Failures of the Atkins Report

by

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A report prepared for submission to Oxford City Council at the request of some residents of Upper Wolvercote and Lakeside, Oxford, following a public 'Technical Meeting' with representatives of the railway companies held at the Oxford Hotel, Wolvercote, on 10 June, 2014

Summary

The Atkins report claims to show that East West Rail will comply with planning permission Condition 19 in relation to plain line vibration. However, it contains many weaknesses. It employs data whose relevance, integrity and objectivity are left open to question. The methods used, including the failure to use safety factors to compensate for uncertainties, are such as to make its predicted vibration levels too low to provide a valid assessment of compliance with Condition 19. There are many major sources of potential error in the predictions. Some of them cannot be quantified without additional information. However, even those that can be estimated are sufficient to show that actual vibration levels are highly likely to breach the limits specified in Condition 19, and could easily exceed the limits by a large margin.

1. Background

1.2 The Technical Meeting

East West Rail Phase 1 is deemed to have been granted planning permission, subject to meeting a set of conditions. Among these is Condition 19, concerning noise and vibration that will be caused in line-side buildings by full implementation of the East West Rail (EWR) scheme. The Scheme of Assessment for plain line vibration [1] (the 'Atkins Report' abbreviated here as 'Atkins'), claims to show EWR will comply with Condition 19, but has been challenged by many line-side residents. To attempt to resolve the problems, a public 'Technical Meeting' (TM) was convened at the Oxford Hotel on 10 June, 2014. An agreed record of the meeting was prepared by some of the residents present – see [2]. The meeting clarified for residents some of the thinking behind Atkins, but failed to resolve most of the perceived inadequacies of it, and even exposed further problems.

1.3 Purpose of this Report

This report is a summary of the major failures of Atkins identified by residents, taking into account further information and clarification arising from the Technical Meeting. The failures of Atkins can be summarised as: failure to use appropriate data in its predictions of future levels of vibration; failure to compensate appropriately for uncertainties in its predictions; failure to validate properly the prediction method; resultant failure to demonstrate compliance with Condition 19.

2. Method used in Atkins to claim compliance with Condition 19

2.1 What exactly is Condition 19 (vibration)?

The condition specifies that vibration doses during the day (0700-2300 hours) and night (2300-0700 hours) expressed in Vibration Dose Value units must satisfy

$$VDV_{\text{day}} \le 0.4 \text{ m s}^{-1.75}; \quad VDV_{\text{night}} \le 0.2 \text{ m s}^{-1.75} \tag{1}$$

'in all occupied vibration-sensitive receptor buildings adjacent to the Scheme'. The VDVs appearing in equations (1) are defined over time periods of part of one day, while details of the trains will vary from day to day. Therefore, the actual VDVs will vary from day to day. Planning permission conditions must be met *at all times*. Hence the only reasonable interpretation of Condition 19 in relation to vibration is that the conditions in equations (1) must be met *every day* for the foreseeable future. The only valid test of compliance, therefore, is whether the *worst case* day and night VDVs to be experienced in the future will satisfy equations (1). At the TM, the representative of Atkins Ltd (Dr Ekici) agreed that this was Atkins' interpretation too – see [2] question Q1.1.

2.2 Method used to predict VDVs

The method of calculation of vibration in terms of VDV is specified in the relevant British Standard BS 6472 [3]. Vibration acceleration signal $a(t)$ is frequency-weighted over a range of frequencies 0.5 Hz – 80 Hz, using weighting given in BS 6472, to form the frequency-weighted acceleration $< a >$. The VDV over a time period from t_1 to t_2 is then calculated from

$$VDV = \left(\int_{t_1}^{t_2} < a >^4 \mathrm{d}t \right)^{1/4} . \tag{2}$$

Atkins' approach to checking compliance with Condition 19 is to predict future VDVs using the following method[1] and then to compare the resulting values with the limits in equations (1). Trains are divided into three types: (p) passenger, (f) normal freight, (s) stone train freight. For each type, a single set of measurements for a single pass-by event (from the data set collected) was chosen as the 'baseline' data set and, from the recorded vibration acceleration, corresponding single-event baseline VDVs VDV_p, VDV_f, VDV_s are computed. These are then assumed also to apply to the locations of all the receptor buildings, for equal train speed and track-to-measurement distance, if the same train were to run in future on the Oxford-Bicester line (known in [1] as the 'OXD' line). To predict VDV_day or VDV_night for a particular receptor building, the contributions from each of p, f and s are obtained by multiplying the baseline VDV by a factor D to account for the distance x from the nearest running rail differing from that of the baseline x_b, a factor S to account for the train speed v differing from that of the baseline v_b, and a further factor N to account for the number n of trains in the corresponding time period. Thus, consistent with equation (2), the VDV is computed

$$VDV = \left[\left(N_\mathrm{p} S_\mathrm{p} D_\mathrm{p} VDV_\mathrm{p} \right)^4 + \left(N_\mathrm{f} S_\mathrm{f} D_\mathrm{f} VDV_\mathrm{f} \right)^4 + \left(N_\mathrm{s} S_\mathrm{s} D_\mathrm{s} VDV_\mathrm{s} \right)^4 \right]^{1/4} . \tag{3}$$

Factors D, S, N are computed as follows.

$$D = \exp\left[-k \left(x - x_\mathrm{b} \right) \right] \tag{4}$$

$$S = \left(v / v_\mathrm{b} \right)^{R/20 - 1/4} \tag{5}$$

$$N = n^{1/4} \tag{6}$$

[1] Here we follow the Atkins 'Approach 2' for the sake of simplicity of the argument. The same conclusions also apply to Atkins 'Approach 1'.

where k is a factor characterising the decay of VDV with distance from the track, and R is an empirical factor characterising the variation of RMS values of $< a >$ with speed v:

$$< a > = < a >_{\mathrm{b}} \left(v / v_{\mathrm{b}} \right)^{R/20} . \tag{7}$$

In terms used by Atkins, R is the gradient of a graph of RMS $< a >$ expressed in dB, versus $\log_{10}$(speed).

This method of calculation would be sound, as a method for predicting VDVs *in the ground* adjacent to the receptor buildings, *but only if appropriate values are used for all the parameters required in evaluating equation (3)*. However Atkins goes further and *assumes* the same VDVs as those obtained from equation (3) also apply *inside* the receptor buildings.

3. Failure to use appropriate data

Unfortunately, the parameters used by Atkins in evaluating equation (3) were *not* all appropriate. They were obtained primarily from one of two sources:

(1) Measurements obtained during the Vibration Monitoring Survey, carried out by Atkins over four days in 2013.
(2) Predictions by Chiltern Railways of train numbers, and maximum train speeds, that are expected after full implementation of EWR.

Since the problem of predicting VDVs is one of predicting the future, there will inevitably be some uncertainty in parameters used in the calculations. But in Atkins the uncertainties are greater than necessary because some parameters used, of a type expected to be location-sensitive, are derived from measurements made at places distant from those to which Condition 19 applies: i.e. inside nine specific buildings on the OXD line. Thus the data used were not appropriate to the problem. Moreover there is uncertainty concerning the reliability and objectivity of data used in the calculations, as shown below.

The Vibration Monitoring Survey consisted of vibration acceleration measurements obtained at two locations: Location 1 (on the Oxford-Birmingham (DCL) main line and an adjacent loop), and Location 2 (on the OXD line, but only ca 220 m from Location 1), during 74 pass-by events (55 passenger, 17 normal freight, 2 stone train freight). Of these, only 7 were recorded on the OXD line. Neither location is close to the critical receptor buildings, and no measurements were made inside any buildings as part of this study. A critical consequence of this policy is that data were not obtained at “geologically and topographically comparable sites” as required by the report of the Inspector Mr J.P.Watson following the Public Enquiry. It leads to avoidable sources of uncertainty in the data, as follows.

3.1 Uncertainty concerning effects of ground conditions

Atkins claims the ground conditions at Locations 1 and 2 are representative of those at the receptor buildings, although this claim is not supported by any geological evidence in the report. Contrary evidence from an authoritative source (British Geological Survey – see [4]) shows that on the flood plain near Locations 1 and 2 there is 3.5 – 5.1m of alluvial deposit above Oxford clay, whereas the geology changes with Oxford clay rising to the surface through Upper Wolvercote and Lakeside (for details see Appendix 1 below). At the TM Dr Ekici claimed private borehole data available to him showed the difference was not as great, with alluvial deposit at Locations 1 and 2 only 2m deep above clay. This information is puzzling, because it conflicts with all the data quoted by BGS from British Rail boreholes actually on this part of the DCL line, which make no reference to clay (see Appendix 1 below).

Whatever is the precise case at Locations 1 and 2, it is clear from BGS information that the geology changes significantly from Locations 1 and 2 to the locations of the receptors, and the latter geology in the upper few metres is more dominated by Oxford clay. Since it is known that vibrations tend to decay particularly slowly in clay[2], as compared to alluvium, this suggests baseline values used VDV_p, VDV_f, VDV_s are likely to be *lower* than would apply if the same trains passed at the same speeds on the same track/track bed at the locations of the receptors. Comparing the decay parameters *k* found in Atkins with an appropriately worst-case value for clay $k = 0.04\ m^{-1}$ (see Gutowski and Dym [6]), values of possible error factors (worst-case VDV / predicted VDV) in the baseline VDVs can be estimated: 1.74 and 1.35 for train types f and p respectively.

Ground conditions also affect the propagation of vibrations beyond the baseline position to the receptors, through the decay parameter *k*. Most receptors are more distant from the track than the positions where baseline measurements were made. This suggests values of *D* used by Atkins were too *low*, again causing predicted VDVs to be too low. From equation (4) the degree of error will vary with the distance from baseline to receptor: for example, for the receptor at 3 Bladon Close an error factor in *D* (and hence in resulting VDVs) of 1.36 and 1.18 for train types f and p can be estimated using *k* values referred to above.

3.2 Uncertainty concerning effects of local topography

A prominent feature of the OXD line's environment is the changing topography as it climbs from the river flood plain, up through a *cutting* in Wolvercote, through a *tunnel*, and onto a prominent *embankment* along Lakeside before becoming level with ground e.g. at Water Eaton. Such changes will certainly affect propagation of vibrations, and hence should be allowed for in differing baseline VDVs for receptors with differing topography. This is an especially important consideration for the cutting, because it has been shown that a train on a railway line in a cutting can produce a higher amplitude of ground-borne vibration than the same train on the same track but on level ground or an embankment [7]. The problem is undoubtedly linked to the higher concentration of the lowest frequency components [7], which tend to decay more slowly with distance than higher frequencies – e.g. see [1] Table 6. But

[2] In the words of the USA Federal Transit Administration [5] "Experience with ground-borne vibration is that vibration propagation is more efficient in stiff clay soils".

because relevant parts of the OXD line were not included in the Vibration Monitoring Survey, no information is available and the error cannot be quantified[3]. The explanations offered at the TM for not following the Inspector's requirements and including measurements at the cutting were considered unsatisfactory by residents. They were: (a) a belief that the cutting would, if anything, reduce vibration amplitude (the reason was not explained), and (b) that it would have increased the number of measurements needed – see [2] question Q2.3.

3.3 Uncertainty concerning vibration levels within buildings

The VDVs appearing in Condition 19 refer to the insides of receptor buildings. However, all the Atkins calculations refer to vibrations in adjacent open ground. It is well known that buildings generally do not vibrate the same as adjacent open ground. If resonances are excited, some floors of a building can experience much greater vibration than those in adjacent ground, as acknowledged by Dr Ekici in [2], and well-known from the literature – e.g. see Dawn and Stanworth [8]. This is a particular potential problem with trains, because the frequencies of vibration and of building resonances may overlap. Nevertheless, the Vibration Monitoring Survey included no vibration measurements within the receptor buildings themselves. Instead, the predicted VDVs for the ground were simply assumed also to apply within the buildings. The resulting error is likely to be significant and building-specific, and cannot be calculated without further information. Nevertheless, it is highly likely that VDVs predicted by Atkins for the ground, even if correct, would be *lower* than VDVs experienced inside at least some of the receptors, if they happen to be susceptible to the frequency content of the vibrations.

3.4 Uncertainty concerning reliability of the measurements

Some of the data recorded in Atkins are clearly incorrect. In Appendix F of [1] "Detailed description of pass-by events", of the 13 freight trains recorded in October

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[3] This omission is especially worrying for residents, because of evidence suggesting that the combined local geology and topography cause Upper Wolvercote to be unusually vulnerable. Rail company experts at the TM stated that vibration damage to buildings caused by railway lines is very rare. But there is much anecdotal evidence of such damage having been caused in Upper Wolvercote over many years.

2013, 6 of them (with 20-30 wagons each) are said to pass by in 0.60 s – 0.63 s. Another with 12 wagons and travelling at 28 mph is said to pass by in 1.7 s. All of these pass-by times are implausible. They were queried by residents at the TM, but no explanation could be provided, or assurance given that they had not corrupted the VDV predictions in Atkins – see [2] question Q2.7. The presence of such gross errors clearly casts doubt on the reliability of the rest of the data in Atkins.

4. Failure to compensate for uncertainties

In addition to the unavoidable sources of uncertainty listed above, there are other sources of uncertainty in the parameters used in a study such as this, where predictions far into the future are to be made on the basis of a finite sample of data gathered in the present. But no significant attempt is made in Atkins to compensate for all but one of them, or for the avoidable uncertainties listed above.

4.1 Uncertainty concerning effects of train statistics

The most influential numbers in the Atkins predictions are the baseline VDVs. Atkins shows a high degree of scatter in measurements of single-event VDVs for each type of train, even when the train speed and measurement distance from the track are constant (Figures 24 and 28 of [1]). In view of this prominent scatter, there are three problems to overcome in selecting baseline VDVs that would give suitably cautious predictions of the worst case overall VDV, as required to assess compliance with Condition 19.

(i) Firstly, how does the future worst case distribution of single event VDVs relate to the distribution of single event VDVs in the current population of trains sampled in the Vibration Monitoring Survey? This is impossible to know. But what is certain is that the nature of the trains running, and hence the population of VDVs generated, will vary over time, as passenger train carriages and freight contracts etc evolve. For example, at the TM several residents pointed out that the type of freight train that produced the highest levels of vibration locally in the recent past (the Didcot fly-ash trains) are currently not running, and therefore were not represented in the population of trains sampled. Although the reply from Network Rail was that there are currently no plans to run such trains again on the OXD line, no guarantee was given that this situation will not change at any time in the future – see [2] question Q3.7. Therefore the distribution of VDVs sampled is likely to give an overall VDV that under-predicts the worst case future values of overall VDV, when heavier freight trains do run.

(ii) Secondly, how does the relatively small sample of single event VDVs measured relate to those of the whole population of trains currently running on the DCL line? This is a sampling problem that implies further questions. Firstly, was the selection of trains unbiased? Atkins provides no guidance. There is no information on how the particular measurement days were selected. No assurance is given that the selection was not biased by fore-knowledge of what trains, especially what type and weight of freight trains, would be running. Similarly, there is no information on how the set of trains sampled on each day was selected from among the larger number of trains running on the chosen day: data from only *ca* 14% of the trains running on those days are included in the Atkins study (see Appendix 2 below). At the TM Dr Ekici stated that all trains were recorded that happened to pass by while the equipment was set up. But he could not say what hours of the day were chosen to have the equipment set up – see [2] questions Q2.4-Q2.6. Again, therefore, the authors of Atkins offer no assurance of lack of bias in the data selection.

We can proceed further only by assuming there is no bias in the data selection: we assume the set of vibration measurements in Atkins represent a random sample of the whole populations of trains of the three types, currently running. Then the second question is, how does the finite set of measured single event VDV values, assumed to be randomly selected, relate to those of the whole population? The approach in Atkins (Approach 2) is to use regression lines fitted through values of VDV versus distance x from the track – via equation (4). The standard errors of the coefficients then quantify the uncertainty in the value of the mean of the whole distribution for each type of train, for given x. For example, for $x = 8.5$ m, the upper 95% confidence limit single event VDV gives a reasonable upper limit on the position of the whole population mean at the baseline position (assuming a normal distribution, there is a probability of only 2.5% that the mean exceeds this value). In Atkins (as clarified by Dr Ekici at the

TM) pass-by events with VDVs close to these are chosen as the baseline events – see [2] question Q3.1. Therefore Atkins can be said to deal with this particular uncertainty appropriately.

(iii) Thirdly, how are the baseline VDVs required for use in equation (3) to be found from the population mean obtained from (ii)? VDVs are sensitive to the statistical distribution of vibration levels over the course of one day/night – see equation (2). For railway vibrations that consist of discrete bursts of vibration, the VDV from equation (2) involves a summation over the number *n* of discrete single-event VDVs occurring during the time period concerned. This also applies to each of the types of train. Thus the baseline VDVs appearing in equation (3), to accurately represent the distribution, must be defined in terms of a summation over the single event VDVs as follows, taking freight as the example:

$$VDV_{\mathrm{f}} = \left(\frac{1}{n} \left(VDV_{\mathrm{f}1}^4 + VDV_{\mathrm{f}2}^4 + ...VDV_{\mathrm{f}n}^4 \right) \right)^{1/4} \quad . \qquad (8)$$

The 4$^{\mathrm{th}}$ power appearing in equation (8) weights high values of single-event VDVs more strongly than low values). Together with the large scatter, this causes the baseline VDV required to represent a distribution of single-event VDVs to exceed the mean single-event VDV by a significant factor. However, this was ignored in the Atkins predictions: no factor was introduced to allow for it – see [2] question Q3.2. The corresponding error factor introduced can be quantified, however, using data from Figures 25 and 29 of Atkins [1]. If the single event VDVs for freight and passenger trains at the baseline conditions are assumed to be normally distributed, then the error factor is 1.16 or 1.18 for trains of type f or p respectively. It should be noted that these differ from the other error factors mentioned in this report, in that they are not uncertainties. They constitute definite errors in the Atkins predictions.

4.2 Uncertainty concerning the effects of track and track bed

Atkins contains no details of the track and track bed to be used on the new OXD line. It implies that they will be precisely identical to those currently in use at Location 1 on the DCL Up line, but that is improbable. Indeed will they even be the same all along the new OXD line, including the parts near and inside the tunnel and bridges.

Predicted VDVs will be subject to error from any variation in track and track-bed. How much difference could a change in track and track bed cause? As an example: Atkins shows the DCL Up line systematically gives approximately 3 dB higher vibration acceleration values than the DCL Down line, at the same location, for the same type of trains running at the same speed. This much difference would correspond to an error factor in baseline VDVs of 1.4.

It emerged at the TM that there is the possibility of a drastically different track bed near or inside the Wolvercote tunnel, with the track being laid on concrete - see [2] question Q3.5. This would be expected to cause greater transmission of vibrations to the ground than conventional sleepers on ballast, and hence to cause buildings located near the tunnel to suffer enhanced vibration. Such a possibility is not even mentioned in Atkins.

4.3 Uncertainty concerning the effects of train speed

The considerable scatter in $< a >$ data versus train speed leads to uncertainty in quantifying the dependence on speed (via the value of R) and hence in the calculation of parameter S. The limited number of data points, in relation to the scatter in the data, means there is uncertainty in the value of R even as it applies at the measurement locations. The value used by Atkins is R = 20. However, using the best (most extensive) set of data available in Atkins (passenger trains on the DCL Up line) and taking the upper 95% confidence limit gives R = 26.8. From equation (5) this indicates a small but significant error in S, with error factor of 1.10, when making a correction of passenger train speed from 75 to 100 mph, as a typical example. This refers to Location 1. In addition, there is the further, unquantifiable, uncertainty in what value of R would apply at the locations of the receptors.

4.4 No safety factors are used to compensate for the many uncertainties

Some uncertainty is a normal feature in design of engineering systems, because input parameters always contain some margin of error. Standard engineering practice is to compensate for this, while guaranteeing satisfaction of design requirements even under worst case conditions, by use of suitable safety factors in the parameters used in design calculations. But in Atkins, notwithstanding the large number of uncertainties*, no significant safety factors are included.*

Tables 32 and 33 of Atkins claim that some elements of safety margin have been included in the predictions. But on inspection these are seen to provide no significant compensation for the large uncertainties, as shown below.

(i) The primary ‘factor of safety’ claimed is the selection of baseline VDVs that are higher-than-average single-event VDVs (Figures 24,28 of [1]). But, as seen above in Section 3.1(ii), this does not represent a factor of safety in the normal sense of the term, since such a higher value is required simply to accommodate the finite sample size of the single-event VDVs measured.

(ii) A second area where Atkins claims to have been cautious, and hence to have introduced a margin of safety, is in the train speeds assumed. The ‘maximum permitted speeds’ were assumed, whereas it is said ‘braking and acceleration problems’ will mean maximum speeds are not achieved in practice ‘for the whole route’. This is not a robust safety margin, since there is no guarantee that maximum speeds will not be achieved at least at some of the critical receptors. Moreover, even if at some receptors true train speeds reach only, say, 75% of the values assumed in the predictions, from equation (5) this would still provide a safety factor of only 1.2.

(iii) A third area where Atkins claims to have been conservative is in its treatment of the stone freight train. This affects two of the nine receptors: 3 Bladon Close and Quadrangle. But the stone train contributes only 0.5% and 3.8% respectively to the predicted VDVs for these buildings, so any reduction in its contribution has a negligible effect.

4.5 Cumulative effect of all uncertainties

From above, it is clear the VDVs predicted by Atkins are subject to large uncertainty. Moreover, the chosen methodology and the absence of safety factors has ensured the uncertainty is largely one-sided. Most of the likely errors are such as to cause predicted VDVs to be too low. Even neglecting the many that cannot be quantified, just those for which reasonable estimates can be made indicate that the Atkins predictions are *far* too low for a valid assessment of compliance with Condition 19. To appreciate the scale of this problem, the error factors estimated earlier in this report can be applied to the calculations of Appendix J.2 of Atkins. This produces huge increases in predicted VDVs. Across all nine receptor buildings, VDV_{day} increases by factors between 2.3 and 3.5, while VDV_{night} increases by factors between 2.3 and 3.9.

5. Failure to validate the prediction method

In a case such as this, where predictions are made containing huge uncertainty, good practice dictates that the prediction method should be validated by careful checking of predictions against actual measurements. But no validation test is included in Atkins.

Atkins does include some comparison of VDV predictions with vibration measurements, that might be considered a validation. The measurements had been made *inside* four of the receptor buildings as part of a much earlier study, reported in the Environmental Impact Statement. At one of them (Oddington Crossing) measured VDVs *exceed* predicted VDVs by factors of up to 2. The final version of Atkins (dated January 2014) [1] speculates that this was caused by exceptional circumstances, associated with the level crossing and not accounted for in the predictions. Therefore (Atkins claims) it does not indicate error in the prediction methodology. At the other three locations, measured VDVs lie below predicted VDVs. However, all these measurements were made in the absence of any simultaneous recording of what train types or train speeds passed by during the period of measurement – see [2] question Q4.2. VDVs were 'predicted' on the basis of speculation about the types and speeds of trains that were running at the time, that cannot be relied on. Therefore this comparison of measured and predicted VDVs does *not* provide a validation of the prediction procedure or reveal any in-built safety margin. Indeed the Atkins report, correctly, does not claim that it does so, and at the TM Dr Ekici agreed it did not constitute a validation – see [2] question Q4.3. Thus *the method and assumptions employed in Atkins remain unvalidated*.

6. Failure to demonstrate compliance with Condition 19

Atkins' predictions of VDVs for the nine receptor buildings cover the ranges (in units of $ms^{-1.75}$) – see [1] Table 30:

$$0.09 \le VDV_{\mathrm{day}} \le 0.22; \quad 0.06 \le VDV_{\mathrm{night}} \le 0.16 \ . \tag{9}$$

Its claim of compliance with Condition 19 rests on the fact that these numbers do not exceed the limits. However, comparing these numbers with the Condition 19 limits, equations (1), it is obvious that compliance with the condition is vulnerable to an increase in VDV_{night} by a factor of only 0.2/0.16 = 1.25. But previous sections have shown the Atkins VDVs, as predictors of worst case VDVs resulting from implementation of EWR, are prone to possible errors much greater than this. Several major sources of potential error cannot even be quantified because of missing information – see Sections 3.2, 3.3, 3.4 and 4.1(i). Where information is available to estimate potential error factors – see Sections 3.1, 4.1(iii), 4.2 and 4.3 - these alone, when applied to the Atkins calculations in Appendix J.2 of [1], lead to predicted VDVs exceeding the Atkins predictions by factors between 2.3 and 3.9 – see Section 4.5 above. These VDVs violate the night-time Condition 19 limit *at all the receptor buildings*, and at several of them exceed the limit by more than 50%, and violate the day-time limit as well.

7. Conclusions

Atkins fails to show convincingly that EWR will comply with Condition 19. In fact, there is a realistic risk of actual worst case vibration levels exceeding the condition limits by a large margin. This would expose line-side residents to unreasonable levels of vibration and would constitute a serious breach of the TWA Order relating to East West Rail Phase 1.

References

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[3] British Standards Institution, *BS 6472-1: 2008 Guide to evaluation of human exposure to vibration in buildings, Part 1: Vibration sources other than blasting.*

[4] http://www.bgs.ac.uk/discoveringGeology/geologyOfBritain/viewer.html (last accessed 10 July 2014.

[5] USA Department of Transportation, Federal Transit Administration, *Transit Noise and Vibration Impact Assessment FTVA-VA-90-1003-06*, http://www.fta.dot.gov/documents/FTA_Noise_and_Vibration_Manual.pdf (last accessed 10 July 2014)

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[8] T.M.Dawn and C.G.Stanworth, *Ground vibrations from passing trains*, Journal of Sound and Vibration 66 (1979) 355-362.

Appendix 1

The British Geological Survey (BGS) website provides detailed measurements of the local geology, obtained from boreholes.

The following information is from all known boreholes relevant to Locations 1 and 2 of the Vibration Monitoring Survey referred to in Atkins.

1. SP50NW423 (British Rail 5) on the Oxford - Birmingham main line (DCL), closest to locations 1 and 2, shows a depth of 2m of "soil and mud" over 2.1m of gravel. No clay is mentioned.

2. SP50NW511, close to the DCL main line, shows 10cm of topsoil, over 0.5m of "made ground", over 1m of superficial soft, silty clay, over 1.90m of flinty gravel and sand. Stiff Oxford clay begins at a depth of 3.5m.

3. SP50NW512, close to the DCL main line, also shows 10 cm of topsoil, over 0.55m of "made ground", over 1.05m of superficial deposits of soft, silty clay, over 2m of sand and gravel. Stiff Oxford clay begins at a depth of 3.7m.

4. SP50NW513, close to the DCL main line, also shows 10 cm of topsoil, over 0.55m of "made ground", over 0.95m of soft clay, over 2m of sand and gravel. Stiff Oxford clay begins at a depth of 3.7m.

5. SP50NW422 (British Rail 4) on the Oxford - Birmingham main line (DCL) shows a depth of 2.1m of "soil and mud" over 2.5m of gravel. No clay is mentioned.

6. SP40NE10 To the west of the DCL main line, shows 0.6m of alluvium, over 3.4m of gravel and sand. Stiff Oxford clay begins at a depth of 4.5m.

7. SP40NE11 Also to the west of the DCL main line, shows 0.3m of soil, over 4.3m of gravel and sand. Firm Oxford clay begins at a depth of 5.1m.

According to the BGS there are two more boreholes close to Locations 1 and 2. They are both on the Oxford - Birmingham main line (DCL), and are labelled SP40NE96 (British Rail 6) and SP40NE97 (British Rail 7) and are "restricted" and only available through GeoRecords Plus+. However, both British Rail 6 and British Rail 7 data are also listed on the publicly available data for SP50NW423 (British Rail 5) as listed above. This states that British Rail 6 has a depth of 1.6m of "soil and mud", over

2.3m of gravel (no clay mentioned), while BR7 has a depth of 0.7m of "soil and mud" over 3m of gravel (no clay mentioned).

In contrast, information from the only borehole on the OXD line is:

SP41SE157, at Lakeside, where the data show 0.2m of topsoil, over 0.5m of "very high plasticity, stiff clay (Weathered Oxford Clay)", over 1.3m of "high plasticity clay (Weathered Oxford Clay)", over 2.5m of "stiff clay (Weathered Oxford Clay)".

The conclusion, therefore, is that all the British Rail borehole data quoted by BGS, show not a single borehole on the Oxford - Birmingham main line (DCL) with any mention of clay, while all other borehole data close to Locations 1 and 2 shows "Stiff Oxford Clay" beginning only at depths of (at least) 4.1m, 3.5m, 3.7m, 4.6m, 4.5m and 5.1m with soft, silty, soil, sand, clay and gravel mixes, identified as alluvium by the BGS, above. In marked contrast, the only borehole data on the Oxford - Bicester line, shows "very high plasticity, weathered Oxford Clay" beginning at a depth of just 0.2m, and extending as deep as the borehole was drilled.

Since the Wolvercote cutting dives increasingly below natural ground level and into a tunnel, the "very high plasticity, weathered Oxford Clay" is at the surface of the track throughout Upper Wolvercote before reaching Lakeside, where it is covered by an extremely thin layer of topsoil.

Appendix 2

The Atkins Vibration Monitoring Survey recorded vibration information from only a small proportion of the trains running on the four days in 2013. We have estimated the number of passenger trains from current timetables and the number of freight trains more approximately by observation.

We assume the time window available for the measurements on each day was 09.00 to 19.00. During the four day measurement period, there would then be the following numbers of trains pass by:

On the DCL line: 284 passenger trains and approximately 150 freight trains.

On the OXD line: 88 passenger trains and approximately 24 freight trains.

Of these, the Atkins survey included (see [1] pages 18-20):

On the DCL line: 51 passenger trains and 16 freight trains.

On the OXD line: 4 passenger trains and 3 freight trains.

Thus only 14% of the available trains were sampled in the Atkins survey.