Technical note

Project:	East West Rail - Bicester to Oxford	**To:**	Andy Milne
Subject:	CONDITION 19 - VIBRATION SCHEME OF ASSESSMENT	**From:**	Inan Ekici
Date:	17 December 2014	**cc:**	Mike Fraser, Chris Brooks

Dear Andy,

CONDITION 19 - VIBRATION SCHEME OF ASSESSMENT

Condition 19 requires that an Independent Expert (IE) is appointed which involves writing a report regarding the robustness of the Vibration Scheme of Assessment (VSoA). This report is then submitted to the Local Planning Authorities with the VSoA. Chris Jones was appointed to fulfil this role. Following submission of the IE's report the Council has appointed Arup to review the information made available to the IE and the conclusions he has reached, as published in his final Report.

Arup's report concluded that there were some uncertainties regarding the robustness of the VSoA which needed to be addressed to allow discharge of the Condition 19. Although the Arup report does not conclude that the vibration criteria will be exceeded, it recommends that there needs to be quantification of some of the cautious and incautious aspects of VSoA before a conclusion as to robustness can be drawn.

The following is our response to issues raised at the meeting between Network Rail (NR) and Oxford City Council, on 12th September 2014, to reach a shared technical understanding of Arup's report and the actions which should arise from it. The actions arising are shown in red and our response to the points raised is detailed below these. The actions arising should be read in conjunction with the minutes of the meeting to provide a background on the discussions held.

***Action** on **Point 5**– NR to provide a commentary on the ERM data, its use in the EIA and issues around using it to check or clarify the VSoA.*

Measurements reported in EIA

It is important to note that the general approach of VSoA is to develop a robust prediction scheme and to use this as the basis of predictions at properties across the study area, rather than undertaking vibration measurements at each property under consideration. Both the IE and Arup are in agreement that this is a reasonable and industry standard approach.

The data presented during the EIA process and the Public Inquiry was primarily collected to address concerns of likely structural damage following publication of the ES. Therefore, the internal measurements were taken near the walls rather than in the middle of the rooms. A secondary aim was to quantify baseline vibration and measuring at the edge of the room results in a stringent assessment for these purposes due to potentially lower amplification due to floor elements at this location. Lower vibration baseline values result in potentially more stringent vibration limits, and the use of vibration data in baseline vibration assessments is therefore different to the way in which the standard is normally used to identify the likelihood of adverse comments when it is the higher levels that are of interest.

In order to identify the response of a floor to ground-borne vibration and to identify areas where vibration will be most likely to result in adverse comments, BS 6472-1:2008 recommends that 'one or two measurement points in a suitable available area, preferably in the central part within one-third and two-thirds of the width/length' would be sufficient. This is intended to identify the highest levels of vibration in a room when this is the purpose of the measurement exercise. However there is no advice in the standard to suggest that measurements undertaken near the walls will not incorporate any amplifications, and the differences between the edge of the room and the centre may be smaller than the overall floor amplification factors that are discussed later in this note. The US FTA provides guidance which also suggests that the amplification will be lower at the wall/floor and wall ceiling intersections, but it does not suggest that no amplification will occur at these locations.

Indeed the vibration data presented at the Public Inquiry makes observations on amplifications noted inside Quadrangle House. Correspondence with Mr Napier at Quadrangle House firstly acknowledged that CRCL recognised that next to the line at the rear of Quadrangle House there were 3 floors constituting a ground floor garage and 1st and 2nd floor two bedroom flats with no basement. Then it went on to say that observations on PPV (peak particle velocity) levels indicate that measurements undertaken at the second storey level are in the region of twice the magnitude of those measured at the ground level (it is recognised here that VSoA incorrectly refers to the ground level as the 'basement', however this does not affect the assessment in the VSoA). However, amplification was not reflected in the measured VDV figures which is the parameter which is required in Condition 19 through the Noise and Vibration Mitigation Policy.

Vibration from a stone train has been monitored at ground floor level (on the 30.07.2010 at approximately 08.15am) and was found to result in a vibration magnitude of 1.0 mm/s PPV which is not significantly higher than other freight train vibration levels which ranged up to 0.7 mm/s. There is no evidence to suggest that this train would result in significantly different amplification factors than other trains. This observation has been taken into account in the assessments and it is considered that the conclusions of VSoA are robust.

For the reasons above the difference between measurements at the edge of the room and the centre is not expected to be as large as the overall factors discussed later in this note. However, due to the potential difference between vibration at edge of the room and at the centre of the floor the measurements are not suitable for this purpose. The IE's check does not form part of the VSoA which is being considered in the IE review. This note therefore focuses on the Arup analysis of the submitted prediction method in the VSoA.

Use of data in the VSoA

As part of the VSoA, the VDVs at each receiver have been estimated for the current situation and, where information was available, compared with measured VDVs reported in the Public Inquiry to provide a sense check. These comparisons were not intended to calibrate the model or to derive amplification factors inside buildings, since the current case predictions and measurements reported in the Public Inquiry are not directly comparable. The differences in the level and composition of traffic are factors which need to be taken into account when undertaking direct comparisons.

The assessments are based on existing train timetable information and predicted timetable for the consented scheme in accordance with the Noise and Vibration Policy. The increase in freight trains are as set out in the Policy. Therefore any measurements at the dwellings will be mainly influenced by the freight trains observed on the day of measurements, rather than the available freight-paths considered in the assessment, which represent a higher number of trains. It is important to note that the noise and vibration schemes of assessment take the additional East West Rail services, as set out in the Noise and Vibration Policy, into account. Additional East West Rail services will not begin until March 2019.

The main purpose of referring to measurements reported in the Public Inquiry was to provide continuity with the previously reported vibration data, recognising the work already undertaken to address concerns about vibration. It was considered that scheme-specific vibration levels, gathered inside the properties under consideration and measured continuously over extended periods of time, were relevant within the limitations discussed above. A further aim was to demonstrate that there is a reasonable margin of safety in the empirical predictions, by erring on the high side when compared with actual measurements of long-term VDVs inside the properties. It is reasonable to assume that this conservative approach will also apply to the predictions for the proposed case, where the project limits are to be satisfied.

***Action** on **Point 6** - NR to explain why zero (amplification factor) has been used by Atkins; and comment on the relevance of the 4x multiplier to this scheme.*

The VSoA assumes that the vibration levels calculated outside the building are representative of those measured on the floor inside the building. This assumption is based on well-established and published industry guidance contained in 'Measurements & Assessment of Groundborne Noise and Vibration' (2nd Edition, 2012), published by the Association of Noise Consultants (ANC). The review by IE confirmed that it is acceptable to base assessments on the estimated levels outside the properties and the IE did not identify a specific requirement to measure vibration levels inside properties when he reviewed the submission.

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The ANC is the trade association for acoustic, noise and vibration consultancy practices in the UK. It formed a Working Group in 1997 to develop the guidelines on vibration. Following the publication of the first edition in 2001, a second revised and updated edition was published in 2012 (as referred to above). The members of the Working Group and the technical editor are all leading experts in the field. The ANC considers that procedures described in the document represent best practice in the field of vibration assessment and measurement and consultants or specifiers may wish to refer to these Guidelines in their work. The Guidance covers, amongst a wide range of matters, vibration transfer from outside to inside of buildings. The nature of advice on transfer functions remains the same between the two editions of the document.

For completeness, Table 14.3 of the Guidance is reproduced below (page 121).

Table 14.3 reproduced from ANC Guidelines.

Ground surface to building slab (in contact with the ground)	Ground surface to foundation	Floor to floor	Floor resonance
0dB at low frequencies (from reference [46])	Wood frame: -5dB 1-2 storey commercial: -7dB 2-4 storey masonry: -10dB Large masonry on spread footings = -3dB Foundation in rock = 0dB (from references [46] & [17])	1-5 floors: -2dB/floor 5-10 floors: -1dB/floor (from reference [17]) -3dB/ floor (from reference [46])	= 5 to 15dB over 16-80Hz (from reference [46]) = 6dB (from reference [17])

[17] US Department of Transportation, Transit noise and vibration impact assessment, (2006) Report FTA-VA-90-1003-06 (Downloadable from www.fta.dot.gov)

[46] Transportation Noise Reference Book. Edited by Paul Nelson, Published by Butterworths, 1987. ISBN 0-408-01446.6.

Foundation response can be defined[1] as the '…level of actual foundation vibration relative to the level of incident ground surface vertical vibration that would exist in the absence of the building structure and its foundations.' According to the ANC guidance, single figure attenuations of 7dB to 10dB could be expected for 2 storey buildings.

On the other hand, once inside the building, amplifications may occur if resonances of the structure coincide with peaks in the ground borne vibration spectrum. The potential single figure amplifications due to floor resonances are given as 6dB.

Experience shows that levels typically go down again for higher floors. The floor-to-floor attenuation is given as 2dB to 3dB per floor.

Using the single figure corrections in ANC guidance, the table below shows the expected amplifications (shown as positive figures) and attenuations (shown as negative figures) in typical properties.

[1] A Prediction Procedure for Rail Transportation Groundborne Noise and Vibration, Nelson, J.T. and Saurenman, H.J., Transportation Research Record 1137, 1987

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Transfer Functions based on ANC Guidance Typical values

	Floor	Ground surface to foundation dB	Floor resonance dB	Floor to Floor dB	Net Effect dB
Typical 2-4 storey	Ground	-10	+6	0	-4
	First	-10	+6	-2	-6
	Second	-10	+6	-4	-8
Typical 1-2 storey	Ground	-7	+6	0	-1
	First	-7	+6	-2	-3

According to the single figure guidance provided by ANC, it is shown that the net effect of transfer function for a typical building could result in attenuations. Therefore on the basis of this assessment, it is reasonable to assume zero transfer function between the levels expected inside the properties and the surface vertical vibrations that exist outside in the absence of the building structure and its foundations. Combined with the observations on measured vibration levels inside the properties, this approach was shown to provide a conservative basis for the VSoA.

It is explained in ANC Guidance that '…the response usually varies with frequency and hence an overall value for amplification and attenuation is difficult to identify…'. For instance for the special case of a floor building slab on contact with the ground soil, the coupling loss is stated to be zero dB at 'low frequencies'. However there is no guidance on the range of frequencies where this applies. For example, VSoA illustrates that the dominant frequency for vibration from a typical freight train close to the railway is 40Hz or greater and therefore the resulting overall attenuations may be higher in this case.

As explained above, amplifications may occur if the resonances of the structure coincide with the peaks in ground borne vibration. Where amplifications do occur, and depending on the vibration frequency under consideration, the range of amplifications are given in ANC guidance as typically between 5dB to 15dB over the frequency range 16Hz to 80Hz. Further guidance is provided in the Transportation Noise Reference Book (TNRB) which qualifies this guidance. According to TNRB the effect of vibration amplification is most pronounced in residential wood-frame houses and the upper limit of amplifications is shown as 14dB, which would approximate to an amplification factor of 5. Additional advice is given in the source reference by Nelson and Saurenman (1983)[2] which explains that the estimated amplification of vibration by floor slabs supported on columns or shear walls due to resonances in the 10 Hz to 40 Hz range is approximately 10 dB, which corresponds to an amplification factor of approximately 3. As stated above, the observed dominant frequency from a typical freight train close to the railway is greater than 40Hz, and the stated amplification may not be realised when considering the full frequency range for deriving VDVs. However in the discussions below an amplification of 10dB is assumed to represent potential amplifications for properties which are not wood frame.

There are 3 properties in this section of the Scheme which are relevant to the discussions. A visual inspection was undertaken by a qualified building surveyor on 11 December 2014 to identify the basic construction details of these buildings. A summary of the details is as follows;

[2] State-of-the-Art Review: Prediction and Control of Groundborne Noise and Vibration from Rail Transit Trains, Nelson, J.T. and Saurenman, H.J., Wilson, Ihrig & Associates, UMTA-MA-06-0049-83-4, Final Report, December 1983

Property	Foundation	Superstructure	Floor
Quadrangle House	Strip/trench filled foundation	Structural Masonry brickwork	First floor – structurally formed precast concrete supported on structural brick columns (ground floor is car park)
2B Bladon Close	Piled (variable depth) and ring beam	Timber Frame	Ground bearing concrete slab
3 Bladon Close	Combination of Strip/ monolithic pad	Structural Masonry brickwork	Ground bearing concrete slab

As highlighted above, the frequency-based amplification figures cannot be applied with confidence to derive robust transfer functions. However the following transfer functions illustrate a reasonable worst case scenario at each property;

Worst case Scenario

	Floor	Ground surface to foundation dB	Floor resonance dB	Floor to Floor dB	Net Effect dB
Quadrangle House	Ground	-10	10	0	0
	First	-10	10	-2	-2
	Second	-10	10	-4	-4
2B Bladon Close	Ground	0	14	0	14
	First	0	14	-2	12
3 Bladon Close	Ground	0	10	0	10
	First	0	10	-2	8

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Using the least favourable transfer functions in each case, which would result in the highest predicted VDVs in each property, the resulting levels are summarised below. It is shown that the project limits would be met.

Summary

			Internal vibration Levels, VDV		
Dwelling	Time Period	Avg VSoA Calculated VDVs (open ground)	Calculated based on Typical transfer functions	Calculated based on Reasonable worst case	Project Limits
Quadrangle House	Day-time	0.14	0.08	0.14	0.4
	Night-time	0.09	0.05	0.09	0.2
2B Bladon Close(*)	Day-time	0.06	0.05	0.30	0.4
	Night-time	0.03	0.03	0.15	0.2
3 Bladon Close	Day-time	0.06	0.05	0.19	0.4
	Night-time	0.03	0.03	0.10	0.2

(*) 2B Bladon Close does not form part of VSoA. It is considered that the predicted VDVs at 3 Bladon Close are a reasonable representation of average vibration levels in open ground at this dwelling, since both properties are a similar distance from the railway.

According to Nelson and Saurenman (1983), one of the source references on which the ANC Guidance is based, '...it is important to recognize that this method was developed to provide a conservative prediction of the levels of groundborne noise and vibration. That is, it estimates the "highest expected" level of ground-borne vibration and not an "average" level…'.

The discussions above indicate that similar levels of attenuations and amplifications may be expected inside typical properties, if the effect of foundation, floors and other building elements are considered together using single figure transfer functions given in ANV Guidance. The resulting levels would be relative to ground surface vertical vibration levels that exist in the absence of a building structure and its foundations, representing the conditions under which the VSoA vibration information was measured. On the basis of single figure transfer functions, it would be reasonable to assume zero change between the VSoA predicted values outside and the expected levels inside the dwellings. Frequency-based transfer functions cannot be identified accurately using published figures due to highly variable nature of building response. On the basis of worst-case frequency based transfer functions, the highest predicted VDVs in each property are shown to be within the project limits. It is considered therefore VSoA results in robust assessments with a reasonable margin of safety in the calculations.

***Action* – Inter-train variability**: OB said that this is not a critical consideration but the measured variability of freight train vibration in the Atkins sample does not correlate with Arup's analysis of heavily trafficked routes. This is likely to be because it was not practical at the time to gather a large sample of data. *NR to provide further justification for their data set and comments on Arup's concerns about it.*

It is noted that the VSoA measurement site was selected carefully, following an initial desk-based investigation and a subsequent site visit of potential sites, to ensure ground conditions were representative of the study area, train speeds were close to the operational speeds of the new railway, the track was at-grade or on a shallow embankment and features which could affect measurements were avoided (such as watercourses, retaining walls and presence of other structures). Measurements undertaken as part of VSoA have monitored all available trains past the measurement point over 3 different days. The sample size is a reflection of the current use of the line.

Freight inter-train variability depends on the design and general condition of the individual trains themselves, rather than the design of the track. It is outside the remit of the Order Scheme to design and build the railway in a way to address inter-train variability from exceptional trains which do not currently form part of the Scheme. It is also noted that the future rolling stock including freight wagons will be subject to Technical Specifications for Interoperability (TSI) intended to reduce noise from rail-wheel interaction. It is considered that improved freight wagon standards will also have a positive effect on the trackside vibration levels. However these potential benefits are long-term aspirations and have not been factored into the VSoA.

The measurements illustrated that the loaded stone train had distinctive vibration characteristics compared with the unloaded stone train and the rest of the conventional freight trains. Therefore it was not considered appropriate to use the loaded stone train as a proxy for all conventional freight. The known day-time operation of the stone train has been specifically taken into account. Currently the stone train operates 2 days of the week. The assessments are based on a typical day when the stone train would be operational, and represents a conservative approach when assessing typical VDVs at the dwellings. With the scheme, there would be an increase in the number of freight movements. However there is no indication that there would be an intensification in use of the stone train. Any increase in stone train activities would be a commercial decision by the operators and governed by market forces. As a conservative approach, it has been assumed that, with the scheme, there could be up to 2 fully loaded stone trains a day (1 on each track, since both tracks are designed to be bi-directional). The total number of conventional freight movements has therefore been proportionately reduced to allow for these movements.

During the months of September to December 2014, additional ballast trains are being run through the night to create a ballast stockpile at Banbury Road sidings. This is removing the need for many thousands of HGV road movements. From March 2015 the line from Oxford North to Banbury Road (Water Eaton) will be closed completely, through to Feb 2016, to allow it to be rebuilt to a modern specification with new ballast, sleepers and rail. Driver training will then be undertaken in Feb 16 before the Chiltern Railways Oxford to London Marylebone service commences in March 2016 with two trains per hour in each direction

There could be potential impacts during the temporary arrangements above. Apart from the exceptional operation of the railway, or exceptional freight trains which are not in an appropriate order of maintenance, the resulting vibration levels are expected to comply with the requirements of Condition 19.

***Action* – Improved track quality**: OB said that at Gospel Oak new track reduced vibration by more than half. He suggested that the output of a track recording car would help to quantify the 'before and after' vibration levels for this locality, or if this could not be done the roughness profile for other sections of track maintained to the current standards and the proposed standards could be provided.*NR to try to quantify this aspect.*

The information from track recording vehicle is not readily available at this moment in time. The Gospel Oak study identified that significant improvements in track quality (on the track in Up direction) have only had a small effect on the vibration generated by the trains causing most annoyance and concluded that the high levels of vibration are characteristics of the trains and not the tracks. The study identifies a combination of train suspension and braking systems as the likely cause of high levels of vibration from individual trains.

It was further noted that track improvements on the track which was in a better condition (Down line) have not resulted in significant improvements in vibration levels. As explained above, VSoA report includes a track inspection report by a qualified permanent way engineer which has not identified any of the observed conditions described in Gospel Oak study which manifest themselves in a poor track.

Although this aspect cannot be quantified, it is considered that an enhanced level of detail on track roughness will not have a significant effect on the findings of VSoA. Although the new track (formation, ballast and rail) will result in a better track quality, and will be maintained to a higher standard than the existing, the difference is not expected to be overly significant when compared with the existing track, which is known to be in a reasonable condition. This assumption therefore results in a robust assessment.

***Action* Speed of trains**: there was discussion around the speed that trains will achieve in practice near to Quadrangle House and Bladon Close. – *NR to provide a commentary reflecting on this.*

All new infrastructure from Oxford North Junction up to a point just west of Oxford Parkway Station is designed for a maximum line speed of 70mph.

Passenger trains on leaving Oxford Station will accelerate to a maximum of 70mph at Oxford North Junction before they begin to decelerate to stop at Oxford Parkway Station. It is likely that in practice trains will not exceed 60mph due to defensive driver techniques on the curve and the limited time they could run at 70mph. Trains travelling in the opposite direction will generally follow the same principles.

The maximum speed of freight trains is limited by their type. For instance stone trains are typically limited to either 50 or 60mph depending on the type of wagon in use.

It is considered that the train speeds assumed as part of the VSoA are a conservative representation of the attainable line speeds through Wolvercote. The factors applied in the VSoA are therefore realistic and result in a robust assessment.

Summary

It is considered that VSoA results in robust assessments with a reasonable margin of safety in the calculations. With specific reference to the issues raised in Arup review, our responses in summary are as follows;

- The general approach of VSoA is to develop a robust prediction scheme and to use this as the basis of predictions at properties across the study area, rather than undertaking vibration measurements at each property under consideration. Both the Independent Expert and Arup are in agreement that this is a reasonable and industry standard approach.
- The VSoA assumption on transfer functions is based on well-established and published industry guidance, and are shown to be reasonable. A worst-case interpretation of the guidance would have resulted in project limits being met at the properties considered.
- Freight inter-train variability depends on the design and general condition of the individual trains themselves, rather than the design of the track. Apart from the exceptional operation of the railway, or exceptional freight trains which are not in an appropriate order of maintenance, the resulting vibration levels are expected to comply with the requirements of Condition 19.
- Assumptions on track quality and train speeds with the scheme are realistic and result in a robust assessment.