Oxford City Council

East West Rail Phase 1 Vibration Scheme of Assessment

Review Expert Report

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Executive Summary

Oxford City Council (OCC) as a Local Planning Authority is in receipt of two applications for the discharge of Condition 19 of the East West Rail Link Phase 1, in respect of a Vibration Scheme of Assessment (VSoA). Condition 19 requires that, when submitted, Schemes of Assessment are accompanied by a report from an Independent Expert (IE) which comments on the robustness of vibration aspects of it.

The Council perceives a gap between, on the one hand the position reached by the IE and Council officers he has advised on the basis of all information he has seen and the application of his knowledge and expertise, and on the other hand, the public perception. The Council has therefore appointed Arup as Review Expert to review the information made available to the IE, the responses the IE has made to Council officers and the conclusions he has reached, as published in his final report.

The methodology for the VSoA has been reviewed. The Review Expert considers the approach taken by the VSoA to be reasonable. Many aspects of the method have employed cautious assumptions which serve to increase the estimate of the vibration dose value (VDV). For some of these aspects, it has not been possible to quantify how cautious the assumptions are. There are two parts of the method where the Review Expert does not believe that a sufficiently cautious approach has been taken. If the uncertainty associated with these two aspects was further accounted for in the predictions presented in the VSoA it would make a material difference to the conclusions. However, because no attempt to quantify the uncertainty associated with all aspects of the model is apparent in the VSoA, it is not possible to state whether the conclusions can be relied upon on the basis of the information provided in the VSoA alone.

If further conclusions are to be drawn from the VSoA, it is recommended that the uncertainty associated with train speed and track quality is quantified.

The correspondence between residents, OCC and the IE has been reviewed. The Review Expert is of the opinion that the advice provided by the IE is sound in the most part. However Arup's project experience of the amplification of vibration that occurs inside a building and the allowance that should be made to account for the variability is different.

Many of the residents' concerns relate to the fact that the predictions of VDV have been based on measurements of vibration at sites outside of Wolvercote and that differences in parameters such as ground conditions add uncertainty to the predictions. The East West Rail Environmental Statement (ES) presents direct measurements of the existing situation inside properties in Wolvercote. In his advice, the IE provides a strong justification why the VDV criteria are unlikely to be exceeded at the receptors in Wolvercote. This justification is based on analysis and corrections made to the directly measured data. On the assumption the vibration measurements made for the Environmental Impact Assessment (EIA) were sound, we also agree that this provides a strong indication that the VDV criteria will not be exceeded at the properties under consideration. There is, however, a discrepancy between the measured VDVs presented in the ES and the predictions made in the VSoA which should be explained. It is recommended that further details surrounding the measurements presented in the ES are sought.

1 Introduction

1.1 Context

Oxford City Council (OCC; 'The Council') as a Local Planning Authority (LPA) is in receipt of two applications for the discharge of Condition 19 of the East West Rail Link Phase 1, in respect of a Vibration Scheme of Assessment (VSoA). Condition 19 requires that, when submitted, Schemes of Assessment are accompanied by a report from an Independent Expert (IE) which comments on the robustness of vibration aspects of it.

The IE for vibration, appointed by the applicant and approved by the LPA, has provided such a report and has concluded that the methods used in the VSoA are robust and may be relied upon. In doing so the IE has taken account of representations from local residents about detailed technical aspects of the VSoA and the work carried out to produce it.

The Council perceives a gap between, on the one hand the position reached by the IE and Council officers he has advised on the basis of all information he has seen and the application of his knowledge and expertise, and on the other hand, the public perception. OOC is seeking to close this gap by means of external expertise paid for at its own expense.

The Council has therefore appointed Arup as specialist consultant (the Review Expert) with sufficient knowledge, skills and experience:

1. To review the information made available to the IE, the responses he has made to Council officers and the conclusions he has reached, as published in his final report.
2. To advise Council officers of whether the conclusions reached may be relied upon.

This Review Expert's report introduces the Review Expert team and experience, outlines the general approach of the review, summarises the findings of the review and makes conclusions and recommendations from its findings.

1.2 Review geographical scope

The East West Rail Phase 1 scheme passes through both the Oxford and Cherwell Districts. This review is only concerned with planning conditions that relate to Oxford City Council's district. The VSoA for plain line vibration included the assessment of vibration at a total of nine receptors. Of these receptors only three are located in the Oxford district: The Quadrangle and 3-4 Bladon Close. The review documented here is limited to these receptors.

1.3 Review Expert Team

Arup is an independent firm of designers, planners, engineers, consultants and technical specialists offering a broad range of professional services.

Arup Group has over 90 offices across Europe, North America, Africa, Australasia and South East Asia, employing over 11,000 people worldwide. In acoustics we have over 140 technical staff across 17 international offices. We are

the largest acoustics practice in the UK and we have offices in Glasgow, London, Manchester, Solihull and Winchester.

In acoustics, Arup engineers have been working in the field of railway noise and vibration control since the 1990s when we were employed during the planning and delivery stages of High Speed 1. Our acoustics team has since had major planning, design and delivery roles in most major infrastructure projects which have been undertaken in the UK since HS1, including Crossrail, Forth Replacement Crossing, East London Line, Thameslink, Thames Tideway and now HS2, as well as numerous projects abroad.

Dr Oliver Bewes BEng EngD MIOA

Oliver is a Senior Consultant in the Acoustics group with 11 years' experience working in the field of railway noise and vibration control. He has a Bachelor of Engineering Degree in Acoustical Engineering and an Engineering Doctorate in Transport Infrastructure Engineering titled *The Calculation of Noise from Railway Bridges and Viaducts*. Both degrees were obtained at the University of Southampton. He is also a Member of the Institute of Acoustics.

Since joining Arup in 2005, Oliver has worked in on many railway projects including noise control for Docklands Light Railway, low noise track design for Crossrail bored tunnels and predicting ground-borne noise and vibration for the proposed HS2 scheme. Of most relevance to East West Rail Phase 1, since 2012 he has managed an on-going project for Network Rail investigating ground-borne vibration from freight trains operating on the Gospel Oak to Barking Line.

Oliver has been responsible for undertaking the review documented here and the checks and validation work required throughout the review.

Dr David Hiller BSc MSc CEng MIMMM MIOA FGS

David is an internationally recognised specialist in ground-borne vibration with over 25 years' experience, including expert witness services relating to vibration from pile driving; alleged building damage due to traffic vibration; and he acted at a planning enquiry on behalf of four hospitals and a theatre, potentially affected by vibration from a new metro. David is a member of British Standards Institute panels for BS8233 *Sound insulation and noise reduction for buildings — Code of practice* and BS5228 *Code of practice for noise and vibration control on construction and open sites*.

Before joining Arup in 2000, David was with the Transport Research Laboratory in Berkshire, where he developed his specialism in ground-borne vibration. This included part time study for his PhD on *The prediction of ground-borne vibration caused by mechanised construction works.*

His current projects include working with Oliver on the Gospel Oak to Barking Line project and he has been appointed as technical lead on a project to predict and assess risks from vibration during construction and operation of a new railway in Singapore.

1.4 Approach

We have reviewed all documentation made available to the IE, in particular:

- East-West Rail: Phase 1, Chiltern Railways Company Limited, Plain Line Vibration Assessment and Mitigation, reference 5114534-ATK-VIB-RPT-80001, revisions P07, 16 January 2014, prepared for Network Rail by Atkins.
- East-West Rail: Phase 1, Chiltern Railways Company Limited, Vibration from Switches and Crossings – Assessment and Mitigation. 5114534-ATK-VIB-80003, Revisions A01 28 January 2014.

Our review has focussed on the aspects most likely to affect the robustness of the work including:

- Source vibration levels used in the predictions
- Variability in the source data
- Corrections for train speed
- Ground vibration decay terms – the method used to account for the reduction of vibration level in the ground with increasing distance from the railway.
- The vibration response of buildings
- Track quality

As part of this review we have undertaken checks of the calculations presented in the reports. We have also compared key aspects of the methodologies employed in these reports to methods employed by the industry and by Arup in our own validated prediction methods.

The assessment of the robustness of the individual aspects of the work has enabled us to form an overall opinion on the robustness of the methodology and hence the risk that the vibration criteria of 0.4 $m.s^{-1.75}$ VDV_{day} and 0.2 $m.s^{-1.75}$ VDV_{night} will be exceeded at nearby sensitive receptors.

At the two receptors considered we have focussed our assessment on the prediction of the night time VDV. This is because the night time VDV criterion is the more onerous.

In coming to a view of whether there is a risk that the requirements of planning condition 19 could fail to be met we have considered the following:

- Whether the predicted VDVs have been calculated in a reasonable manner
- Whether prediction/measurement uncertainty has been allowed for by the use of cautious assumptions and the uncertainty has been quantified and, if not, could the residual uncertainty make a material difference to the conclusions of the VSoA.

For each aspect we have assessed whether a cautious or incautious approach has been taken. In some cases it has been possible to quantify how cautious the approach is by referring to the data presented or data published elsewhere. In other cases it has not. Where further information would allow uncertainty to be better quantified we have highlighted this.

In addition to the above we have reviewed:

- The IE's report on the VSoAs
- Correspondence from residents received after the submission of the VSoAs and the IE report up to the 17th July 2014. These include the concerns from residents summarised in a report titled "Failures of the Atkins Report"
- Advice from the IE to OCC to assist in their responses to the residents.

Due to the number of responses received from the residents it has not been possible to comment on each issue raised by the residents and the IE's response individually. We have however commented on whether we believe that the IE's advice can be relied upon and whether it adequately addresses the concerns as summarised by the residents.

2 Reviewer's findings

2.1 VSoA methodology

The VSoA for plain line track presents two methods for predicting the VDV at nearby receptors. For the receptors considered here both approaches give the same results. For brevity our review has been limited to "Approach 1 – Decay curves in one-third octave bands".

General approach

The general approach of using measured vibration source terms and ground vibration decay terms to predict ground vibration outside properties at other sites is a reasonable. The approach is also the basis of the validated ground vibration prediction methods successfully employed by Arup and other practitioners on many railway schemes.

Source data

All VDV predictions for the night time period at The Quadrangle and Bladon Close have been based upon vibration levels from two train events from the sample of data collected, one representing freight and another representing passenger stock (It is assumed in the VSoA that the loaded stone train will not operate at night past these receptors). We have compared the source vibration levels of the selected trains with those from trains in the Arup database of measurements. Source vibration levels are highly dependent upon the condition of the train and the track at the measurement site so it is not possible to make definitive quantitative comparisons between different measurements without further information, however, in terms of level, the VSoA measurements lie approximately in the middle of the range of measurements in Arup's database.

Track quality

All predictions of VDV have been based on measurements of trains operating on the existing tracks. While the tracks have been visually inspected, the parameters most important for vibration generation have not been quantified, such as the rail roughness or the transfer function of vibration transmission from the rail to the wayside. Newly installed track is likely to be of a much better quality than the existing track, meaning that this aspect of the prediction is in effect cautious.

However without a better understanding of the current and future condition of the tracks it is not possible to quantify the potential impact of this on the overall robustness of the predictions.

Inter train variability seen in measured data

Figures 14 and 18 of the Plain Line Assessment Report show all measured data for freight and passenger trains, respectively. The data show a large variation in level between different trains. This is expected. The VSoA methodology has dealt with this variability by basing all VDV predictions on a train event that lies on the upper bound of all the measured data. The VSoA states that 95% of all passenger measurements and 90% of all freight measurements are on or below the regression curves used to predict the impacts of the scheme. For freight, an event that is 2.5dB (1.3×) higher than the mean was used and for passenger trains an event that was 3.5dB (1.5×) higher than the mean was used. However, because of the natural variation in vibration that occurs and the way that VDV is weighted towards the highest events, freight and passenger VDVs will not have been globally over predicted by 33% and 50% respectively. The typical over prediction for freight and passenger trains would be complex to estimate, but it is likely to be less than 33% and 50%.

Inter train variability – experience at other sites

The proposed scheme includes allowance for more freight trains during the day and during the night. It is possible that this means the types of train on the proposed scheme will be more variable than those in current use. Arup's experience of monitoring freight train vibration on a line with a similar amount of traffic as is proposed for East West Rail is that ground vibration close to the railway is more variable than demonstrated by the sample of freight train measurements presented in the VSoA.

The actual variation will depend upon the number and variety of trains using the route so it is not possible to quantify here. However, from our experience, the vibration level a the loaded stone train is near the upper bound of VDVs that Arup has measured close to a freight line. Assuming that this train operates once at night in the vicinity of The Quadrangle and Bladon Close would provide a reasonable estimate of this upper bound VDV.

Corrections and assumptions for train speed

The VSoAs employ a correction for speed (V) that follows a $20\log_{10}(V)$ relationship which is slightly modified to account for the change in duration of a vibration event as the speed changes. This is a reasonable approach which is in line with other validated method for groundborne noise prediction.

The methodology has assumed that all trains will operate at the permitted line speed of the railway. This is a likely to be a cautious assumption; however it is not possible to assess the impact of this on the overall robustness of the methodology without further information about the proposed speed profile of the scheme.

Ground vibration decay terms

The ground vibration decay terms (ie the rate at which vibration reduces away from the railway) calculated for the VSoA are not critically important to predictions of VDV at The Quadrangle and Bladon Close. This is because the

source data used was measured at a similar distance from the railway as the two receptors.

Vibration response in buildings

The methodology presented in the VSoA makes the assumption that vibration measured on the open ground outside a property will be similar to the level that would be measured inside a property. In our opinion this is an incautious assumption.

While the assumption may be appropriate for the transfer of vibration between the ground and the building foundation, in our experience, suspended floor resonances serve to amplify vibration in the frequency range important to perceptible vibration. The planning condition is not clear in defining the location within the building where the criteria apply. However it is standard to assess vibration at a point where the greatest vibration is expected[1]

Referring again to the methods developed for HS1, the transfer function between vibration measured outside and vibration inside the property was investigated using measurements made in properties close to the London Underground. Simultaneous measurements of train vibration were made in eight separate properties with wooden suspended floors. Measurements were made outside on the ground and inside on the ground and first floor at a point close to the room centre. The measurements were highly variable between properties; however VDV measured inside was always greater than outside. On average the VDV on the ground floor was two times the VDV measured outside and VDV on the first floor was four times the VDV measured outside. The measurements used to derive this relationship have not been published, however, the relationship has been used to predict VDV throughout the design and development of HS1 and subsequently in the HS2 environmental statement[2]

The relationship has since been further validated with vibration measurements from tunnelling activities[3] and freight train vibration inside and outside of properties[4].

It is important to note that the amplification factors for ground and first floor discussed above are not industry standard guidance. They are adopted by Arup based on its own experience of measurements made inside properties and available literature.

2.1.1 Summary

Table 1 below summarises the Review Expert's assessment of the robustness of the individual aspects of the VSoA methodology for predicting ground-borne vibration.

[1] BS 6472: Part1: 2008 Guide to evaluation of human exposure to vibration in buildings. Vibration sources other than blasting
[2] High Speed Two Environmental Statement – Vol 5 Appendix SV-001-000 Annex D1 Annex D1 - Operational assessment - ground-borne sound and vibration.
[3] Hiller D.M., Bowers K.H., Crabb G.I. The prediction of noise and vibration disturbance above tunnels. Proc Underground Construction 2001, pp 721-732, The Hemming Group Limited, London.
[4] Gospel Oak to Barking Vibration Investigations.

The table identifies whether each aspect of the model has used cautious or incautious assumptions. Where the uncertainty can be quantified an estimate of the potential under or over-prediction of that part of the method is given.

It can be seen that the estimated over prediction resulting from the cautious assumption that all freight trains will generate vibration 1.3 times the mean level would be offset if the stone train were to run at night. Thus, the most important potential source of uncertainty that remains concerns the assumption for the transfer of vibration from outside to inside.

From the information presented in the VSoA it is estimated by the Review Expert that the VDVs may have been underestimated by just over four times. However it has not been possible to quantify the uncertainty of the VSoAs cautious assumptions associated with track quality and train speed, hence they are not accounted for in this estimate. For these reasons it is not possible to state whether the conclusions of the VSoA can be relied upon on the basis of the information provided alone.

Given that the uncertainty estimated in Table 1 would make a material difference to the conclusions of the VSoA, if a decision to discharge the planning condition is to be based on the conclusions of the VSoA alone it is important that further information is sought to quantify this uncertainty, in particular:

- Estimates of the realistic operational speed of trains as they pass The Quadrangle and Bladon Close. If applicable, different train speeds may be assumed for the freight and stone trains.
- An estimate of the reduction in vibration that will be achieved through track improvement works.

Table 1: Estimate of residual uncertainty of the methodology used in the VSoA

Aspect	**Impact on predicted VDVs**	**Estimated over or under prediction* of VDV by VSoA**
Source data	Neutral	-
Track quality	Cautious	Cannot quantify
Inter train variability (Measured data)	Cautious	<1.3× for freight <1.5× for passenger stock
Inter train variability (Future situation)	Incautious	(1.4×) assuming stone train runs once at night
Speed correction	Neutral	-
Speed assumptions	Cautious	Cannot quantify
Ground vibration decay terms	Neutral	-
Vibration response of buildings	Incautious	(4×) on first floor of properties
Note: *under prediction shown in brackets		

2.2 Independent Expert's report and advice to OCC

The residents' concerns originally expressed in email and letter correspondence were eventually summarised in a report titled "Failures of the Atkins Report", written by C.P.Buckley and K.G.Dancey. The concerns related to the uncertainty associated with the following factors:

- Differences in ground conditions at the measurement and prediction sites
- Differences local topography between the measurement and prediction sites
- Vibration levels within buildings relative to vibration in the ground
- Allowing for variability in train vibration measurements
- Track and track bed
- Train speed

It is our opinion that the advice provided to OCC by the IE in response to the residents is sound and provides well sourced information which should allay most of the concerns of the residents identified above.

As identified in the previous section, Arup's project experience in two areas is different, meaning that we would offer alternative advice about the following:

- The amplification of vibration that occurs inside a building; and
- The allowance that should be made to account for the variability of train vibration of the proposed scheme.

In addition to advice provided to the OCC relating directly to the VSoA and the residents' concerns, the IE provides a strong justification for why the VDV criteria are unlikely to be exceeded at the receptors in Wolvercote when the Scheme opens. The justification is reproduced below:

"*The reasons for measurement of vibration at L1 and L2 were only partly to provide information for the predictions. It was necessary to add to the VDV measurements made for the environmental impact assessment because they provided no idea of decay with distance or of frequency content. However, distances are not changing significantly at the Wolvercote properties (it is more important at the Bicester end of the line).*

A simple and approximate check of the reasonableness of the VDVs expected at Wolvercote can be performed. At the Quadrangle the EIA-measured VDV over several complete days on the 2nd storey, inside the building. $VDV_{day\text{-}time}$ *was up to a maximum of about 0.04* $ms^{-1.75}$ *and* $VDV_{night\text{-}time}$ *also 0.04* $ms^{-1.75}$.

The train speed through Wolvercote is to be raised from 25 mph to 60 mph. This implies a factor of increase, based on 6 dB per doubling of speed, of 1.9.

The worst increase in numbers of trains is that of 1 freight train during the night-time period to 8 during the night time period. Factors of increase of passenger trains and freight train during the day are smaller. The factor of 8 intensification, if applied to all trains, would imply a factor of increase of 1.7 (or assuming that the night-time dose depended entirely on freight train vibration). For the daytime, the bigger possible factor of 1.7 would depend on assuming that the VDV were due entirely to the passenger trains.

Thus day-time or night-time VDVs can be estimated at no more than around 0.13 $ms^{-1.75}$. A reasonable margin still exists even in the night-time case before the VDV criterion is exceeded. This extremely simple 'checking' estimation is very close to the values estimated in the Chiltern Railways Noise and Vibration Policy document for the line improvement, document CD/1.29/2.1, 2011. This check does not rest at all on the measurements at L1 or L2, the Atkins prediction scheme, nor on any of the work done by Atkins."

On the assumption that the vibration measurements made for the EIA were sound, we also agree that this provides a strong indication that the VDV criteria will not be exceeded at The Quadrangle or Bladon Close once the scheme is operational. This is because the assessment is based upon direct measurements of vibration inside properties in Wolvercote. These therefore take account of the local parameters such as geological conditions and the building amplification specific to the buildings in question.

The IE notes that VSoA over estimates the existing VDVs measured inside the Quadrangle by a factor of two. If the amplification factor of four times to account for building amplification was applied to the VSoA predictions, the existing VDVs would be overestimated by a factor of eight. This is a large discrepancy which should be explained. It is recommended that further details surrounding the measurements presented in the EIA are sought.

3 Conclusions

The methodology of the VSoA has been reviewed. In coming to a view of whether there is a risk that the planning conditions could be exceeded we have considered the following:

- Whether the predictions of VDV have been calculated in a reasonable manner
- Whether prediction/measurement uncertainty has been allowed for by the use of cautious assumptions and the uncertainty been quantified, and, if not, could the residual uncertainty make a material difference to the conclusions of the VSoA

The approach taken by the VSoA is a generally reasonable. Many aspects of the method have employed cautious assumptions. It has not been possible to quantify how cautious the assumptions are for some aspects of the method particularly for track quality and train speed.

There are two aspects of the method where we do not believe that a cautious approach has been taken:

- The assumption that vibration outside a property will be similar to the vibration inside; and
- The assumption that the inter-train variability of the future freight operating on the line will be similar to the variability measured on the existing lines.

If the uncertainty associated with these aspects was further accounted for in the predictions presented in the VSoA it would make a material difference to our conclusions. However it is important to note that the uncertainty of two of the cautious assumptions made is yet to be quantified, hence it is not possible to state

whether the conclusions of the VSoA can be relied upon on the basis of the VSoA alone.

The correspondence between residents, OCC and the IE has been reviewed. We are of the opinion the advice provided by the IE is sound in the most part. However Arup's project experience in two areas is different, meaning that we would offer alternative advice concerning the amplification of vibration that occurs inside a building and the allowance that should be made to account for the variability of train vibration of the proposed scheme.

In his advice the IE provides a strong justification why the VDVs are unlikely to be exceed at the receptors in Wolvercote, based on the measurements made for the East West Rail EIA. On the assumption that the vibration measurements made for the EIA were sound; we also agree that this provides a strong indication that the VDV criteria will not be exceeded at the Quadrangle or Bladon Close once the scheme is operational. There is however a large discrepancy between the measurements presented in the EIA and the VSoA predictions which warrants explanation.

3.1 Recommendations

If a decision to discharge the planning condition is to be based on the conclusions of the VSoA alone it is important that further information is sought to quantify this uncertainty, in particular:

- Estimates of the realistic operational speed of trains as they pass The Quadrangle and Bladon Close. If applicable, different train speeds may be assumed for the freight and stone trains.
- An estimate of the reduction in vibration that will be achieved through track improvement works.
- A discrepancy between the measured VDVs presented in the EIA and the predictions made in the VSoA which should be explained. It is recommended that further details surrounding the measurements presented in the EIA are sought.