ArupAcoustics

Appendix C

Assessment of Vibration at Proposed Residential Properties

Contents

C7.1 INTRODUCTION

The site of the proposed mixed development is bounded by a major railway network immediately to the south, which pass through the Bristol Temple Meads Station. This section of railway line can be viewed as being made up of four major through-lines, consisting of two 'up' and two 'down' lines, off of which are various other loops which either terminate or continue through and out of the western end of the station. These railway tracks run along a high bricked viaduct, which is elevated approximately 8m above the local ground level of both the proposed site and the intervening surrounding areas. The main through-lines are situated furthest from the northern side of the viaduct and from the site itself. There is also a service road situated alongside the nearest railway, on the northern side of the viaduct. This provides an additional buffer zone between rail traffic and the site. Whilst most passenger trains stop at this station, and therefore have slow entry and exit speeds, as this section of railway follows a tight radius curvature, a speed restriction is enforced throughout this particular section of railway, which applies to non stop 'through' trains as well. This is of particular relevance to the occasional freight trains that also pass through Temple Meads Station.

Due to the close proximity of this railway to the closest residential buildings on this proposed development, it was recommended that a vibration survey be undertaken to determine the potential impact rail traffic vibration may have on the nearest of the planned dwellings and their future occupants.

There are four common effects on people and the buildings they occupy from low frequency noise and vibration from railway trains. These can be categorised as perceptible vibration inside the building, groundborne noise, possible cosmetic (and in extreme cases structural) damage, and impairment of equipment function. For this particular study, it was evident that only 'perceptible' vibration and groundborne noise issues would need to be assessed.

As part of the general assessment of the site, Arup Acoustics assessed the potential impact of vibration from railway trains on the proposed mixed development, in particular the nearest proposed residential dwellings. Vibration measurements were carried out on the 15 and 26 March 2005, by Daniel Howells and Andrew Officer of Arup Acoustics. During these two survey periods, normal train services were operating along this section of railway.

C7.2 METHOD OF ASSESSMENT

Perceptible Vibration

The effects of vibration from the railway may be assessed using BS 6472 (1992) 'The evaluation of human exposure to vibration in buildings' [1].

Disturbance caused by perceptible vibration is quantified using a Vibration Dose Value (VDV), this takes account of the level of vibration generated by each event, the duration of each event and the total number of events within the day (07:00 to 23:00 hrs) and night (23:00 to 07:00 hrs) periods. When determining the potential disturbance to humans, vibration should be measured in all three orthogonal axes to represent the basicentric coordinates, back to chest (x), side to side (y) and head to foot (z). If the orientation of the occupants is varying or unknown with respect to the detected vibration, the weighted values should normally be obtained for all axes and the highest value used.

The criteria applicable to residential buildings are shown in Table 1 below with criteria applicable to offices in Table 2; special buildings should be considered individually.

Probability of adverse comment	VDV $ms^{-1.75}$ 16 hr Daytime (0700 – 2300 hrs)	VDV $ms^{-1.75}$ 8 hr night-time (2300 – 0700 hrs)
Low	0.2 – 0.4	>0.13
Possible	0.4 – 0.8	>0.26
Probable	0.8 – 1.6	>0.51

Table 1: **Criteria for assessing disturbance in residential premises (BS: 6472)**

Probability of adverse comment	VDV $ms^{-1.75}$ 16 hr Daytime (0700 – 2300 hrs)	VDV $ms^{-1.75}$ 8 hr night-time (2300 – 0700 hrs)
Low	0.4	0.37
Possible	0.8	>0.74

Probable	1.6	>1.46

Table 2: Criteria for assessing disturbance in office premises BS: 6472

Groundborne Noise

The term groundborne or re-radiated noise is directly related to ground vibration energy. This vibration energy is transferred into the building fabric via the foundations and substructure, which then transmits into structural elements such as walls, floors and ceilings, which act like sounding boards. Groundborne noise is generally manifested as audible low frequency noise or 'rumble' within the building.

Although there is no UK or International Standard which proposes acceptable levels of groundborne noise from railways, there are US and UK guidance documents on this subject [2 & 3]. This and other experience identifies that there starts to be some impact on people in properties when the level exceeds 35dB$L_{Amax,slow}$. Consequently, in the UK, design aims for railways have been set at 40dB$L_{Amax,slow}$ (eg rail schemes such as Channel Tunnel Rail Link, Docklands Light Railway, Bank Line Extension, Woolwich Line Extension, Jubilee Line Extension, and Thames link 2000). A criterion of 40dB$L_{Amax,slow}$ is also consistent with the London Underground Ltd (LUL) complaints history. The work undertaken by LUL in the early 1990s identified that over 56,000 properties in London experience levels over 40dB but that only 0.5 % of these had complained. The LUL work [4] concluded that "...people are much more tolerant [to groundborne noise] than had been previously presumed"

Guidance on sleep disturbance in terms of L_{Amax} is also provided by the World Health Organisation (WHO) [5], which recommends a level not exceeding 45L_{Amax}, dB for a single event, to avoid sleep disturbance.

Historically, the assessment of train noise has been made using Noise Rating (NR) curves for non-residential buildings. However, there is a RIBA publication [6]", which provides guidelines on permissible levels of groundborne noise using the maximum rms A-weighted (dB,$L_{Amax,slow}$) sound pressure level. For cellular offices, a range of 45-50dB$L_{Amax,slow}$. is an acceptable limit, whilst for open plan offices, 50-55dB$L_{Amax,slow}$. would be an appropriate upper limit.

The calculated groundborne noise levels are presented in Table 5. These have been derived from 1/3 octave band rms vibration velocity data, obtained from the analysis of the raw vibration time histories of each measured train vibration event.

This report does not consider the effects of possible excitation of lightweight building elements such as windows, which may resonate as a result of low frequency airborne noise.

C7.3 VIBRATION MEASUREMENT INSTRUMENTATION

The ground vibration survey was carried out using specialist transducers and multi channel data analysis and storage instrumentation. The instrumentation used was as follows:

- SVAN 948 4 channel vibration analyser;
- PCB 393 B12 high sensitivity accelerometers.

This instrumentation permitted the acquisition of both VDV (Vibration Dose Values) and vibration velocity data. Vibration velocity spectra could be observed 'live' as the events occurred, to ensure 'clean' data was obtained. Any spurious events which appeared to corrupt the actual 'event' to be measured, was rejected. The data sample for each train event (pass-by) was subsequently stored into the instrument's onboard memory. This data was then post-processed after completion of the survey.

Whilst the SVAN 948 permits immediate computation of VDV's for each train event, further post processing was required to derive the resultant VDV for daytime and night-time periods, as indicated in BS 6472. To do this, typical daytime and night-time rail traffic flows have been determined for passenger trains using counts made whilst on site. Freight train movements are also known to use this section of line on occasions, although none were measured during the two survey periods. It is known that the freight trains travel at similarly slow speeds to passenger trains, due to the tight curvature of the tracks. They also use the main through-lines, which are situated furthest from the Waterfront site.

C7.4 METHODOLOGY

Where conditions permit, vibration measurements should be taken on a structural surface supporting the human body. However, when conducting measurements prior to development this is not possible. In these cases, measurements should ideally be taken on the underlying ground surface, by using vibration transducers mounted onto 'special' ground spikes, so long as they are driven into firm, undisturbed ground. However, on this particular site, it was found that the ground proved unsuitable for this method as a lot of the area close to the viaduct has recently been disturbed, with large earth mounds over to the east corner of the site. Therefore a suitable but equally valid approach used on this occasion was to measure outside the site at equivalent locations in terms of distance from the railway.

Alternative locations were selected east of the site along Oxford Street. Two vibration locations were used, positioned along the kerbside. The use of a 'special' three-footed steel plate was used to efficiently transfer vibration energy from the ground into the transducers. The plate was located onto kerbstones, which whilst embedded well into the underlying ground, still have a relatively low mass, which provide a similar alternative to a true 'unloaded' ground condition. This enables 'free field' vibration levels to be measured so as to provide data on the vibration energy present within the ground under unrestricted conditions.

Location V1 was situated on the kerb approximately 2m from the viaduct structure, and was used to provide an indication of the 'worst case' vibration that was likely to be transmitted from the viaduct structure. It is considered that the viaduct structure itself is built upon shallow spread footings, rather than deep piled foundations, therefore the energy transfer at ground level will not have had chance to be attenuated significantly. Location V2 was situated on the opposite kerbside, approximately 11m from the viaduct. This location can be regarded as similar in distance from the viaduct as is the closest part of the expected footprint for plot ND5 (as shown in Figure 1).

The propagation of vibration is heavily dependent on the composition of the intervening ground. Whilst it can require several measurements across a large site, the Waterfront site has a relatively small profile parallel to the railway source in this case, and it was considered that the vibration would be largely consistent across the closest exposed section. It has also been assumed that the ground conditions would be mainly homogeneous at the piled foundation levels required for the proposed buildings. Furthermore, until details of the required pile depths are known, no estimate of potential attenuation can be applied to the surface vibration levels, to apply to the predicted VDV and structureborne noise values given in Section 5 below.

To enable a satisfactory representative analysis to be carried out, data capture for a statistically significant number of trains was obtained and recorded.

Structureborne Noise

Structureborne noise levels (L_{Amax}) that have been predicted to occur inside the buildings, have been calculated using the 'highest' measured maximum spectra, which is derived by taking the highest level attained from any of the individual train events recorded. Whilst this by-product is unlikely to occur during any one particular train passby, it provides a conservative 'worst case' spectra with which to assess the possibility of structureborne noise issues. The 'averaged' maximum spectra have also been derived, providing a more realistic and generally more repeatable spectra to evaluate and assess for structureborne noise.

C7.5 RESULTS

Vibration Results

To quantify the disturbance caused by perceptible vibration in accordance with BS 6472, the period VDV's for each element of the basicentric coordinate system (x,y,z) have been calculated at the measurement locations. Realistic railway traffic flows for a typical day were calculated from train pass-by events observed during the survey period. The rail traffic is largely made up from a combination of both Electric Multiple Units (EMU) and Diesel Multiple Units (DMU) passenger services. Throughout the whole survey period, it was estimated that the speed of observed train pass-bys along this section of track was in the order of between 10 to 20mph. There were no obvious restrictions limiting train services along this section of line at the time of the survey. Therefore it has been assumed that the train services were running at normal operational speeds and frequency.

A transfer function of 4 has been applied to the measured 'free field' vibration levels as measured on the underlying ground, which allows for 'worst case' amplification at 1st floor and subsequent floor levels. This is based on Arup Acoustics' empirically based experience from previous studies of vibration transmission through buildings. However, this can reasonably be expected to reduce for floors above 1st floor level. The process of vibration transfer through a building is complex, and the level of amplification and attenuation of vibration can vary widely due to excitation of particular resonances of building elements, dependent on the variable frequency content of the train's vibration signature.

On the basis of these assumptions, the following Vibration Dose Values (VDVs) have been calculated using the procedure detailed in BS 6472.

Table 3 and 4 show both the calculated ‘Ground Floor’ and derived ‘1st Floor’ VDV ms –1.75 levels for the daytime (07:00-23:00hrs) period, and night-time (23:00-07:00hrs) based upon estimated rail traffic, derived from train counts made over timed hourly periods from site observations, and using the maximum measured VDV measured for each train type ie ‘worst’ case scenario.

Basicentric Coordinates	**VDV ms $^{-1.75}$**		
	Daytime		**Night-time**
Z	0.05		0.03
X	0.02		0.01
Y	0.02		0.01

Table 3: Calculated ‘Ground Floor’ Vibration Dose Values (VDV) at location V2, for each of the basicentric coordinates.

Basicentric Coordinates	**VDV ms $^{-1.75}$**		
	Daytime		**Night-time**
Z	0.18		0.11
X	0.10		0.06
Y	0.07		0.04

Table 4: **Calculated ‘1st Floor’ Vibration Dose Values (VDV) at location V2, for each of the basicentric coordinates.**

Structureborne Noise

The predicted groundborne noise levels which may arise within rooms of buildings situated close to the railway are presented in Table 5 below. These have been calculated using empirically derived methods developed by Arup Acoustics of relating the vibrational energy coupling to the building structure to the sound re-rediated within a typical domestic room. The ‘Maximum Train Event’ levels are derived by taking the highest ‘Maxima’ in each third octave band, measured from all measured train events. This is taken as the ‘worst case’ scenario, and is unlikely to occur in reality. Even so, this provides a useful indicator to the highest possible noise levels that could be achieved. The ‘Average Train Event’ levels provide a more realistic idea of the likely groundborne noise levels that may be generated on a regular basis by the majority of train pass-bys. These levels take account of likely coupling losses between the ground and the building foundations. They also take account of amplification between columns and mid spans of floors, as well as amplification and attenuation which may occur between successive floors.

Measurement Position	**Noise Level, $L_{Amax,slow}$ dB**	
	Maximum Train Event	**Average Train Event**
V1 – 2m from Viaduct	46	37
V2 – 11m from Viaduct	42	31

Table 5: **Calculated groundborne noise levels for ‘worst case’ Maximum’ and ‘Average’ maximum train events.**

C7.6 ASSESSMENT

Perceptible Vibration

The calculated VDV levels shown in Table 3 and Table 4 above for all of the measurement positions for both day and night periods are predicted to fall well below the category for “low probability of adverse comment” for the expected land use of commercial offices and retail, and comfortably below for residential use. Given that this result is derived from data measured at the closest point between the railway and the closest part of the development, it is reasonable to expect that the rest of the site can also be rated as being of “low probability of adverse comment”.

The results in Table 4 have been calculated for first floor levels, based on a transfer function of 4, which is considered to represent a ‘worst case’ scenario for possible amplification which may occur at 1st floor level. Perceptible levels of vibration can reasonably be expected to reduce for each subsequent level. However the level of amplification and attenuation will depend upon how efficiently the vibration is transmitted through the building structure.

Groundborne Noise

Calculated ‘worst case’ maximum and ‘average’ maximum levels of groundborne noise at location V1 are 46 and 37dB$L_{Amax,slow}$ respectively. The hypothetical ‘worst case’ maximum would be deemed to be excessive for residential properties, but would be permissible within proposed office spaces, as defined by the criterion provided in the Royal Institute of British Architects (RIBA) ‘Commercial Offices Handbook’[6]. Whilst this measurement location was very close to the Viaduct (ie 2m from Viaduct) and consequently unrelated to the actual location of the development, it does provide a useful datum point. The calculated ‘worst case’ maximum and ‘average’ maximum levels predicted at location V2 are 42 and 31dB $L_{Amax,slow}$ respectively. Whilst the 42dB $L_{Amax,slow}$ would be regarded as close to the acceptability criteria set out in Section 2.2, this level is unlikely ever to occur, even during freight train pass-bys. The more realistic ‘average’ maximum would suggest that predicted noise levels at this location would be well below the threshold levels of 40dB suggested in Section 2.2, and also well below the 45 L_{Amax}, dB level as defined for a single event, which is deemed to cause sleep disturbance in terms of L_{Amax} , as stipulated by the World Health Organisation (WHO) [5].

Conclusions

A study has been conducted to assess the potential impact of vibration from railway trains on the proposed mixed development, in particular the nearest proposed residential dwellings.

The results show that, according to the relevant Standard, the levels of vibration are such that there would be “low probability of adverse comment” at the closest occupied position.

Considering the potential for groundborne noise, the predicted levels of noise break-out that are likely to occur in practice indicate that noise levels would be acceptable at the closest residential location (Location V2) according to the available assessment criteria.

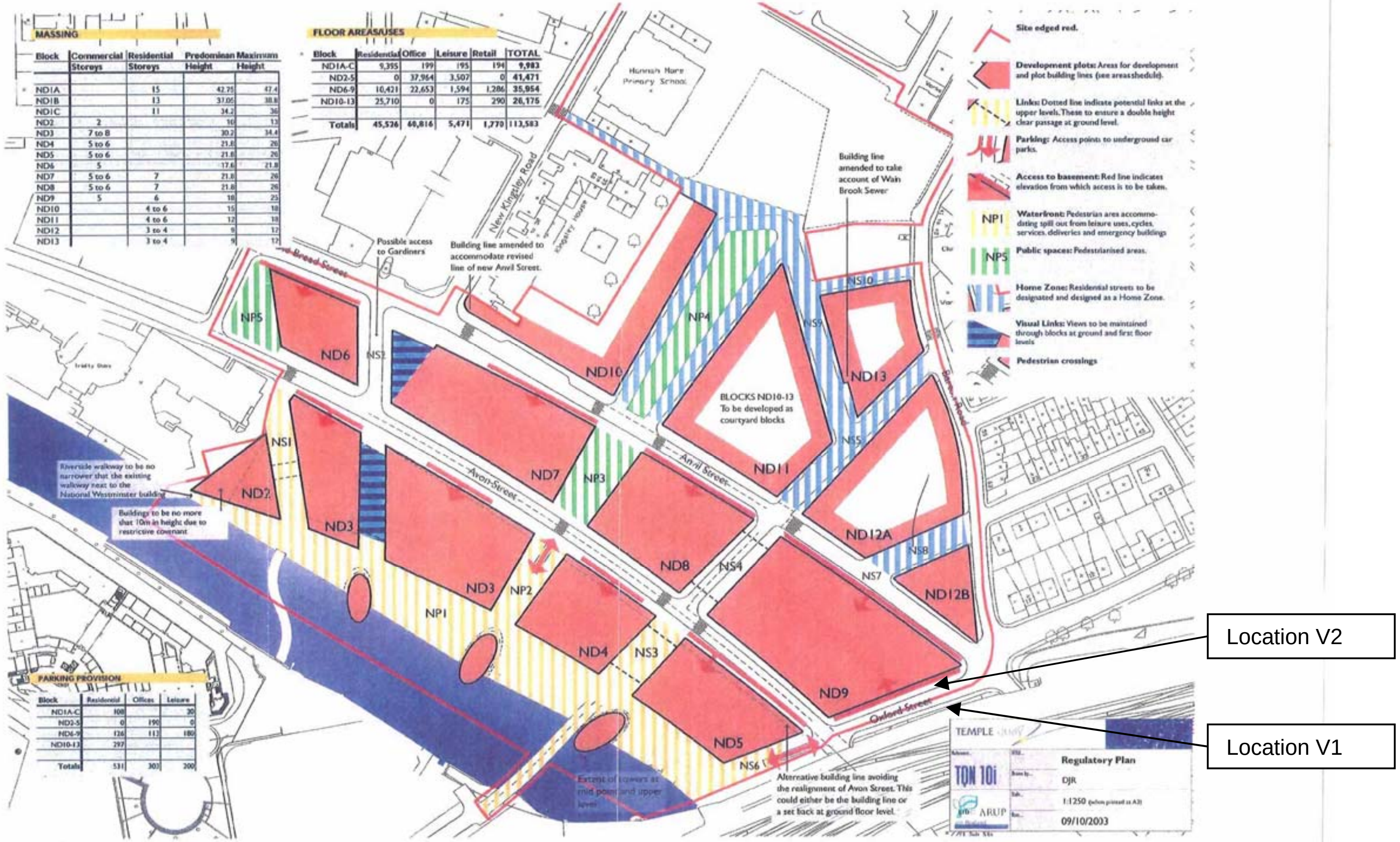

Figure 1: Vibration Monitoring Locations

REFERENCES

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