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THE ASSESSMENT OF VIBRATION EFFECTS ASSOCIATED WITH THE OPERATION AND CONSTRUCTION OF THE CHANNEL TUNNEL RAIL LINK

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1. INTRODUCTION

Ashdown Environmental Limited (AEL) assessed the vibration effects associated with the operation and construction of the Channel Tunnel Rail Link (CTRL) as part of the overall environmental assessment of the proposals. The assessment rationale and the criteria applied are described in this paper. The calculation procedures employed are described elsewhere [1]. This introductory section outlines the overall rationale and lists the principal sources from which the assessment criteria were derived.

All the potential sources of appreciable vibration associated with the construction or operation of the CTRL were considered including the passage of trains on the CTRL, the passage of trains on other railways, construction and maintenance activities and road traffic. The principal concerns addressed by the assessment were the effects upon people and/or activities. This was achieved by considering predicted stimuli levels at properties. Where predicted stimuli levels exceeded quantitative criteria for a property this was termed an impact. The severity of impacts on residential properties were classified on the basis of a semantic scale. This enabled the significance of effects to be assessed, principally in terms of the number, severity and duration of impacts.

Three potential types of effect were assessed; the effects of groundborne noise upon the use of residential and non-residential properties, the effects of perceptible vibration upon the occupants of, and activities carried out inside residential and non-residential properties and vibration effects on buildings. Criteria for groundborne noise from trains in tunnels are presented in Section 2. Perceptible vibration criteria are listed in Section 3 and the criteria used to assess potential effects on buildings are given in Section 4.

Effects due to particular sources of vibration were considered at four levels: Level 2, Level 1, Commentary and Considered Highly Unlikely to be Significant.

Effects assessed at Level 2 were considered on the basis of impacts upon individual or representative groups of resources by comparing the results of calculated levels of vibration and/or groundborne noise against appropriate quantitative criteria, taking baseline levels into account where relevant. This level of assessment was carried out where:

(i) sufficient detailed information was available upon which to base a detailed assessment; and

(ii) there existed a suitably robust calculation procedure.

Effects assessed at Level 1 were considered on the basis of predicted levels against quantitative criteria where:

i) the information upon which the assessment was based would not support a highly detailed assessment; and/or

ii) the available prediction method was not sufficiently accurate to support a highly detailed assessment.

Effects addressed at Commentary Level were considered on the basis of professional judgement supported by the available information with regard to source levels, propagation characteristics and community response. Effects were addressed at commentary level where there was only limited available detail about the activity giving rise to the potential effects or about the subjective response to the stimulus or because no suitable calculation methodology was available.

Some potential effects were identified that were Considered Highly Unlikely to be Significant on the basis of professional judgement and current knowledge. Such effects were not considered further in the assessment.

A summary of the effects considered, together with the levels of detail in which they were considered, is given in Table 1.

SOURCES OF IMPACT	EFFECTS*				
	PERCEPTIBLE VIBRATION EFFECTS ON RESIDENTIAL USE	GROUNDBORNE NOISE EFFECTS ON RESIDENTIAL USE	PERCEPTIBLE VIBRATION EFFECTS ON NON-RESIDENTIAL USE	GROUNDBORNE NOISE EFFECTS ON NON-RESIDENTIAL USE	EFFECTS ON STRUCTURES
OPERATIONAL					
Trains - Surface (CTRL)	2	C	2	C	CHUS
Trains - Tunnel (CTRL)	1	2	1	2	CHUS
Trains (Other lines)	1	1	1	1	CHUS
Operational Road Traffic	C	CHUS	C	CHUS	CHUS
Maintenance Activities	CHUS	CHUS	CHUS	CHUS	CHUS
CONSTRUCTION					
Piling	1	CHUS	1	C	1
Tunnelling	C	C	C	C	C
Other overground works	CHUS	CHUS	CHUS	CHUS	CHUS
Other underground works	CHUS	CHUS	CHUS	CHUS	CHUS
Construction Rail Traffic	1	1	1	1	CHUS
Construction Road Traffic	C	CHUS	C	CHUS	CHUS
Changes in Operational Rail Traffic During Construction of the CTRL	1	1	1	1	CHUS

* 2 - Level 2 Assessment
1 - Level 1 Assessment
C - Commentary Level Assessment
CHUS - Considered Highly Unlikely to be Significant

TABLE 1: SUMMARY OF EFFECTS AND LEVELS OF DETAIL OF ASSESSMENT

Sources for the Criteria Used

Groundborne Noise

There are no appropriate British Standards or International Standards for the assessment of groundborne noise.

The groundborne noise criteria were principally derived from the following sources:

i) the American Public Transit Association Guidelines for Design of Rapid Transit Facilities (The APTA Guidelines) [2];

ii) the Draft Guidance Manual for Transit Noise and Vibration Impact Assessment prepared for the Urban Mass Transportation Administration, US Department of Transportation (The Draft USDTp Guidance) [3]; and

iii) London Transport complaints history data [4].

The APTA Guidelines were published in 1981 and have been widely used in the United States. The Draft USDTp Guidance, however, has not been published yet, but its publication is understood to be imminent. It should be noted that the Draft USDTp Guidance is not intended to be a revision of the APTA Guidelines. However, it is understood that the USDTp Guidance, which specifies impact criteria for groundborne noise, was developed in the United States upon the basis of experience of the application of the APTA Guidelines, which specify 'design goals'.

Perceptible Vibration Impacts upon the Use of Resources

Impact classification criteria have been developed principally upon the basis of BS 6472 [5].

Potential Impacts on Structures

No quantitative criteria were developed for operational effects upon structures as the passage of trains, especially high speed trains on modern well-maintained track, is highly unlikely to lead to levels of vibration likely to have any, even slight or cosmetic effects upon structures.

The stringent criteria listed in BS 5228: Part 4 [6] for minor or cosmetic (ie non-structural) damage were used as the basis of identifying potential impacts from vibration due to construction works, principally piling or tunnelling, which warranted further more detailed investigation with regard to potential effects upon buildings. In addition to BS 5228: Part 4, consideration was also given to the advice contained in BS 7385 [7].

2. IMPACT CRITERIA FOR GROUNDBORNE NOISE FROM TRAINS IN TUNNELS

Criteria for Impacts on the Use of Residential Resources

Individual residential properties predicted to be subject to a groundborne noise level in excess of the evaluative criteria threshold were termed 'impacts'. The severity of individual impacts was classified by reference to the semantic scale shown in Table 2.

dB $L_{Amax,S}$	CLASSIFICATION
35 - 39	low
40 - 44	medium
45 - 49	high
> 49	very high

TABLE 2: CRITERIA FOR THE CLASSIFICATION OF GROUNDBORNE NOISE IMPACTS UPON RESIDENTIAL RESOURCES

The groundborne noise levels shown in Table 2 refer to predicted $L_{Amax,S}$ noise levels near the centre of a dwelling room due to the passage of a single train.

Criteria for Impacts on the Use of Non-Residential Resources

The criteria for non-residential resources were used in a slightly different manner to application of the residential criteria. The criteria were used as trigger levels to determine where individual resources would require a further investigation. The assessment of effects on individual resources predicted to be potentially subject to a level in excess of the criteria was carried out on the basis of professional judgement in liaison with other specialists where appropriate.

Non-residential resources were grouped into four sensitivity bands. Further investigations were carried out where the predicted $L_{Amax,S}$ from a train was at least that shown in Table 3 for the appropriate class of resource.

BAND	CLASSIFICATION	INDICATIVE EXAMPLES OF RESOURCES	CRITERION ($L_{Aeq,8}$)
GBN1	Potentially Highly Sensitive	Radio Studios Television Studios Professional Recording Studios Film Studios Concert Halls Audiological Testing Facilities	25
GBN2*	Potentially Sensitive	Medical Facilities Research Establishments Laboratories Editing Suites and Post Production Facilities Libraries Places of Worship Law Courts Theatres	35
GBN3*	Office, Retail, General Community or Institutional	Offices Shops Public Halls Exhibition Halls Dental Surgeries Museums Art Galleries Community Centres Educational Establishments Cinemas Rehearsal Rooms	40
GBN4*	General Industrial, Manufacturing or Distribution	Factories Warehouses Workshops General Industrial Installations	50
Notes: *	If a resource houses facilities which are potentially more sensitive to groundborne noise, it should be treated wholly or partially as being in the appropriate category.		

TABLE 3: NON-RESIDENTIAL GROUNDBORNE NOISE CRITERIA

3. IMPACT CRITERIA FOR PERCEPTIBLE VIBRATION

Two sets of criteria were developed for the assessment of perceptible vibration. One set of criteria, based upon vibration dose value (VDV) were developed for where it was possible to predict the number, duration and level of vibration events. Where it was only possible to predict the levels of events, assessments were based upon peak particle velocity criteria. The quantities referred to relate to the predicted vertical vibration levels at the centre of the floor of the room of interest.

Criteria for Impacts on the Use of Residential Resources

The following VDV criteria were applied.

i) In The Absence of Appreciable Existing Levels of Vibration: Where the baseline VDV from environmental (ie external) sources was less than 0.22 $ms^{-1.75}$ (07:00 - 23:00) and 0.13 $ms^{-1.75}$ (23:00 - 07:00), impacts due to predicted levels of vibration from trains on the CTRL were classified according to the categories shown in Table 4 (with the proviso that the operation of the CTRL was predicted to give rise to a change in vibration level of at least 25%, in terms of VDV for the appropriate period, with respect to baseline levels).

DAYTIME (07:00 - 23:00) 16 HR VDV ($ms^{-1.75}$)	NIGHT-TIME (23:00 - 07:00) 8 HR VDV ($ms^{-1.75}$)	CLASSIFICATION
> 0.22 - 0.31	> 0.13 - 0.18	Slight
> 0.31 - 0.44	> 0.18 - 0.26	Moderate
> 0.44 - 0.62	> 0.26 - 0.37	Substantial
> 0.62	> 0.37	Severe
Note: The higher of the two classifications was used where daytime and night-time impacts differed.		

TABLE 4: CLASSIFICATION OF PERCEPTIBLE VIBRATION IMPACTS UPON RESIDENTIAL RESOURCES NOT SUBJECT TO APPRECIABLE BASELINE VIBRATION

ii) Residential Resources Subject to Appreciable Baseline Vibration: Where the baseline VDV from environmental (ie external) sources was more than 0.22 $ms^{-1.75}$ (07:00 - 23:00) or 0.13 $ms^{-1.75}$ (23:00 - 07:00), impacts due to changes in the predicted overall levels of vibration associated with the opening of the CTRL were classified according to the resultant percentage increase in VDV categories shown in Table 5.

INCREASE IN VDV	CLASSIFICATION
25 - 40%	slight
> 40 - 100%	moderate
>100 - 185%	substantial
> 185%	severe

Notes: 1. Percentage increase in VDV for both Day and Night was calculated.

2. The higher of the two classifications was used where daytime and night-time impacts differed.

TABLE 5: CLASSIFICATION OF PERCEPTIBLE VIBRATION IMPACTS UPON RESIDENTIAL RESOURCES SUBJECT TO APPRECIABLE BASELINE VIBRATION

Where only the levels of events could be predicted, impacts were identified where predicted PPVs exceeded 0.28 mms^{-1} during daytime or evening periods or 0.20 mms^{-1} during night-time periods.

Criteria for Impacts on the Use of Non-Residential Resources

Where the VDV could be predicted, resources predicted to be subject to a VDV in excess of that shown in Table 6 for the appropriate class of resources, were subject to further investigation. The investigation was carried out with the assistance of other specialists where considered appropriate.

Where only the vibration level could be predicted, the PPV criteria shown in Table 7 were applied.

BAND	CLASSIFICATION	INDICATIVE EXAMPLES OF RESOURCES	DAYTIME (07 - 23:00) 16 HR VDV ($ms^{-1.75}$)	NIGHT (23 - 07:00) 8 HR VDV ($ms^{-1.75}$)
VIB1	Potentially Highly Sensitive	Medical Facilities Dental Surgeries Optician's Facilities Hazardous Installations Laboratories Research Establishments Telephone Exchanges Manufacturers using particularly vibration-sensitive equipment Services which require particularly vibration-sensitive equipment or are otherwise particularly vibration-sensitive	0.11	0.09
VIB2*	Potentially Sensitive	Radio Studios Television Studios Professional Recording Studios Film Studios Editing Suites and Post-Production Facilities Rehabilitation Centres Libraries Law Courts Theatres Places of Worship Concert Halls	0.22	0.18
VIB3*	Office, Retail, General Community or Institutional	Offices Shops Public Halls Exhibition Halls Museums Art Galleries Community Centres Educational Establishments Cinemas Rehearsal Rooms	0.43	0.36
VIB4*	General Industrial, Manufacturing or Distribution	Factories Warehouses Workshops General Industrial Installations	0.87	0.73
Notes: *	If the establishment houses laboratories or other facilities which are potentially more sensitive to vibration, it should be treated wholly or partially as being in the appropriate category.			

TABLE 6: NON-RESIDENTIAL PERCEPTIBLE VIBRATION VDV CRITERIA

VIBRATION SENSITIVITY CLASSIFICATION BAND	PPV (mms^{-1})
VIB1	0.14
VIB2	0.28
VIB3	0.56
VIB4	1.12

TABLE 7: NON-RESIDENTIAL PERCEPTIBLE VIBRATION PPV CRITERIA

4. CRITERIA FOR VIBRATION EFFECTS ON BUILDINGS

Buildings were considered in three categories as shown in Table 8. The criteria applied are shown in Table 9. The levels shown are freefield vertical PPVs calculated at the position of the part of the building closest to the vibration source.

Although structure bands STR1 and STR2 are addressed by the same criteria, properties in the STR1 band are historic or otherwise irreplaceable, difficult to repair or specially sensitive buildings. The identification of such buildings was necessary in order to evaluate the significance of effects. This approach is supported by BS 7385: Part 2, which advises that although important buildings which are difficult to repair may require special consideration on a case by case basis, a building of historical value should not be assumed to be more sensitive to damage unless it is structurally unsound.

BAND	CLASSIFICATION	INDICATIVE EXAMPLES OF RESOURCES
STR1	Historic or Otherwise Irreplaceable, Difficult to Repair or Specially Sensitive Buildings	Listed Buildings Ancient Monuments
STR2	Low Rise Residential or Buildings of Similar Construction	Houses Houses converted into Flats
STR3	All Other Buildings and Structures	Tower Blocks Office Blocks Steel Framed Factory, Warehouse Units Structures related to transport, power or water infrastructure

TABLE 8: CLASSIFICATION OF STRUCTURES

STRUCTURE CLASSIFICATION BAND	INTERMITTENT VIBRATION PPV (mms^{-1})	CONTINUOUS VIBRATION PPV (mms^{-1})
STR1	5	2.5
STR2	5	2.5
STR3	20	10
Note:	Impulsive piling is considered to give rise to intermittent vibration whereas vibratory piling is considered to give rise to continuous vibration.	

TABLE 9: VIBRATION CRITERIA FOR POTENTIAL CONSTRUCTION IMPACTS ON STRUCTURES

5. SUMMARY

In the course of the vibration assessment of the CTRL, a comprehensive vibration assessment methodology was developed. The overall assessment rationale is described in this paper. The criteria applied to the assessment of vibration effects from both construction and operation of the CTRL are also described. Criteria are presented for groundborne noise or perceptible vibration affecting residential or non-residential resources and potential vibration effects on buildings.

REFERENCES

1. Procedures for Calculating Groundborne Noise and Vibration from Rail Guided Vehicles in Buildings. R J Greer, R A Hood, P R Williams and L P Jephson. Euronoise 95. Vol 1 pg 275 - 281. 1995.

2. American Public Transit Association. Guidelines for Design of Rapid Transit Facilities. 1981.

3. United States Department of Transportation Federal Transit Administration. Guidance Manual for Transit Noise and Vibration Impact Assessment. (Unpublished - due for publication shortly).

4. Office of the Scientific Advisor. London Transport Executive. Complaints of Railway Noise Received by London Transport 1969 - 79. 11 December 1979.

5. British Standards Institution. Guide to Evaluation of Human Exposure to Vibration in Buildings (1 - 80 Hz). BS 6472. 1992.

6. British Standards Institution. Noise Control on Construction and Open Sites. Part 4 Code of Practise for Noise and Vibration Control Applicable to Piling Operations.' BS 5228: Part 4: 1992

7. British Standards Institutions. Evaluation and Measurement for Vibration in Buildings. Part 2 Guide to Damage Levels from Groundborne Vibration. BS 7385: Part 2. 1993.