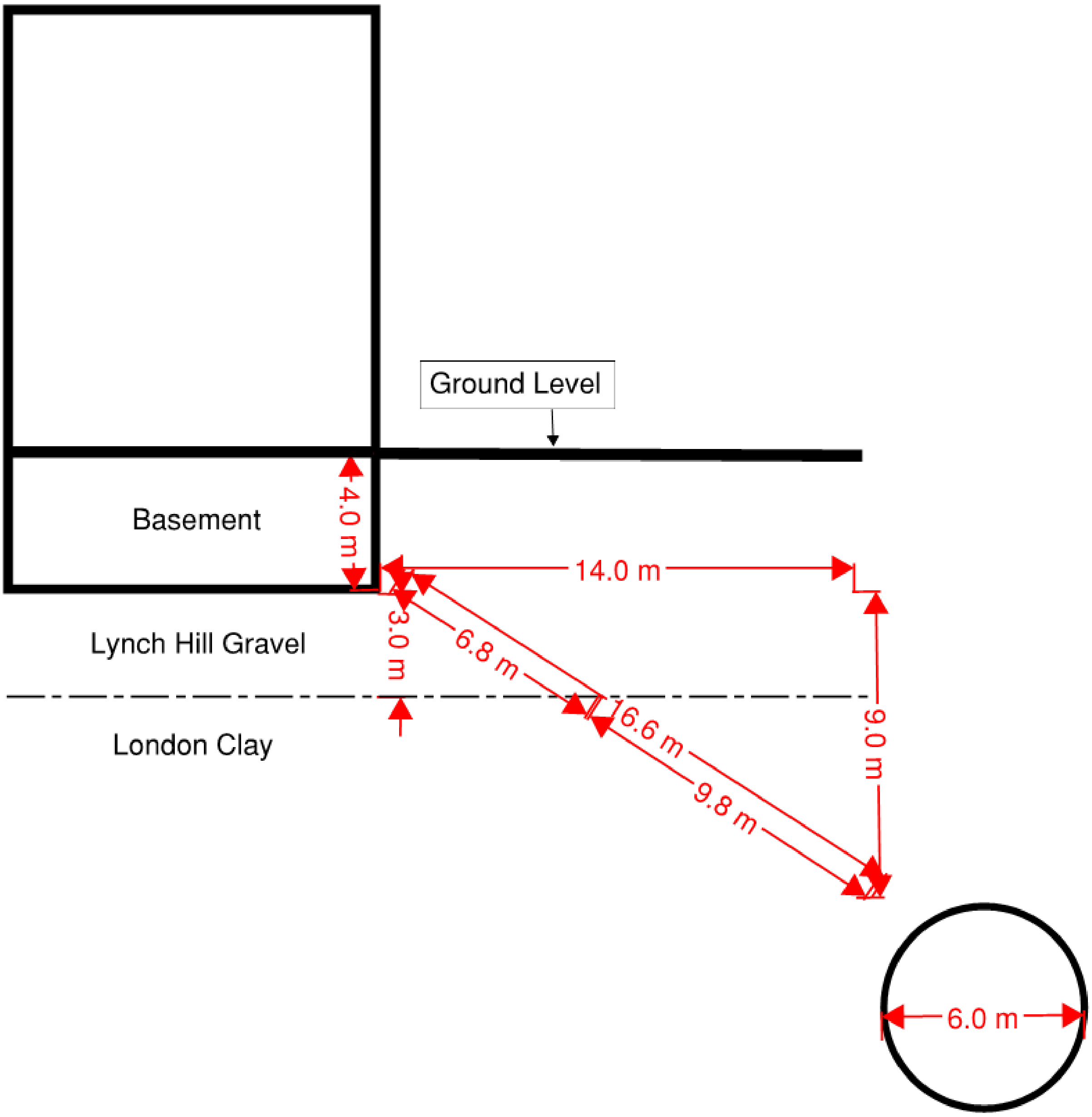
The effects of vibration associated with Crossrail underground trains running in close proximity to the proposed office development at 8-10 Stukeley Street have been assessed in terms of re-radiated noise within the new office units. The assessment has been undertaken with reference to the methodology described in paragraph 5.2 Appendix A of Crossrail Information for Developers: December 2016.

The results of the assessment indicate that that re-radiated levels in the residential units are expected to be of the order of $L_{Amax,s} =$ 33-39dB which is compliant with the Crossrail requirements.

The noise level predicted is by no means inaudible. It is essential to note that a low rumble of passing trains is likely to be evident within the office space, however this is expected to be at an acceptable level in accordance with Crossrail guidance. Physical vibration is also expected to be within acceptable limits.

The predicted internal, structure-borne, re-radiated noise levels are within the Crossrail requirements for internal re-radiated noise. It is therefore concluded that building isolation is not required.

Appendix A - Sketch showing approximate distances used in calculations


Ground Level
Basement
4.0 m
14.0 m
3.0 m
6.8 m
Lynch Hill Gravel
6.6 m
9.0 m
London Clay
9.8 m
6.0 m

Appendix B - Calculations

Table B1: Groundborne Noise Level Calculation dB (London Clay Loss Factor = 0.5)										
	Frequency (Hz)									
	20	25	31.5	40	50	63	80	100	125	160
Tunnel Vibration Velocity	89	93	101	105	96	94	90	92	90	85
Propagation Losses	1.2	2.2	2.8	3.5	4.4	5.6	7.1	8.9	11.1	14.2
Distance Attenuation	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3
Coupling Losses	11	12	12.5	12.5	12	12	11	11	11	10
Resonance Amplification	6	6	6	6	6	6	6	6	6	6
Vibration Velocity Basement	76	78	85	89	79	76	72	72	68	61
Re-radiated Noise Level	46	51	58	62	52	49	45	45	41	34
A-weighted Noise Level ($L_{Amax,S}$)	-2	7	19	27	22	23	22	26	25	20

Table B2: Groundborne Noise Level Calculation dB (London Clay Loss Factor = 0.1)										
	Frequency (Hz)									
	20	25	31.5	40	50	63	80	100	125	160
Tunnel Vibration Velocity	89	93	101	105	96	94	90	92	90	85
Propagation Losses	0.4	0.6	0.7	0.9	1.1	1.4	1.8	2.2	2.8	3.6
Distance Attenuation	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3
Coupling Losses	11	12	12.5	12.5	12	12	11	11	11	10
Resonance Amplification	6	6	6	6	6	6	6	6	6	6
Vibration Velocity Basement	77	80	87	91	83	80	77	78	76	71
Re-radiated Noise Level	50	53	60	64	56	53	50	51	49	44
A-weighted Noise Level ($L_{Amax,S}$)	0	8	21	30	25	27	27	32	33	31

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