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VIBRATIONS AND NOISE FROM TRAINS IN TUNNELS

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1.0 INTRODUCTION

Trains passing through tunnels can produce vibrations in buildings which could be of a sufficient magnitude to cause some disturbance to occupiers of overlying dwellings. In this paper the work that has been undertaken to arrive at relevant criteria for use in assessing the vibration impact of new railways is discussed. In addition information will be provided on the calculation procedure that has been developed to predict the levels of vibration and re-radiated noise from trains in tunnels.

A calculation procedure to determine the noise levels (L_{Aeq} and L_{Amax}) from railways has also been developed and the paper describing this calculation procedure will be given at the 1991 Autumn Conference of the Institute of Acoustics [1].

2.0 UNITS AND STANDARDS FOR VIBRATION ASSESSMENT

In excess of 800 measurements of train vibration have been undertaken for Ashdown Environmental Limited (AEL) by the Transport and Road Research Laboratory (TRRL). This has given a large body of data from which to develop empirical models to predict the levels of vibration from various types of trains.

The factors that affect the generation and propagation of vibration can be split into two groups. The train type, length, axle, weight axle unsprung mass, and track design will affect the level of vibration at source. The type of lithology and any stratification of the ground will then govern the propagation of this vibration to distant structures.

For intermittent vibration, such as that generated by trains, vibration is best described using some form of average over a given period. We use the 16 hour period RMQ velocity as the preferred daytime measure which takes into account the vibration generated by each train and the number of train movements between 06.00 and 22.00 hours. The 8 hour period RMQ velocity is used to assess vibration levels at night time between 22:00 and 06:00 hours. The use of RMQ averaging for intermittent impulsive signals, being fundamentally supported by BS 6472 [2].

The peak particle velocity (PPV) is the maximum value of the particle velocity recorded during the measurement period. The Resultant PPV is used to assess the effects of vibrations on building structures.

For re-radiated noise inside buildings which is often the most important effect for trains travelling in tunnels we use the dB(A) decibel scale.

Evaluation Criteria

Subjectively Perceived Vibration

The lower limits for acceptable levels of building vibrations are governed by considerations of comfort or annoyance of residents. Work efficiency and health are only affected by very much higher levels of vibration.

The British Standard BS 6472 (2) describes human response to vibration at different frequencies and velocities, from which it is possible to derive levels of vibration described using the Period RMQ velocity which may cause varying degrees of adverse comment. These are presented in Table 1.

The levels of intermittent vibration in a vertical direction with components between 8 and 80 Hz below which adverse comment is unlikely can be obtained from BS 6472 are as follows:

* Daytime - 0.28-0.56 mms^{-1} (measured as 16 hr RMQ velocity)
* Night-time - 0.20 mms^{-1} (measured as 8 hr RMQ velocity)

Damage to Buildings

There is no equivalent British Standard for effects on buildings although one is in preparation. Maximum vibration velocities are given in a German standard, DIN 150 (3) 'Structural Vibration in Buildings' below which it is considered that structural damage to buildings is most unlikely. Three standards are given for:

* commercial and industrial buildings - 10 mms^{-1}.
* residential and similar buildings - 6 mms^{-1}
* buildings of intrinsic value (e.g. historic buildings) - 2.5 mms^{-1}

These levels of vibration are very much lower than those recommended in other countries or those shown to have not caused damage in buildings [4]. It follows that use of these threshold levels will fall on the side of caution.

Re-Radiated Noise

Re-radiated noise can cause annoyance at levels of vibration lower than the threshold at which the vibration can be felt and certainly below levels at which the vibration becomes annoying.

The American Public Transit Association (APTA) (5) has provided guidelines for maximum acceptable levels for different dwelling types. The recommended maximum internal levels for residential dwellings are presented in Table 2 and for other buildings in Table 3. These values are in agreement with the maximum internal noise levels recommended by the BRE (6).

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Critical Working Areas

BS 6472 offers some guidance on the protection of Critical Working Areas (CWAs). These include for example hospital operating theatres or some precision laboratories. It recommends that CWAs are considered as a sensitive subdivision of human exposure to vibration and proposes a limit some what stricter than that for human exposure during night-time.

Whilst human perception of vibration is determined by magnitude of the vibration and the number of events, effects on CWAs will be associated with single events. Accordingly the use of the RMQ average velocity calculated for each train passby is appropriate. This has been called the event RMQ velocity.

The event RMQ velocity is compared against a stringent criterion of 0.14 mms^{-1}.

3.0 PREDICTION OF VIBRATIONS GENERATED TRAINS

AEL have been involved in evaluating the potential environmental impacts of noise and vibration generated by new railway lines. This involves the calculation of the night-time 8 hour and day-time 16 hour period RMQ velocities, the re-radiated noise level expected inside buildings and the resultant PPV at distances of up to 800 m from the tracks.

(1) The speed of the train vibration levels will increase with the speed of the train);

(2) The sprung and unsprung mass of the train;

(3) The design and condition of the track: (designs which can reduce vibration include the use of resilient mountings, and continuous rather than jointed rails. Maintaining the track regularly to remove any roughness will also limit vibration);

(4) The mounting of the track: (either ballast or on concrete slabs).

(5) The effects of the underlying lithology on the source levels of vibration;

(6) The nature of the surrounding lithologies: (vibration is reduced (attenuated) more in clays, than in sands or chalks); and

(7) The design of affected buildings: (lightweight and flexible structures may cause the level of vibration at the ground surface to be amplified through the building, so that vibration in an upstairs room might be greater than at ground level).

Additionally for trains travelling through tunnels the following additional factors affect the observed vibration levels:

(8) The depth of the tunnel: (the level of vibration at the ground surface will decrease as the distance between the tunnel and the surface increases); and

(9) The design of Tunnels: (the design of the tunnel may influence the transmission of vibration to the surrounding grounds).

The models are empirical in nature being evolved from measurements which have intrinsic variability. According to err on the side of caution the 95 percentile levels of the measured vibration at 10 m from the varying track designs have been used as source terms.

Predictions of the vibration effects at specific buildings requires knowledge of the building structure. This will allow evaluation of any increase in the vibration above the levels at the building foundations.

Vibration Damage to Buildings Calculation

As an example of the methodology Figure 1 shows the predicted PPVs at distance from high speed trains (HST) travelling at 200 kph in tunnels with slab track permanent way. The analysis shows that there is very little possibility of structural damage to buildings (even older or historical structures) at distances greater than 10 m from the track.

Directly Perceived Vibration

The predictions of the Period RMQ velocity values at distances from track are shown in Figures 2 and 3 for both the day and night-time periods for the same HSTs travelling through tunnels. These predictions are shown for a variety of soil types, compared against the thresholds for the low possibility of adverse comment assuming 150 trains and 20 trains for the day and night time periods respectively.

The analysis indicates that at distances greater than 10 m from the track the vibration expected is considerably below the level which has even a low probability of causing adverse comment.

Re-radiated Noise

This is the most likely cause of annoyance, associated with trains in tunnels. For trains travelling on the surface this noise will be lower in level than that directly radiated by the train.

The predicted re-radiated noise levels are shown against distance for the various soil types in Figure 4. This shows that for HSTs operating at 200 kph in tunnels maximum levels of between 35 and 40 dB(A) might be experienced at distances of approximately 15 to 30 metres in chalk or clay and 25 to 40 metres in mixed sand and clay.

These predictions suggest that residential dwellings in rural areas will become adversely affected by re-radiated noise if they are closer than 30 to 45 m from the track depending on the geology of the local ground. These critical distances reduce to 15 to 30 m range in urban areas where higher background noise levels already exist.

Critical Work Areas

The threshold event RMQ velocity level above which vibration will affect the operation or manipulation of sensitive equipment is shown on Figure 2.

Sand and mixed sand and clays show the highest levels of vibration. Using these worst cases, CWAs will be unaffected at radial distances greater than 30 m from trains running on the surface although this reduces to 20 m from the track for clay and chalk soils. These critical distances are lower when the trains are travelling in tunnels.

4.0 FURTHER WORK

Work is still ongoing in the following areas;

i) to assess the effect of train brake type (i.e. disc brakes versus tread brake).

ii) to assess the effect of unsprung and sprung mass of the train;

iii) to validate the transfer function between ground vibration at building vibrations and re-radiated noise levels inside the building as put forward by existing research (7).

5.0 CONCLUSIONS

A detailed empirical model has been developed to calculate the vibration levels at distance from railway lines (both high speed, slower passenger and freight services).

The model includes evaluation of re-radiated noise generated inside buildings by ground borne vibration.

The devised model includes the effects of several parameters hitherto unaddressed unadversed or open to question. These include the effects of slab track and train speed.

Further work is continuing to assess other important unassessed areas of investigation as set out in section 5.

6.0 ACKNOWLEDGEMENTS

Ashdown Environmental Limited wishes to express its thanks to the Transport and Road Research Laboratory for the measurements undertaken and their technical support in development of the models contained herein.

7.0 REFERENCES

1. P R Williams, R A Hood and K M Collins Calculation of Train Noise. IOA Autumn Conference 1991.

2. British Standards Institution 6472: 1984 British Standard Guide to Evaluation of Human Exposure to Vibration in Buildings (1 Hz to 80 Hz).

3. Deutsches Institut fur Normung e.V. (1975) Vibrations in Buildings Parts 1-3

4. R A Hood and C P Marshall The effects of a simultaneous traffic vibrations on a dwelling house. Transport and Road Research Laboratory Report No. 44 1987.

5. American Public Transit Association (1981) Guidelines for Design of Rapid Transit Facilities.

6. Building Research Establishment. Thermal, Visual and Acoustic Requirements in Buildings. BRE Digest 226. 1979.

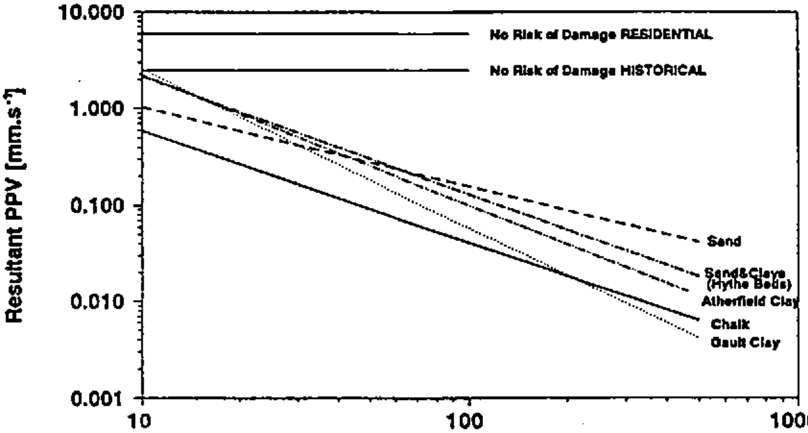

FIGURE 1 : PREDICTED RESULTANT PPV VALUES FROM HIGH SPEED TRAINS IN TUNNELS

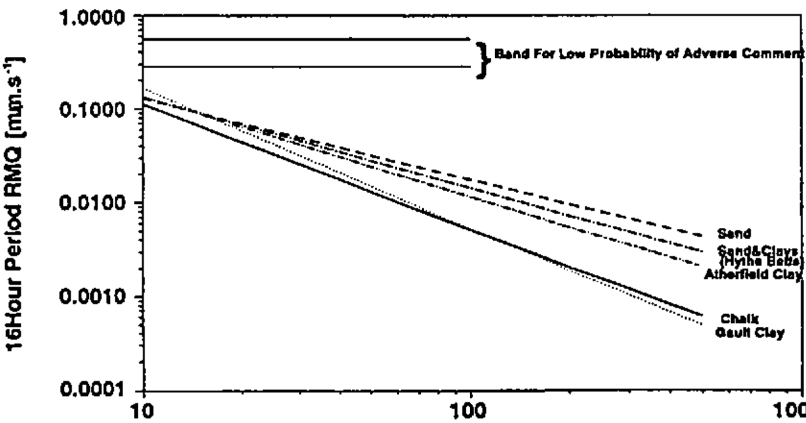

FIGURE 2 : PREDICTED DAY-TIME 16Hr PERIOD RMQ VALUES FROM HIGH SPEED TRAINS IN TUNNELS

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Calculations based on trains travelling at maximum speed of 200kph on slab track
150 Train Movements

Revised 16/09/91

	Low Probability of Adverse Comment	Adverse Comment Possible	Adverse Comment Probable
Day	0.28 - 0.56 mms^{-1}	0.56 - 1.12 mms^{-1}	1.12 mms^{-1} or greater
Night	0.20 mms^{-1}	0.40 mms^{-1}	0.80 mms^{-1} or greater

TABLE 1: PERIOD RMQ VIBRATION VELOCITY AT WHICH VARIOUS DEGREES OF ADVERSE COMMENT MAY BE EXPECTED IN RESIDENTIAL BUILDINGS (BS 6472 [1])

	Maximum Groundborne Noise Level Design Goal, dB(A)		
Community Area	Single Family Dwelling	Multi Family Dwelling	Hotel/Motel Buildings
Low Density Residential	30	35	40
Average Density Residential	35	40	45
High Density Residential	35	40	45
Commercial	40	45	50
Industrial/ Highway	40	45	55

TABLE 2: AMERICAN PUBLIC TRANSPORT ASSOCIATION GUIDELINES FOR MAXIMUM RERADIATED NOISE INSIDE HABITABLE PREMISES [3]

Type of Building or Room	Maximum Re-radiated Noise Level Design Goal dB(A)
Concert Halls and TV Studios	25
Auditoria and Music Rooms	30
Churches and Theatres	35
Hospital Sleeping Rooms	35-40
Courtrooms	35
Schools and Libraries	40
University Buildings	35-40
Offices	35-45
Commercial Buildings	45-55

TABLE 3: AMERICAN PUBLIC TRANSPORT ASSOCIATION GUIDELINES FOR MAXIMUM RE-RADIATED NOISE IN OCCUPIED BUILDINGS [3]

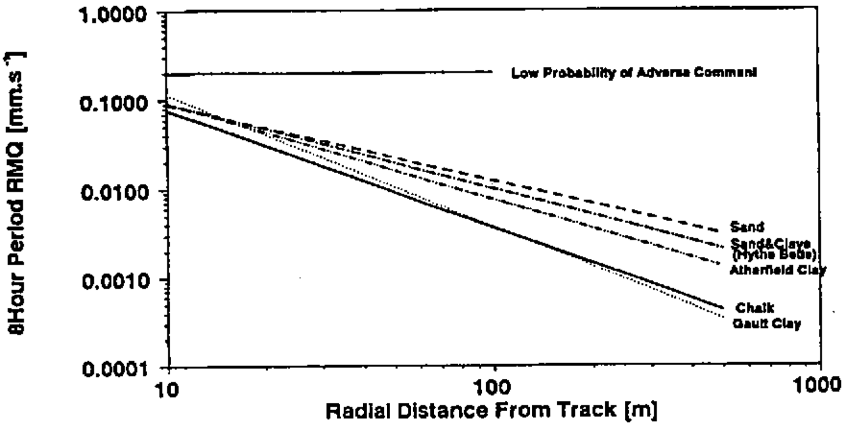

FIGURE 3 : PREDICTED NIGHT-TIME 8Hr PERIOD RMQ VALUES FROM HIGH SPEED TRAINS IN TUNNELS

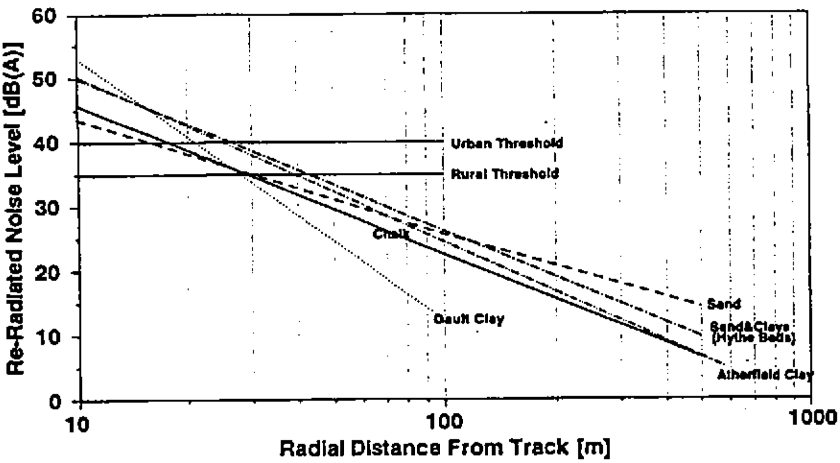

FIGURE 4 : PREDICTED RE-RADIATED NOISE FROM HIGH SPEED TRAINS IN TUNNELS

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Calculations based on trains travelling at maximum speed of 200kph on slab track
20 Trains Movements

Revised 16/09/91