Appendix 14.1: Sloy Pumped Hydro Storage Scheme: Proposed Construction Vibration Limits

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Vibration From Construction Activities

Without detailed knowledge of the exact construction plant specifications, local geology and test measurements (which could not be undertaken until during the construction period), it is not possible to undertake useful vibration predictions. Rather, it is more appropriate at this stage to advise on a set of appropriate vibration limits that could be used for the protection of the closest receptor, NSR1 - Sloy Power Station Bungalow.

A number of British Standards are available that provide guidance in respect of the measurement and assessment of vibration. With regards to environmental vibration effects (as opposed to occupational health effects) the key documents relevant to the Proposed Development are;

- *BS 7385-2:1993*;
- *BS 6472-1:2008*; and,
- *BS 5228-2:2009+A1:2014*.

BS 7385 2:1993 'Evaluation and measurement for vibration in buildings. Guide to damage levels from groundborne vibration,' presents guidance in relation to the effects of vibration on buildings, whereas *BS 6472-1:2008 'Guide to evaluation of human exposure to vibration in buildings'* is concerned with the effects of vibration on humans. Both of these standards document the impacts that are associated with environmental vibration effects, regardless of the vibration source (except for blasting, which is covered in separate documents).

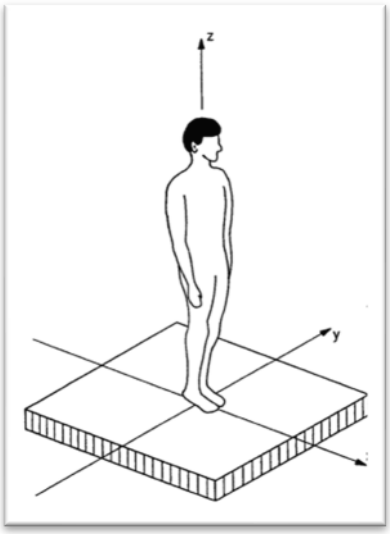
In contrast, *BS 5228* is for use specifically for construction activities only, though it does draw on the data presented in both *BS 7385* and *BS 6472*.

Vibration Criteria Related to Effects on Buildings

Threshold values to determine the potential for damage to buildings are detailed in *BS 7385 2:1993*. The unit of measurement used for this assessment method is the Peak Particle Velocity (PPV), which is quantified in mm/s.

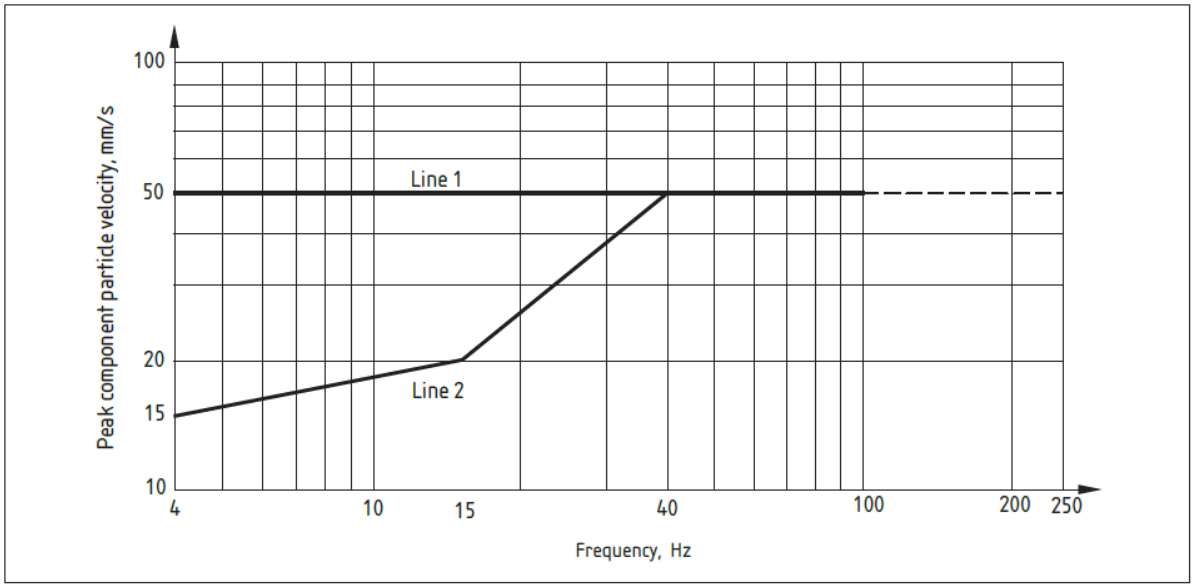
Vibration is measured in three separate axis (indicated in Image 1 as x, y and z), which are known as longitudinal, transverse and vertical. The assessment is made against the Peak Component Particle Velocity, which is the maximum PPV measured in any one of these three axes.

Image 1: The Three Axis of Vibration



The Standard provides limits for transient vibrations at which cosmetic building damage could occur and these are indicated in Figure 1 of the standard, which is replicated here as Image 2.

Image 2: Transient Vibration Guide Values for Cosmetic Damage to Buildings



Line 1 represents reinforced or framed structures such as industrial and heavy commercial buildings, whereas Line 2 represents *"unreinforced or light framed structures. Residential or light commercial type buildings*". It is the values in Line 2 that are of interest here.

Beyond cosmetic damage, minor damage may occur at twice the values shown in Image 2 and major damage may occur at four times the values. Table 1 presents these levels in tabular form.

Table 1: Transient vibration guide values for building damage

Peak Component Particle Velocity (mm/s)	Damage Levels for residential buildings
15mm/s PPV for a frequency of 4Hz, rising to 50mm/s PPV for a frequency of 40Hz and above	Cosmetic
30mm/s PPV for a frequency of 4Hz, rising to 100mm/s PPV for a frequency of 40Hz and above.	Minor
60mm/s PPV for a frequency of 4Hz, rising to 200mm/s PPV for a frequency of 40Hz and above.	Major

The monitoring of PPV in respect *BS 7385-2* is relatively straight-forward and can be done through the mounting of a small tri-axial accelerometer on an external façade of the receptor.

Vibration Criteria Related to Effects on Persons in Buildings

In contrast, *BS 6472-1:2008* provides threshold values to determine the probability of '*adverse comment*' as a result of perceived vibration within buildings. In this regard, the standard states;

"The first overt sign of an unfavourable reaction to building vibration is adverse comment, whereby occupants express negative responses to the vibration. The prevalence of adverse comment depends on specific circumstances, which can include parallel effects such as re-radiated noise. The acceptable magnitudes for building vibration might depend similarly on these parallel effects. This British Standard provides best available information on the application of methods of measuring and evaluating vibration in order to assess the likelihood of adverse comment."

Humans are particularly sensitive to vibration and can perceive vibrations at very low levels that are significantly less than those needed to cause cosmetic damage to buildings. Thresholds of perception can be in the region of 0.14mm/s^{-1} to 0.3mm/s^{-1}. In this regard *BS5228-2* states;

"Vibrations, even of very low magnitude, can be perceptible to people …"

"Vibration nuisance is frequently associated with the assumption that, if vibrations can be felt, then damage is inevitable; however, considerably greater levels of vibration are required to cause damage to buildings and structures…." and,

"In residential accommodation, vibrations can promote anxiety lest some structural mishap might occur …. although such levels are unlikely to be encountered as a result of construction and demolition activities"

Vibration within buildings can be either continuous, intermittent, or occasional and may or may not be impulsive (i.e. build up to a rapid peak, rather than a gradual increase). In order to provide an appropriate metric for the assessment of human response to these different types of vibration *BS 6472-2* provides a method to calculate a Vibration Dose Value (VDV), which takes into account the total amount of time that vibration can occur within specific time periods.

Table 1 of the standard, replicated here as Table 2, provides a range of VDVs that might result in adverse comment.

Table 2: Vibration Dose Value ranges which might result in various probabilities of adverse comment within residential buildings.

Place and Time	Low probability of adverse comment, ms-$^{1.75}$ (i)	Adverse comment possible, ms-$^{1.75}$	Adverse comment probable, ms-$^{1.75}$ (ii)
Residential buildings 16 hour day	0.2 to 0.4	0.4 to 0.8	0.8 to 1.6
Residential buildings 8 hour night	0.1 to 0.2	to 0.4	0.4 to 0.8

i. Below these ranges adverse comment is not expected

ii. Above these ranges adverse comment is very likely

In respect of the above values, BS6472-2 states;

"*Vibration magnitudes that would normally result in adverse comment can sometimes be tolerated, particularly for temporary disturbances or infrequent brief events; an example would be a construction project. However, to reduce adverse comment, the affected community would usually need to be advised*

of the likely effects, the duration of the activity and that the likelihood of building damage is very low even when vibration levels are well above perception thresholds.

The monitoring of VDV in respect of *BS 6472-1* during a construction project is much more difficult than measurements for *BS 7385-2*, as it relies on monitoring within the residence. Any movement from occupants, use of washing machines and other appliances etc. can affect the measured values. Therefore, only PPV levels that can be recorded externally are typically monitored.

Vibration Criteria for Construction Activities

Although *BS 6472-2* provides threshold values in VDV, for construction projects it is usual to only assess using the PPV metric. This is described in *BS 5228-2*, which states;

"Whilst the assessment of the response to vibration in BS 6472 is based on the VDV and weighted acceleration, for construction it is considered more appropriate to provide guidance in terms of the PPV, since this parameter is likely to be more routinely measured based upon the more usual concern over potential building damage. Furthermore, since many of the empirical vibration predictors yield a result in terms of PPV, it is necessary to understand what the consequences might be of any predicted levels in terms of human perception and disturbance."

Table B.1 of *BS 5228-2*, reproduced here as Table 3, provides guideline PPV levels that can be used in a construction setting, rather than having to rely on the VDV *BS 6472-1* thresholds.

Table 3: *BS 5228* Guidance on Effects of Vibration Levels

Vibration Level [A] [B] [C]	Effect
0.14 mm/s-1	Vibration might be just perceptible in the most sensitive situations for most vibration frequencies associated with construction. At lower frequencies, people are less sensitive to vibration.
0.3 mm/s-1	Vibration might be just perceptible in residential environments.
1.0 mm/s-1	It is likely that vibration of this level in residential environments will cause complaint but can be tolerated if prior warning and explanation has been given to residents.
10 mm/s-1	Vibration is likely to be intolerable for any more than a very brief exposure to this level in most building environments.

A. The magnitudes of the values presented apply to a measurement position that is representative of the point of entry into the recipient.
B. A transfer function (which relates an external level to an internal level) needs to be applied if only external measurements are available.
C. Single or infrequent occurrences of these levels do not necessarily correspond to the stated effect in every case. The values are provided to give an initial indication of potential effects, and where these values are routinely measured or expected then an assessment in accordance with *BS 6472-1 or -2*, and / or other available guidance, might be appropriate to determine whether the time varying exposure is likely to give rise to any degree of adverse comment.

For the assessment of vibration effects on buildings, *BS 5228-2* refers to the guideline values previously detailed in *BS 7385-2* (as summarised in Table 1).

Proposed Vibration Limits

With due regard to the above, it is proposed that external vibration PPV limits are set (and monitored) for the duration of the construction period at the nearest residential receptor (NSR1) to ensure that vibration levels remain below the levels denoted by 'Line 2' in Image 2: *Transient Vibration Guide Values for Cosmetic Damage to Buildings*.

In the event of a complaint in respect of human response to vibration (as opposed to potential building damage), then the external equivalent PPV limit of an internal 0.3 mm/s^{-1} internal limit should be defined with due regards to points A, B and C of Table 3, through the calculation of a transfer function based on on-site measurements.