Appendix A9.8

Operational Groundborne Noise and Vibration

Operational Groundborne Noise and Vibration

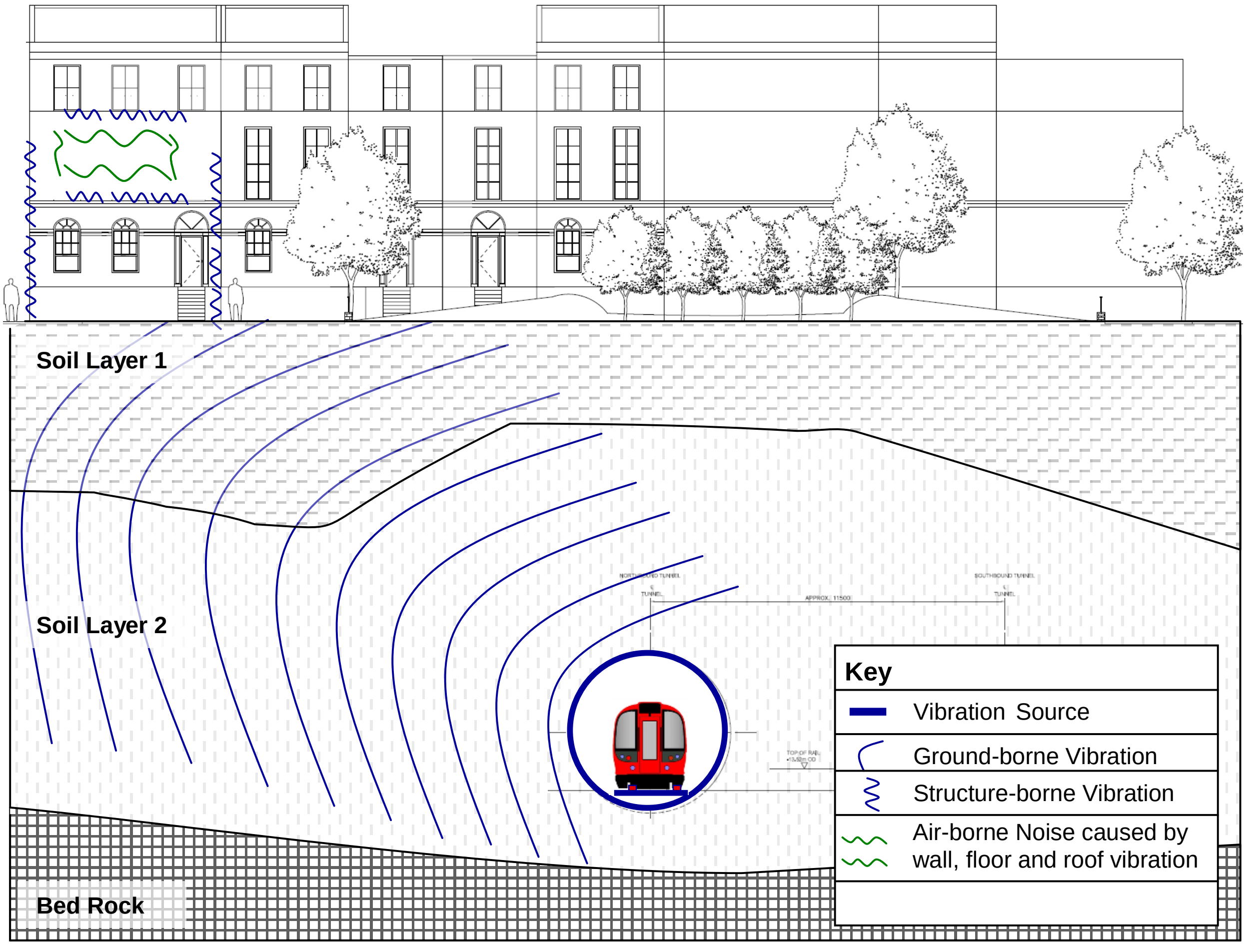
A9.8.1. The operation of the new southbound running tunnel has the potential to create new groundborne noise and vibration impacts within buildings close to the alignment of the proposed tunnel. The impacts from the operation of the new tunnel have been assessed using a combination of empirical data and mathematical modelling.

A9.8.2. Underground rail traffic has the potential to generate ground borne noise within properties above the line. Vibration is generated by trains due to the interaction between the roughness of the running surfaces of the trains' wheels and the rail of the track. This roughness, the amplitude of which is typically less than a millimetre, generates a fluctuating force at the contact patch between the wheels and rails. This force generates vibration that propagates into the rails and vehicle wheels, where it is radiated as airborne noise; and also propagates into the ground.

A9.8.3. The vibration is of sufficient amplitude that it can propagate into buildings above the railway tunnel. When it enters such structures, it can be perceived as feelable vibration, but more commonly, it causes the structural elements of the building to vibrate and radiate sound into rooms within the building. This audible sound is known as ground borne noise.

A9.8.4. This vibration phenomenon is illustrated in Figure A9.8.1

Figure A9.8.1: Groundborne noise and vibration due to underground trains



A9.8.5. Groundborne noise is a particular problem for underground railways. When a building is located next to a surface railway, any noise will be heard as a combination of the airborne noise and ground borne noise combined. As such, the significance of the groundborne noise for surface railways is low since the majority of situations will have the airborne noise as the dominant component.

A9.8.6. When a railway runs in a tunnel, there is no airborne noise component. As such, the groundborne noise is heard in isolation. This, coupled with the lack of any visual stimulus for the passing trains, makes ground borne noise a particular consideration when planning new underground railways.

A9.8.7. Groundborne noise has a particular difference to most sources of environmental noise. When considering noise from sources such as surface railways or highways, the noise that is heard inside a building is the result of the noise that transmits through the façade of the building, typically through the windows. As such, if levels of environmental noise are considered to be too high within a building, it is possible to reduce these noise levels by increasing the performance of the installed glazing.

A9.8.8. This is not possible for groundborne noise since the sound is caused by the response of internal building elements to external vibration. As such, increasing glazing performance will have no effect on the groundborne noise. It may even have the reverse effect since increased glazing performance can decrease background noise levels within rooms, which may make the ground borne noise more noticeable.

A9.8.9. Therefore, it is very difficult to provide mitigation to buildings located close to underground railways. The most effective method of mitigating groundborne noise is through the careful design of the railway to minimise the vibration at the source.

A9.8.10. Groundborne vibration is produced by the interaction of the wheels and rails. This radiates the vibration from the base of the tunnel. One aspect of this phenomenon is that the presence of the tunnel provides what is effectively a screen to the vibration produced at the base of the tunnel. This results in a ‘shadow’ area directly above the tunnel and the highest levels of vibration are typically found a few metres to the side of the tunnel alignment.

Background

A9.8.11. The proposed new southbound tunnel will be an SCL tunnel which is to be constructed to the west of the current southbound tunnel alignment. The current southbound tunnel will become part of the station passenger circulation area upon completion of the project.

A9.8.12. The proposed tunnel alignment is expected to intersect with piles of four buildings. The engineering solution for these pile interceptions involves either supporting the load of the piles on the tunnel structure, or removing the end section of pile and isolating just above the tunnel lining, both of which are likely to increase vibration transfer into the buildings above.

A9.8.13. The prediction of the groundborne noise and vibration from the new southbound running tunnel has provided an assessment of the expected groundborne noise and vibration levels for buildings with pile interceptions and also for the other buildings likely to be worst-affected by the tunnel.

Prediction Methodology

A9.8.14. The prediction of vibration and groundborne noise from the new running tunnel has been divided into three separate aspects:

- site specific empirical source data;
- mathematical modelling of tunnel-structure interaction; and
- mathematical modelling of trackforms.

A9.8.15. Each of these aspects of the vibration propagation path has been considered separately with the predictions for each location formed from a combination of the necessary results for each section.

A9.8.16. The prediction methodology relies on site specific measurement data wherever possible. The measurement of vibration allows for the direct evaluation of the relevant levels and as such provides the lowest levels of uncertainty when compared to a purely mathematical method.

A9.8.17. Source data measured inside selected buildings along the route have been acquired to determine the expected vibration levels inside buildings. The buildings selected cover the range of construction types for the study area around the proposed new southbound tunnel.

A9.8.18. Where the new tunnel introduces design features that are not contained within the empirical data, mathematical modelling is used to provide a prediction of the effects of this feature in terms of the vibration difference between the source data location and the location for which the prediction is required.

A9.8.19. There are particular features of the BSCU that require specific mathematical modelling, namely the effects of the tunnel structure, the effect at the pile interception locations and the effects of different trackform designs.

A9.8.20. The prediction of vibration and groundborne noise is required to provide the expected levels in terms of the vibration dose value for assessing the effects on whole body vibration and in terms of the L_{AFmax} for assessing the effects on noise. The details of the relevant criteria are provided in Chapter 9.

Source Data

A9.8.21. The use of accurate source data is the most important aspect of the modelling process. This requires that source data are acquired for as many aspects of the situation to be modelled as possible. These source data consist of measured floor vibration levels inside buildings above the existing Northern line tunnels in buildings potentially affected by the BSCU.

A9.8.22. These source data include inherent consideration of aspects such as rolling stock characteristics, propagation from tunnel to building and building transfer functions.

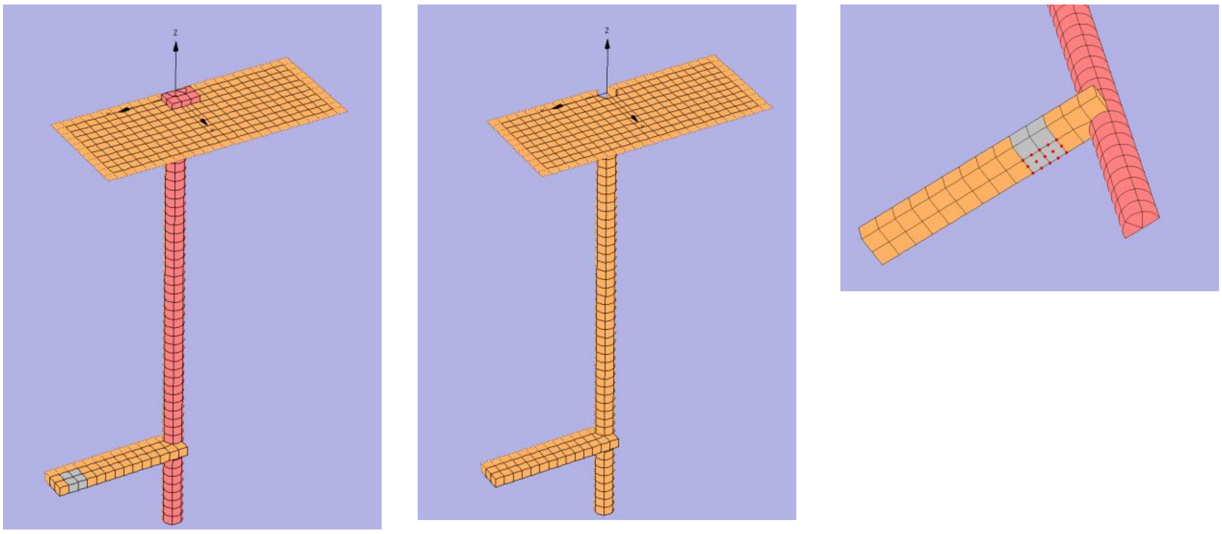
A9.8.23. Source data are acquired in terms of floor vibration levels in one third octave band spectra. These are averaged over a 125 ms time period to ensure that they can be used to calculate the L_{AFmax}.

Tunnel-Pile Interaction Modelling

A9.8.24. To study the effects of when the tunnel is either in contact with, or very close to, the piled foundations of buildings, mathematical modelling has been used to provide calculations of how the tunnel interacts with piles.

A9.8.25. For this, use has been made of a three-dimensional boundary element (BE) and finite element (FE) package called BEASTS [1], [2], [3]. This uses finite elements for structures such as a pile and boundary elements for the continuum of soil in which it is embedded. To model vibration propagation in three-dimensions in a sufficient volume of soil using finite elements would require a very large number of elements. This is because a large volume of soil out to several compression wavelengths from the region of interest must be modelled and elements must be small compared to the much shorter shear wavelength. This would be prohibitive in terms of computational resources. Therefore, boundary elements are used since only the boundaries of the soil, such as the interfaces between the soil and the finite-elements, have to be meshed with elements. Figure A9.8.2 depicts the FE/BE model that has been used.

Figure A9.8.2: Finite element/boundary element model



A9.8.26. It is deliberately abstracted and simplified to study propagation as a function of the presence of a pile. It does not model a building nor a tunnel structure as these would lead to a large model. By keeping the model relatively small, many computations can be carried out with variations of parameters in order to

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[1] Andersen, L. and Jones, C.J.C., Coupled boundary and finite element analysis of vibration from railway tunnels—a comparison of two- and three-dimensional models, *Journal of Sound and Vibration,* 293 (3-5), 611 – 625, 2006.

[2] Andersen, L. and Jones, C.J.C. Three-dimensional elastodynamic analysis using multiple boundary element domains. *ISVR Technical Memorandum*, 2001, 867.

[3] Andersen, L. and Jones, C.J.C. BEASTS a computer program for boundary element analysis of soil and three-dimensional structures. *ISVR Technical Memorandum*, 2001, 868.

explore the effects of distance from source to pile, extent of the pile and stiffness of the ground.

A9.8.27. A model for a 1 m diameter pile is presented in Figure A9.8.2 . On the left the whole model with pile cap and 25 m pile modelled with finite elements is shown. The surface of the ground is modelled at a distance of 20 m using boundary elements and the whole pile is wrapped in boundary elements that are fully coupled structurally to the finite elements. In the centre of Figure A9.8.2 , the model is shown with the finite elements removed so that just the sheath of boundary elements can be seen.

A9.8.28. Using these boundary elements, a homogeneous continuum of soil is modelled that extends outwards to infinity. The propagation from the FE structure is modelled as waves radiating from the structure without reflection at any boundary except, to the extent it is defined, by the ground surface.

A9.8.29. The boundary elements depicted with dotted line edges are false elements used in the model to define the direction of continuation of the edge of the model. For efficiency, the model uses symmetry about the *x-z* plane.

A9.8.30. The element edge size is limited to 0.5 m. Since the BE elements are nine-noded quadrilaterals with quadratic order shape functions and the finite elements are generally compatible, there are at least five nodes per shear wavelength (2 elements) of the soil at 250 Hz. The model has been tested against a simpler analytical solution to show that it is valid up to at least about 200 Hz. Therefore, it covers the range of frequency that is most important for typical groundborne noise.

A9.8.31. A strip of finite elements is placed at a depth of 20 to 20.5 metres from the surface. This provides nodes at which loads can be applied and also allows visualisation of the motion of the soil. The grey elements in Figure A9.8.2 (left) are attributed the stiffness of concrete. This is where the load is applied. However, in order to avoid a resonance of the concrete load footing within the soil, the density of the footing is the same as the surrounding soil.

A9.8.32. The model is used in the frequency domain to calculate the response at nodes on the surface to a force of unit amplitude spread as a pressure over elements on the footing. By changing the material properties of the finite elements, the distance of the footing from the pile can be varied.

A9.8.33. It has been convenient to load the footing on its underside as illustrated in the right hand section of Figure A9.8.2. This shows just the finite-elements. The elements attributed the material parameters of soil are shown in orange, the footing, grey, and the pile, pink. The radius of the pile is 0.5 m and the hexahedral finite-elements are 0.5 m wide. The centre of the loaded footing is therefore 1.75 m from the axis of the pile but the distance from the edge of the footing to the cylindrical surface of the pile is only 0.75 m.

A9.8.34. The material parameters of the soil and concrete elements of the model are given in Table A9.8.1. The soil representing the London clay is used in most analyses.

Table A9.8.1: Material parameters used in the modelling

Material	Youngs modulus N/m^2	Poisson's ratio	Density kg/m^3	Loss factor	S-wave speed m/s	P-Wave speed m/s
Concrete	20 x 10^9	0.15	2500	0.03	1865	2910
Concrete with the density of the clay	20 x 10^9	0.15	1980	0.03	2096	3266
Soft London Clay	**286 x 10^6**	**0.49**	**1980**	**0.08**	**220**	**1570**
'Sandy' soil	230 x 10^6	0.2	1980	0.08	220	360
Stiffer London Clay	462 x 10^6	0.49	1980	0.08	280	2000

A9.8.35. In order to check that the model element discretization produces sufficiently accurate results for the study, a small number of results have been compared with an exact model for the axisymmetric response of a load on a circular footing[4]. The exact model represents homogeneous half-space ground with a surface of infinite extent. The excitation is a vertical unit pressure distributed over a circular footing and can be placed at any depth within the half-space.

A9.8.36. The circular elements of the pile itself have been used to apply an oscillating unit load at the surface or at a depth of 20.5 m. The latter is the depth of the arm of elements on which the excitation is placed in the main study. In order to make the model equivalent to the exact model the elements representing the pile cap have been omitted in these analyses.

A9.8.37. It is judged that the boundary/finite element discretization is adequate up to about 200 Hz for the study of differences in response because of changes in the materials of the elements.

Trackform Modelling

A9.8.38. The modelling of trackforms has been carried out using the Igitur model[5]. This model is used to calculate the change in vibration response at an observation point on the surface of a half-space, beside the track, due to a change in the track or vehicle parameters.

A9.8.39. The track is represented as a two-dimensional, infinite, layered beam resting on a three-dimensional half space. Track components are attributed properties as if continuous along the track, using the following parameters:

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[4] Kausel, E and Roësset, JM, "Stiffness Matrices for Layered Soils", Bulletin of Seismological Society of America, Vol. 71, No. 6, pp. 1743-1761, December 1981.

[5] Jones, CJC, "Ground borne noise from new railway tunnels", Proc. Internoise 96, Liverpool, UK (1996), Book 1, 421-426.

A9.8.40. The wheelset (unsprung mass) acts on the rail via a linearised contact stiffness, while a wheel and rail roughness is introduced as a differential displacement function across the contact spring. The vehicle suspension is modelled as a complete one-dimensional system for each wheelset, including primary and secondary elements, bogie and body masses. The half-space foundation model represents the frequency-dependent support stiffness distribution under the track and provides a suitable summation of the contributions of vibration from all points along, and across the width of, the track.

A9.8.41. The model allows several different sets of variables to be modified, giving options for track type, vehicle type, and the condition of the interface. For the vehicle, different unsprung masses and different suspension designs can be considered. For the track, a complete range of different trackforms can be represented, using various combinations of layers as components, including ballasted and non-ballasted designs.

A9.8.42. There are two principal mechanisms to be considered in the generation of vibration in the general case, both of which are necessary for a theoretical prediction of actual emissions:

- the dynamic forces as the unsprung mass of the wheel is excited vertically as it moves over the irregular profile of the track; and
- the quasi-static displacement caused by successive axle loads as they pass over a point in the track.

A9.8.43. The first of these tends to be dominant at higher frequencies, although the specific frequency range over which this becomes true depends on the train speed and the condition of the track as well as its design. Igitur uses only the former mechanism in its simulation of the excitation and therefore is not able fully to simulate all the effects at low frequencies in the near-field. This is because changes in design that cause a significant modification of the quasi-static excitation usually do so as a result of some form of load spreading.

A9.8.44. Close to the track, changes in trackform are likely to result in differences in response to the quasi-static as well as the dynamic excitation. Away from the track and particularly on layered ground that restricts the propagation of low frequency vibration, the difference will tend towards the change in dynamic response alone. This is particularly the case when working primarily with source data acquired inside buildings above tunnels.

A9.8.45. Therefore, the prediction according to Igitur is considered to be a reasonable estimate of a specific difference at a normal observer point, given suitable parametric information.

Empirical Data

A9.8.46. The last element of the modelling process is to use an empirical formulation to use the predicted floor vibration to calculate the expected levels of groundborne noise. This is done using the Kurzweil formula, a well-established formula based on the principle of the groundborne noise being proportional to the average vibration velocity of the room surfaces. The Kurzweil formula is given by:

$$L_p = L_v - 27$$

WhereL_p is the groundborne noise level, dB re 20μPa; and
L_v is the average room vibration velocity level, dB re $1x10^{-9}$m/s

A9.8.47. This formula has been found to apply to a wide range of situations.

Trackform Design

A9.8.48. The design of the permanent way is based on the use of a resilient baseplate track system. This will be used throughout the new southbound running tunnel. The current preference is for a Delkor baseplate system.

A9.8.49. It is recognised that the pile interception locations will require a track system that provides a higher degree of vibration isolation than a normal resilient baseplate system. As such, a high performance track system will be required to reduce groundborne noise levels to buildings whose piles are intercepted.

A9.8.50. The current information on the foundations of buildings above the new southbound tunnel indicates that there are four buildings where pile interceptions are expected, namely:

- 6-8 Prince’s Street;
- 8-10 Mansion House Place;
- New Court, St Swithin’s Lane; and
- 33 King William Street.

A9.8.51. There are also other buildings above the alignment of the new tunnel with piled foundations where the current records drawings do no indicate that a pile interception is expected. However, it is known that there may be some uncertainty on the information contained within these record drawings. As such, the tunnel has been designed with sufficient space allowance to ensure that if additional piles are encountered during construction, a high performance track system can be installed to provide the necessary groundborne noise attenuation to those buildings in addition to the specific locations mentioned above.

A9.8.52. To ensure that the vibration requirements are met at each of the pile interception locations, the high performance track system will be provided throughout the extent of the tunnel where the pile interceptions occur and also for 25 m either side of the this section of track. This will ensure that the vibration will not transmit through the tunnel lining from the conventional sections of the track and 'short-circuit' the isolation provided by the high performance track.

Site Surveys

A9.8.53. The vibration produced by Northern Line trains in the vicinity of Bank Station forms the basis of the prediction methodology. The measurement of the vibration from these trains within the buildings required for the assessment will provide the most robust set of source data.

A9.8.54. Measurements of the groundborne vibration levels have been carried out at a number of locations within the study area, namely:

- 6-8 Prince's Street;
- Mansion House;
- 8-10 Mansion House Place;
- New Court, St Swithin's Lane;
- St Mary Abchurch;
- St Clement's Church; and
- Adelaide House.

A9.8.55. These locations have all been used to define vibration source data for use in the predictions. At each location, the nature of the source including the railhead roughness, the transmission path from the tunnel to the building and the ground to building transfer function are incorporated into the empirical data.

A9.8.56. At each location, the vibration on the floor of the building is recorded as a raw acceleration time history direct from the accelerometer. This allows the maximum resolution of the data to be obtained.

A9.8.57. To enable the survey data to be used in the modelling, they have been analysed to give the maximum 0.125 ms one third octave band spectrum from each train passby. These have then been averaged over at least 10 trains to enable the use of a typical spectrum in the predictions, as required by the London Underground guidance.

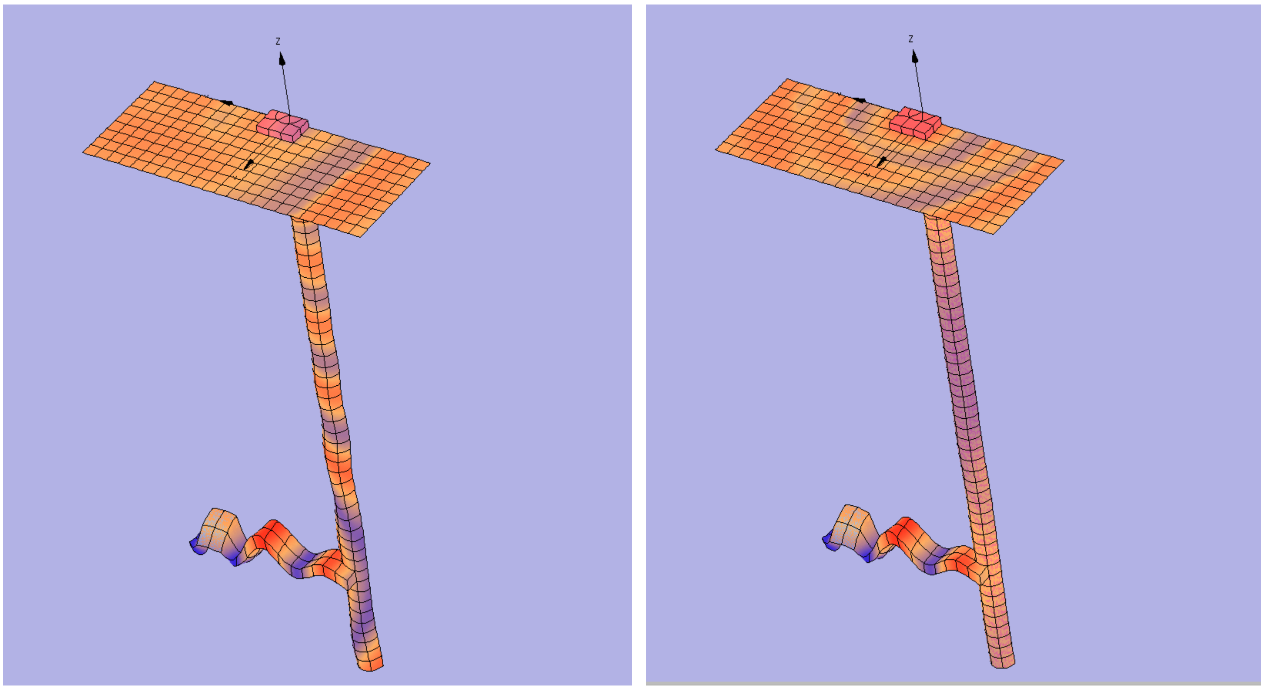
A9.8.58. Some of the sites at which source data have been acquired are within piled buildings. These buildings will include some effects due to the modification of the vibration transmission path by the presence of the piles. To account for this, the FE/BE modelling has been used to determine this effect and to incorporate this into the source data and provide generic source data without the effects of piles that can used as the basis of the predictions for all locations.

Modelling Results

A9.8.59. The results of the modelling are provided in this section. The first stage of the modelling has been the determination of the effect of the pile interceptions, namely how the vibration changes when the tunnel is close to or in contact with the piles of a building.

A9.8.60. Figure A9.8.3 presents a side-by-side comparison of the responses of two models for the situation of the forcing frequency of 100 Hz.

Figure A9.8.3: Comparison of response of example models with and without the pile



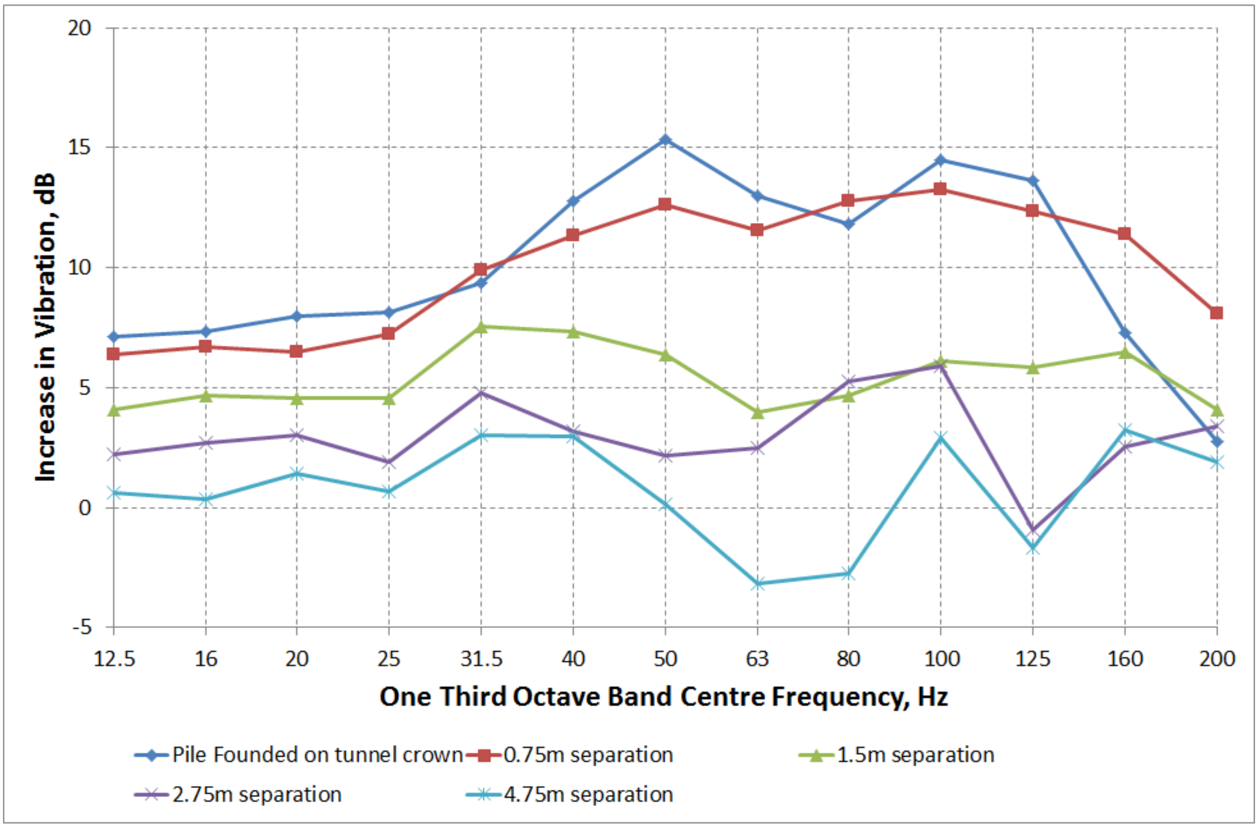
A9.8.61. The first, (left), has the finite elements of the pile set to the same material parameters as the soil in the surrounding half-space. The second model (right) has the finite elements of the pile set to the material properties of concrete. The figure shows a representation of the response of the model to the load on the footing which has its centre-line at 5.75 m from the axis of the pile. There is therefore 4.75 m of soil between the two.

A9.8.62. In Figure A9.8.3 (left) the waves of vibration can be seen propagating away from the footing. Although most of the soil domain is not visualised because it is modelled using the boundary elements, the waves in the finite-element arm and in the pile mesh can be seen to form the pattern of circular wave fronts ‘radiating’ in the soil towards the ground surface and the pile cap. In Figure A9.8.3 (right), the vibration propagates along the finite element arm within the soil very similarly to Figure A9.8.3 (left). However, at the pile, longer wavelengths of vibration are seen because of the much stiffer concrete material. Thus, also the vibration at the surface around the pile cap is changed.

A9.8.63. Although Figure A9.8.3 is a useful visualisation of the propagation of vibration, it does not present appropriate behaviour for a quantitative comparison of the effect of the pile upon the propagation of vibration. The method of assessing the effect of the pile at different distances is developed first by averaging the response over the whole pile cap and at positions on the uncovered ground surface of the model. The vertical and lateral components are then combined to give a measure of the source that would give rise to noise inside buildings.

A9.8.64. The model has been used to carry out a sensitivity test on different parameters used in the modelling; however, the primary purpose of the models has been to determine the effects of varying the distance between the tunnel and the pile. The results of this modelling is provided as Figure A9.8.4.

Figure A9.8.4: Results of FE/BE modelling



A9.8.65. These results show the increase in vibration that results from the different distances between tunnel and pile. These have been used to determine a correction to be used to account for this distance. In addition, the effects of having the pile in direct contact with the tunnel structure are also evaluated. It can be seen that when a pile is within 1 m of the tunnel lining, there is very little attenuation as the vibration propagates through the soil and groundborne noise levels are increased by 12 dB for typical groundborne noise spectra, which is comparable with the increase produced by having the pile in direct contact with the tunnel lining.

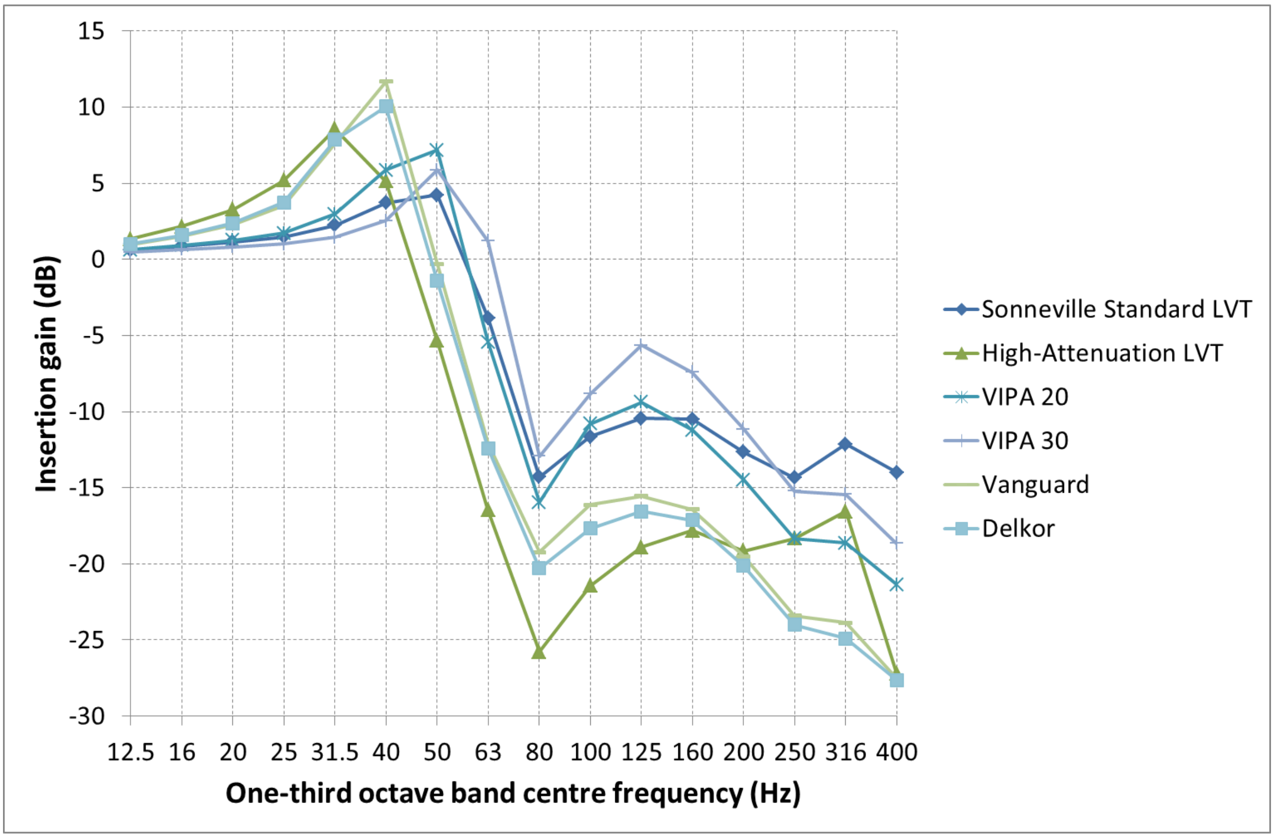
A9.8.66. Once the pile is separated from the tunnel by 1.5 m, the vibration begins to attenuate through the soil and the 1.5 m separation is predicted to increase groundborne noise levels by 6-7 dB for typical groundborne noise spectra. However, at a distance of 4.75 m, the presence of the pile is predicted to cause an increase of up to 2 dB for typical groundborne noise spectra.

A9.8.67. The application of these results to the source data allows for the prediction of the groundborne noise levels within the buildings above the new southbound tunnel and allows for the evaluation of the different distances that there are between the tunnel and the piled foundations of each building.

A9.8.68. The correction for different trackforms has been carried out using the Igitur modelling discussed previously. The modelling has been carried out for a series of different trackform options.

A9.8.69. The results of this modelling for a range of standard resilient trackforms are presented in Figure A9.8.5.

Figure A9.8.5: modelling results for standard resilient trackforms

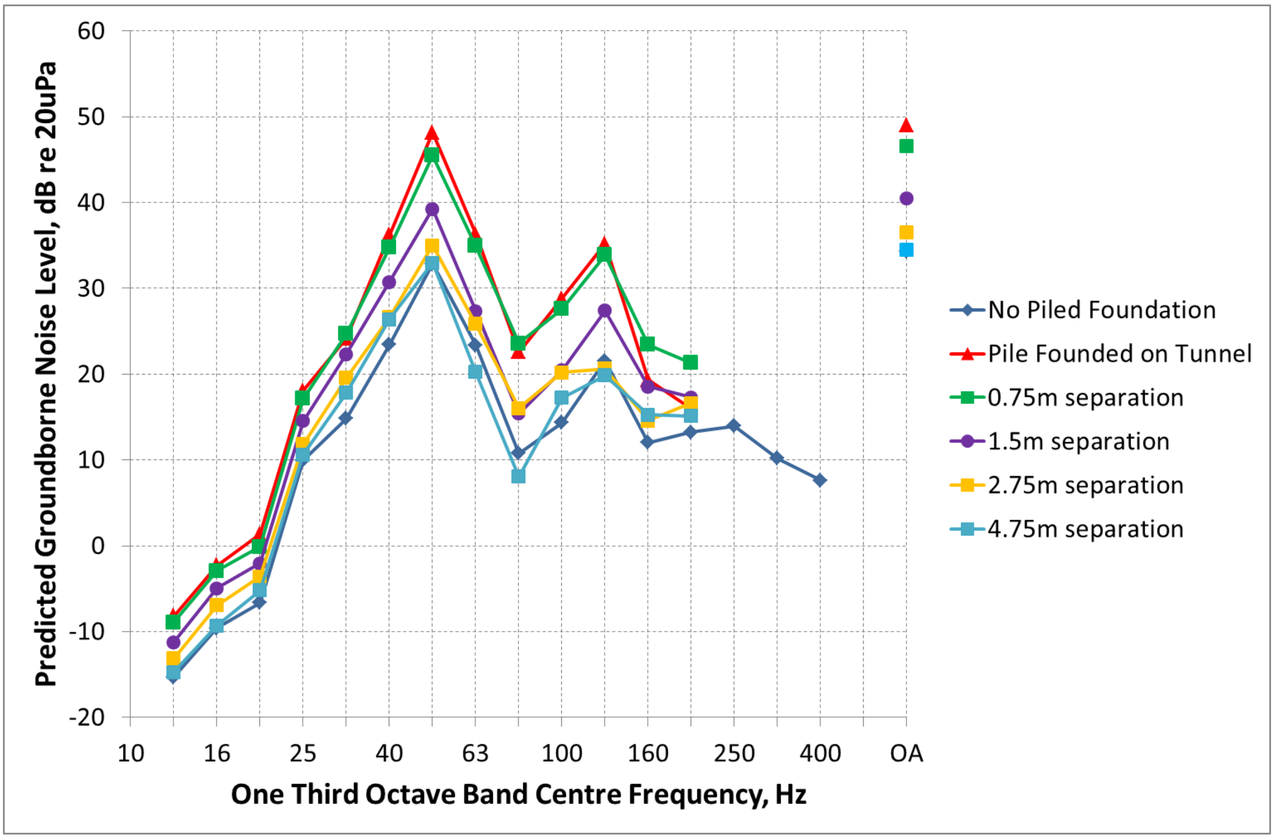


A9.8.70. These results show the expected insertion gain for each trackform option compared to standard London Underground track of bullhead rail and pit block sleepers. These results are applied to the vibration source data to enable a prediction of the vibration levels within each building along the route.

A9.8.71. The preference for the trackform to be used in terms of the design of the permanent way is the Delkor baseplate. The prediction of vibration and groundborne noise levels have been carried out based on using the Delkor system as the reference trackform design for the new southbound running tunnel.

A9.8.72. When combining the source data with the results of the FE/BE modelling and the trackform modelling, the results shown in Figure A9.8.6 below are obtained. These results are presented in terms of the 0.125 ms A-weighted sound pressure level, which is equivalent to the L_{AFmax}.

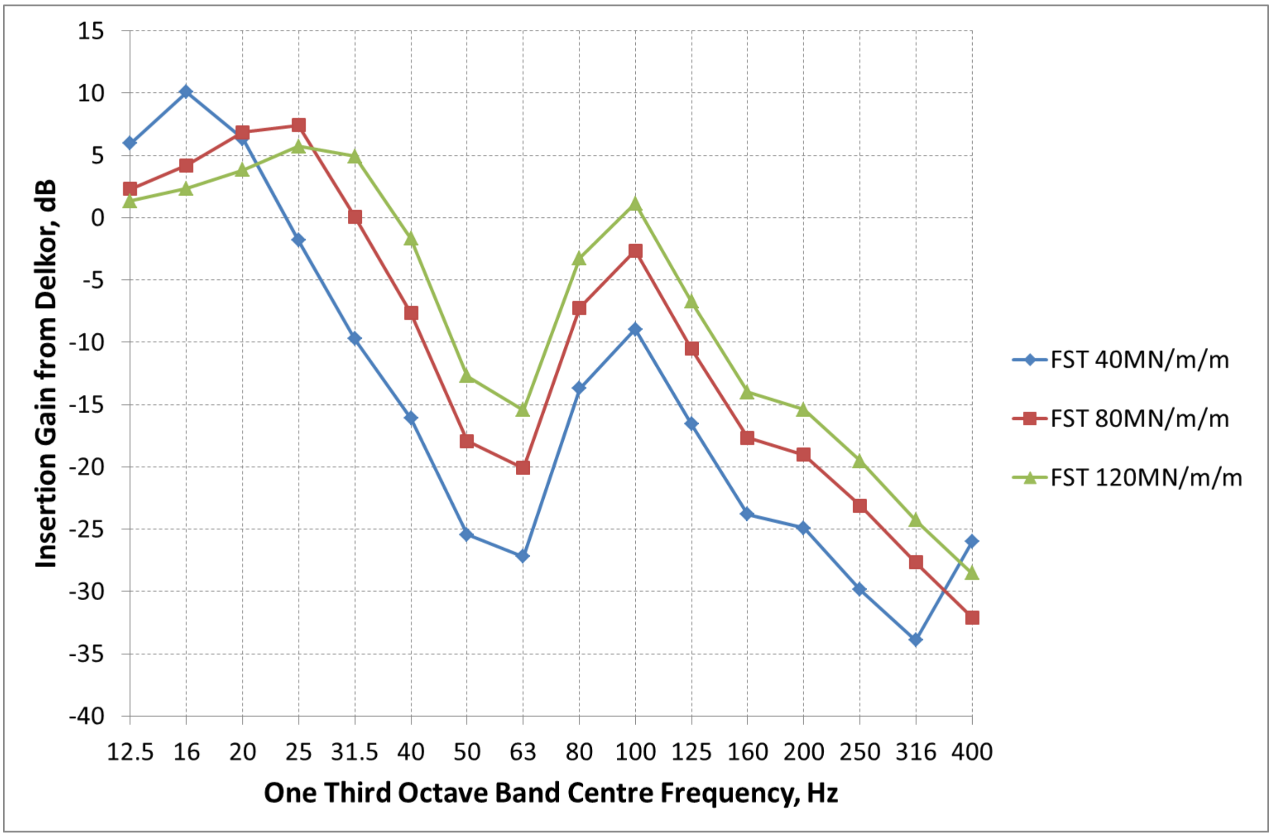
Figure A9.8.6: Results of groundborne noise modelling



A9.8.73. These results show that where a building has either no piles, or the piles are greater than 5 m from the tunnel, groundborne noise levels are predicted to be no more than 35 dB L_{AFmax}. When the pile is founded on the tunnel lining, groundborne noise levels with a standard resilient trackform are predicted to be above the design target. As such, a high performance track system is required.

A9.8.74. The prediction of the performance of a high performance track system has been used to determine if it is possible to meet the requirements at the pile interception locations. The predicted performance of some example track systems are presented in Figure A9.8.7 below. For the purposes of the ES, the high performance track systems have been assumed to be a floating slab track, although the final form of the track system will be determined at detailed design stage. These are presented as an insertion gain compared to the reference Delkor baseplate system.

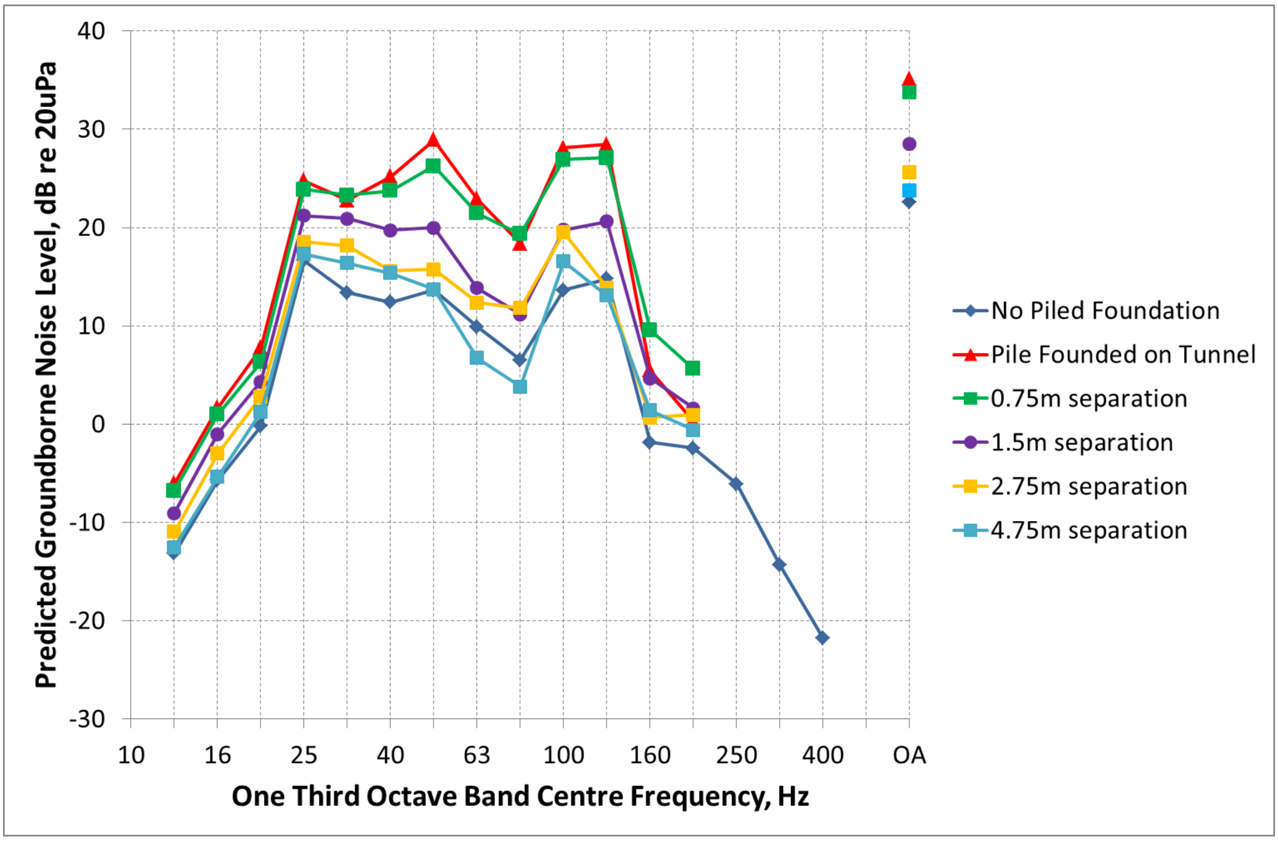
Figure A9.8.7: Predicted insertion loss for high performance track systems



A9.8.75. The results in Figure A9.8.7 above show that to reduce the dominant 40 and 50 Hz frequencies in the predicted groundborne noise levels, a medium or low stiffness (80 or 40 MN/m/m) high performance track system may be required.

A9.8.76. When the results for the 80 MN/m/m stiffness high performance track are combined as part of the predictions, the following results are obtained.

Figure A9.8.8: Predicted groundborne noise levels with a 80MN/m/m stiffness high performance track



A9.8.77. These results show that when the pile is directly connected to the tunnel lining, the use of a high performance track system is able to reduce the predicted groundborne noise levels to 35 dB L_{AFmax}. The use of this high performance track system has been used the ES as incorporated mitigation.

Results of Modelling

A9.8.78. The modelling has been used to determine the expected groundborne noise and vibration levels inside the selected sensitive receptors close to the alignment of the new southbound running tunnel.

A9.8.79. It should be noted that the project is not providing any alterations to the track within the existing northbound tunnel and as such the ground borne noise and vibration levels from trains in that tunnel will not change as a result of the BSCU.

A9.8.80. The receptors chosen for the assessment are primarily those which are directly above the southbound tunnel. This is because those are most likely to experience a change in groundborne noise and vibration levels as a result of the BSCU, particularly in the pile interception locations.

A9.8.81. The majority of these receptors are office buildings, with the exception of Mansion House and St Mary Abchurch. St Mary Abchurch is of ecclesiastical use and Mansion House is used for various functions, the most sensitive of which is a residential area which is not in general use, although is used occasionally.

Vibration

A9.8.82. The vibration predictions have considered the buildings that are most sensitive to groundborne vibration, which are primarily residential buildings. In addition, the study has considered the locations where building piles will be intercepted by the new tunnel.

A9.8.83. The vibration predictions are provided in terms of the day and night VDV_b, which have been estimated for each receptor. The results of the predictions are provided in Table A9.8.2.

Table A9.8.2: Predicted Groundborne Vibration Levels

Receptor	Predicted Vibration Dose Value	
	Day (07:00-23:00)	Night (23:00-07:00)
6-8 Prince's Street	0.067	0.048
Mansion House	0.012	0.008
8-10 Mansion House Place	0.067	0.048
New Court, St Swithin's Lane	0.067	0.048
St Mary Abchurch	0.012	0.008
28 Martin Lane	0.012	0.008
33 King William Street	0.067	0.048

A9.8.84. These results show that vibration dose values are all predicted to be well below 0.2 $ms^{-1.75}$ during the daytime and 0.1 $ms^{-1.75}$ during the night, which means that they are rated by *BS 6472-1:2008* as being less than low probability of adverse comment and are below LOAEL. As such, these predicted vibration levels are a very low impact and at high sensitivity receptors, gives rise to a minor effects which are not significant.

Groundborne Noise

A9.8.85. The assessment of effects from groundborne noise is based on the absolute level of predicted noise at the lowest floor of the building, where effects would be greatest.

A9.8.86. The predictions have been undertaken for the identified receptor locations along the route of the new running tunnel. The results of the predictions are shown in Table A9.8.3.

Table A9.8.3: Predicted Groundborne Noise Levels

Receptor	Predicted Groundborne Noise Level, dB L_{AFmax}
6-8 Prince’s Street	35
Mansion House	34
8-10 Mansion House Place	35
New Court, St Swithin’s Lane	35
St Mary Abchurch	34
28 Martin Lane	34
33 King William Street	35

A9.8.87. The assessment assumed that the new tunnel intercepts the piled foundations of 6-8 Prince’s Street, 8-10 Mansion House Place, New Court and 33 King William Street. As such, the predictions assume a high performance trackform at these locations, such a floating slab track, which will reduce the vibration transfer into the intercepted piles. At the remaining locations, the predictions have assumed that the tunnel will be constructed with a standard trackform including resilient baseplates.

A9.8.88. These predictions demonstrate that the expected groundborne noise levels are no more than 35 dB L_{AFmax}. Therefore, the magnitude of the impact is considered to be very low, which when considered at high sensitivity receptors, gives rise to a minor effects which are not significant.

Conclusions

A9.8.89. The design for the track will enable the new running tunnel to operate with no significant adverse effects. The groundborne noise and vibration assessment has investigated the potential effects that could arise as a result of the pile interceptions and the track will be designed and constructed to ensure that operational groundborne noise and vibration will not be significant at all identified noise sensitive receptors within the study area.