ARUP

Subject	East West Rail Phase 1 – Arup responses to Paul Buckley's correspondence dated 6th March 2015		
Date	21 April 2015	Job No/Ref	237838-00/H03-OB

1 Introduction

Oxford City Council (OCC) 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). The VSoA comprises a Plain Line Report, a S&C report and a covering letter, dated 16th May 2014[1,2]. Condition 19 requires that, when submitted, a VSoA must be accompanied by a report from an Independent Expert (IE) which comments on the robustness of the vibration aspects.

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 took 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 and on the other hand, the public perception. The Council 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.

On 29th of August 2014 Arup submitted a report (*R01-OB*) which detailed the findings of our review. The report concluded that there were some areas of the VSoA where a material change to the conclusions would occur if more cautious assumptions were adopted. Arup also highlighted that there were areas where cautious assumptions had been made. Overall, we advised that the applicant should be asked to provide additional evidence of the basis for several VSoA assumptions and therefore broadly how cautious the VSoA was, before Arup could advise whether the IE's conclusions could be relied upon.

On 12th September 2014, a meeting was held between OCC, Network Rail (NR - who are seeking discharge of Condition 19) and ERM (technical advisors to NR), Atkins (technical advisors to NR and authors of the VSoA) and Arup. In this meeting it was agreed that NR's technical advisors would respond to several of the recommendations made by Arup in report *R01-OB.*

In December 2014, Atkins issued a note which provided further information on the items raised at the September meeting. This technical note was made public in January 2015. On the 10th February

---

[1] 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.
[2] 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.

2015, comments were received from the public which identified inconsistencies in the technical note and identified that Switches and Crossings (S&C) had not been considered. Arup made Atkins aware of these matters and advised that the S&C should be included in the technical note. The technical note was subsequently revised and re-issued to Oxford City Council on 18th February 2015.

On the 11th March 2015 Arup issued our response (H01-OB) to the final submission of the Atkins' technical note (the Technical Note) to OCC. Arup's response summarised our recommendations to Council Officers (i.e. whether the conclusions reached by the IE, may be relied upon). Shortly afterward our responses were made public.

On the 27th March 2015 Paul Buckley (PB) submitted to OCC comments on our response to Atkins' Technical Note. The comments were his own but also expressed views shared by a number of track-side residents of the Oxford District portion of the EWR scheme. In his submission, PB sought further comment or clarifications from Arup.

On the 15th of April 2015 we issued a document (H03-OB) which provided the clarifications requested in PB's submission of 27th March.

The clarifications in H03-OB were limited to issues raised by PB which directly relate to our advice to OCC. Arup are aware that, since our appointment in August, residents have raised concerns on a number of additional matters relating to the VSoA.

A comprehensive summary of the remaining concerns was provided in email correspondence from PB to OCC on the 6th of March 2015. In this correspondence five 'major worries' relating to the VSoA were listed. It is understood that these are worries shared by many residents.

The purpose of this document is to provide OCC with advice on the matters raised so that they may respond to the residents. In the following section each of the points raised by PB are reproduced. Our clarifications are provided below each respective point. In some cases we are aware of advice the IE has given OCC to respond to similar questions raised by the residents[3]. Where we believe that this advice is relevant to the point raised we have made reference to this advice and have reproduced the advice in Section 3 of this document.

We are aware of separate and similar correspondence to OCC by Keith Dancey (KD). We have reviewed this correspondence and consider that responses to the 'worries' raised by PB on the 6th March will also provide relevant advice to cover all points raised by KD.

2 Responses

2.1 Point 1

1. *Many of us remain very doubtful about the relevance and integrity of the Atkins data being used by them, and indeed by myself, in all the predictions of vibration.*

    (a) *The geology where the measurements were made is definitely different from that of Upper Wolvercote: yet no convincing case has yet been made for why, nevertheless, they can be relied upon to predict vibration levels in Upper Wolvercote. The only*

[3] Notes on technical issues for the vibration assessment for the Chiltern Line Upgrade through Wolvercote – Notes written by the IE and issued to OCC on the 23rd of July 2014

attempt at a justification (at the June 2014 Technical Meeting) was vague and of the hand-waving variety. This is not acceptable to the concerned and discerning residents of Wolvercote.

(b) The topography is also very different. In particular, some houses close to the track are also near the steep cutting, and in some cases near the tunnel entrance: locations all very different in topography from the flat ground on Port Meadow where the measurements were made. There is great anxiety among some residents that these complexities could produce very high levels of vibration, unpredictable with the one-dimensional approach used in the VSoA. Could the new, higher, levels of vibration at locations such as this, even cause ground movement by triggering instability in the cutting? Residents would very much welcome an independent assessment of the situation in Wolvercote from Arup.

Regarding point (a), we interpret this as a concern that differences in the geological conditions at the VSoA measurement site (Port Meadow) and at the locations of sensitive receivers in Wolvercote are sufficient that they make the predictions presented in the VSoA unreliable.

The IE responded to this concern in his advice to OCC in July 2014. His advice is still relevant to this point and is reproduced in Section 3.1. In his advice the IE presented a comparative analysis of the ground response of the VSoA measurement site and Wolvercote. He made use of available borehole data. The comparative analysis showed that the ground response at both locations is similar and use of the Port Meadow data is likely to provide a cautious estimate of ground vibration over most of the frequency range of interest. On that basis, the analysis presented by the IE provides confidence that it was reasonable of Atkins to use data measured at Port Meadow to predict the vibration impact of the Scheme through Wolvercote.

Arup's experience of predicting the vibration impact of railway schemes has included the development of empirical ground-vibration prediction procedures[4] using measurements made on soils in the UK, France and Germany. In our experience, while typically there are large differences between the train vibration data observed on different generic classes of geology (i.e. chalk, sands or clay), there is a much smaller degree of variation within each generic classification. Given that the ground response at both borehole locations (based on the IE's sensitivity analysis) appears to be characterised by the clay layers, Arup think it is reasonable that Atkins' have used source data obtained in Port Meadow to predict the vibration throughout Wolvercote.

Regarding point (b), we interpret this as a concern that vibration source data measured next to a railway operating at grade (where the track follows the local ground surface) cannot be used to reliably predict vibration from parts of the Scheme operating on embankment, cutting or in tunnel.

The IE responded to this concern in his advice to OCC in July 2014. His advice is relevant and is reproduced in Section 3.2.

We concur with his statements and we also know from our experience of vibration prediction that ground vibration levels measured close to cuttings, embankments and cut and cover tunnels can reliably be predicted with train vibration source data measured from trains operating at grade with no special consideration of the topography close to the track. We do not therefore share the concerns raised by PB on this point.

[4] Developed for HS1 and since implemented on other rail systems in the UK and worldwide

2.2 Point 2

2. *Anecdotal evidence encourages doubt about the VSoA data. There is a long history of evidence that attenuation of vibrations from the railway line in Upper Wolvercote is much less than PREDICTED with the data used in the VSoA. Even worse is the history of structural damage, apparently caused by vibrations from the railway, and yet the levels of vibration PREDICTED are said to be too low to cause structural damage. All of this arouses suspicion that the ground in Upper Wolvercote is unusually susceptible to vibrations, which therefore will not be realistically modelled using data obtained on Port Meadow. This problem has been articulated in connection with the EWR proposals at many public meetings and in writing. Keith Dancey has assembled a substantial data base of evidence. Yet this concern has never been seriously addressed by any of the railway companies. It would be very helpful to residents if Arup would offer their opinion on what causes the unusual behaviour of the ground in Wolvercote, and its likely impact on the accuracy of the predictions made by Atkins for EWR, which currently ignore it.*

We have interpreted this as a concern that existing structural damage in properties close to the scheme, reported by PB and KD, is a result of train vibration and that this has led to a perception that the ground through Wolvercote is unusually susceptible to vibration.

The IE has provided relevant advice to OCC on this point. The advice is reproduced in Section 3.3.

We understand the concern of residents and that the presence of damage in a property may be a source of anxiety. However the presence of perceptible levels of vibration is not evidence that any building damage has been caused by train vibration. We have not been shown the database of evidence compiled by KD so we are unable to comment on it. Our advice on building damage criteria and sources of building damage other than vibration is given below.

<u>Building damage criteria</u>

Like the IE, we refer to British Standard BS 7385: Part 2: 1993 (*Evaluation and measurement for vibration in buildings. Guide to damage levels from groundborne vibration*). Guide values for transient vibration in terms of peak particle velocity (PPV), above which cosmetic damage could occur, are given in BS7385: Part 2 and are reproduced in Figure 1.

The standard says that these "*vibration levels … are judged to give a minimal risk of vibration-induced damage*".

In addition, BS 7385: Part 2 also states that "*the probability of damage tends towards zero at 12.5 mms^{-1} peak component particle velocity*."

These criteria are for damage described as "cosmetic". Cosmetic damage is defined in BS ISO 4866: 2010 (*Mechanical vibration and shock - vibration of buildings - guidelines for the measurement of vibrations and evaluation of their effects on buildings*) as "*The formation of hairline cracks on drywall surfaces, or the growth of existing cracks in plaster or drywall surfaces; in addition, the formation of hairline cracks in mortar joints of brick/concrete block construction*." BS ISO 4866 also describes minor and major damage as follows.

Minor damage is "*The formation of large cracks or loosening and falling of plaster or drywall surfaces, or cracks through bricks/concrete blocks*.

Major damage is "*Damage to structural elements of the building, cracks in support columns, loosening of joints, splaying of masonry cracks, etc*."

BS 7385: Part 2 states that minor damage is possible at vibration magnitudes which are greater than twice those for cosmetic damage and major damage may occur at greater than four times the values for cosmetic damage.

The guide values described above relate to transient vibration. For continuous vibration, of a nature such that it might give rise to dynamic magnification due to resonance of building elements, the standard states that guide values may need to be reduced by 50 per cent. The standard also notes that there are insufficient case histories of continuous vibration causing damage to substantiate this reduction but it is based on common practice.

The term 'continuous vibration' is not well defined in the standard; however, making the cautious assumption that freight does cause continuous vibration of the building, the most cautious trigger value for the onset of damage is 6.25 mms^{-1}. At 6.25 mms^{-1} PPV the probability of damage resulting from continuous vibration is zero. We have seen no evidence that buildings in Wolvercote have been exposed to vibration levels of this magnitude as a result of the current scheme.

The guide values apply to residential properties of all types; there is no differentiation in the standard for different construction types for residential buildings. BS 7385: Part 2 also notes that vibration criteria for buildings of historical value only need to be lower if a building is structurally unsound.

The British Standards Institution also gives information on vibration in BS 5228: Part 2: 2009 + A1:2014 (*Code of practice for noise and vibration control on construction and open sites – Part 2: vibration*) and is consistent with BS 7385. In addition to vibration damage criteria, BS5228: Part 2 also provides guidance on human response to vibration in terms of PPV. The guidance is useful because it illustrates that humans will perceive vibration which is significantly below the levels that are likely to cause damage to a building. This guidance is reproduced in Table 1.

Main causes of cracking in buildings

The Association of Noise Consultants *Guidelines for the measurement and assessment of ground-borne noise and vibration* provides advice on the potential sources of cracking in buildings:

"The second important fact to appreciate is that cracking commonly occurs in buildings whether they are exposed to vibration or not, e.g. ceilings, wall junctions, doorframes, lintels and sills etc. Cracks are not, in themselves, an indication of vibration-induced damage. There are many reasons why buildings crack and the true cause should be ascertained. For example internal or external disturbances such as the effects of temperature, moisture, differential settlement, trees, occupational loads, overloading, pre-stressing forces, material creep and chemical changes can all cause cracks. The natural cracking rate can be significantly increased by an external disturbance such as ground excavation or excessive vibration[5].

Cracks can be triggered instantaneously, necessitating ongoing monitoring surveys to determine the rate of further movement.

Alteration or refurbishment of buildings can also be a common cause of cracking.

[5] We consider that vibration would be excessive if it exceeded the limits set out in BS 7385.

A small increase in cracks, or crack dimensions, should not, however, be taken as evidence of damage due to vibration.

Extensions, alterations or settlement resulting in changes in the static load distribution can result in an increased rate of cracking. The stability of the building structure will naturally affect the sensitivity to external or internal disturbance (see above). If a building is in a very unstable state, then it will tend to be more vulnerable to the possibility of damage from vibration or other disturbance.

Buildings also expand and contract preferentially along existing weaknesses (cracks) both diurnally and seasonally. For a building with significant defects, this continually varying expansion and contraction may return repaired and re-decorated buildings to previous defective states within several years or even months."

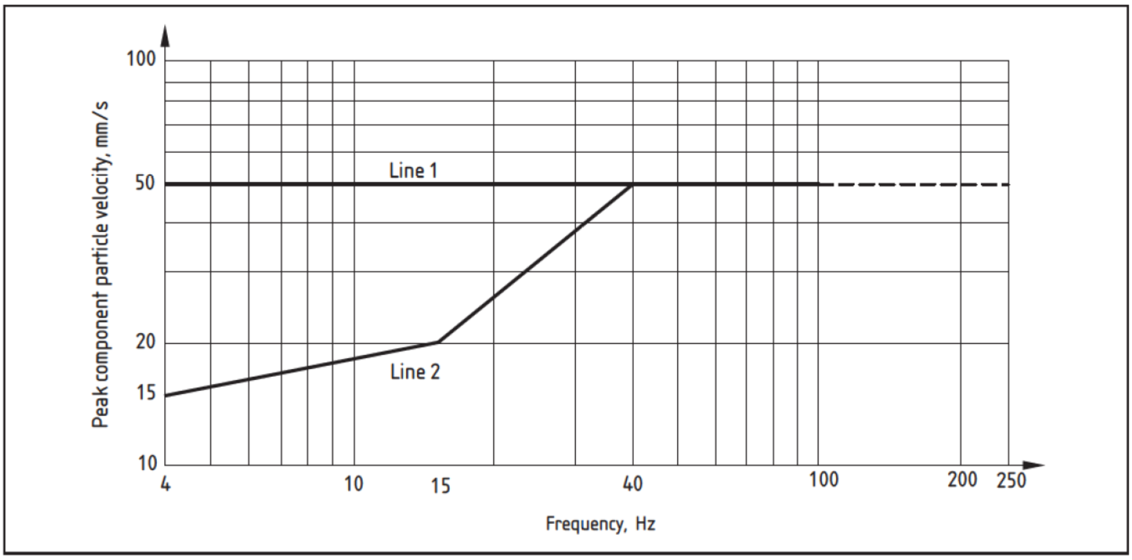

Figure 1: Vibration guide values from BS 7385-2: 1993 for cosmetic damage

Table 1: Guidelines on the human response to peak particle velocity inside buildings.

PPV (mms^{-1})	Effect
0.14	Vibration might be just perceptible in the most sensitive situations for most vibration frequencies associated with construction. At lower frequencies, people are less sensitive to vibration.
0.3	Vibration might be just perceptible in residential environments.
1.0	It is likely that vibration of this level in residential environments will cause complaint, but can be tolerated if prior warning and explanation has been given to residents.
10	Vibration is likely to be intolerable for any more than a very brief exposure to this level.

2.3 Point 3

3. *There is lingering doubt about the integrity of the data presented in the VSoA (both parts). Some information given there is obviously wrong. This casts doubt on the integrity of the rest of the two documents. It is possible that the errors are simple cases of lack of proof-reading of the manuscript. Or they could reflect deeper misunderstandings on the part of the authors, and could even have corrupted the conclusions reached in the VSoA. These concerns have never been addressed publicly. It would be very helpful indeed, and much more professional, if Atkins could acknowledge the errors that are there, and indicate what in-house quality control measures they have applied to give confidence that there are no other hidden bugs. This need is made all the more urgent by continuing errors appearing in the various versions of the recent Technical Note. It would be very helpful to residents to learn from Arup of other errors they have spotted, of which we may not yet be aware.*

As stated in *R01-OB*, as part of this review we have undertaken checks of the calculations presented in the VSoA. We have also compared key aspects of the methodologies employed in the VSoAs to methods employed by the industry and by Arup in our own validated prediction methods. Arup can provide assurance that we have not identified any errors in Atkins' work in addition to those identified by PB which were subsequently responded to by Atkins in the Technical Note issued on the 18th February 2015.

2.4 Point 4

4. *For a project on the scale of EWR, affecting hundred* [SIC] *of homes and thousands of residents, it is very poor practice indeed for there to be no attempt at a serious validation of the methods and data used in prediction of vibration. This would have been effective in providing confidence among residents that Atkins' methods are sound. The recent Technical Note is honest in making clear that the earlier vibration measurements made by ERM inside some Wolvercote buildings do not constitute such a validation. Therefore residents find themselves left having to trust Atkins and NR that their methods are sound, in spite of all the evidence to the contrary, for example as illustrated above. In my opinion this is not satisfactory. Arup in their report already raised doubts about the integrity of the ERM data as a source of validation. It would be extremely helpful to residents to have from Arup an up-dated assessment of how confident we can be of the Atkins prediction methodology overall, now we have clarity that there has been no validation exercise at all.*

The prediction method presented in the VSoA was designed specifically to predict vibration from trains operating on the proposed Scheme in that:

- source data was taken in the locality of Wolvercote;
- trains currently operating on the current scheme were used as source data; and
- source data were measured at speeds as close as practicable to the line speed of the Proposed Scheme.

These steps were taken to limit the prediction uncertainty associated with extrapolating these measurements to other locations in Wolvercote. In addition, following consideration of how the assessments have dealt with uncertainty throughout the prediction chain, Arup consider the assessments presented in the VSoA, as clarified in the Technical Note of 18th February 2015, to be sufficient. Because of this we consider it reasonable for Atkins to apply the VSoA prediction method to properties in Wolvercote without further validation against an independent dataset.

3 Previous relevant advice by the IE

3.1 Rough check of comparative vibration response at various locations – from [3]

"*The proper way to assess propensity of a ground location or area to ground vibration is from measurements of vibration. The approach echoed by the words of the enquiry are 'at a representative similar site'. In practice measurement sites are often not particularly close to any specific building of interest. A great deal of judgement and compromise has to be made in choosing an available sufficiently representative site. Land ownership and the politics of an enquiry or other considerations often limit the choice; engineers are not free to ignore these constraints, even in the pursuit of good science. In this case emphasis was put on obtaining data from trains at relevant speed. I approve of this because the biggest factor in the change from the current to the future VDVs is the change of train speed.*

The question has therefore been raised in submissions to Oxford City Council of the suitability of the sites 'L1' and 'L2' at Wolvercote junction in predicting vibration at Wolvercote.

In February 2013 Atkins had carried out their first set of measurements for their prediction scheme. These were made on the mainline at a location where the relevant rolling stock travelled at roughly the speeds of upgraded line between Bicester and Wolvercote. I inspected borehole data and carried out some simple calculations of vibration response using my judgement of the likely parameters of the soil. This exercise was only intended, and can only be used, as a check of the reasonable suitability of the site.

It is not direct measurement evidence, and factors that also affect vibration such as the track structure, and vehicle dynamics do not feature. Please do not take these calculations to be any more than they are intended to be, 'a sanity check' or a demonstration of likely, rather than known, effects.

When first commenting on the 'schemes of assessment of vibration' in February 2013 (as they stood then, not how they are now), I looked at borehole information and was concerned that the location where initial measurements had been made had a (albeit thin) layer of limestone only a few metres below the surface. I used some simple calculations of vibration response which I used to demonstrate to the LPAs that Atkins first measurement location was not suitable. That data was not used. Atkins then chose the site L1/L2 at Wolvercote junction for measurements which had to represent the whole area from Wolvercote to Bicester.

The simple calculation predicts vertical and lateral response (radially) from a unit vertical dynamic force applied over a small circular area of the ground surface. The calculation method has been used by many people internationally as part of the way of determining shear wave speeds and other dynamic properties of the ground.

Fortunately for guidance on material parameters in Oxford clay, measurements of the dynamic properties of the relevant materials, have been carried out at Steventon, close to the Great Western Main Line, another Oxford clay site south of Reading and in London on similar clay. These *measurements are consistent in that showing layers close to the surface having shear wave speeds of the soft, near-surface material of 120 m/s and 400 m/s eventually at some depth. The layer depths are not the same at these sites as at Wolvercote; the boreholes provide light on that. For the parameters of gravel (200 m/s), compacted gravel (245 m/s), and alluvial deposits (80 m/s) I have used other shear wave measurements at sites within my experience in the UK.*

Figure 2 presents the velocity response ('mobility' is response velocity divided by the exciting force) at 10 m for various idealisations of the ground layers at different locations."

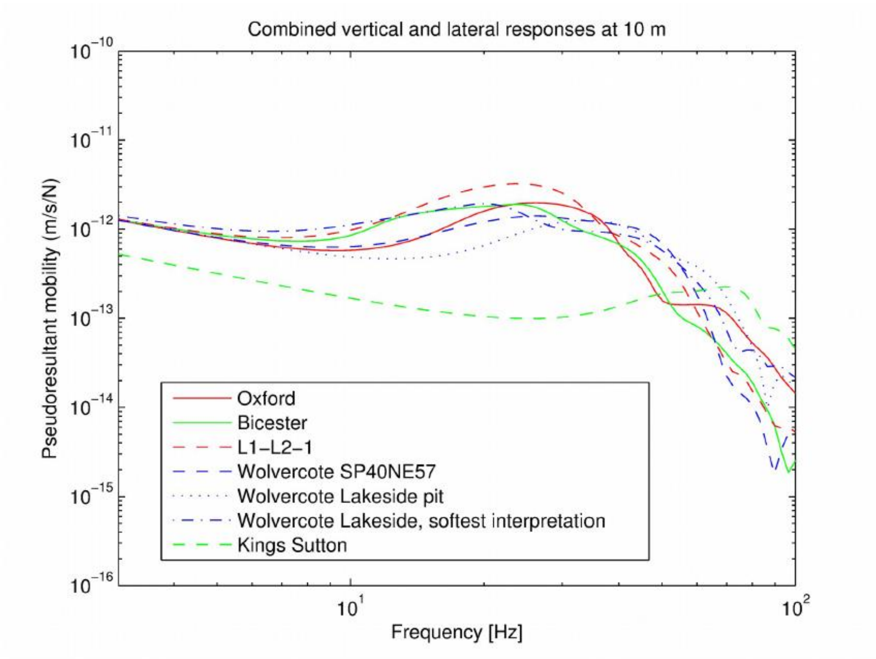

Figure 2. Simple calculation of relative vibration responses to a constant amplitude (unit) load at 10 m.

"*The Oxford, Bicester and Kings Sutton responses are those presented in my notes made for the LPAs in February 2013. The significantly lower response at King Sutton means that a prediction scheme based on these measurements would likely predict levels of vibration below what could be expected alongside the Bicester - Oxford line. In comparison to this the curves representing locations closer to the Oxford - Bicester line are much closer together. They all come together at very low frequency because, at low frequency, the vibration transmission depends on the deeper situated material and I have seen that throughout the whole area the ground becomes the same stiff Oxford clay at some depth. No other, much deeper, rocky material is expected to have influence in the frequency range we are interested in.*

For Wolvercote, within that line, specifically I have made three calculations. One based on my best interpretation of the SP40NE57 bore hole and two, more uncertain in interpretation, based on the lakeside pit information (SP41SE157); a 'best' interpretation and one that errs on the side of assuming soft materials.

For the L1/L2 site the borehole information is clear but I have erred on the side of caution by assuming a compacted gravel shear wave speed for the gravel layers that are labelled as river terrace deposits. A higher response is indicated at the L1/L2 site over most of the frequency range. Only the more pessimistic interpretation of the Lakeside data exceeds this slightly."

3.2 Cuttings and Embankments – from [3]

"*The effect of cuttings has already been discussed. There is little effect on the propagation of vibration of a normal cutting as the surface waves follow the surface of the ground even though it is not flat. Time has allowed the materials at the bottom of a cutting to weather to similar conditions as other areas of ground surface, particularly where the ground is a deep drift of clay without any bedrock layers close to the surface.*

There is an effect in cutting where sometimes poor drainage conditions have led to a more damaged foundation than at better drained locations. Thus, the track may deteriorate faster between maintenance cycles and respond less well to maintenance.

Embankments on the Victorian-built network were made merely by heaping surface material (usually from the nearest cutting) in order to continue the elevation of the track. No geotechnical engineering was used (soil reinforcement, treatment, or compaction, geotextile/geoweb layers, or even good drainage). Some cinder (from steam days) and old ballast often forms a thin top layer. Thus, an embankment of 2 or 3 metres height has small effect in altering the propagation conditions compared to what would have been beneath the track if it were 'at grade'.

Modern embankments are very different. They have all the benefits of geotechnical design to made a stable foundation which leads to lower maintenance requirements. They are very stiff in comparison to old embankments (high shear wave speed) and so tend to lead to lower non-propagating near-track vibration as well as lower roughness for the generation of propagating vibration. This is why I approve of NR installing new embankment at the two vibration-sensitive crossing sites on the line."

3.3 Building damage criteria – from [3]

"*Assessment of vibration in buildings for the likelihood that they may cause building damage is covered by BS 7385, which itself is now aligned with an international standard (ISO 4866). BS 7385 provides PPV threshold below which there is said to be no evidence even of cosmetic damage to buildings. In this context, 'cosmetic damage' is described as hair-line cracks in plaster and the like.*

Cracks in buildings however, do exist. In clay areas only brand new buildings do not display the evidence of clay shrinkage that occurred particularly due to the relative drought in southern England in the last couple of decades of the 20th century. Therefore cracks are not deemed to be evidence of vibration damage. Only measured levels of vibration that are known to cause cracks can be (or is) regarded as evidence. An appendix in BS 7385 makes this very clear.

The standards state the threshold as a function of the dominant frequency in the vibration to which a building is subject. Vibration at 1 Hz has to exceed 5 mm/s peak particle velocity; at 4 Hz it is 15 mm/s and above 40 Hz it is deemed that a PPV exceeding 50 mm/s is required to trigger the risk (not certainty, the standard emphasises) of cosmetic damage. In the EIS it is implied that 15 mm/s PPV would be the limit criterion for the project.

PPVs cannot be converted to a corresponding rms amplitude. However, bearing in mind that complaints of vibration arise when the level just exceeds the threshold of perception at 0.1 mm/s rms, and that a doubling of vibration amplitude is regarded as a step up in discomfort level, it becomes clear that vibration of sufficient magnitude to cause building damage could not be lived with for comfort. I have come across building damage due to railway vibration only once in more *than 25 years' experience. This was due more to the building method, with breeze block walls which were not tied in at the corners of the building, than the actual level of vibration. It was not in or near Oxford.*"

This page is intentionally left blank