

FIELD MEASUREMENT OF VIBRATION IN COMPLIANCE WITH BS6472

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1. INTRODUCTION

The reasons for and philosophy behind the review that has led to the new edition of BS6472 'Guide to evaluation of human exposure to vibration in buildings (0.5 Hz to 80 Hz)' have been introduced [1],[2]. The intention of this paper is to cast light on the problems with field measurement of vibration apparently perceived by some practitioners and to introduce the guidance on it provided in the new edition of the standard.

The author is indebted to Hugh Hunt for having found and exhibited at a recent Institute of Acoustics meeting the following quotations:

"Common sense will carry one a long way but no ordinary mortal is endowed with an inborn instinct for vibrations."

"Vibrations are too rapid for our sense of sight ... common sense applied to these phenomena is too common to be other than a source of danger".

Prof. C. E. Inglis, FRS, James Forrest Lecture, 1944

In peril, then, of relying too much upon common sense, the origins of the guidance on field measurement of vibration provided in the new edition of BS6472 will be introduced in the context of a wider review of the problems involved.

2. THE STANDARD: VIBRATION MEASUREMENT IN PERSPECTIVE

It is not the purpose of a British Standard to provide a textbook on how to carry out measurements. The technical panel convened to review BS6472 thought about how far it should or could go in guiding practitioners on practical measurement procedures. It was itself guided by the advice advanced in foregoing standards and also in the Association of Noise Consultants' Guidelines [3], a more appropriate format for a general tutorial and textbook and a relevant companion to the Standard.

The principal object of the guidance in the new BS6472 is not to prescribe a measurement method to which the practitioner must rigidly adhere but rather to warn of the variables and leave the individual to make choices according to resources and measurement objects. It is quite acceptable to deviate from the guidance but essential to report any deviation in detail. The critical point is to understand how any such deviation might affect the measurement outcome and therefore the limitations circumscribing the result. A detailed report should allow a third party independently to reach the same conclusions.

The advice can be simply summarised: think about the application, choose an appropriate method, document it. If convenience demands compromise or deviation from the ideal without jeopardising the value of the measurement then the rule is clear and simple: report it! The very best advice for every scientific practitioner is: document every experiment or observation in such a way that an unknown third party could repeat it independently and obtain the same result.

3. INSTRUMENTATION

Compact, robust vibration meters capable of generating results as VDV's are slowly becoming available but practitioners in the field are still very widely using bespoke equipment, often post-processing data captured on site on tape or a solid state device to obtain VDV's. The question of measurement consistency has often been raised. In response the Association of Noise Consultants (ANC) undertook a 'Round Robin' exercise to test the consistency of inter-laboratory measurements of VDV under controlled conditions. The principal result of that practical exercise was that results from twelve different measuring systems, most of them bespoke systems put together by the participating practitioners rather than proprietary instruments, were consistent to within the equivalent of plus or minus 1dB, broadly equivalent to that of type 1 sound level meters [4]. In some part the perception of inconsistency might be influenced by the use of linear units by people accustomed to decibels.

It has been suggested that BS6472 should cross refer to BS EN ISO 8041 [5] as a normative standard for defining the tolerances of measuring instruments. At present it does not. The results of the ANC Round Robin exercise demonstrate that in appropriately expert hands accurate vibration measurements can be made in many different ways with diverse instrumentation. Strict adherence to BS EN ISO 8041:2005 could have excluded some of the instruments and techniques used in that exercise. It is not the desire of the BS6472 technical review panel to restrict or to prohibit approaches to measurement. The onus is on the practitioner to explain and to justify, and if necessary to prove, a chosen measurement method.

4. SAMPLING

As in all practical acoustics, the core of the measurement problem is statistical and involves averaging within a sample or across samples. In order to characterise the motion of a building element or of the ground the various wave regimes must be summarised in either or both of the time and frequency domains. Phase relationships might be significant under some circumstances in the measurement of VDV. The result of a desk study by members of the BS6472 review panel suggested that in most circumstances phase information can be ignored without significantly affecting the result, though summing third-octave components to obtain a weighted acceleration value has been excluded partly because of the loss of phase information. Clearly the chosen transducer must have the right response characteristics for the task. Where to place it, how to mount it and how long to sample for are all significant further variables. The panel considering the new edition of BS6472 stopped short of providing further detailed advice. The ANC Guidelines are a more appropriate source.

Frustrated with the inherent fragility of accelerometers and the palpable unsuitability of the laboratory vibration meters then available for work on site, the author started some fifteen years ago to investigate the availability of geophones and seismometers sufficiently sensitive for environmental vibration work. That search led to the development by a seismograph manufacturer of software to calculate VDV's and the author uses a compact, integral unit incorporating a triaxial geophone array as primary measurement tool.

A benefit of an integral instrument is that it can simply be screwed to a levelling plate in three-point contact with a building element (e.g. floor, windowsill) or the ground, levelled and left under its own weight to log vibration events. A suitable plate is specified in a Norsk Standard [6], which directs that provided that the mass of the whole assembly exceeds 1.5kg the plate can be used on floors fitted with carpets or other soft coverings. The magnitudes encountered in everyday planning and complaint investigation work are unlikely to be great enough to break the contact of a 1.5kg load under gravity on the vibrating surface. Correspondingly, the load imposed by the instrument is insignificant on a concrete slab, beam or the ground surface. The modifying influence of the load applied by the transducer on the test surface does become a concern if, by rule of thumb, the former exceeds 10% of the mass of the latter.

Unstaffed surveys can be undertaken with instruments incorporating magnitude and/or duration triggers either by programming the device with magnitude and/or signal duration thresholds or by setting it into a mode in which only the maximum magnitude per period is captured. Storing complete waveforms requires a great deal of memory and the survey duration is therefore limited. The disadvantages of logging only period maximum magnitudes are that if the whole time history is not logged events cannot be attributed to sources through pattern recognition and nor can VDV's be calculated. Even in staffed surveys it is not uncommon for vibrations to be logged that cannot be attributed to any observed event. One practical solution is always to monitor simultaneously at at least two locations. Train-induced vibration in a building, for example, can be monitored both within and on the ground outside. Only events correlated between the two records need be interpreted.

The availability of magnitude and duration thresholds can help to exclude unwanted events but measurement in occupied buildings is always problematic. Vibrations generated internally by people walking, slamming doors and so on can be difficult to exclude because their magnitudes might exceed those generated by the external source under investigation. Even duration triggers are fallible. The use of a differently located 'control' is beneficial, even in a staffed survey. Independent instruments with synchronised clocks are accurate enough for event attribution but not for investigating phase relationships between, for example, external free-field and internal building response signals. A single hub receiving signals from the transducer array is required for the latter.

The experience of a human subject is extremely hard to investigate for obvious reasons, not least that a living being moves. The investigation of vibration perceived in a favourite armchair should take the subject into account but loading the chair with sandbags might not be adequate. The homogenous sand would not respond in the same way as a human body with its various frequency response characteristics. Perhaps the solution would lie ultimately in the development of an 'artificial human'. The panel decided that advice on the minutiae of sampling is beyond the scope of BS6472. The standard, however, provides a platform for investigations and a study, for example, of the effect of loading a house floor with the weight of a human subject on its response to an external vibration could be within the capability of an Institute Diploma project.

5. BS6472 MEASUREMENT REQUIREMENTS

5.1 Part 1, general vibration

The aims in revising the standard were to address specifically some of the difficulties reported by those perplexed by the 1992 edition and to lay down the core objectives as simply as possible. Part 1 of the redrafted standard sets out the stall on general measurement:

"The object of measurement is to quantify the properly weighted acceleration of the motion and to derive from it the VDV for the subject(s) over day and/or night evaluation periods."

Ideally this should be achieved tri-axially in real time, the axes now chosen to represent the building in which the subject experiences or might experience the vibration rather than their posture. Uniaxial measurement is allowed, the object being to characterise the motion resolved along the axis on which the greatest magnitude of weighted acceleration occurs.

Given that it is not a British Standard's job to provide a textbook the instruction on transducer mounting is as simple as:

"Transducers should be mounted so as to reflect faithfully the motion of the object or surface being measured. There should be no loss-of-contact or resonance to affect the measurement over the relevant frequency range. ... The transducer mounting system used should be reported."

The last clause is vital. Accurate measurement and interpretation of results depends crucially on understanding the capabilities and limitations of the measurement system and method. Provided that what was used and how it was used are recorded faithfully, an interpreter removed from the

experiment by time and distance can determine the reliability of the reported result. The text refers to the ANC Guidelines for further practical advice on how to mount the transducer.

A preference and then a reminder to record any deviation from it make up the advice on what to record:

“Preferably the unweighted, band-limited acceleration time history should be recorded and retained and the required VDV obtained by subsequent analysis. Alternatively, the weighted acceleration may be evaluated directly in the field, or another parameter measured and the required VDV obtained indirectly. Whatever method is adopted, the instruments and settings used should be reported and a complete technical description given of any indirect method employed.”

The Standard still prefers that for general vibration measurement a raw acceleration time history should be the primary object and that the VDV, clearly now the objective for undertaking assessment, obtained from it by subsequent analysis. However, given the diversity of possible approaches the authors did not want to prohibit alternatives so again the key instruction is to document and to report everything. At frequencies over about 12Hz (vertical, w_b) or 4Hz (horizontal, w_d) the weighting curve is close to equivalence with constant velocity so the use of seismometry directly to measure velocity is technically sensible and the Standard does not preclude it.

One of the difficulties anecdotally reported by practitioners that informed the review process was that of measuring a subject's exposure to vibration at the point of contact between the subject's body and the vibrating surface. The new edition allows that:

“...it is seldom possible to identify such a position uniquely and therefore it is more normal to measure at a location that would be expected to give rise to the highest levels of vibration to which the occupants would be exposed. Where measurements are made other than at the point of entry of vibration to the body, an allowance should be made for the transfer function between the measurement point and the point of entry to the body. It is essential that this allowance is reported with the measurements.”

Guidance is offered on the measurement of vibration on floors:

“Vibration should be evaluated on the floor of the room implicated (where any complaint originates, or where the greatest adverse comment is predicted) at or near the point of greatest weighted acceleration. This will usually depend on two factors: whether the excitation is external or internal; whether the floor is “low frequency” or “high frequency”.”

Advice is provided on how to locate measurement points taking these factors into account. Whether a floor is high or low frequency can be judged by undertaking a heel-drop test. It is advantageous if the measuring apparatus in use will allow in-situ frequency analysis of the preliminary test before substantive measurements are commenced as the locations will be determined by the floor response.

Advice is given on measuring the vibration experienced by a subject using an item of furniture:

“If particular furniture is implicated in a complaint, it might be possible for the transfer function between the furniture/complainant and the floor surface to be estimated. The estimate and justification should be reported in detail.”

The compilation of a database of transfer functions will be a desirable outcome from application of the standard and publication of reports. Indeed, the need for published transfer functions both from the free field into structures and from structural elements into supporting surfaces, furniture and so on is the next most pressing after the need for a dose / response relationship for evaluation of exposure.

The emphasis throughout the standard on reporting is re-asserted in a new Annex that sets out a checklist of the information to be reported.

Vibration from blasting is now covered in a separate and entirely new Part 2 to the Standard. The guidance on measurement is different and specific.

5.2 Part 2, vibration from blasting

The impulsive vibration from blasting is perceived differently and occurs in a distinct time domain compared with general vibration. It has long been measured and assessed in velocity units and the review panel saw no evidence to justify change. Consequently Part 2 of the new BS6472 advises that:

“For blasting, the current practice is to measure the peak particle velocity (ppv) using velocity transducers. Currently used vibration measuring equipment or seismographs should be able to typically measure over the range $0.0001 \text{ m}\cdot\text{s}^{-1}$ ($0.1 \text{ mm}\cdot\text{s}^{-1}$) to $0.1 \text{ m}\cdot\text{s}^{-1}$ (100 mm s^{-1}) over the frequency range 4.5 Hz to 250 Hz.”

Consistently with Part 1, however, it allows that other instruments can be used provided that velocity characteristics can be derived and provided, too, that the method and instrumentation are fully reported. The ANC's Guidelines are referred to for advice on transducer mounting. The transducer should usually be mounted on a well-founded hard surface outside, but as close as possible to, the building of interest.

Part 2 deviates in one intriguing way from Part 1 in warning explicitly that:

“Results obtained might differ slightly among sets of equipment.”

This sentence, carried over from the 1992 edition of the standard, might not survive the final editing process. The ANC's 'Round Robin' exercise demonstrated inter-laboratory consistency to within the equivalent of plus or minus 1dB. Noise measurement standards do not warn of the variation in results from different sound level meters despite the tolerance for type 1 of plus or minus 2dB.

6. CONCLUSIONS

The requirements of the new edition of BS6472 in respect of vibration measurement can be summarised as:

- Think about the signal to be measured
- Carry out a preliminary investigation if practicable, e.g. by a heel drop test to establish floor response
- Choose equipment to suit
- Locate and mount transducer(s) thoughtfully
- For general vibration: preferably obtain a raw acceleration time history for post-processing
- For blasting vibration: preferably obtain a velocity time history
- Report in detail the equipment and procedures used

The standard does not preclude or exclude any measurement method but does demand that detailed records are kept. It provides a checklist to encourage thorough reporting.

An oft-stated object of standards is to provide the level playing field from which experiments to develop the field may be launched. That development will rely on the publication of reports, as amply encouraged in the new edition.

7. REFERENCES

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