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RAILWAYS AND VIBRATION - A SUGGESTED PLANNING GUIDANCE FOR NEW HOUSING

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INTRODUCTION

This paper describes some of the work carried out in Rugby a few years ago concerning the railway and vibration caused by it. It suggests a method of measuring vibration on land on which houses are to be built, and a criterion by which to judge the suitability of the land for housing. It draws together some published opinion.

Rugby is a railway town. The railway divides it and over much of this century and the last, it was a major employer in the town. In excess of 19 miles of B.R. track (all electrified) runs through the Borough and there is local speculation that the old Great Central line (axed by Beeching in the 60's) may be re-opened as a private railway.

About 10 years ago a complaint appeared on my desk from the MP concerning railway vibration to houses on an estate near the railway. The press also became involved and an article appeared in the papers at the same time. That article generated other complaints.

It was decided, therefore, to visit householders on the estate and carry out a survey.

THE SURVEY

A short questionnaire was devised and this question included to try to gauge the extent of peoples perception to vibration from trains - "Please tell me how if at all, you are affected by noise or vibration from the railway?" When all the replies were in the answers to that question were sorted into 3 categories:-

1. Badly affected by vibration.
2. Not bothered by vibration.
3. Partly affected.

The results of the analysis suggest that 15% are badly affected, about 47% bothered. but not so severely, and about 38% not bothered at all. The distance of the respondents houses from the track ranged from 20 metres to more than 120 metres.

VIBRATION MEASUREMENTS - BADLY AFFECTED

Following the analysis of the survey it was decided to take measurements of vertical acceleration levels at all the houses where "badly affected" responses had resulted. The most consistent vibration signal (and the higher level) seemed to be generated by Inter-city trains travelling at high speeds (Ref. 1). It was therefore decided to use only vibration signals generated by trains on the nearest track to the measuring position (the down main). Only Inter-city trains travelling at normal operating speeds were used (about 110 mph), each train was timed in order to ensure that as far as possible errors caused by train speed variation were kept to a minimum.

The measurements were carried out using the following equipment:

B + K portable vibration meter type 2511
B + K accelerometer Type 4370
B + K portable level recorder type 2306
Steel cube for mounting accelerometer ($100mm^2$) and weighing about 6.5kg.

The procedure was to impact the block onto the ground, usually on a lawn or where this was not possible, onto the earth. In this way a firm, non-rocking base was attained. The accelerometer was screwed onto the block handtight and with the axis of least sensitivity normal to the track, all the equipment was then connected and set up in this way: R.M.S., acceleration LL 3Hz. It was usual to spend about 1 hour carrying out the measurements during which time about 6 high speed trains had used the down main line.

DISCUSSION

The information thus obtained prompted other questions, two of which are germane to the purpose of this paper, and the first question is:

"Should new housing be built on land subject to perceptible vibration from passing trains?"

In a recent publication the author suggests:-

"Research has shown that vibration which only occurs at isolated intervals for example, domestic building vibration generated by a passing bus causes the same level of annoyance as continuous vibration" (Ref. 2).

In the same document:

"In special areas and in the home, high standards are required and this is characterised by an absence of perceptible vibration" (Ref. 2).

B.S. 6472:1984 reinforces this view by, "...experience has shown in many countries that complaints of building vibration in residential situations are likely to arise from occupants if the vibration levels are only slightly in excess of perception levels" (Ref. 3).

J. M. Fields (Ref. 1) published a study in 1979 which suggests that at about 70 metres from the track 25% of those questioned expressed a little annoyance when trains make the house vibrate or shake.

So you can see that there is a measure of evidence supporting the contention that vibration can cause distress to people when it affects their houses. The quoted passages generally imply that an absence of vibration to housing is the target to aim for and that is my view also.

Whilst it may be desirable that houses should not be subject to vibration, such a target only becomes feasible at the house (or railway) planning and construction phase; by which I mean that either, land should not be used for housing if perceptible vibration is likely to occur; OR that any houses built should be designed in such a way as to isolate them from vibration; OR, that if new rail track is to be laid then it should be designed and constructed in such a way as to isolate the land from vibration, particularly if there are houses on it. Which brings me onto the second question:-

VIBRATION PERCEPTION

"At what level does vibration start to become perceptible?"

It was decided to try to identify by discussions with householders, houses which had been built at around the places where vibration from passing trains was only just discernible, then carrying out measurements there. The previous set of interviews showed the approximate locations. The technique involved visiting houses presumed to be situated at around the threshold of perception and carefully interviewing the occupants. Each householder visited was asked "Do you sometimes feel vibration in the house from the trains?"

The criteria used to judge an answer as indicating a point of perception threshold would usually rely on a person feeling the house shaking slightly, but not always; sometimes he might perceive train vibration as rattling ornaments or shaking pictures on the wall.

Examples of responses judged to reflect a perception level include "occasionally I feel vibrations" (100m 0.007ms^{-2}) and "can definitely feel vibration but only just" (185m 0.012ms^{-2}).

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The following graph shows the results of the measurements plotted as amplitude V distance from the track (Fig. 1) When all levels are averaged the result is very nearly $0.01ms^{-2}$.

B.S. 6841:1987 states "...there is a large variation between individuals in their ability to perceive vibration. For a median perception threshold of approximately $0.015m^{-2}$ the interquartile range of responses may extend from about $0.01ms^{-2}$ to $0.02ms^{-2}$" (Ref. 4).

Reiher and Meister state that "...an amplitude of 10μ is just perceptible at 5Hz but would be annoying at 50Hz. Expressed in terms of peak velocity the threshold of perception corresponds to a velocity of 0.3mm/s" (Ref. 5).

Shortly after the survey had been completed my department acquired an F.M. cassette recorder, and the technique changed. Measurements of high speed trains were recorded and the recording played back into a narrow band analyser. A computer programme calculated the RMS value between 1 and 80Hz. At first, it was the practice to perform broad band measurements and FM recordings simultaneously. After several surveys had been recorded and analysed, it became clear that there was very little difference between the RMS value and the broad band level of recordings taken on the study site and on some other sites.

At Rugby the figure of $0.01ms^{-2}$ measured between 1Hz and 80Hz is the Department's planning guidance and where this level is exceeded then the recommendation supported by the planning officers is that housing should not be built there.

IN CONCLUSION

The study was carried out in response to an increasingly urgent need for a guidance by which to judge the suitability of land for new housing. Rugby in common with many other local authorities has adopted noise guidelines but nowhere could I find any reference to vibration guidelines which would be suitable for this type of situation. One way of course would be to sterilise a strip of land adjacent to the track but there would be no guarantee of its effectiveness. It is often said that a house is the biggest investment that most of us are ever likely to make, and it is therefore most important that all possible measures are taken by Local Authorities to protect that investment.

It occurs to me that when people have expressed their view that they are badly affected by train vibration I think that they are partly expressing fear of what the shaking is doing to their house and partly annoyance, say in being woken up. Here I think it is worth saying that if people are daily reminded of their worry when ornaments etc. rattle or when they can feel their house shudder, then they are not going to feel as settled or happy in their home as they have a right to be.

Finally even with this apparently draconian guideline it has still been possible to recommend that houses be built within 50 metres of the track with no isolation measures built in.

TO SUM UP

J. M. Fields has shown that 25% of people questioned can be a little annoyed about house shakes at 70m and about 13% very annoyed at 30m from the track.

My findings suggest (Fig. 2) that at levels greater than 0.018ms^{-2}, 15% of people questioned may be badly affected and that at levels of around 0.01ms^{-2} people will start to feel their house shake or will start to see ornaments, pictures etc. tremble.

My view is that houses should not be built on land receiving vibrational acceleration of this level, unless adequate isolation features are incorporated.

REFERENCES

[1] J. M. Fields, "Railway Noise and Vibration annoyance in Residential Areas"
[2] B. S. I. - Draft Standard - Guide to the Evaluation of Human Exposure to Vibration and Shock in Buildings, Addendum 1
[3] British Standard Guide to Evaluation of Human Exposure to Vibration in Buildings (1Hz to 80Hz) (B.S. 6472:1984)
[4] British Standard Guide to Measurement and Evaluation of Human Exposure to Whole-body Mechanical vibration and Repeated Shock (B.S. 6841:1987)
[5] R. J. Steffens, "Structural Vibration and Damage"

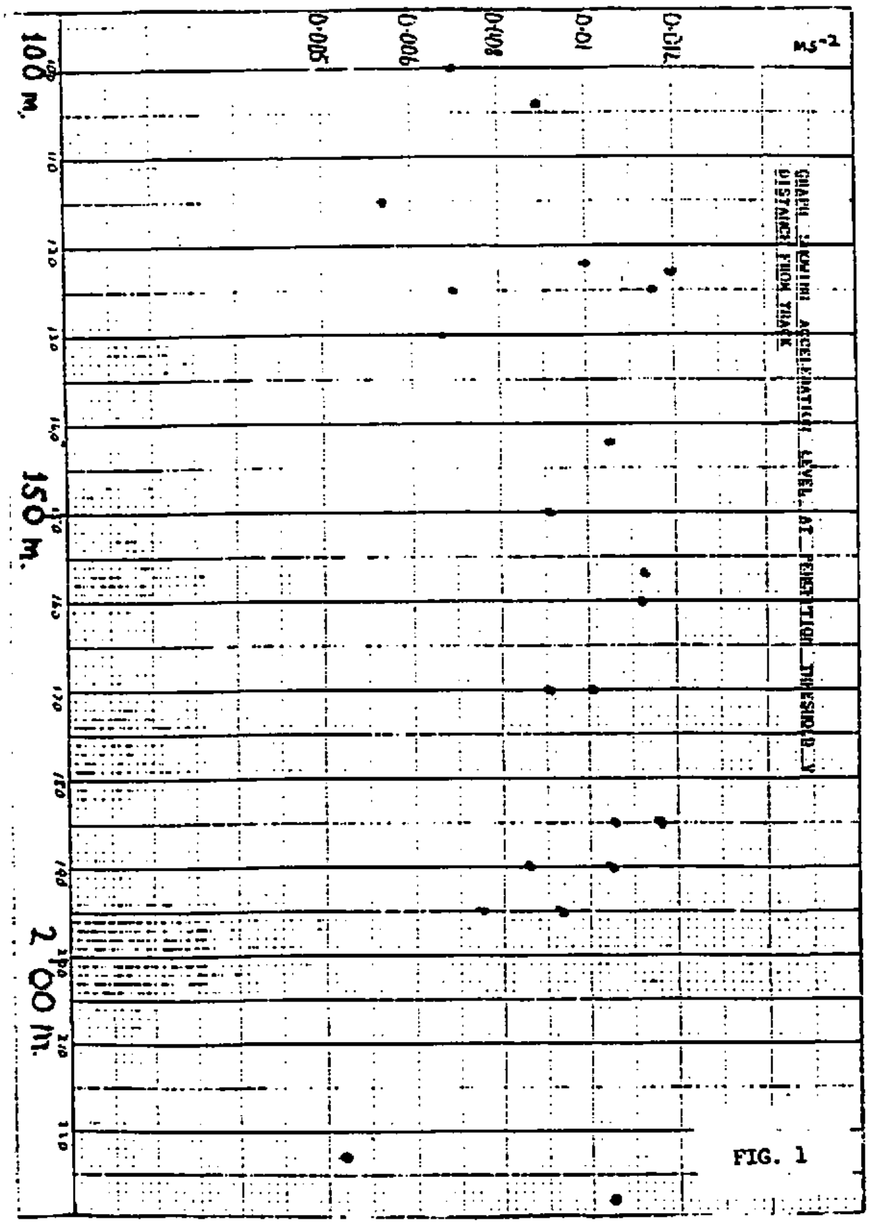
100 m.
150 m.
200 m.
0·005
0·006
0·008
0·01
0·012
ms-2
DISTANCE FROM TRACK

FIG. 1

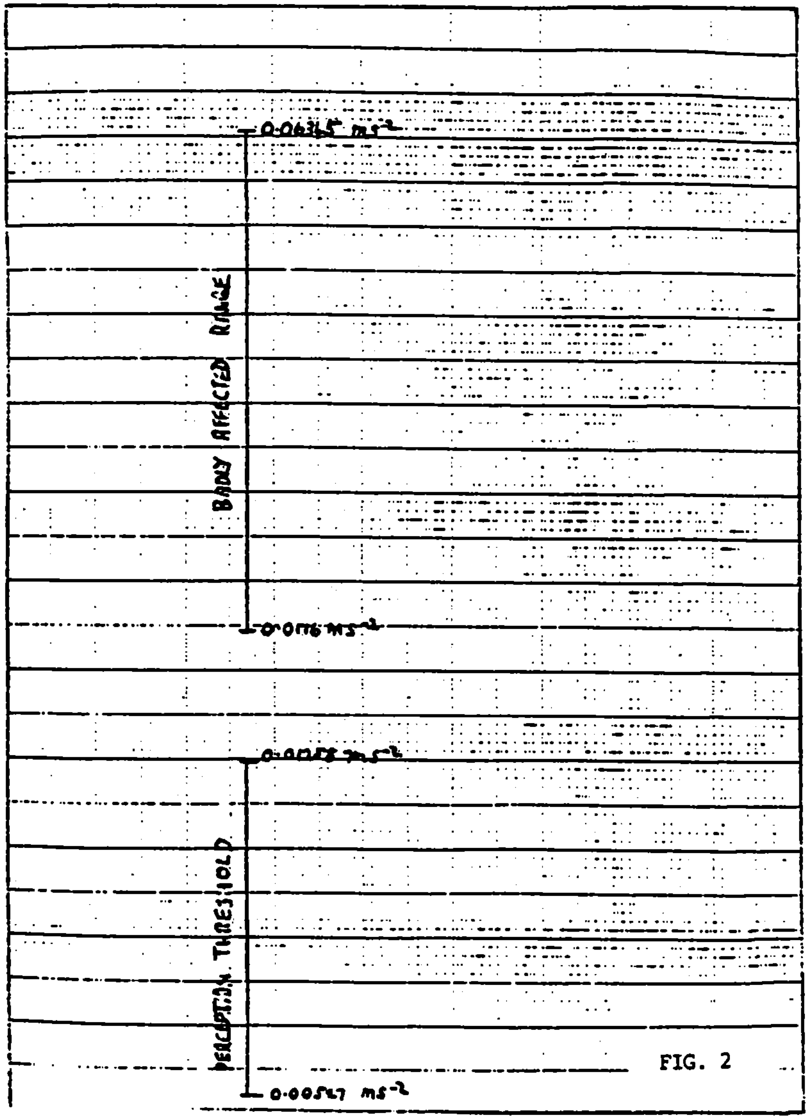
0.06365 ms-2
BADLY AFFECTED RANGE
0.0116 ms-2
PERCEPTION THRESHOLD
0.00527 ms-2

FIG. 2

TOWARDS VIBRATION DOSE STANDARDS - A DISCUSSION PAPER

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Existing British Standard guidance on the assessment of nuisance vibration (1) appears to be reasonably effective with regard to continuous vibration such as might arise from an industrial process, but ambiguous and inadequate when it comes to the assessment of intermittent vibration events. Partly in recognition of this shortcoming, Griffin has developed the concept of vibration dose value (VDV) (2), a quantity which may be thought of as analogous with noise SEL, based on the root mean quad magnitude and duration of a vibration episode.

The dose concept has itself been adopted in a subsequent British Standard (3) which provides a clear framework for further work on the human response to vibration stimuli but which stops short of defining limiting values to quantify nuisance. The use of the VDV and estimated VDV (eVDV) to evaluate intermittently occurring nuisance vibrations in dwellings has been explored elsewhere (2), (4), (5) and needs no further exposition here.

These new assessment parameters have been found by the authors and others (6) to represent effectively the intermittent, irregular vibrations which probably give rise to the majority of complaints from the public about vibration nuisance. As direct measuring vibration dose meters are about to become generally available the means to make the measurements either directly, or indirectly by estimation, will become more widespread so that the need for assessment criteria with which to compare the measured values becomes pressing. Our purpose here is to advance the debate over criteria and, in so doing, to shed some light on the use of eVDV.

The 'satisfactory' magnitudes for continuous vibration given in BS 6472 are an obvious starting point. It seems reasonable to take these as the basis for derivation of dose equivalents of the steady magnitudes assuming that they occur over the day, night or some other period of interest. There are, however, a number of problems which make this simple proposition more complicated than it at first appears. The complications become apparent when each component of the eVDV algorithm is considered more carefully. The definition given in (3) for eVDV is

$$\text{eVDV} = [(a \times 1.4)^4 \times b]^{\frac{1}{4}}$$

where a = weighted rms acceleration value (ms^{-2})
b = event duration (s)

and the eVDV is calculated in units of $ms^{-1.75}$ because dimensionally it is composed as follows:

$$\left\{\left(\frac{m}{s^2}\right)^4 \times s\right\}^{1/4} = \left(\frac{m^4}{s^7}\right)^{1/4} = \frac{m}{s^{1.75}}$$

For steady, constant vibration the rmq and rms magnitudes are approximately equal but for 'peaky' events with crest factors of up to 6 the rmq may be approximated from the rms by use of the empirical factor 1.4.

The weighting of acceleration value 'a' is crucial. The actual VDV should (and, indeed, can only) be obtained from the weighted root mean quad acceleration signal; the weighting curves (which may be thought of as being precisely analogous with the A-weighting curve familiar from noise measurement) are themselves defined in British Standard 6841 (3). In contrast with BS 6472 (1) which effectively makes use of only two weighting curves (implicit in the base curves, both for acceleration and velocity, for the z and the x/y axes), BS 6841 defines six curves, each of which has a quite specific role. Those particularly relevant in the assessment of nuisance, classified in the Standard as 'discomfort' and 'perception', are w_b which is principally applicable to z axis measurements and w_d which is the corresponding weighting for x/y axis measurements. A further curve, w_g, is defined for the assessment of vibration affecting manual and visual tasks. For the sake of clarity and simplicity the rest of this discussion will be concentrated on the assessment of z - axis vibration; the principles and problems raised are on the whole equally applicable to the x/y axis case.

The base curve for z axis vibration given in BS 6472 approximates most closely to the w_g weighting curve given in BS 6841. If we take the curve in BS 6472 as the basis for the new dose standard, therefore, it will be wrongly weighted according to BS 6841. Perhaps the solution would be to take the lowest value in BS 6472 curve and to apply the BS 6841 w_b weighting factor for each third-octave band to that value to derive a new base curve. Alternatively we could simply assume that the most sensitive part of the base curve represents the key to the perception of nuisance and that we might insert that value into the eVDV equation, as if it represented the weighted value.

The next problem is that of whether it is more legitimate to include or to exclude the constant factor for approximating rmq from rms. Since the BS 6472 base curves are assumed to represent continuous vibrations it could be argued that this empirical factor should be excluded in the setting of an equivalent standard (though not, of course, in the estimation of the VDV from the rms value for an event).

Lastly, the period of measurement, b, presents a problem. BS 6472 is opaque when it comes to periods of assessment; the base curve values are intended to represent tolerable levels of continuous vibration over a period of sixteen hours, which does not correspond with any of the 'standard' day or night periods used in the assessment of noise impact. The question arises then as to whether it should be assumed that the 'day' and 'night' time values given in BS 6472 each refer to a notional 16 hour period so that this should be the value substituted for 'b', or whether the day and night sub-periods are implicitly dealt with in the base curve multiplication factors so that other periods such as 15 hours (day; 07.00-22.00) and 9 hours (night; 22.00-07.00) could be inserted.

In estimating vibration dose values, use can be made of the fact that the w_b weighting factors equate with constant velocity values at $f \geq 16$Hz. Consequently it is possible to measure a vibration rms velocity magnitude and substitute this directly for 'a', using only a constant multiplier to achieve numerical identity. The error introduced if a significant proportion of the energy in the measured signal is in frequency bands

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centred below 16Hz is such that the eVDV will be over estimated rather than underestimated. Furthermore, in the frequency bands centred at 16Hz and above the modulus of the w_b weighting factor is twice the modulus of the w_g weighting factor so that if the BS 6472 base curve values are adopted an extra factor of 2 must be included to approximate w_b weighting.

In summary, then, a <u>true</u> vibration dose value (VDV) cannot be obtained other than by processing the input signal from an accelerometer through a true rmq integrator and appropriate weighting circuitry. It is not possible, therefore, to derive notional VDV criteria with any degree of certainty from the BS 6472 reference curves and when VDV measuring equipment becomes widely available it will become necessary to attempt to identify new vibration nuisance criteria through field study and social survey. In the mean time estimated VDVs based on rms values may be obtained from existing direct measuring equipment. Velocity values may be used as well as acceleration values and might in fact represent better estimates of weighted rmq acceleration than do rms acceleration values. Standards for the assessment of eVDVs may be derived from the BS 6472 base curves, though a number of assumptions must be made.

The authors propose that the following assumptions are reasonable:

a) that the most sensitive part of the BS 6472 base curve, the minimum threshold of perception level, $0.005 ms^{-2}$, should be taken to represent 'a'

b) that the x 1.4 factor for conversion of rms to rmq should be omitted

c) that the criterion values should be based upon 'standard' evaluation periods of 15 hours (07.00-22.00) for 'day' and 9 hours (07.00-22.00) for 'night'.

Thus, for w_g weighting, in dwellings by day for which 2 x the base curve is taken as the 'satisfactory' level

$$eVDV_{LIM} = [(0.005 \times 2)^4 \times 15 \times 60 \times 60]^{\frac{1}{4}} = 0.15 \ ms^{-1.75}$$

and the corresponding night-time value, for which 1.4 x the base curve is taken as the 'satisfactory' level would be

$$eVDV_{LIM} = [(0.005 \times 1.4)^4 \times 9 \times 60 \times 60]^{\frac{1}{4}} = 0.09 \ ms^{-1.75}$$

These implicitly 'g-weighted' values would be multiplied by 2 to obtain approximate 'b-weighted' values, as recommended in BS 6841 for perception/discomfort determination. The equivalent 'w_b' criteria are therefore

daytime : $0.30 \ ms^{-1.75}$
night-time : $0.19 \ ms^{-1.75}$

These apply only to dwellings; the factors given in (1) for multiplication of the base curve values to derive 'satisfactory' levels in other types of building must be taken into consideration where necessary, as must the BS 6472 recommendation that 'adverse comment' may be expected at twice these values. Furthermore, different criteria should be derived, along similar lines but using appropriate base values and weighting, for vibration in the x and y axes. It is important to distinguish between the two different weightings implied in the proposed criteria and that the report of a site investigation must clearly state which has been used in the assessment of field results.

While these criteria would be directly applicable when investigating vibration in existing buildings the further question of coupling and amplification factors arises when ground vibration is being assessed on an undeveloped site as part of the pre-development planning process. This problem has been investigated and the result of pre- and post-construction surveys suggests that a source spectrum -dependent analysis of green field ground vibration provides the most accurate prediction of vibration in proposed buildings (7). More simply, for conventionally constructed dwellings a coupling factor of x 1.2 for the ground floor and x 2.4 to 2.7 for first and second floors seems to provide a reasonable estimate.

Consequently, z-axis criteria for ground vibration evaluation on green field sites could be determined as

day, for ground floors:	$0.25 ms^{-1.75}$
night, for first floors:	$0.08 ms^{-1.75}$

with the latter based for the sake of simplicity on a coupling factor of 2.5.

REFERENCES

[1] BS 6472: 1984 'British Standard Guide to Evaluation of human exposure to vibration in buildings (1 Hz to 80 Hz)'.

[2] M J GRIFFIN, 'Evaluation of Vibration with Respect to Human Response', SAE Technical Paper Series 860047, SAE, Warrendale, Philadelphia (1986).

[3] BS 6841: 1987 'British Standard Guide to Measurement and evaluation of human exposure to whole-body mechanical vibration and repeated shock'.

[4] C M NELSON, 'Measurement and analysis techniques for the evaluation of human exposure to vibration', Proc. Inst. of Acoustics, 11, (5), p167-174 (1989).

[5] A W JAMES, 'Vibration dose values - notes for consultants', Proc. Inst. of Acoustics, 11, (5), p159-165 (1989).

[6] M J GRIFFIN and C G STANWORTH, 'The generation and perception of vibration from rail traffic', Track Technology, Thames Telford Ltd, London, p215-223 (1985).

[7] R RANDELL, 'Ground vibration and its effects on building habitability', Proc. Inst. of Acoustics, 11, (5), p121-128 (1989).