RELIABILITY OF ASSESSMENT CRITERIA FOR BUILDING FLOOR VIBRATIONS UNDER HUMAN EXCITATION

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Abstract

Vibration serviceability of floor structures under internal human excitations is a key criterion that determines the acceptability or otherwise of both new-build structures and those that have been altered or subjected to a change of use. To assist structural engineers in the design of such floors and the assessment of the vibration environment, there are a number of guidelines and standards that propose limits for various occupancies. This paper focuses on vibration serviceability of office floors under human excitation and examines actual responses acquired from whole day monitoring of four typical office floor structures. The reliability of the limits proposed in the various guidance documents is assessed, with the key conclusions that limits based on R factors are not particularly reliable and assessments on the basis of vibration dose values are more reliable but the currently specified limit in BS6472 may be too high.

1. Introduction

Vibration serviceability of floor structures under internal human excitations is a key criterion that determines the acceptability or otherwise of both new-build structures and those that have been altered or subjected to a change of use. To assist structural engineers in the design of such floors and the assessment of the vibration environment, there are a number of guidelines and standards that propose limits for various occupancies.

However, amongst these guidelines and standards there is a lack of consistency in both the approaches used for vibration serviceability assessment and also the recommended vibration limits. With particular focus on office floor vibrations, the purpose of this paper is to present measurement data from four structures that have been monitored and for which vibration time histories have been analysed to determine their performance assessment according to the various criteria. These are then compared with the subjective assessment of the floors so that the reliability of the criteria may be assessed.

2. Vibration assessment guidelines and standards

The following documents have been used for this work:

- BS6472-1 Guide to evaluation of human exposure to vibration in buildings - Part 1: Vibration sources other than blasting (British Standards Institution, 2008).
- Steel Construction Institute (SCI) Publication P354 Design of Floors for Vibration: A New Approach (Steel Construction Institute, 2009).

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- Concrete Centre CCIP-015 A Design Guide for Footfall Induced Vibration of Structures (Concrete Centre, 2006).
- Concrete Society Technical Report 43 Appendix G Vibration Serviceability of Post-Tensioned Concrete Floors.

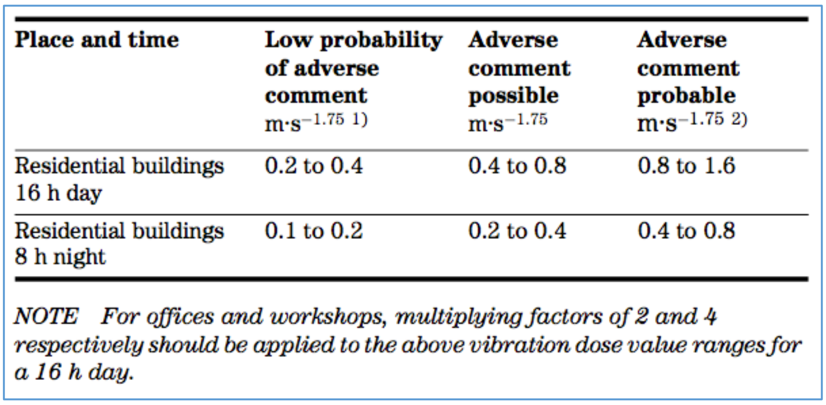
In recent years, most guidance documents for floor vibrations have used root-mean-square (RMS) accelerations as the vibration descriptor most representative of human response to vibration. A further convention that has become established is the use of so-called ‘R factors’ to represent multiples of the baseline RMS acceleration of 0.005 m/s^2. This is true of the SCI P354, CCIP-015 and CS TR43 documents evaluated here. The limits recommended for office floors are summarised in Table 1.

Table 1: R factor limits from guidance documents.

Document	**Vibration Limit (R factor)**
SCI P354	8
CCIP-015	4
CS TR43 App G	4

BS6472-1 represented a departure from the more traditional RMS acceleration approach and proposed that assessment should be carried out on the basis of vibration dose values (VDVs). However, it fell short of recommending limiting values of VDV and instead gave the guidance shown in Table 2 below. Hence the limit for office buildings is considered to be 0.4-0.8 $m/s^{1.75}$, which in practice would usually be taken as 0.8 $m/s^{1.75}$.

Table 2: Vibration dose value ranges which might result in various probabilities of adverse comment within residential buildings (after BS6472-1:2008).



Place and time	**Low probability of adverse comment** $m\cdot s^{-1.75}$ 1)	**Adverse comment possible** $m\cdot s^{-1.75}$	**Adverse comment probable** $m\cdot s^{-1.75}$ 2)
Residential buildings 16 h day	0.2 to 0.4	0.4 to 0.8	0.8 to 1.6
Residential buildings 8 h night	0.1 to 0.2	0.2 to 0.4	0.4 to 0.8

NOTE For offices and workshops, multiplying factors of 2 and 4 respectively should be applied to the above vibration dose value ranges for a 16 h day.

An important concept used for vibration assessment is that of ‘frequency weighting’, in which frequency weighting curves are applied to measured time history data to attenuate frequency components in measured signals to which humans are less sensitive. For office floors, the W_b weighting function as defined in BS6841 (British Standards Institution, 1987) is most commonly applied, as shown in Figure 1.

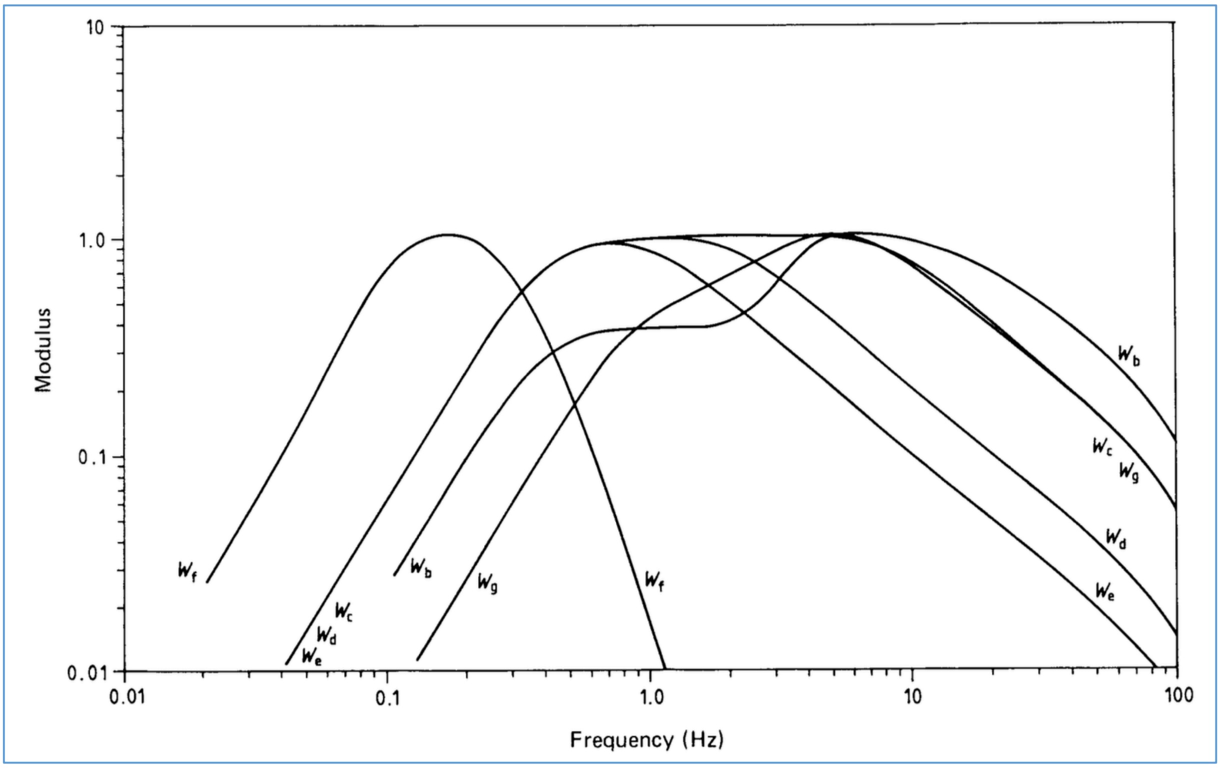


Figure 1: Moduli of frequency weightings given in BS6841:1987.

3. Experimental Investigations

3.1 The Structures

Results from four structures in the UK are presented in this paper, as described below. All of these floors were of composite steel/concrete construction supported by steel frames. However, they had a range of performances, which are of interest in this work.

- Structure A: An office floor, which had attracted complaints from its occupants. This structure was monitoring for three consecutive days.
- Structure B: An office floor, which subjectively was assessed by its occupants as being borderline acceptable.
- Structure C: An office floor, which also was subjectively assessed by its occupants as being borderline acceptable.
- Structure D: A floor in a college building, which was being excited by activities in a gymnasium and which was deemed by its occupants as being clearly unacceptable.

3.2 Data Acquisition and Analysis

For each of the four structures, raw acceleration time history data were acquired using high quality accelerometers (Endevco 7754A-1000 or Honeywell QA750) and data acquisition hardware (Data Physics Mobilyzer II or National Instruments CompactRIO). The accelerometers were located on the floor structure at a point of high response and data were acquired for at a complete working day (three days in the case of Structure A).

The data were sampled at at least 200 Hz so that frequencies up to 80 Hz would be well-represented in the measured time histories. Subsequent to the data acquisition, the following data analysis steps were carried out:

- BS6841 W_b frequency weighting was applied
- Running RMS trends were calculated using 1 s integration time
- The peaks of the running RMS were determined for RMS-based assessment, otherwise known as maximum transient vibration value (MTVV)
- Cumulative VDVs were calculated
- Maximum VDVs were established (i.e. the cumulative VDV at the end of the day)

3.3 Results

Figure 2 shows typical in-service monitoring results obtained from Structure A. In the upper plot, the W_b frequency weighted time history is shown in blue and the 1 s running RMS trend is shown in red. The lower plot shows the cumulative VDV, with the overall VDV for the whole day being the maximum value at the right side of the plot.

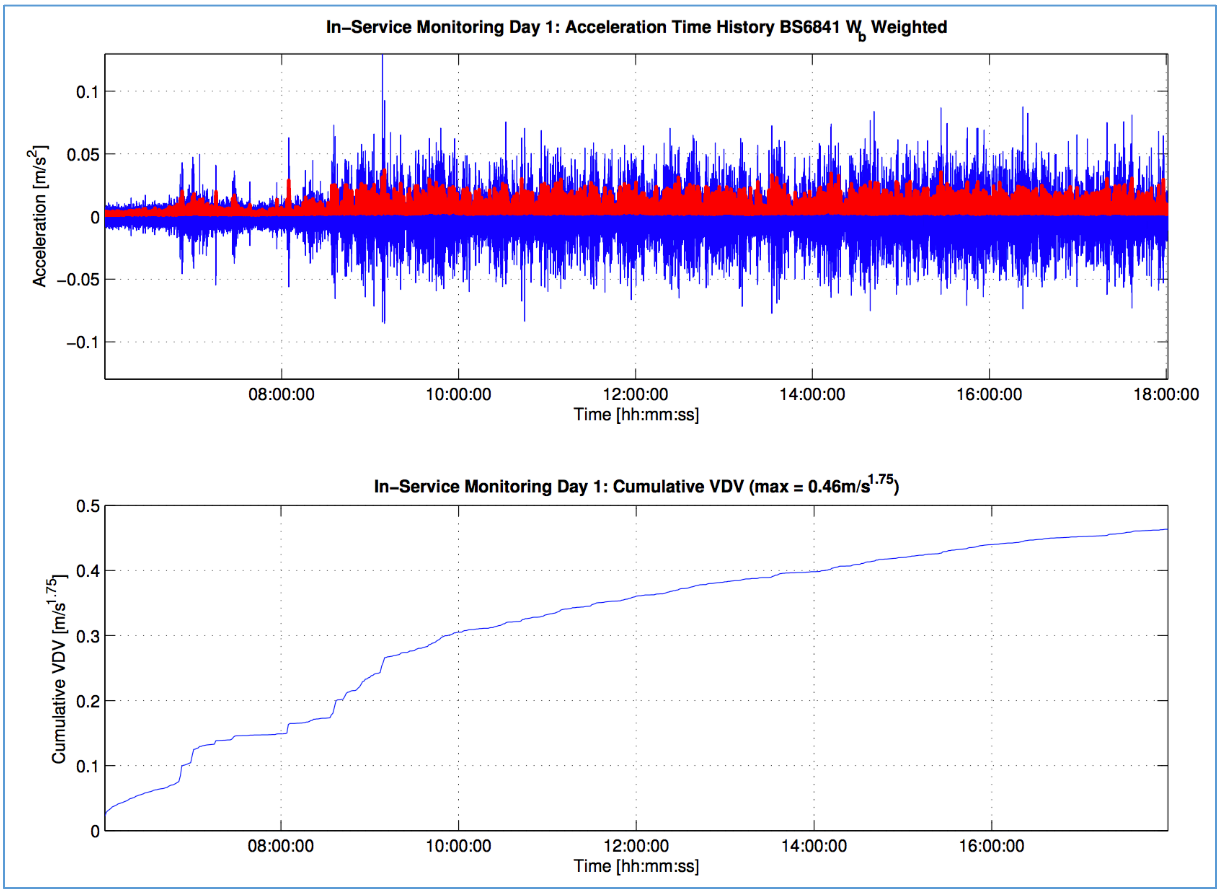


Figure 2: Typical in-service monitoring results from Structure A.

The results for all structures are shown in Table 3.

Table 3: In-service monitoring response results for all structures.

Structure	**Day**	**MTVV** **[m/s^2]**	**R factor**	**VDV** **[m/s$^{1.75}$]**	**Monitored period**
A	1	0.036	7.2	0.46	06:00-18:00
A	2	0.040	8.0	0.46	06:00-18:00
A	3	0.036	7.3	0.45	06:00-18:00
B	1	0.038	7.6	0.16	06:00-18:00
C	1	0.060	12.0	0.15	07:00-19:00
D	1	0.076	15.1	0.36	06:00-19:00

4. Discussion of Results

As mentioned in Section 3.1, Structures A and D were subjectively assessed to be unacceptable and Structures B and C were subjectively assessed to be borderline acceptable.

Examining first the measured R factors, the measurements do not seem to correlate well with the subjective assessments. Structure A had the lowest R factor even though it was subjectively assessed as unacceptable. It also showed a degree of variation between the three days of monitoring carried out. Structure C, which was deemed to be borderline acceptable had quite a high R factor of 12.0 which is above the allowable limits specified in Table 1. Is it possible that the R factor based assessment approach may be improved by considering probability distributions of R factors over time and taking a value with a certain percentage chance of exceedance, rather than an absolute peak. In this case, such a procedure should be verified and clearly described in guidelines or codes.

Considering the subjective assessments of the three structures, the VDV values appeared to give a better indication of structural acceptability. The two problematic structures (A and D) had relatively high VDVs whereas the borderline acceptable structures (B and C) had relatively low VDVs. Nevertheless, all structures had VDV values well below the limit specified in BS6472:2008 of 0.8 m/s$^{1.75}$, which indicates that this limit may be too low for these sorts of structures and excitations.

5. Conclusions

The key conclusions are as follows:

- The correlation between measured R factors and subjective assessment of performance was not particularly good.
- The correlation between measured VDVs and subjective assessment of performance was better than for R factors, although the limit in BS6472 seems to be too high.

Considering these conclusions on the basis of this limited dataset, it is clear that there is a need for a further programme of research to carry out more extensive in-service monitoring of structures together with subjective assessments, with a view to improving understanding of reliable vibration descriptors and acceptable limits.

6. Acknowledgements

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7. References

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