Proceedings of the Institute of Acoustics

VDV AS AN INDICATION OF ANNOYANCE FROM STEADY STATE VIBRATION

David Trevor-Jones

Rendel Science and Environment, Great Guildford House, 30 Great Guildford Street, London SE1 0ES.

1. INTRODUCTION

The work of Griffin and various collaborators has led to the establishment of vibration dose value (VDV) as a useful descriptor of human vibration. Griffin suggests[1] that VDV offers a robust method of assessing the severity of all motions, from single bumps to continuous 24 hour exposure. VDV is especially valuable as a descriptor of impulsive and intermittent vibration as it is independent of averaging time and is not limited by waveform (e.g. to motions with low crest factors). Its use has been endorsed in the latest revision of BS6472[2] and enthusiasm among practitioners has been encouraged by the publication of tentative assessment standards and by the availability of proprietary equipment capable of directly measuring it.

The enthusiasm with which VDV, and those tentative standards in Appendix A of BS6472, have been embraced may, however, be too indiscriminate. Although Appendix B of the standard advises that VDV may be used to assess impulsive and intermittent vibration it gives no further guidance on the boundaries of impulsiveness or intermittency or on the types of source beyond which the technique might be inappropriate. That such limitations might exist is acknowledged by Griffin, and is illustrated here in two similar case studies.

VDV AS AN INDICATION OF ANNOYANCE

2. CASE HISTORIES

In both VDV was adopted to describe and assess the acceptability of vibration in buildings arising from nearby construction activity. In both cases the motion was intermittent but occurred in steady, well behaved episodes lasting between one and five minutes, repeated up to forty times a day.

The feature of both assessments which concerned their respective investigators was that the cumulative daily VDV assessed against the standards in BS6472 table 7, fell into the 'low probability of adverse comment' category whereas they and their complainants considered that the vibration was unacceptable. Both cases had arisen because adverse comment had, indeed, been reported.

The available details of the two cases are given below. In the first the source of the vibration was pile case driving using a vibratory driver. The forcing frequency was probably about 25Hz. In the second the source was sheet pile extraction using vibration to loosen the piles. The frequency was not investigated. In both cases there were dwellings nearby and residents had experienced some concern about the vibration. The data refer to vertical motion.

		VDV $ms^{-1.75}$	t sec		a(r.m.s) mms^{-2}
Case 1	Pile 1a	0.0676	40	)	~ 1 mms^{-1}
	Pile 1b	0.0636	20	)	(ppv)
	Pile 1	0.0781	60	)	
Case 2					
	Pile 1	0.0832	180		48.8
	Pile 2	0.0944	300		58.0
	Pile 3	0.1200	270		-

In Case 1 the investigator felt that the vibration was sufficiently severe to warrant a review of the working method and the local authority considered enforcement action. The event VDV suggests that forty piles could have been driven per day while the summed dose remained at the lower end of the range delivering 'low probability of adverse comment' in table 7 of BS6472:1992.

In Case 2 a complainant claimed that light building elements such as doors and windows rattled and that a mirror had been broken. The investigating officer commented that the daily VDV, estimated as 0.28 $ms^{-1.75}$, corresponded with a 'low probability of adverse comment' rating but that 'the subjective impression was that nuisance would be caused'. The vibration could be readily detected through the body and by hand on the walls of the complainant's room.

Having eliminated the possibilities of equipment malfunction and operator error, the search for an explanation for the mismatch between assessment and impression raises three questions. Firstly, does the waveform of the motion influence the result of the assessment? Secondly, should a measure of the impulsiveness or intermittency come into the assessment? Thirdly, are the assessment standards proposed in table 7 of BS6472 adequate?

3. QUESTION 1: THE WAVEFORM

VDV has an amplitude and a time component. This question concerns the former. In the case of a sine wave the root mean quad (r.m.q.) amplitude is about 0.78 times the peak, or about 10% greater than the root mean square (r.m.s.) amplitude. The relative difference increases with increasing crest factor, which is probably why the r.m.q. and derived dose value better represent human response to shocks,jolts and short term event vibrations than does r.m.s. description.

VDV AS AN INDICATION OF ANNOYANCE

In the case of a well-behaved, steady motion the r.m.q. cannot be less than the r.m.s. averaged over the same period and the apparent mismatch between the VDV and subjective judgement on the two cases above cannot be a function of the amplitude component of the dose value.

4. QUESTION 2: THE INTERMITTENCY

This question concerns the time, or duration, component of the VDV. It is logical to assume that the human response to vibration is time dependent. A motion which is tolerable for ten seconds may not be remotely tolerable for ten minutes or ten hours. The time and amplitude dependency of the response and the interaction between the two components can be expressed by the relation $a^n t = k$, where amplitude (a) and duration (t) combine to produce a constant response, represented by k. The interdependence is represented by the exponent (n). A value of 2 relates to root mean square, and of 4 to root mean quad averaging.

The time dependency of the human response to episodic vibration stimuli has been studied by a number of authors whose work has been reviewed by Howarth[3]. Although opinion has swung strongly towards a view that $a^4 t = k$ adequately represents the response to the whole range of vibrations, from the shortest single shock, to 24 hour exposure to a continuous random motion, there appears to be sufficient room for doubt that the existence of special cases cannot be ruled out.

Howarth bases the review on the time dependency curve presented in International Standard 2631, which for exposures from 10 minutes to 8 hours suggests an $a^2 t = k$ relation. This, it appears, was drafted on the basis of some very limited and possibly questionable, results from a single semantic scaling and a single predictive study. The categorisation of investigation methods extends to three further classes, magnitude estimation, matching and rating.

Each investigation method class has systematic shortcomings which can distort the results of a study. Semantic scaling ('describe this vibration') studies can be undermined by the absence of a consistent reference point, while predictive studies ('how long could you stand this vibration') are limited by the subject's lack of experience upon which to base judgement. While the earlier studies tended to adopt these methods, later ones have tended towards magnitude estimation ('how does this vibration relate to the reference'), matching ('adjust this vibration until it matches the reference') and rating ('how do you rate this exposure compared with that exposure'). All studies of human response to any sort of stimulation are vulnerable to distortion through some effect of the experimental method and the estimation, matching and rating methods for vibration are no exception. Howarth identifies as shortcomings task difficulty, the small sizes of the studies and that they have tended towards the observation of the responses of subjects to fairly short term stimuli over short periods under laboratory conditions. Howarth's and Griffin's reviews do not always make clear whether any particular study was designed to investigate a discomfort or an annoyance response and it is possible that the two might differ.

Where a duration response study does indicate a stronger time dependency than that implicit in the $a^4t = k$ relation, it seems to be associated with higher frequencies (around 30Hz). The possibility that the mismatch between measured VDV and subject response in the cases which inspired this paper arises from the under estimation of duration is therefore not completely ruled out by the conclusion of Howarth and Griffin that $a^4t = k$ seems generally to apply in the majority of, if not all, cases.

5. QUESTION 3: THE STANDARDS

The table of vibration dose values presented in BS6472 appears in an Appendix and may therefore be viewed as a proposal rather than as definitive. The values in the table are, indeed, derived directly from the base curves for r.m.s. acceleration presented in the main body of the standard. The derivation is via the estimation formula, eVDV = 1.4 x a (r.m.s.) x $t^{0.25}$, in which the 1.4 is itself an arbitrary constant. Griffin has shown that the eVDV approximation predicts true VDV very well in the case of vibration in buildings caused by passing trains, but it may not work so well for other types of signal.

More importantly, however, no large scale survey of human responses to different types of vibration, characterised by VDV, has been undertaken. It is possible that the VDV/response relationship does resemble the established r.m.s. acceleration/response relationship assumed in BS6472 and other standards, but until a substantial survey can be undertaken neither the degree of resemblance nor any source specific effect will be unknown.

Formidable difficulties confront the designer of a survey to evaluate the VDV/response relationship for a wide range of vibration affecting the occupants of buildings in the real world. Perhaps while these are being confronted a start could be made on validating table 7 of BS6472 through a user survey such as that which has been employed to gauge the effectiveness of BS4142:1990.

The National Physical Laboratory has conducted a survey which has involved users of the standard in filling in a simple form describing each case to which they have applied it. The survey has been described fully by Porter[4]. The results have cast a very interesting light on the use of the standard by practitioners in the field, as well as technically validating the assessment method.

A similar survey form could be designed and distributed amongst those carrying out vibration assessments in the field, particularly those responding to complaints. The applicability of table 7 in general terms could be investigated and a more focused study or research project could then be designed if it was found that the case studies mentioned here, for example, reflected a widescale phenomenon.

ACKNOWLEDGEMENT

The author acknowledges the assistance of the Environmental Health Department of the London Borough of Ealing.

REFERENCES

1. GRIFFIN, M J Handbook of Human Vibration. Academic Press, London. ISBN 0-12-303040-4 (1990).

2. British Standard 6472: 1992 Guide to evaluation of human exposure to vibration in buildings (1 Hz to 80 Hz). BSI, London (1992).

3. HOWARTH, H V C A review of experimental investigations of the time dependency of subjective reaction to whole-body vibration. United Kingdom Group Meeting on Human Response to Vibration, Loughborough University, 22-23 September 1986.

4. PORTER, N Study of the Application of the revised BS4142: 1990 'Method for Rating Industrial Noise Affecting Mixed Residential and Industrial Areas'. Proc. Proc. Inst. Acoustics, 13, (8) p31-42 (1991).