

**Transport and Works
Act 1992
Application for the
Proposed London
Underground (Victoria
Station Upgrade) Order**

**Victoria Station
Upgrade**

**Objector –
Victoria Palace Theatre**

**Proof of Evidence of
Richard Greer BSc
MIOA, Arup Acoustics**

Reference: OBJ21.P4

**PROOF OF EVIDENCE:
RICHARD GREER**

1 Experience and Qualifications

- 1.1 My name is Richard James Greer. I am an Associate Director of Arup, and a member of the European leadership team for the firm's acoustic business, Arup Acoustics, that is an independent acoustic consultancy established in 1980, and the largest acoustic consultancy in the UK.
- 1.2 My qualifications and experience of relevance to this case are:
- 1.2.1 an honours degree in Engineering Sound and Vibration;
 - 1.2.2 corporate membership of the Institute of Acoustics;
 - 1.2.3 being the vice chairman, chairman and immediate past chairman of the Association of Noise Consultants between 2003 and 2006;
 - 1.2.4 a principal author of the Association of Noise Consultants Guidelines on the Assessment of Groundborne Noise and Vibration;
 - 1.2.5 membership of ISO committee TC108/SC2/WG8 writing standards for "Groundborne noise and vibration from Rail Systems" (by invitation);
 - 1.2.6 membership of the UK Railway Forum's Noise Policy Group (by invitation);
 - 1.2.7 18 years experience in transportation acoustics (especially railways) including many publications and (award winning) journal papers; and
 - 1.2.8 being Noise and Vibration Manager for the delivery of the Channel Tunnel Rail Link (now High Speed 1) and detailed involvement in many other major rail schemes in London including the Kings Cross & St Pancras Underground Station Upgrade, East London Line and Thames Link Programme.

2 Evidence, Scope and Structure

2.1 In my evidence I shall:

- Section 1 Introduce myself.
- Section 2 Explain the ground my evidence is intended to cover.
- Section 3 Introduce in general terms the forms of noise and vibration impact that can arise from development works and their potential effect on people and buildings.
- Section 4 Describe the Victoria Palace Theatre ('the Theatre'), the proposals for its extension and its context with regard to acoustic matters.
- Section 5 Establish existing noise and vibration in the Theatre and the acoustic of the auditorium.
- Section 6 Describe the development proposals: Victoria Station Upgrade (VSU), Victoria Line Upgrade (VLU) and Victoria Transport Interchange (VTI).
- Section 7 Establish, based on information published by the promoters of the development schemes, the nature and scale of the noise and vibration impact on the Theatre arising from the **construction** of the VSU scheme both alone and in combination with VLU and VTI.
- Section 8 Establish, based on information published by the promoters of the development schemes, the nature and scale of the noise and vibration impact on the Theatre arising from the **operation** of the VSU scheme both alone and in combination with VLU and VTI.
- Section 9 Review additional mitigation proposed by the promoters to reduce or remove predicted adverse noise and vibration effects on the Theatre, including a review of the different scheme options considered by LU.
- Section 10 Make recommendations for additional noise and vibration mitigation required to protect the interests of the Theatre.

Section 11 Provide conclusions.

2.2 In preparing my evidence I have had due regard to the evidence of the following witnesses on behalf of the Victoria Palace Theatre:

- Mr Brian Conley (OBJ21.P1)
- Mr John Earl (OBJ21.P2)
- Mr Jeremy Edge (OBJ21.P3)
- Mr Peter Loveday (OBJ21.P5)
- Mr Jon Satow (OBJ21.P6)
- Mr Paul Spiers (OBJ21.P7)
- Mr Julian Stoneman (OBJ21.P8)
- Mr Colin Wilson (OBJ21.P10)

3 Noise and Vibration - General

3.1 I have included a schedule of terminology at Appendix RG1.

Airborne Noise

3.2 Airborne noise generated by sources such as road traffic, railways, mechanical equipment and construction are everyday experiences for most people.

3.3 The indicators used to objectively quantify and assess noise in the context of my evidence are presented in Appendix RG1.

3.4 Increasing magnitudes of airborne noise give rise first to perception, and then an increasing likelihood of annoyance, severity of annoyance and activity disturbance and ultimately at very high levels risk of adverse health effects..

Groundborne Vibration

3.5 Groundborne vibration, which has a number of manifestations and potential effects as discussed below, is more rarely encountered.

3.6 Construction activities, especially those that involve impacts, and the operation of trains (through the interaction forces between the steel wheels and rails) can cause groundborne vibration. The resulting vibration is transmitted and filtered through intervening ground and / or receiving building structure where foundations, walls, floors and ceilings may be caused to vibrate.

Vibration in the Building Structure

3.7 At extremely high magnitudes of vibration – which are generally rare - there is a risk that the vibration might give rise to building damage (and damage to contents such as computer equipment, telephone equipment etc). British Standard 7385 part 2 (refer to Appendix RG2) and BS 5228 part 4 (refer to Appendix RG3) provide guidance on the effect on buildings. It is important to note that, based on industry experience and the British Standard, the magnitude of vibration required to give rise to even a low risk of cosmetic damage to a property is so high that the property would be uninhabitable. Increasing vibration, at this extreme level of magnitude, gives rise to increasing risk of cosmetic damage and ultimately risk of structural damage.

- 3.8 Older structures and historic structures may be more susceptible to damage than modern robust structures and hence it is common to assess the impact of vibration on such structures at a lower level on a risk basis.

The Effect of Building Vibration on its Occupants

- 3.9 Inside a building vibration may be perceptible to occupants as either feelable vibration and / or audible noise generated by the vibration. Audible vibration is generally described as groundborne noise, structureborne noise or re-radiated noise. I have used the term groundborne noise in my evidence.
- 3.10 Guidance and criteria for the assessment of human response to vibration in buildings is provided by British Standard 6472 (refer to Core Document VSU.B37).
- 3.11 Increasing magnitudes of groundborne noise and vibration – which are treated separately as they do not always occur together – give rise first to perception, and then an increasing likelihood of annoyance, severity of annoyance and activity disturbance.

4 The Victoria Palace Theatre (the ‘Theatre’)

The Theatre

- 4.1 The Theatre and its history are set out in the evidence of Mr Satow and Mr Earl respectively.
- 4.2 Victoria Palace Theatre (VPT) has 1550 seats and is currently staging the show Billy Elliot, Monday-Saturday (19:30 start), with matinee performances on Thursday and Saturdays (14:30 start)
- 4.3 Mr Satow notes the importance of insulating the performance space from everyday noise and vibration to enable the audience to be immersed in an alternative environment created by the performers.
- 4.4 Mr Satow also notes that, whilst very successful, the Theatre, like London’s other West End Victorian and Edwardian theatres, was built for a different age and for audiences with different expectations of comfort. They were also built for a different age in terms of external environmental noise levels – one without significant road traffic and one with less railways. The external fabric, especially entrances and exists, were therefore not designed to keep out the levels of external noise that now exist. Also when designed there was less need to acoustically separate the auditorium from front of house areas, hence there are for example only single doors (rather than sealed lobbied door sets) between the bar areas and the auditorium. This means that, by modern standards, the auditorium can be adversely affected during performances by both external and internal noise. Section 5 of my evidence provides detail on the external noise that is experienced in the Theatre’s auditorium.

Extension Proposals

- 4.5 Mr Satow’s evidence outlines the proposals that have been developed to bring the Theatre up to date in terms of front of house facilities, back of house facilities and theatre systems thus allowing it to remain one of the top musical venues. Mr Satow’s evidence notes that without the improvements the Theatre will continue to slip down the rankings as investment elsewhere raises the bar for technical facilities.

- 4.6 The proposals are predicated on the redevelopment of the areas to the north and east of the Theatre by London Underground's Victoria Station Upgrade and Land Securities Victoria Transport Interchange projects. These projects are outlined, in respect of noise and vibration, in Section 6 of my evidence and more generally in the evidence of Mr Satow and Mr Edge.
- 4.7 The proposals were submitted for planning and list building consent on 3 June 2008.

5 **The Theatre's Acoustic and Existing Noise and Vibration**

5.1 The auditorium of the Theatre is currently affected by noise from a number of sources, both internal and external.

5.2 The auditorium also currently experiences vibration, particularly from London Underground train services, that is on occasion perceptible. However, noise within the auditorium is far more significant and hence my evidence in the remainder of this section concentrates on this issue.

Existing Noise Levels

5.3 Appendix RG4 presents an outline survey of the existing ambient and background noise levels inside and outside the Theatre.

5.4 The survey shows that the main auditorium is subject to audible road traffic noise and significant levels of groundborne noise from London Underground (LU) train services.

5.5 Road traffic noise breaks into the Theatre via a number of acoustic 'weak spots' in the external sound insulation of the building fabric; principally:

5.5.1 the fire escape doors to the rear of the stalls on the (stage) right side of the auditorium facing Allington Street;

5.5.2 the loading doors that are back stage / stage right facing Allington Street;

5.5.3 the single glazed windows in the stage right dressing facilities (also facing Allington Street); and

5.5.4 the entrance doors towards the back of the stalls on the (stage) left side where noise from Victoria Street is currently audible (the entrance doors to Victoria St provide only partial attenuation).

5.6 Further internal surveys were undertaken on 21 and 22 August (refer to Appendix RG5) to collect more measurements of the groundborne currently generated in the Theatre's auditorium by LU services. For these surveys the theatre systems were switched off. These systems, especially the current sound mixing desk, significantly elevate the internal background and ambient noise levels. The initial survey work (Appendix RG4) was undertaken in the under stage area to avoid these

elevated noise levels but also to provide baseline data at a location that could sensibly be used as a monitoring location during the VSU construction works. The survey on the 22 August was attended by LU staff including LU's noise and vibration specialist advisor.

5.7 Additional surveys were also undertaken on 5th September and 30th September to confirm ambient and background noise levels inside the auditorium from sources other than the LU trains (refer to Appendix RG5). Currently, excluding LU trains, the loudest source of ambient noise is the theatre systems (including the sound mixing desk). This is creating levels of around NR 35 L_{eq} (i.e. approximately 40 dB L_{Aeq}) across the majority of the stalls. The noise generated by the theatre systems is likely to explain the 39 dB minimum level recorded by LU during a performance at the Theatre. This relatively high ambient noise level for a theatre, and the 'white noise' character to the theatre systems noise, helps mask the impact of underground train noise on quieter sections of the production. There are however limits on the levels of background noise that can be tolerated without affecting the types of production that can be presented, as discussed later in my evidence.

5.8 Critical listening to the groundborne noise generated by the LU services reveals the following:

5.8.1 There are high levels of groundborne noise throughout the stalls, on the stage, in the under stage area, wings and all back stage areas.

5.8.2 The levels of groundborne noise are significantly lower in the circle and grand circle (suggesting that the majority of the noise is being radiated by the floors rather than the walls or ceilings).

5.8.3 Groundborne noise from the District and Circle (D&C) Lines that run under Victoria St just to the south of the Theatre are either inaudible in the auditorium, stage and back stage areas or are indistinguishable from the quieter Victoria Line services – refer to Figure RG1. This Figure was produced by LU and its agreement for its use in my evidence reflects common ground in measurement methodologies and results. It is worth noting that the track system used on the D&C lines is continuous welded rail, with spring fasteners and resilient rail pads to concrete sleepers on ballast. This form of track is likely, all other parameters remaining equal, to give rise to lower levels of groundborne noise than the track system installed in the

Victoria Line station tunnels as described later in my evidence. It should also be noted that it would not be possible to install this type of track system in the Victoria Line tunnels because it has a greater construction height (tunnel invert to rail head) that, whilst compatible with the D&C cut and cover tunnels is too tall to fit in the smaller diameter Victoria Line tunnels. It should be noted, as discussed later in my evidence that there is a range of track systems available that could be installed in the Victoria Line tunnels and which would provide significant mitigation of groundborne noise compared to the current track (refer to Appendix RG6).

5.8.4 Groundborne noise from the southbound Victoria Line services (that pass directly under the Theatre) is significantly greater than northbound services (that pass just to the west of the Theatre).

5.8.5 Groundborne noise from southbound services is characterised by distinct impulses, caused as train wheels pass over joints in the track.

5.8.6 There is a distinct ‘on set’ to the groundborne noise from southbound trains. This may occur as trains traverse from the running tunnel into the station platform tunnel. The track in the station tunnel is traditional bull head rail, fastened by iron rail chairs to hard wood (Jarrah) blocks that are set directly into the tunnel invert concrete track bed (refer to Appendix RG6). This form of track provides very little mitigation of groundborne noise. There are a number of joints in the rail along the length of the platforms. This is consistent with the noise heard in the Theatre. It is understood that the track system outside of the station tunnels may be different. LU has committed to provide further information but has yet to provide this information.

5.9 Groundborne noise levels in the stalls generated by LU trains were recorded in a range of 37 to 44 dB $L_{Amax,Slow}$ (refer to Appendix RG5). This is similar to the range of levels recorded previously in the under stage area (Appendix RG4). It is important to note that the higher levels are generally generated by southbound services and the lower levels by northbound services, which are significantly quieter, with loudest trains generally not exceeding 40 dB $L_{Amax,Slow}$.

The Theatre's Acoustic

- 5.10 The Theatre has a controlled acoustic appropriate for speech and reinforced sound. The reverberation time of the auditorium was measured on 27 August 2008 and the results are presented at Appendix RG5. The reverberation of the auditorium increases at low frequency. This will tend to increase the levels of groundborne noise, which is a low frequency phenomenon, generated in the Theatre by passing underground trains and dilute any variation in levels of groundborne noise across the stalls.

The Effect of Groundborne Noise on the Theatre's Productions

- 5.11 The prime acoustic requirement of a theatre is to have an acoustic environment that supports the unassisted voice of the performers and ensures sound quality and speech intelligibility for the audience. The acoustic of the room should enhance the performer/audience bond thereby enhancing the theatre experience. Supporting the unassisted voice requires not only a suitable geometry in the room, but also the tight control of ambient and background noise from other sources.
- 5.12 The VSU Supplementary Environmental Statement [core doc reference VSU.A31] identifies that levels of groundborne noise from trains above 25 dB $L_{Amax,Slow}$ give rise to a significant impact on theatres. This is common ground.
- 5.13 The difference between this 'standard' 25 dB $L_{Amax,Slow}$ evaluative criterion for theatres and the current Victoria Line train noise levels of 37 to 44 dB $L_{Amax,Slow}$ demonstrate how adversely affected the Theatre already is by groundborne noise. It is important therefore, as set out later in my evidence, that this situation is not made worse by the VSU proposals.
- 5.14 As a consequence of the existing high levels of internal ambient noise inside the Theatre in particular groundborne noise from the Victoria line as discussed earlier in this section of my evidence, performances use sound reinforcement. Use of reinforcement and the nature of the performances presented allows for amplified sound levels across the audience. This allows for higher internal ambient noise levels than an auditorium with a natural acoustic and no sound reinforcement. However, reinforced sound is not ideal for all types of theatrical performance, there are limits to the level of amplification appropriate for the theatrical performance and also there is a need for relative quiet, for dramatic effect, during a performance.

- 5.15 As discussed earlier in my evidence the noise generated by theatre systems, especially the mixing desk, is relatively high for a theatre. However, with a reinforced sound this relatively high ‘white noise’ from the electrical and electronic equipment actually helps mask to some extent the impact of the train noise events that would otherwise be more disturbing during quieter periods of a performance. As with amplification there are practicable limits on the background noise, both continuous and intermittent, that is consistent with theatrical productions. However, as considered in more detail later in my evidence, the Theatre Operator’s ability to selectively elevate the ambient noise levels in the Theatre to mask other, non controllable, intermittent noise sources such as underground trains is an important means of ensuring an appropriate acoustic environment for performances.
- 5.16 The evidence of Mr Conley, an actor in a long running production in the Theatre, identifies the impact of groundborne noise on performers and that any increase would significantly affect performances.
- 5.17 Control of ambient noise inside the auditorium and other parts of the Theatre are required at many other times associated with the Theatre’s business (for example; rehearsals, auditions, actors preparing for performances back stage etc). This is particularly the case for the current production, Billy Elliott, which includes children in the cast. The cast therefore has to regularly change increasing the number and importance of rehearsals. The Theatre may therefore be occupied and sensitive to noise and vibration from lunchtime until after an evening performance many days of the week.

Noise Criteria to protect the Theatre Productions

- 5.18 My evidence and that of Mr Conley, Mr Stoneman and Mr Satow is that to ensure that there is no permanent impact on the Theatre there should be no increase in the noise in the auditorium, stage and back stage areas as a consequence of the VSU project. It is therefore recommended that the following noise limits be defined for the Theatre auditorium, stage and back stage areas in connection with the VSU works.

- 5.18.1 Loudest Victoria Line southbound train
 $\leq 44 \text{ dB } L_{Amax,Slow}$
- 5.18.2 Loudest other LU service including Victoria Line Northbound trains
 $\leq 40 \text{ dB } L_{Amax,Slow}$
- 5.18.3 Loudest external event with an on-time longer than 15 seconds (e.g. escalator noise)
 $\leq \text{NR } 25 (L_{eq})$

5.19 For construction, that is a temporary activity, it is appropriate to relax the above criteria. It is therefore recommended that the following noise limits be defined for the Theatre auditorium, stage and back stage areas in connection with the VSU construction works.

5.19.1 During performances

Loudest intermittent construction event
 $\leq 40 \text{ dB } L_{Amax,Slow}$

Loudest construction event with an on-time longer than 15 seconds
 $\leq \text{NR } 30 (L_{eq})$

5.19.2 During rehearsals

Loudest intermittent construction event
 $\leq 45 \text{ dB } L_{Amax,Slow}$

Loudest construction event with an on-time longer than 15 seconds
 $\leq \text{NR } 35 (L_{eq})$

5.20 It will be important to ensure that the construction criteria recommended above are tested as construction and modified if necessary to ensure that there is no adverse impact on performance and rehearsals and also there is no undue constraint on construction activity.

5.21 In addition to the measured levels of noise in the Theatre, there are two other key matters that shape the limits recommended above:

5.21.1 Controlling the frequency with which loud intermittent events occur. Currently it is the southbound Victoria Line trains that are clearly the loudest intermittent events in the Theatre. Whilst these events can occur every 3 to 4 minutes, the impact on a performance would significantly increase if the noisiest events occurred more frequently - hence the need to ensure that the northbound Victoria Line services get no louder (they are currently around 5 dB quieter than the southbound services) and that no other intermittent events are louder than the northbound services.

5.21.2 Providing the Theatre Operator the ability to provide appropriate masking sound (like the current mixing desk) up to a level of NR35 where it should mask break in noise from other sources and reduce the disturbance caused by the loudest Southbound Victoria Line trains. To avoid the overall ambient noise levels increasing and also to ensure that the Theatre's masking noise dominates over any noise break-in from VSU works it is necessary to limit the noise generated by VSU permanent systems to NR25.

6 The Development Proposals

The Victoria Station Upgrade (VSU) Project

- 6.1 VSU is a major improvement project being promoted by Transport for London through its London Underground operation.
- 6.2 Subject to approvals, advanced works would commence in 2009 and the overall project would be completed by 2016 [core doc reference VSU.A32].
- 6.3 In respect of construction noise, noise and vibration, the following proposed VSU works are of significance:
 - 6.3.1 utility works around the Theatre (airborne noise)
 - 6.3.2 demolition of Elliot House and 120 to 124 Victoria Street (airborne noise, structure-borne noise and vibration)
 - 6.3.3 surface construction activities on the plots generated by the demolition of Elliot House and 120-124 Victoria Street (airborne noise)
 - 6.3.4 underground construction of the PAL - Paid Area Link (groundborne noise and vibration)
 - 6.3.5 underground construction of the northern escalator shaft (groundborne noise and vibration)
- 6.4 In respect of operational noise, noise and vibration, the following proposed VSU works are of significance:
 - 6.4.1 fixed plant and equipment in the surface works (airborne noise)
 - 6.4.2 escalators in the new Northern Escalator shaft (groundborne noise)
 - 6.4.3 the Northern Escalator shaft and PAL Central section that are to be constructed between the Theatre foundations and the Victoria Line tunnels (risk of increasing groundborne noise generated in the Theatre by the Victoria Line train services)

The Victoria Transport Interchange (VTI) Project

- 6.5 This mixed use development is being brought forward by Land Securities (LandSec). The construction of the surface elements of the scheme on the development plots generated by the demolition of Elliot House and 120-124 Victoria will generate noise that would, without mitigation, cause adverse effects on the Theatre. However, the improvements to the sound insulation of the external fabric of the Theatre that should be provided by the VSU project, as discussed later in my evidence, will also protect the Theatre from airborne noise generated by the VTI construction.
- 6.6 Mr Chapman's evidence for LandSec's objection to the VSU project (OBJ3/P3) presents three alternative alignments for the PAL. The effect of these revised alignments in terms of noise and vibration impacts on the Theatre is considered later in my evidence.

The Victoria Line Upgrade (VLU) Project

- 6.7 This is a separate project being taken forward by LU. It is understood that it is wholly within permitted development rights. During meetings, LU it has advised that in overview VLU will in time:
- 6.7.1 provide new rolling stock (2009 stock); and
 - 6.7.2 refurbish / replace infrastructure and equipment especially signalling equipment.
- 6.8 More detailed information has been requested from LU as to the nature of these works, their timing and their effect on noise and vibration in the Theatre. However, no information was provided until LU's evidence was published. Mr McKenna's evidence at Section 13 (core document reference VSU.P1) provides some information. This makes clear for the first time that VLU will increase the frequency of services during peak hours from 28 to 33 trains per hour in each direction (an 18% increase) and might increase train speeds. Also Mr Thornely-Taylor's evidence at section 9 (VSU.P6) now identifies that track renewal is planned in the area around the Theatre in 2008. All of these matters could have an impact on the levels of groundborne noise experienced inside the Theatre either in isolation or cumulatively with the VSU works. I shall return later in my evidence to LU's failure to consider such cumulative effects either in the ES or the SES (core document references VSU.A13 and VSU.A31).

6.9

As discussed later in my evidence, save for realignment of the proposed underground works away from the Theatre, improvements to the track on the Victoria Line is the only reasonably practicable means of mitigating any permanent groundborne noise effect. Use of low vibration track systems is a proven means of mitigating groundborne noise impacts and effects. LU therefore has an opportunity to provide this mitigation through the VLU project. However, from the outset of my discussions with the VSU team they have advised that they have little knowledge of the VLU project and no ability to influence it [refer to Appendix RG7]. Further, it now appears that the opportunity to make use of the next cycle of track renewal as a means to secure mitigation might have been lost (as the works are to be undertaken in 2008).

7 **Construction Noise and Vibration Impacts on the Theatre**

Victoria Station Upgrade (VSU)

General

- 7.1 The scheme and the promoter's assessment of the environmental impact arising from it are presented in the Environmental Statement (ES) submitted with the Transport & Works Order Application (refer to core document VSU.A13).
- 7.2 On 5th August the promoter issued a Supplementary Environmental Statement (SES). The SES is presented as a Non-Technical Summary [Core doc reference VSU A32] and a Main Report [Core doc reference VSU.A31] with a series of Technical Appendices. Technical Appendix B – Noise and Vibration - is particularly germane to my evidence. Overall the SES is a substantial volume of work. Combined with the revised Order Documents and Planning Direction Drawings, more than 35 new or revised documents have been issued. Many of these are relevant to the assessment of the likely noise and vibration impact of the works on the Theatre. The late issue of these documents has necessarily hampered preparation of my evidence.
- 7.3 Overall the assessment methodology adopted by VSU for the assessment of noise and vibration generally accords with current practice for this type of project.
- 7.4 My evidence in this section considers construction effects of the scheme as considered, or not, by the promoter's ES and SES. I come to the predicted operational effects in the next section of my evidence. In respect of noise vibration, the SES (VSU.A31 Technical Appendix B – Noise and Vibration) highlights that it entirely supersedes the equivalent Appendix to the original ES.
- 7.5 The SES main report makes clear that during the construction works the Theatre will be surrounded by substantial noise sources and at many times vibration sources for approximately 7 years (2009 to 2016):
- 7.5.1 To the north (Theatre stage end): Elliot House and a number of other properties will be demolished to make way for a major construction site.

- 7.5.2 To the east: 120, 122 and 124 Victoria Street will also be demolished to make way for another major construction site. This matter is not copied across to the Noise and Vibration technical appendix that incorrectly refers in a number of locations to 175 to 179 Victoria Street (these properties are also to be demolished but are more distant from the Theatre).
- 7.5.3 To the south (Theatre foyer end): Construction works will be undertaken in Victoria St and traffic noise will continue (albeit reduced at times by traffic management).
- 7.5.4 To the west: Construction works will be undertaken in Allington Street and traffic noise will continue (significantly increased at times by traffic management and increased temporary use and a bus and taxi route during the works).
- 7.5.5 Underneath: parts of the new Northern Escalator shaft and Paid Area Link (centre) will be excavated directly under the Theatre.

Airborne Noise

- 7.6 The SES predicts a daytime maximum construction noise level of 86 dB LAeq outside the Theatre during the advanced utility works. For the main works the SES predicts a daytime maximum construction noise level of 93 dB LAeq outside the Theatre [refer to core doc VSU.A31 Technical Appendix B]. This compares to existing ambient levels of 64 to 70 dB LAeq primarily from road traffic which are already audible in some parts of the stalls during performances [refer to core doc VSU.A31 Technical Appendix B and Appendix RG4]. I have not considered the predicted night-time construction as the night-time period of 2300 to 0700 falls outside performance times at the theatre.
- 7.7 Without substantial mitigation in excess of that proposed by VSU – which I shall return to later in my evidence - such levels of construction noise would have a very significant effect on theatre operations; **quite simply they would stop productions.**

Groundborne Noise from Worksite Activity

- 7.8 The SES identifies that without mitigation significant groundborne noise effects will be experienced by the Theatre during the demolition of Elliot House, 175 – 179 Victoria Street, (presumably this is an error and should refer to 120 to 124 Victoria Street) and during jet grout works via basement of Duke of York PH.
- 7.9 The scheme works will also involve the construction a new North Escalator Shaft, and the PAL Centre tunnel which in part run under the Theatre. No construction groundborne noise impacts are predicted during the construction of these tunnels and shafts but extensive experience suggests that there is a significant risk that the groundborne noise criterion of 25 dB $L_{Amax,Slow}$ specified in the Technical Appendix will be significantly exceeded during these works. This risk is increased given that the tunnelling, by intent, will be through ground hardened by the jet grouting. This will increase the force required to excavate the material that in turn will increase levels of groundborne noise and vibration generated.

Groundborne Vibration from Worksite Activity

- 7.10 Of greatest significance in terms of construction is the assessment of the potential effect of the demolition of Elliot House, and 124 Victoria St. This was reported in the ES, and is reported again in the SES for the unmitigated scheme, as a potential major significant effect. The 50 percentile confidence prediction is for vibration magnitudes of 12 mm/s PPV and the 95 percentile confidence prediction is for vibration magnitudes of 54 mm/s PPV to arise (refer to Table 9.6 of VSU.A31 Technical Appendix B). These predictions are for the foundations of the Theatre. These values compare with an evaluation criterion of 3 mm/s PPV for listed and potentially vulnerable buildings (Table 5.1 of VSU.A31 Technical Appendix B).
- 7.11 Comparing these latter predictions with the relevant British Standards (refer to Appendices RG2 and RG3) and professional experience there is a significant risk of not just substantial cosmetic damage but also a risk of structural damage to parts of the building. These magnitudes of vibration would also give rise to a risk of damage to electronic equipment and fixtures and fittings. It is my professional opinion that the nature and extent of these risks is not made clear within the ES and SES and this is inconsistent with EIA good practice.

- 7.12 The SES also identifies that the demolition works are likely to give rise to a major significant effect in terms of the exposure of any occupants to vibration (i.e. annoyance). However, the periods of high exposure are likely to be the same periods where the vibration on the building is so high that there is a risk of building damage. It is unlikely therefore that the Theatre could be occupied during these works due to health and safety concerns associate with building damage.

Victoria Transport Interchange

- 7.13 The construction of the surface elements of the scheme on the development plots generated by the demolition of Elliot House and 120-124 Victoria will generate noise that would, without mitigation, cause adverse effects on the Theatre. However, the improvements to the sound insulation of the external fabric of the Theatre should be provided by the VSU project (discussed later in my evidence) will also protect the Theatre from airborne noise generated by the VTI construction.

- 7.14 In accordance with good practice the VSU SES considers the potential cumulative effects of the VSU and VTI projects. No significant cumulative construction noise or vibration effects have been identified.

Victoria Line Upgrade

- 7.15 The VSU SES does not consider the potential cumulative effects of the VLU and VSU projects nor VSU, VLU and VTI projects. This is contrary to good practice for Environmental Impact Assessments.

Operational Noise and Vibration Impacts on the Theatre

Victoria Station Upgrade (VSU)

Airborne Noise

- 8.1 With regard to operational impacts, the following statement from the SES Non Technical Summary (VSU.A32) reports the promoter's findings: "*The intention is that the project design will ensure noise and vibration from the new plant meets the required criteria. No significant effects are predicted for the operating phase.*" This is a positive commitment. However, to protect the Theatre it is important that design noise criteria relevant to the Theatre are agreed and enforced. This could be achieved by a protective provision. Recommended design criteria are presented in section 5 of my evidence.

Groundborne Noise

- 8.2 In the context of groundborne noise generated by the operation of the escalators in the shaft proposed under the rear wall of the Theatre, the comments I make at 8.1 also apply here.
- 8.3 Whilst the ES and SES consider the effect of the permanent works on traffic (car) patterns and hence associated noise levels, neither the ES nor the SES assess the potential effect on the Theatre of changes in groundborne noise from underground train services arising as a direct consequence of the scheme. This is surprising and I would consider bad practice given that the Theatre's professional team queried the oversight on several occasions whilst the SES was being drafted [for example refer to Appendix RG7]. More recently, Mr Thornely-Taylor's evidence does consider this key matter (refer to section 9 of VSU.P6).
- 8.4 As discussed earlier in my evidence, the Theatre is currently subject to significant levels of groundborne noise as a result of the operation of train services through the London Underground (LU) running tunnels. At present the Theatre foundations are separated from the running tunnels that are constructed wholly within London Clay, by layers of River Terrace Deposits and made ground [refer to VSU.A31 Technical Appendix F], which affords some attenuation of the train vibration.
- 8.5 As discussed earlier the VSU scheme involves the construction of the Paid Area Link (PAL) northern tunnel, PAL central tunnel and Northern Escalator tunnels either under or directly adjacent to the

Theatre. As set out in Mr Satow and Mr Wilson's evidence, the Promoter's scheme proposes that to protect the Theatre from settlement the ground around the new underground constructions will need to be reinforced before the tunnels are excavated. The VSU proposals are that the ground reinforcement would be via Jet grouting (injection of concrete to stiffen the ground).

8.6 The VSU Planning Direction drawings [core doc ref VSU.A35] suggest a uniformly shaped area of ground treatment around each underground construction through the River Terrace Deposits and that there should remain untreated ground between the Jet Grout works and the Theatre / Duke of York PH foundations (the Duke of York is part of the Theatre's structure). The sketches in Mr Satow's evidence (SK03 and SK04 at his Appendix D) illustrate the way in which the jet grouting is more likely to be effected. The sketches show firstly that the cross-sectional 'shape' of the area to be treated will not be uniform; secondly that the area to be treated may well be larger than that suggested by the Planning Direction Drawings; and thirdly that because of the constraints on where equipment can be positioned it is possible that jet grout columns could connect with the Theatre / Duke of York foundations in a number of locations. Mr Essler's evidence as VSU's ground treatment expert (VSU.P4) also shows the same features, with the grouted soil in discrete columns rather than the potentially misleading homogenous mass which is shown on the other project drawings. Mr Chapman's evidence for LandSec (OBJ3.P3) highlights that jet grouting in River Terrace Deposits is not an exact operation with certain outcomes in terms of the nature and form of the treated ground in every location. Whilst it is not my specialist area, anecdotal evidence suggests that grout might also migrate to unintended locations in spite of diligent execution of the works. Based on the evidence of other experts, there is therefore a significant risk that a more 'rigid' or altered connection could be formed between the Victoria Line running tunnels and the Theatre. This and other physical changes associated with installation of the ground treatment and physical works between the tunnels and the Theatre give rise to a risk, a significant risk in my professional opinion, that the works would increase significantly the already high levels of groundborne noise within the Theatre.

8.7 In his evidence, Mr Thornely-Taylor (VSU.P6) advises that since the publication of the SES, he has developed a computer model of the Theatre, the ground, the existing Victoria Line works and the proposed VSU works in order to predict the effect of the matters described above

on the levels of groundborne noise in the Theatre. He also advises that the modelling work has been based on 'worst-case' assumptions.

8.8 Whilst the development of this model is welcome, the lateness of its development has necessarily hampered the preparation of my evidence, and reflects again a failing in the scoping of the Environmental Statement. At the time of writing my evidence the final results of the model and modelling assumptions have still to be made available. I am therefore not aware of what in objective terms is meant by Mr Thornely-Taylor evidence at 9.2.29 that describes as a "small increase" in groundborne noise levels. Nor is it clear that this assessment adequately reflects: the works proposed; the Theatre's construction; the uncertainties in the VSU works in terms of groundborne noise outcomes; and the cumulative effect of the VSU and VLU projects.

8.9 As noted earlier in my evidence, objective assessment and the Theatre's operator and performers agree that any perceptible increase in groundborne noise levels from the underground train services, even a "small increase", and it is my opinion that there is a significant risk that the increase could be significantly greater, is likely to have a significant adverse effect on the operation of the Theatre. Opportunities to mitigate this potential effect are presented in the next section.

8.10 As discussed earlier in my evidence, the extent of the groundborne risks is also dependant on the location of the underground works. Sections 9 and 10 of my evidence consider mitigation options associated with relocating the underground works.

Victoria Transport Interchange

8.11 The SES considers the cumulative effects of VSU and VTI. No cumulative noise and vibration effects on the Theatre are identified.

8.12 The alternate alignments for the Paid Area Link (PAL) proposed by Land Sec as part of its VTI proposals and their implications for groundborne noise in the Theatre are discussed in Section 10 of my evidence.

Victoria Line Upgrade

8.13 The SES does not consider the cumulative effects of VSU and VLU even though this was raised with the VSU team before the SES was published. This is not consistent with EIA practice and is a significant omission because, not with standing the issues associated with the

VSU underground works raised earlier in my evidence, the VLU works themselves could give rise to significant effects on the Theatre.

9. **Assessment of Additional Mitigation put forward by Promoters**

Construction

General

- 9.1 Protected by appropriate mitigation measures (physical measures, noise and vibration limits, and robustly framed and implemented management systems), it is entirely possible to successfully demolish buildings and undertake major construction immediately adjacent to operational Theatres. The ongoing Abford House works adjacent to the Apollo Theatre and several other projects including works adjacent to Wigmore Hall, with which both Arup Acoustics and Mr Tornely-Taylor were involved are examples. It is however unrealistic for the SES to present an impression as it does that construction noise and vibration effects are entirely mitigable. Even with appropriate mitigation in place it is inevitable that there will be periods over the project's seven year duration where there will be disturbance from construction. The effect this could have on the Theatre's business is considered in the Mr Stoneman, Mr Satow and Mr Earl's evidence.
- 9.2 For a project the scale of VSU, it is appropriate and good practice for noise and vibration mitigation measures to be part generic (applying project wide), part works specific, part location specific and part receptor specific. It is also inevitable and appropriate that at any early stage of a project the focus is on the generic measures (especially management systems) and receptor specific measures. This is because the detailed mitigation to be included in the works themselves cannot be confirmed until a contractor is appointed. The generic and receptor specific mitigation therefore need to provide a framework within which the works specific mitigation is developed and agreed at a later stage. The next sub-sections and the next full section of my evidence consider receptor specific mitigation for the Theatre. However, first I will consider the project wide generic project wide mitigation measures and management systems. Before doing so it is worth concluding that experience shows that for construction noise mitigation well defined and rigorous protective provisions are essential to ensure that the intended mitigation is delivered.
- 9.3 The SES (VSU.A31) brings forward a well developed Code of Construction Practice (CoCP) [core doc ref VSU.A31 technical Appendix E] that includes matters such as Community Relations. However, the CoCP does not detail critical matters such as the cascade of management and monitoring responsibilities to the contractors and

what overarching management, supervision and auditing functions LU will undertake to ensure its contractors' performance. From professional experience it is critical that these matters are defined and that the CoCP and specific measures for the Theatre are enforced through a protective provision. Only then will the process carry the 'weight' required to ensure its faithful application during seven years of construction and also provide the Theatre a means of redress should there be a significant non-compliance during the execution of the works.

Airborne Noise

- 9.3 The SES (section 1.6 of VSU.A31 Technical Appendix B) identifies a range of mitigation measures including the need to improve sound insulation of the Theatre's external fabric. However, the commitment is only to the fire exit to Allington Street. Whilst this is agreed that the sound insulation of this fire exit needs to be improved, improvements are also required in many other locations as noted earlier in my evidence.
- 9.4 Whilst improvements to the sound insulation of the fabric of the building will enable construction airborne noise to rise significantly above the existing road traffic noise levels without disruption to performances, it would not be sufficient to allow the levels to increase to the projected 93 dB(A) outside the theatre – more than 20 dB(A) higher than the existing road traffic noise levels. Thus to protect the Theatre, noise limits – such as those presented at section 5 of my evidence – need to be defined and enforced during performance and rehearsal periods. It is recommended that such limits are enforced through a protective provision.

Groundborne Noise

- 9.5 The Jet Grouting trials reported in the SES suggest that the jet grouting works could be undertaken without significant effect (VSU.A31 Technical Appendices B and G).
- 9.6 The SES highlights the significance of groundborne noise from demolition and other works (e.g. jet grouting). However, the mitigation identified (Section 1.5 VSU.A31 Technical Appendices B) is specific to breaking out of hard standing in association with jet grouting works only (i.e. there is no allowance for its application to other activities such as demolition works such as will be required for Elliot House and 124 Victoria Street). A commitment to use, as is reasonably

practicable, low noise & vibration construction methods and especially demolition methods around the Theatre is required and would be consistent with good practice.

9.7 The main SES (VSU.A31) at footnote 3 to Table 8.1 suggests in part such a commitment: “*Alternative methods of removing those parts of the structure nearest to the affected buildings so as to minimise the effects of vibration will be investigated, where practicable.*” However, this is not reflected in the Technical Appendix B and is limited in its application. A more appropriate commitment is discussed at Section 10 of my evidence.

9.8 With regard to the risk of significant groundborne noise effects arising from the construction of the underground works, mitigation could be provided by one, or a combination, of three means:

9.8.1 low vibration construction techniques (there are limitations);

9.8.2 undertaking the works outside of sensitive periods for the Theatre (this is unlikely to be viable as tunnelling works generally need to be undertaken continuously to minimise settlement); and/or

9.8.3 thirdly relocation of the works away from the Theatre. This last point is also relevant to the risk of operational groundborne noise risks as discussed later in my evidence.

9.9 In respect of the last form of mitigation listed above, several of the options considered by LU for different routes for the Paid Area Link, especially Option 2 B/C, would have considerably less noise and vibration impact on the Theatre as would the ‘Option1A’ scheme brought forward by Land Securities (OBJ3.P3, Exhibit 12). These options are presented in Section 10 of my evidence. Additionally, earlier LU options presented the new Northern Escalator tunnel further north (and therefore clear or nearly clear of the Theatre’s north wall) – refer to Mr Satow’s evidence at Appendix H). The more northerly location would reduce the risk that these VSU works increase the levels of groundborne noise in the auditorium from Victoria Line services. The evidence of Mr Satow, Mr Spiers and Mr Wilson provide more background on the need to relocate the escalators to minimise impacts on the Theatre and to permit the Theatre extension proposals.

Groundborne Vibration

9.10 As noted earlier in my evidence, LU's assessment of the vibration impact on the Theatre arising from demolition works, without mitigation, is identified as a major impact. One that my evidence has shown would give rise to temporary closure of the Theatre and damage to the Theatre. The SES (VSU.A31) also assesses the impact with the mitigation presented at sections 1.5 and 1.6 of the Technical Appendix B. Based on this mitigation the SES concludes that there would be no significant effect. At face value this appears positive. However, careful review of the proposed mitigation is inadequate:

9.10.1 As discussed earlier in my evidence the commitment to low vibration construction methods applies only to breaking out of hard standing (and not demolition);

9.10.2 The mitigation (in terms of building damage) is primarily in the form of repairing damage to plaster work (Mr Earl's evidence identifies that this mitigation is inappropriate in respect of the historical and grade listing context of the Theatre);

9.10.3 The mitigation takes no account of the fact that whilst vibration is being generated that could damage the building, the Theatre would be unusable because of the level of annoyance (and concern) to occupants not to mention the health and safety aspects;

9.10.4 The mitigation further takes no account of the fact that, as discussed further in the evidence of Mr Wilson and Mr Earl, that the Theatre would remain unusable after exposure to such vibration until a condition survey and safety inspection provided the 'all clear'.

Operation

9.11 With regard to operational impacts, the following statement from the ES Non Technical Summary reports the promoter's findings: "*The intention is that the project design will ensure noise and vibration from the new plant meets the required criteria. No significant effects are predicted for the operating phase.*" Whilst this is a positive commitment it needs to be linked to specific design criteria as discussed at Section 5 of my evidence.

- 9.12 No mitigation is presented in the SES for operation groundborne noise effects as this issue was not assessed in the SES. I have noted before that this is a significant failure in the environmental impact assessment process.
- 9.13 In his evidence Mr Thornely-Taylor states “LUL will ensure that there is no material deterioration of the current situation as regards levels of noise and vibration from Victoria line trains experienced in the auditorium.” This is a welcome proposal but as described earlier in my evidence and that of other Theatre witnesses, any increase would have an adverse effect on the Theatre.

Recommendations for Additional MitigationConstruction (Temporary Works)

- 10.1 My evidence has shown that the construction of the proposed VSU scheme would give rise to significant noise and vibration effects on the Theatre. Inadequate mitigation is brought forward by the SES to reduce or remove these effects. If the Order is confirmed I recommend that additional mitigation specific to the Theatre is necessary and that it should be defined by protective provisions to cover the following areas:
- 10.1.1 A requirement to improve the sound insulation performance of the Theatre's building fabric (e.g. fire exist and loading doors to Allington Street).
 - 10.1.2 A requirement to undertake noise generating works at times when the Theatre is not in sensitive use (this is generally after the normal construction working hours save for a number of afternoons per week for matinees and rehearsal times);
 - 10.1.3 Definition of noise limits to be imposed at other times (i.e. during evening performances, matinee performances and rehearsals). Section 5 of my evidence presents suggested internal noise limits.
 - 10.1.4 A requirement to evaluate and then employ all reasonable and practicable low vibration construction methods.
 - 10.1.5 Definition of vibration limits of 3 mm/s PPV on the foundations of the Theatre and/or 0.4 m/s^{1.75} VDV on any floor in the Theatre. Where these limits are exceeded the Theatre should be closed for the duration of the works and until vibration falls below the criteria and a health & safety 'all clear' has been given in respect of building damage. Works during the closure should be undertaken in accordance with a work specific Vibration Management Plan that shall be prepared and agreed with the Theatre before the works commence. This shall set out matters such as: nature of the works; their duration; steps to minimise vibration, why it is not practicable to keep vibration below the criteria defined, pre and post condition surveys, monitoring to be undertaken during the works and sign off process for ensuring safe entry for the Theatre staff and Theatre patrons. These vibration limits should

also be enforced during work with a lower warning value also agreed that would trigger temporary cessation and review of works to ensure either that the limit values would not be exceeded or that an accepted Vibration Mitigation Plan is in place.

- 10.1.5 A requirement for monitoring and management regimes to ensure compliance with defined guide values and limits should be put in place including the actions to be undertaken in the events that trigger values or limits are approached or exceeded. For the avoidance of doubt, the works should be stopped if the trigger or limit values are exceeded during works until an alternative method or mitigation is identified.
- 10.1.6 A requirement that monitoring of new works will be undertaken before shows and works will be stopped if limits are breached. In the event that works cannot be stopped then the show will have to be cancelled and compensation provided.
- 10.1.7 A requirement for a condition survey before and after works and to make good any vibration damage caused where there is no practicable alternative to the form of construction giving rise to the damage.
- 10.1.8 A requirement to plan construction works based on noise and vibration predictions and to use the method and plant that minimises the noise and vibration impact in so far as is reasonably practicable. This will link to the commitment already in the CoCP or the contractors to seek s.61 consents and then adhere to them.
- 10.1.9 A requirement to provide advanced notification of construction activity stages.
- 10.1.10A requirement for the Theatre to be afforded the opportunity to review in good time relevant project and contractor documents: for example, Site Environmental Management Plans and applications to the Local Authority for prior consent for construction works and associated steps to minimise noise (under s.61 of the Control of Pollution Act).

Operation (Permanent Works)

- 10.2 The most significant issue is the potential for the VSU underground works to give rise to increased levels of groundborne noise.
- 10.3 My evidence has shown that there is a substantial risk that the VSU underground works could give rise to a significant permanent groundborne noise effect on the Theatre. This matter was not covered by the SES and hence no mitigation has been put forward by LU to reduce or remove the effect.
- 10.4 Section 5 of my evidence presents noise limits that would mean that there would be no increase in noise levels compared to the current situation and would ensure that there is no long term adverse effect on the Theatre. If the Order is confirmed I recommend that these should be the subject of a protective provision. Additionally, LU should be compelled to consider and provide as necessary mitigation to meet the noise limits. Mitigation options are discussed in the following sub-sections of my evidence. Without such mitigation there would be an unacceptable, adverse impact upon the Theatre as I have described in my evidence.

Operation (Permanent Works): Improvement of the Track in the Victoria Line Tunnels

- 10.5 There is a wealth of successful experience world-wide in the use of resilient elements in track systems to reduce groundborne noise from underground railways. Appendix RG6 provides examples including systems used by LU.
- 10.6 There are several new build rail projects in London that are successful examples of the use of resilient track as a means of mitigating groundborne noise. LU's Jubilee Line Extension uses very resilient base plates and, in very sensitive locations floating slab track. Also Channel Tunnel Rail Link's London tunnels, through which trains pass at 230 km/h, highly resilient booted sleepers have been installed. In both cases the lines operate very successfully with little or no adverse comment in respect of operational groundborne or vibration.
- 10.7 Providing improved noise and vibration control to existing track is a more complex task. The work has to be programmed in a manner that minimises disruption to passenger services. This tends to make work slower and more expensive. Also there are, particularly for the LU 'deep tunnels' that have a small diameter, a range of design and

operational constraints including limits on the depth of the track construction. This restricts the generic types of track system that can be installed. Some of these constraints are eased in platform areas as larger diameter tunnels are used. This is relevant as the Theatre lies over the platform areas of Victoria Line underground station.

10.8 Notwithstanding these challenges, the LU track will have to be renewed on a cyclic basis and hence renewals provide a opportunity to provide groundborne noise mitigation to the benefit of the VSU project.. Whilst it now appears from My Thornely-Taylor’s evidence (VSU.P6) that some track renewal work is programmed for the area in 2008, and hence the opportunity to use this to provide mitigation required for the VSU project has been lost, the detail of these renewals is not known and hence opportunities to provide mitigation may arise again in future maintenance and renewal cycles.

10.9 It is therefore relevant to note that the track system installed in the Victoria Line tunnels is old, and may even date back to the opening of the station. The track in the platform areas comprises bull head rail, fastened by cast iron rail chairs to wooden (Jarrah) blocks that are set into the concrete invert of the tunnel. There is therefore relatively little resilience under the rail and hence the vibration generated at the wheel / rail interface is little reduced as it is transmitted into the tunnel and then the ground. Additionally the rail is jointed, generating the “thumpety-thump” that not only increases groundborne noise levels but also is an acoustic feature that draws attention to the noise increasing the level of disturbance caused.

10.10 LU has over a number of years track undertaken improvements to the track in many deep tunnel lines (refer to Appendix RG6) which have made improvements to the levels of groundborne noise generated in overlying property:

10.10.1 On many lines new long rail strings have been installed with new rail fastenings featuring spring clips and relatively resilient rail pads. The principle benefit compared to the current track is that it reduces the number for joints and hence reduces the “thumpety-thump” noise.

10.10.2 In some platform areas track has been replaced with the design described at 10.10.1 but with the rail either resiliently fastened to sleeper blocks or directly fastened to trapezoidal shaped blocks that have a resilient ‘boot’

around them (the 'T4 Sleeper'). This installation might reduce groundborne noise at the Theatre by 5 dB(A) or more.

10.10.3 LU has installed test sections of highly resilient rail fasteners in a number of locations. Of particular relevance is a section of test track on the Victoria line just out side Oxford Street station where Pandrol's Vanguard has been installed and has been in operation for around 8 years. Since this test installation the Vanguard resilient rail chair has been used extensively across the world. In terms of groundborne noise mitigation is one of the best performing rail fastening systems available. Installation in the platform areas under the Theatre could reduce groundborne noise levels by over 10 dB(A). This would be greater than a subjective halving of loudness.

10.11 Thus, should VSU predictions or measurements show that the noise limits in Section 5 are exceeded then it should be entirely practicable to provide mitigation of groundborne noise by improvements to the track and this could be affected as part of any renewal.

Operation (Permanent Works): Alternative Alignment for VSU underground works

10.12 LU considered a variety of options for the alignment of its proposed underground works under and around the Theatre.

10.13 With reference to LU's Scheme Option selection report (VSU.A31 Technical Appendix C), Option 2 B/C is the best option for the Theatre as it directs the Paid Area Link (PAL) away from the Theatre. This will remove the construction and operational noise impacts associated with these works.

10.14 Options 3A, 3B, 4a, 4b, 4 link 1 and 5 are all also better than the promoted scheme. Whilst with these schemes the PAL still passes under the Theatre (which may be a concern regarding settlement and risk of tunnel collapse as discussed in the evidence of Mr Wilson), from a noise and vibration perspective the PAL would pass under the south east corner of the Theatre away from the Victoria Line running tunnels. This would remove the risk that the PAL underground works could permanently increase groundborne noise in the Theatre.

- 10.15 The preferred alternative option – Option 1A - presented in the evidence of Land Securities for the PAL alignment (OBNJ3.P3 exhibit 12) is similar in noise and vibration terms to the options discussed at paragraph 10.14. The Land Securities preferred PAL option is therefore better in terms of risk of operational noise impact on the Theatre than the alignment promoted by LU. Option 1 A also reduces or removes a number of other impacts on the Theatre as noted in the evidence of Mr Satow, Mr Wilson, Mr Spiers and Mr Loveday.
- 10.16 As discussed earlier in my evidence, removing the risk of increased operational noise and vibration in the Theatre would, without providing vibration isolation in the Victoria Line track, also require the Northern Escalator shaft to be moved northwards. As described in the evidence of Mr Satow and Mr Wilson, moving the escalator shaft northwards would also facilitate the Theatre owner’s plans to improve the fly tower and back of house facilities. To remove the risk of operational noise from the main auditorium the ‘foot’ of the Northern Escalator shaft would need to be moved north of the Theatre’s current north wall. To the extent that the VSU works would then present a risk of increased noise transmission into the Theatre’s northern extension, mitigation could be provided if necessary in the design of the extension (e.g. base isolation of the new structure and movement joint between the extension and the existing building).
- 10.17 As presented at Appendix H of Mr Satow’s evidence, all of LUs earlier VSU proposals located the Northern Escalator shaft approximately 5 m further north of the current proposed location. Whilst I understand that moving the escalator north would require moving the current Signalling Equipment Room (SER), the VSU proposals propose a new SER. Hence at present I do not understand why the Escalators cannot be moved further north, as was previously proposed. The Theatre is awaiting drawings and further information from LUL and I will provide further views to the inquiry when that information is available.

11. Conclusions

11.1 My evidence has demonstrated that there are significant failings in the VSU Environmental Statement and Supplementary Environmental Statement and that LU's proposals would, without protective provisions, give rise to significant temporary and permanent noise and vibration effects on the Theatre. The Theatre's performances and rehearsals would be adversely affected by noise and vibration. Furthermore, the construction vibration predicted by London Underground (LU) during the demolition of Elliot House and would result in damage to the Theatre.

11.2 The principal issues are presented below in order of importance.

Permanent Noise and Vibration

11.3 The auditorium of the Theatre is currently affected by noise from road traffic and severely affected by groundborne noise from underground train services (Victoria Line). The difference between the 'standard' 25 dB $L_{Amax,Slow}$ ¹ evaluative criterion for theatres (as defined in the VSU Environmental Statement) and the current Victoria Line train noise levels of 37 to 44 dB $L_{Amax,Slow}$ demonstrate how adverse the effect is.

11.4 As a consequence of the existing high levels of internal ambient noise inside the Theatre, performances use sound reinforcement. Use of reinforcement and the nature of the performances presented allows for amplified sound levels across the audience. This allows for higher tolerable internal ambient/background noise levels than for an auditorium which relies on a natural acoustic. However, reinforced sound is not ideal for all types of theatrical performance and there are limits to the level of amplification appropriate for the theatrical performance.

11.5 The impact of train noise is partially masked by noise generated by theatre systems (e.g. the mixing desk). As with the level of amplification through the sound reinforcement system there are practicable limits on the levels of masking sound/noise, both continuous and intermittent, that is consistent with theatrical productions as there is a need for relative quiet during a performance to create dramatic effect.

¹ Maximum noise level during a train pass by

- 11.6 The levels of sound reinforcement and masking noise in the Theatre are already high for Theatrical production.
- 11.7 Any increase in groundborne noise from the trains would have an adverse effect on performances in the Theatre. This technical view is supported by performers and promoters.
- 11.8 VSU proposes to construct two tunnels (Northern Escalator and Paid Area Link Central tunnels) between the Theatre foundations and the Victoria Line running tunnels. The tunnels will be constructed in the ‘soft’ ground under the Theatre and hence Jet Grouting is proposed to locally strengthen the ground to reduce settlement. There is a substantial risk that these works increase the transfer of groundborne noise into the Theatre resulting in a significant increase in levels.
- 11.9 LU did not consider this matter in its Environmental Statement (ES) nor in the Supplementary ES (SES) despite the Theatre raising it as an issue whilst the SES was being drafted. This is contrary to EIA good practice.
- 11.10 LU’s evidence now considers the matter and states “LUL will ensure that there is no material deterioration of the current situation as regards levels of noise and vibration from Victoria line trains experienced in the auditorium.” This is a welcome proposal but as described in my evidence and that of other Theatre witnesses, any increase would have an adverse effect on the Theatre.
- 11.11 Section 5 of my evidence presents noise limits that would mean that there would be no increase in noise levels compared to the current situation and would ensure that there is no long term adverse effect on the Theatre. If the Order is confirmed I recommend that these should be the subject of a protective provision. Additionally, LU should be compelled to consider and provide as necessary mitigation to meet the noise limits. Mitigation options are discussed in my evidence and are to either replace the track in the Victoria Line platform tunnels with a low vibration resilient track form or to move the VSU underground works away from the Theatre.

Construction Noise and Vibration

General

- 11.12 Major construction has been successfully undertaken immediately adjacent to operating Theatres many times before. In overview mitigation would be via: improvements to the sound insulation of the Theatre; implementation of appropriate noise and vibration limits; and reliable implementation of robust construction planning, management and monitoring procedures that are in addition to those already put forward by the VSU project.
- 11.13 If the Order is confirmed I recommend that the mitigation set out in my evidence, and which is summarised here, should be the subject of a protective provision or provisions.

Construction Vibration

- 11.14 Vibration during construction is a fundamental issue during the demolition of Elliot House and 120-124 Victoria Street. During these works LU's SES predicts that vibration on the building foundations to rise to 54 mm/s PPV² compared to the SES criterion for building damage of 3 mm/s PPV.
- 11.15 The SES brings forward mitigation but only in respect of making good damage caused.
- 11.16 Mitigation is available: e.g. low vibration demolition methods but LU has provided any commitments.
- 11.17 Vibration during construction will be an issue, in terms of groundborne noise as the tunnels mentioned above are constructed. This could disturb performances and rehearsals.
- 11.18 Mitigation is possible: e.g. review the construction method and time works for non performance periods as necessary but LU has not, as yet, provided any commitments.

² Peak Particle Velocity

Construction Noise

- 11.19 There are a number of sound insulation 'weak-points' in the Theatre's external fabric through which road traffic noise 'breaks-in'.
- 11.20 Road traffic noise is already, at times, disturbing inside the auditorium and the highest construction noise levels predicted by LU are some 20 dB greater³ than the current road traffic noise.
- 11.21 Without mitigation construction noise would stop productions.

³ A 3 dB change is usually just noticeable and a 10 dB change is a subjective doubling/halving of loudness

FIGURES

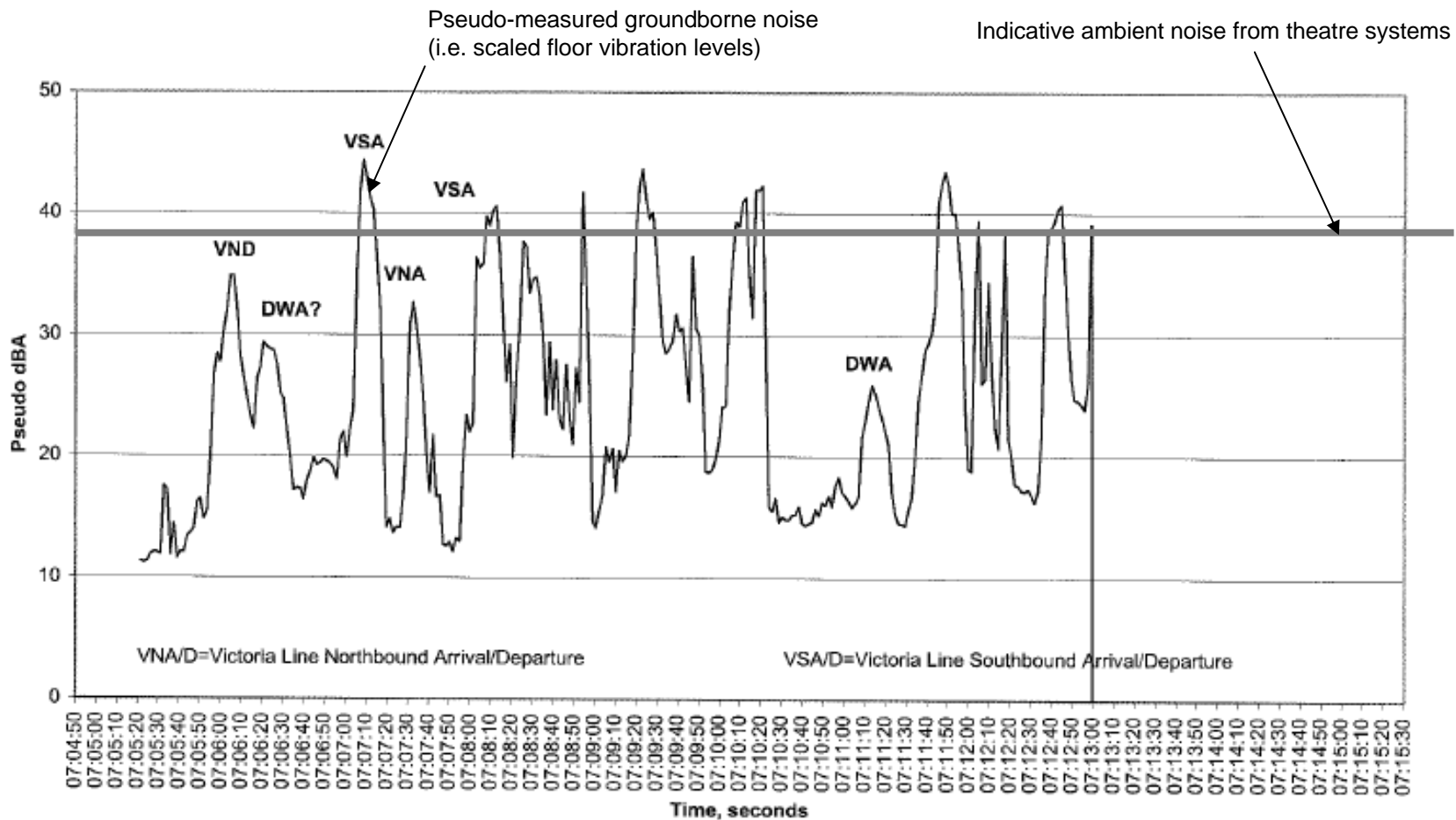


Figure RG1: Pseudo-Measured Groundborne Noise in Theatre Auditorium

Recorded by Rupert Thornely-Taylor for LU: Common Ground - Presented with agreement