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GROUNDBORNE PROPAGATION OF INDUSTRIAL NOISE AND VIBRATION TO HOUSING

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1 INTRODUCTION

Whilst the main emphasis on groundborne propagation of vibration has generally been directed towards such operations as piling, blasting and rail transportation, vibration from industrial sources such as presses, large guillotines and forges can be significant at nearby residential properties, either as perceptible vibration, or as re-radiated noise. It is, therefore, appropriate to consider the vibration implications of industrial activities on residential properties in addition to the noise emissions and local planning authorities may impose conditions relating to vibration effects from industrial premises where an application for change of use or an extension of an industrial operation is submitted, or when considering new residential development near industrial sites.

This paper reviews two case studies where such conditions were imposed and specialist assessments of the vibration effects were required. The first study related to the extension of an existing industrial facility to accommodate large milling machines, while the second involved a planning condition imposed on the refurbishment and redevelopment of a previously commercial site for residential use.

2 GUIDANCE AND CRITERIA

General advice to planning authorities on the effects of vibration and vibration induced noise on housing has not been included in planning guidance such as PPG 24[1], except for a comment at Annex 3, paragraph 4, relating to vibration from railways and, in particular, vibration and re-radiated noise from trains running in tunnels. This refers to the criteria for acceptable levels of vibration given in BS 6472[2], but makes no further reference to acceptable levels of re-radiated noise from railway vibration. There is no guidance on groundborne vibration and consequent re-radiated noise from industrial sources at Annex 3 paragraphs 19 and 20 (*Noise from industrial and commercial developments*), although reference is made to the general guidance on noise levels in buildings given in BS 8233[3], which may be considered applicable to re-radiated noise resulting from propagation of vibration. In the absence of specific planning guidance on perceptible vibration, however, it would be expected that the criteria given in BS 6472 would be applicable.

3 CASE STUDY 1 – EXTENSION OF INDUSTRIAL PREMISES

This study concerned an application for an extension to an existing industrial premises, situated on land between residential properties in an area of mixed residential and commercial land uses. In addition to conditions relating to the control of airborne noise, the planning consent included the requirement that details of “anti-vibration mountings for all machinery” be submitted to the local authority.

The Applicant subsequently installed four large milling machines in the extension and a variety of smaller machine tools in the pre-existing part of the premises. The latter were to be bolted directly to the ground slab, while the large mills were founded on a 1 m deep concrete slab poured directly onto the bedrock. The junctions between the mill foundations and the normal ground slab incorporated a resilient joint. This foundation was consistent with the recommendations of the manufacturers of the mills for a rigid and stable base that did not allow relative movement of the mill table and cutter head that could lead to misalignment. The large mills were to be used for the shaping of billets of steel to form dies for automotive mouldings and the process included heavy cutting initially to rough out the die, prior to the finer and more accurate finishing cuts.

The Applicant considered that the resilient joint would provide adequate isolation of the mills and that the planning obligation had, therefore, been discharged.

Subsequent to operations starting at the premises, the local planning authority requested details of the vibration isolation and a demonstration that the conditions relating to airborne noise had been met. It is understood that complaints relating to noise and vibration from the milling operations had been received from the occupants of a residential property located approximately 40 m from the mills. The English Cogger Partnership was, therefore, commissioned to undertake an assessment of the airborne noise and groundborne vibration levels at the site and determine whether the planning conditions could be considered to have been discharged.

3.1 Vibration Measurements

Measurements of groundborne vibration were undertaken in the car park, which was contiguous with the internal factory slab, using an accelerometer attached with beeswax to the surface. The measurement location was aligned with the mills at a distance of 10 m from the nearest façade and 15-35 m from the mills. Vertical vibration acceleration levels were measured in the ⅓-octave bands in the range 0.8 Hz-1 kHz, initially with no mills running, then with various combinations of operating conditions at maximum cutting rates. The measured acceleration levels are shown in Figure 1, from which it can be seen that, whilst ground vibration levels were significantly above the background level in the range 20 Hz-315 Hz, they were well below the threshold of perceptibility. These levels also represent worst case conditions (maximum cutting rates) and the mills would generally be operating at much finer cuts, with lower levels of induced vibration.

The nearest residential properties are further than 20-30 m from the mills and limited additional attenuation of the vibration levels would be expected at the foundations of these buildings. Whilst some amplification can occur in building elements, particularly lightweight floors, the vibration measured would not normally be expected to result in perceptible vibration when subject to such levels of such amplification, although this could not be ruled out under certain extreme cutting conditions, where a peak in the vibration spectrum coincides with one of the low order natural frequencies of a lightweight floor. The measured levels are such that, whilst perceptible vibration might occasionally occur under such circumstances, this would be expected to be within the criteria specified for satisfactory magnitudes of building vibration with respect to human response (BS 6472 curves 2-4 for daytime and curve 1.4 for night-time). It should also be noted that vibration above 80 Hz, where the higher levels of vibration acceleration from the milling was found to occur, is not normally significant in the context of human perceptibility.

3.2 Re-radiated Noise

Although vibration levels were shown to be below levels at which perceptible vibration could occur at residential properties, and it could be concluded that the planning condition relating to vibration had been discharged without the need for isolation other than the resilient joint at the junction of the machine foundations and the normal ground slab, complaints of perceived noise at a nearby property were also investigated.

Noise from milling could be heard in rooms facing the industrial premises and, whilst the overall (A-weighted) level of daytime background noise was unaffected, the character of the sound made it distinguishable and identifiable – so much so that the stage of the cut could be determined. The noise clearly resulted from re-radiation from the walls of the house and could be detected using an accelerometer. It is understood that the house foundations continue down to the same shallow bedrock as the mill foundation slabs and this resulted in relatively good coupling between the source and receiver.

The re-radiated noise also affected the main bedroom of the house and was reported as being disturbing from time to time (this was assumed to be when roughing out was undertaken during the night shift), although absolute noise levels were within the criteria recommended in BS 8233 for bedrooms at night (30-35 dB L_{Aeq}).

3.3 Mitigation Strategy

Whilst it could be argued that vibration levels were sufficiently low for the planning condition relating to vibration to have been discharged adequately without isolation of the mill foundations from the bedrock, re-radiated noise was causing a disturbance and was potentially a statutory nuisance. The disposition of the nearby residential development was such that properties other the one assessed could also have been affected.

Ideally, effective mitigation could be achieved without adversely affecting the mill alignment by mounting the machines on isolated inertia blocks, designed to de-couple the machine from both the floor slab and the bedrock. The cost of this, when undertaken retrospectively, would, however, have been prohibitive to the company and could not be justified on economic grounds. It was, therefore, concluded that the only cost-effective solution would be to restrict use of heavy cutting to daytime hours and to limit depth of cut during the evening and at night to a range that did not result in unacceptable levels of re-radiated noise. The use of 6-fluted cutters, rather than the 2-fluted cutters generally in use, to provide a higher flute excitation frequency, was also to be assessed.

4 CASE STUDY 2 – RESIDENTIAL DEVELOPMENT

The second study involved a development site adjacent to an established industrial premises. The site comprised an existing retail building fronting the street and a storage building to the rear. The redevelopment proposals were for conversion of the retail and storage buildings to residential use and additional new residential units further to the rear of the site, on open land. The existing and proposed buildings were adjacent to the boundary with the industrial premises and the foundations of the residential and industrial buildings were within 2 m of each other.

The local authority was concerned that airborne noise and groundborne vibration from plant and machinery, and in particular a guillotine used for cutting steel plate of up to 13 mm in thickness, would be intrusive. The authority granted consent subject to a condition requiring that:

Before the development hereby permitted is commenced a sound insulation scheme shall be submitted to and approved by the Local Planning Authority and completed to its reasonable satisfaction. The approved scheme following its installation shall thereafter be permanently retained and maintained. The agreed scheme shall provide for protection from vibration from neighbouring factory premises.

The English Cogger Partnership was commissioned by the local authority to assess the developer's proposed scheme to determine whether the condition could be considered to be discharged. The authority also served notice preventing further structural works until it was satisfied that the planning condition could be met.

4.1 Proposed Vibration Isolation Strategy

The strategy for the existing buildings was constrained by the requirement to retain the existing shell, which was of a traditionally built stone construction, with walls approximately 400 mm in thickness. Although the remainder of the building would be of new construction, the upper floor joists had to provide lateral restraint to the principal façades which limited the degree to which these could be isolated from the main structure. The ground floor slab was to be cast over a thermally insulating foam layer, with no vibration isolation incorporated.

For the upper floors, the developer proposed to install a proprietary resilient flooring system incorporating visco-elastic damping strips laid over the joists, which were isolated from the wall brackets with an 8-10 mm rubber pad. The plasterboard ceilings were to be supported from proprietary resilient bars. An independent wall lining system was to be installed along the façade facing the industrial premises, forming single aspect accommodation. Although the bedrooms were to be separated from the exposed façade by a lobby, the living rooms extended the full depth of the building.

The new building, comprising a terrace of town houses, was of conventional masonry cavity wall construction and did not incorporate any strategy for the control of groundborne vibration, although a single aspect design had been used to minimise airborne sound transmission.

4.2 Vibration Assessment

At the time of the commission to review the vibration control strategy, the buildings were in a partially completed state. Chipboard base flooring panels had been installed on the upper floor joists of the existing building, but the resilient flooring system, ceilings and independent wall lining had not been installed. The building had been roofed, but the stairs had not been installed. The town houses had no floors or roofing installed, although the joists had been fitted.

Vibration levels were recorded at first floor level in the existing building during the operation of each item of equipment likely to give rise to groundborne vibration (the guillotine, a travelling crane and a hole punch) using an accelerometer mounted at the centre span of the floor and on the rear façade. Background vibration levels were also recorded and an assessment of the principal natural frequencies of the floor derived from a series of impacts (heel drops).

Operation of the equipment was clearly audible in the building and noise measurements were also undertaken in the living area and stairwell, to determine the relationship between noise and vibration levels. Measurement of noise levels in the empty stairwell enabled the airborne noise level to be determined without the influence of re-radiation from the floor.

The floor vibration acceleration levels due to operation of the guillotine are shown in Figure 2, together with the floor response determined from heel drops. Excitation of the floor by the guillotine is evident and was found to be above the level of perception, with the dominant energy being in the 16 and 20 Hz ⅓-octave bands and the 400 and 500 Hz ⅓-octave bands. Vibration of the wall is shown in Figure 3, with a peak at 31.5 Hz. The noise levels in the living room and stairwell are shown in Figure 4 and show that, in addition to a sharp peak at 63 Hz, there was also a significant contribution at 400-500 Hz. The latter would appear to be related to the excitation of the floor at these frequencies.

It was concluded that, whilst the internal partitions and floor loadings when occupied would change the responses of the building elements, there remained a significant risk that perceptible vibration and structureborne noise would remain evident on completion and that the proposed mitigation strategy would not be adequate to discharge the planning condition. Specifically, the joist support pads would be unlikely to provide significant attenuation of the frequencies below 100 Hz, although a limited reduction in the higher frequency re-radiated noise may have been expected with the resilient flooring system in place.

4.3 Recommendations

A conventional building isolation system was considered to be impracticable for both the existing buildings (because of the construction) and for the new town houses (because the walls and roof supports had already been built). It was, therefore, recommended that the flooring systems for both the existing building and the new town houses be redesigned to provide improved isolation of the floors and ceilings, based on a maximum system natural frequency of 12 Hz. In the existing building this would incorporate 38 mm thick plasterboard ceilings suspended from spring hangers and two layers of 25 mm timber flooring supported on resilient battens on the existing joists. Internal partitions would then be supported on resilient strips.

The new town houses would have joists located on bearings at the support brackets, to give a natural frequency of 11 Hz. Vertical internal partitions, floors and ceilings would then be supported off the isolated joists.

Careful detailing of services penetrations to prevent bridging of the vibration isolation systems was required in both buildings.

These proposals were deemed to be acceptable to the planning authority and the condition was considered to be discharged.

5 CONCLUSIONS

These case studies demonstrate that, whilst vibration is often recognised as a significant planning issue and planning conditions relating to control of vibration and re-radiated noise may be imposed, the response by the applicants can be insufficient to deal adequately with the issues and enable the condition to be properly discharged.

This may be due, at least in part, to a lack of understanding of the principles involved and of the solutions necessary to deal with low frequency energy. It is clearly essential that any vibration mitigation strategy is considered at the earliest stages of a development and suitable remedial measures incorporated into the structural design. As has been shown by these studies, it is often not practicable or cost-effective to undertake remedial works retrospectively. In the first study, the only viable solution to the problem of re-radiated noise from the industrial operations was to impose limitations on the work undertaken at the site, while in the second case, it was only possible to install limited vibration mitigation because the local authority had recognised the problem in time to stop construction until a satisfactory solution had been designed for the buildings.

REFERENCES

[1] Department of the Environment, (1994) *PPG24: Planning and Noise*, The Stationery Office, London

[2] British Standards Institution (1992), *BS 6472: 19992, Guide to Evaluation of human exposure to vibration in buildings (1 Hz to 80 Hz)*, British Standards Institution, London

[3] British Standards Institution, (1999) *BS 8233: 1999, Sound insulation and noise reduction for buildings – Code of practice*, British Standards Institution, London

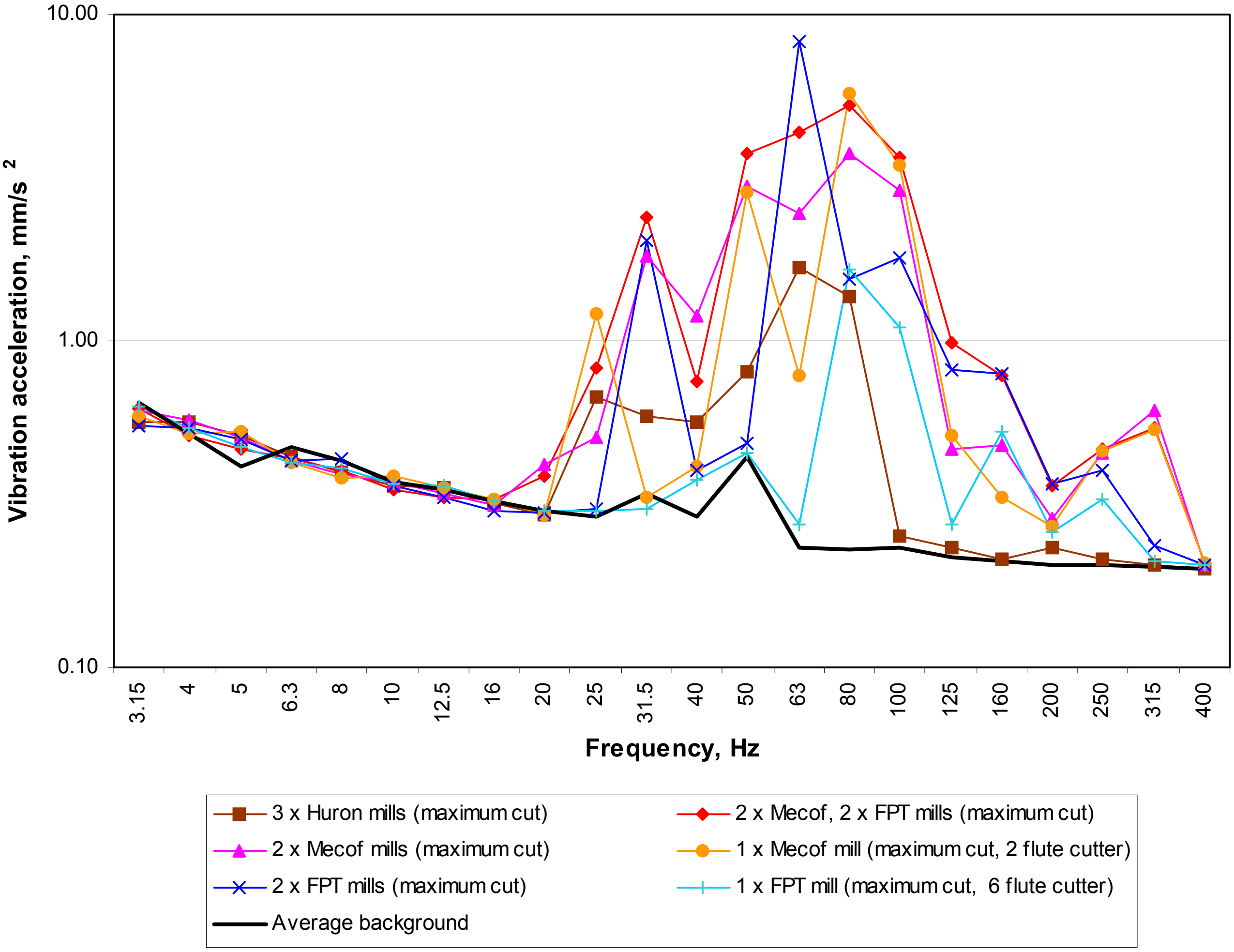

FIGURE 1: Vertical vibration acceleration levels from milling operations

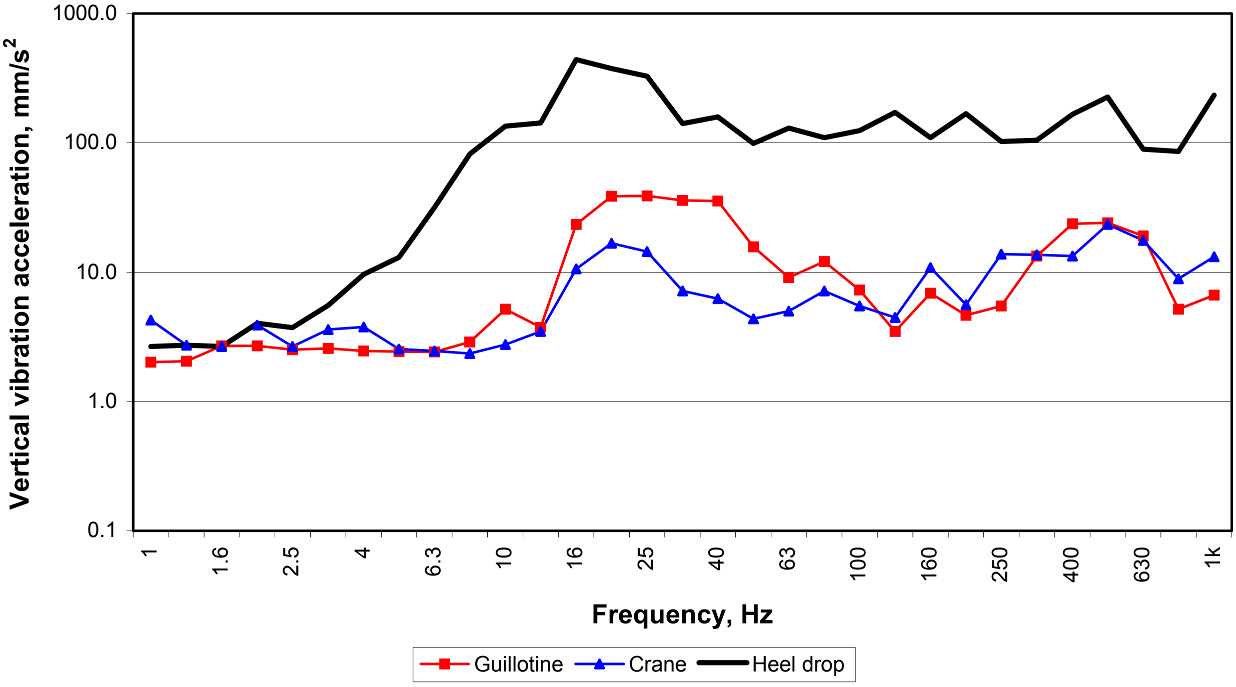

FIGURE 2: Vertical vibration at centre span of first floor due to operation of guillotine and crane

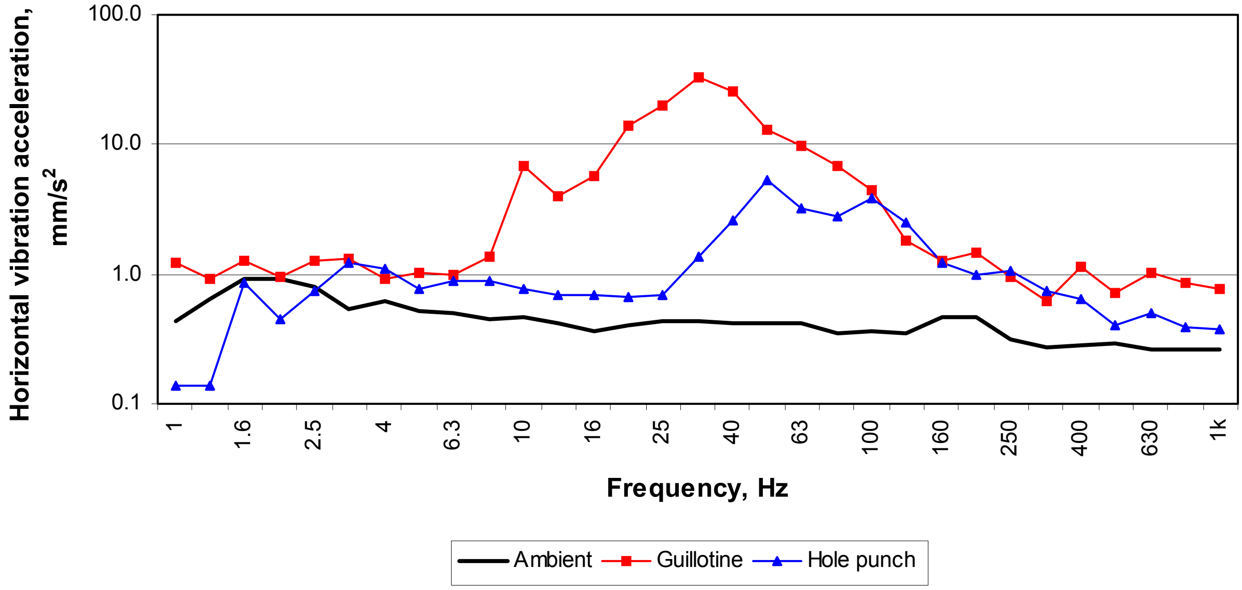

FIGURE 3: Horizontal vibration at centre of first floor wall due to operation of guillotine and crane

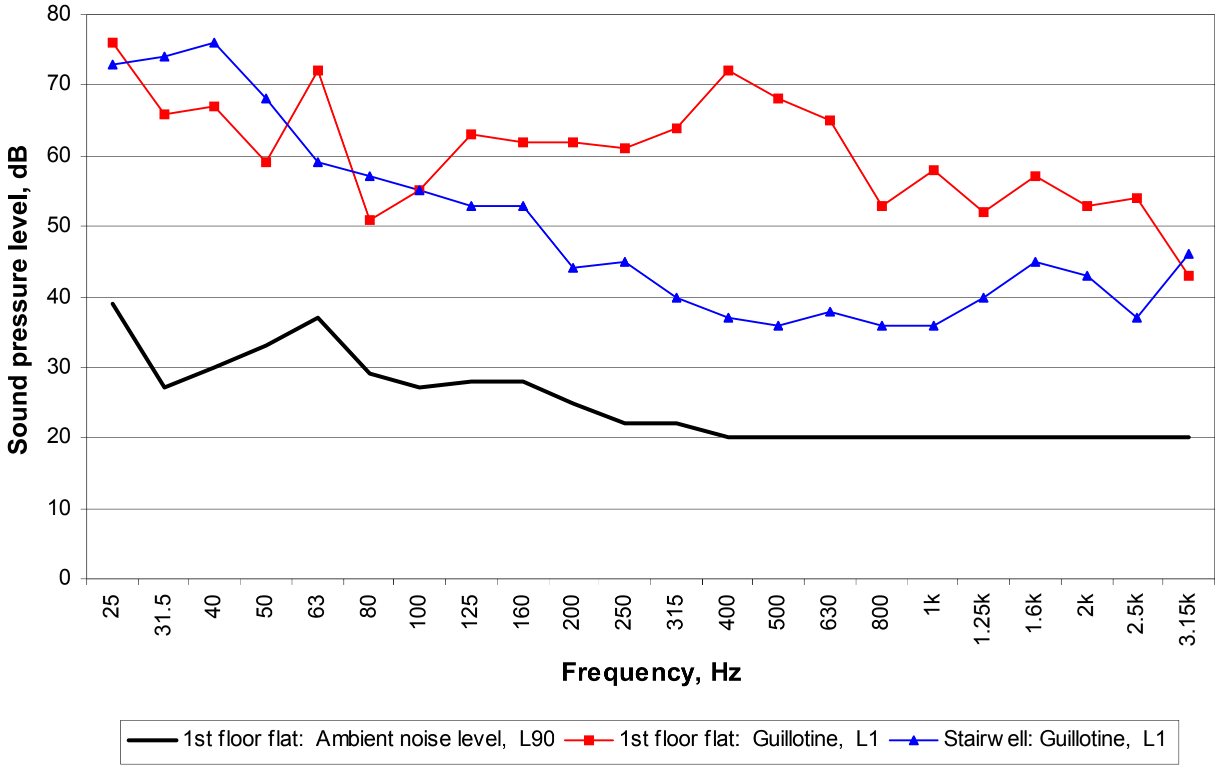

FIGURE 4: Noise levels due to operation of guillotine