Proceedings of the Institute of Acoustics

INDUSTRIALLY INDUCED LOW FREQUENCY NOISE & VIBRATION IN RESIDENTIAL BUILDINGS

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1. INTRODUCTION

This paper describes a system developed to provide comprehensive coverage of the sound & vibration spectra within the residences of low frequency noise/vibration sufferers situated near to industrial sites. Case studies are employed to illustrate the effectiveness of the integrated acoustic/microseismic approach.

Standard acoustic techniques alone have often proved ineffective at tackling low frequency problems, yet seismic techniques alone are insufficient in many cases to prove that a statutory nuisance exists. By combining the two disciplines, the chances of determining the source of the disturbance and the propagation path (airborne, groundborne or both) is greatly enhanced. Remedial work can then be undertaken to alleviate the problem.

A German national standard (DIN 45680) was utilised in the case studies to assess the measured levels of airborne noise. This proved to be a good predictor of annoyance.

2. EXPERIMENTAL TECHNIQUE

2.1 Equipment

Data were logged on a six channel Vibrosound 24-bit A/D recording system with a bandwidth of 0-125 Hz. The a.c. outputs from a three-component seismometer, microphone and window-mounted accelerometer were fed into the Vibrosound. This system was set up to provide recordings of the sound and vibration levels in an unoccupied bedroom. Over a period of several days and nights, ten-second time series events were collected which could later be analysed in both time and frequency domains. Another seismometer was also located on the ground floor slab; this was linked to a PC that recorded the ground vibration and allowed groundborne and airborne disturbances to be distinguished. (*Figs 1 & 2)*.

2.2 Analysis

Individual time series events were analysed in both the time domain and, by Fast Fourier Transform, in the frequency domain. The length of the events analysed (ten seconds) gave a resolution in the frequency spectra of 0.1 Hz. The presence of characteristic frequency components or impulsive events helped to match the disturbance to specific machinery parts in nearby industrial sites, particularly where rotating machinery with fixed operating frequencies were present. In this way, a process of elimination could be carried out to decide which elements of the site(s) were to blame for the noise nuisance leading to complaints, and what course of action could be taken to reduce the overall noise/vibration levels in the residences of the complainants.

2.3 Standards Used To Assess Noise/Vibration Levels

The British national standards designed to deal with industrial noise pollution problems may not always be adequate in dealing specifically with low frequency noise, being based on A-weighted sound pressures in which low frequencies are significantly de-emphasised. In the research outlined in this paper, the German national standard DIN 45680 [reference 1] was used to ascertain whether or not the sounds recorded were of an acceptable level and/or nature. DIN 45680 places particular emphasis on tonal and impulsive/fluctuating low frequency noise, and has been reported to be a reasonable predictor of whether or not a low frequency noise is likely to give rise to complaints in residential areas [reference 2]. In the analysis third octave bands were constructed by applying a root-mean-square method to the sound pressure-frequency spectra, so that the dB(Linear) levels of the bands could be compared with the DIN-recommended levels.

BS 6472 [reference 3] is the British national standard in which recommended levels of vibration in residential areas are laid down. There is some controversy over the levels given, particularly for intermittent vibration. It is thought by some researchers to be too liberal, in terms of acceptable night-time low frequency vibration levels in the home [reference 4]. However, no viable alternative has yet been devised.

3. CASE STUDY A

3.1 Initial Investigation

Measurements were made at three households on a housing estate near to an industrial site over a period of one month. In addition, the residents were asked to log their subjective impression of how the disturbance varied over the monitoring period.

FFT analysis of the time series data showed the presence of fluctuating low frequency tones on the estate (see *Fig 3*). These were apparent in the data recorded by the microphone and window-mounted accelerometer channels of the Vibrosound.

Two of the tones (12.5 Hz and 38 Hz) were sometimes at a dB level that would be considered disturbing according to the German national standard DIN 45680 (see *Fig 3*). The variation of amplitude of the tones with distance was consistent with them emanating from the nearby industrial site. It was found that in the 40 Hz third octave band, which contains the 38 Hz tone, the RMS sound pressure levels most often exceeded the recommended DIN level in the household whose occupants reported most disturbance during the monitoring period (that is, the house nearest to the suspect site).

No excessive groundborne vibration levels were recorded in the households; night-time levels were generally more than two orders of magnitude below those prescribed in BS 6472. This, combined with the high amplitudes measured by the window-mounted accelerometer, led to the conclusion that the disturbance had an airborne transmission path.

A further study was proposed with a view to pinpointing the source.

3.2 Sequential Shutdown Experiment

Following on from the previous study, a sequential shutdown experiment was arranged one evening in conjunction with the local council and the suspect industrial site. Each item of machinery was shut down in turn, and then switched on again in turn, whilst sound & vibration levels were monitored at the nearest household to the industrial site. In addition, residents of the housing estate made detailed notes on their subjective experience of the level of disturbance throughout the experiment. The residents were not told which items of plant were operational at any given time, though this information was logged and provided to the investigating team for analysis.

Results of this test confirmed the findings of the previous study i.e. that during full operation of the plant, a fluctuating low frequency noise was present in the house of tonal character. Peaks of 12.5 Hz and 38 Hz were prominent in the frequency spectra. The periods when the 40 Hz third octave band exceeded the DIN-recommended dB level, correlated reasonably well with the times when the residents reported that they could hear a noise similar to the one that led to the complaints. *Figs 3 & 4*, which were constructed respectively from data recorded just before and just after total shutdown, illustrate these points.

The disturbance was again shown to have an airborne transmission path and the variation in level from when all machinery was in full operation to when all was shut down, showed beyond reasonable doubt that the industrial site under study was the source of the noise. In addition, the source was traced to two particular items of plant (fans with operating frequencies around 38 cycles per second which were operational during the time of *Fig 3* but not *Fig 4*); these were selected for implementation of noise control measures.

3.3 Further Investigation

A third experiment is proposed for this case study, to take place after noise control measures have been implemented. This would test the effectiveness of the noise control measures, in terms of reducing the low frequency noise levels and subjective disturbance at the housing estate.

4. CASE STUDY B

4.1 House Measurements

The technique outlined above was used in another, similar case study. Equipment was set up in an unoccupied bedroom of a house near an industrial estate where the residents had complained about a local low frequency noise/vibration problem. This noise was described as having a 'throbbing' character. Monitoring took place over a period of four consecutive nights. Again, the residents made notes outlining their subjective impressions of the intensity of the disturbance throughout that time.

FFT analysis of the microphone time series data yielded two significant peaks in the frequency spectrum around 50 Hz, namely 48.1 Hz and 49.3 Hz (*Fig 5(b)*). On the two nights perceived as 'relatively noisy' by the residents, the amplitudes of these peaks were such that the RMS sound pressure level for the 50 Hz third octave band tended to exceed the level recommended in DIN 45680 by about 1-2 dB (*Fig 5(c)*). Conversely, on the two nights described by the residents as 'reasonably quiet', the 50 Hz third octave band had a dB level which fell below the DIN curve by typically 2-3 dB.

Furthermore, the close proximity of the two frequencies (the peaks are 1.2 Hz different in frequency) raised the possibility that they were 'beating' together to create the fluctuating sound levels. This was compatible with a 'throbbing' occurring at around 1 cycle per second as described by the residents, and also as perceived by the authors on site. A digital Butterworth band-pass filter was applied to some of the ten second events from the microphone channel, to create time-domain filtered records for the 50 Hz third octave band; these illustrate the fluctuations due to 'beating' quite well (*Fig 6(a)*). This also illustrates the flexibility of the methodology used and described in this paper.

Once again, excessive vibration levels were not picked up in the ground floor slab of the house. Vibration levels at night, when traffic was minimal, were at least an order of magnitude below those recommended in BS 6472. Thus it was again concluded that the transmission of the disturbance was airborne.

4.2 Factory Investigation

With the co-operation of the proprietors, a factory close to the household where the measurements had taken place was investigated to see if the source of the 48.1 Hz and/or 49.3 Hz tones could be located. It was found that a fan within the factory had an operational frequency around 49 Hz; indeed, an accelerometer mounted on the fan casing showed there to be a peak present in the vibration spectrum at precisely 49.3 Hz. No source of the 48.1 Hz peak was found. However, it is hoped that if noise control measures were to be carried out on the fan identified, the other peak might have 'less to beat against' and thus the problem might at least be reduced.

5. CONCLUSIONS

The case studies outlined above demonstrate the advantages of taking an integrated acoustic/microseismic approach when tackling low frequency noise/vibration problems. A lot of useful information can subsequently be obtained by recording raw data in the time domain which can then be processed in numerous ways. Both time series and frequency spectra can be constructed and other informative analysis such as filtering may be carried out. The relatively long event lengths (10 s) give rise to frequency spectra with high frequency resolution (0.1 Hz) which aids source determination. The wide range of instrumentation used (three-component seismometers, microphones and accelerometers) gives great scope for analysis and allows transmission paths to be ascertained.

The German national standard DIN 45680 proved to be a reasonably good predictor of whether a particular low frequency noise in a residential area is likely to give rise to complaints, particularly where that low frequency noise is strongly tonal and/or fluctuating/impulsive in character. DIN 45680 may be a useful tool for researchers or local authorities investigating similar problems.

6. REFERENCES

[1] DIN 45680 : 1997. Messung und Bewertung tieffrequenter Geräuschimmissionen in der Nachbarschaft.

[2] D PIORR & K H WIETLAKE (1990). Assessment of Low Frequency Noise in the Vicinity of Industrial Noise Sources, *Journal of Low Frequency Noise & Vibration*, 9(3).

[3] BS 6472 : 1992. Evaluation of Human Exposure to Vibration in Buildings (1 Hz to 80 Hz).

[4] Personal communication, Dr David Manley, Low Frequency Noise Sufferers' Association.

Figure 1 *EQUIPMENT SET-UP*

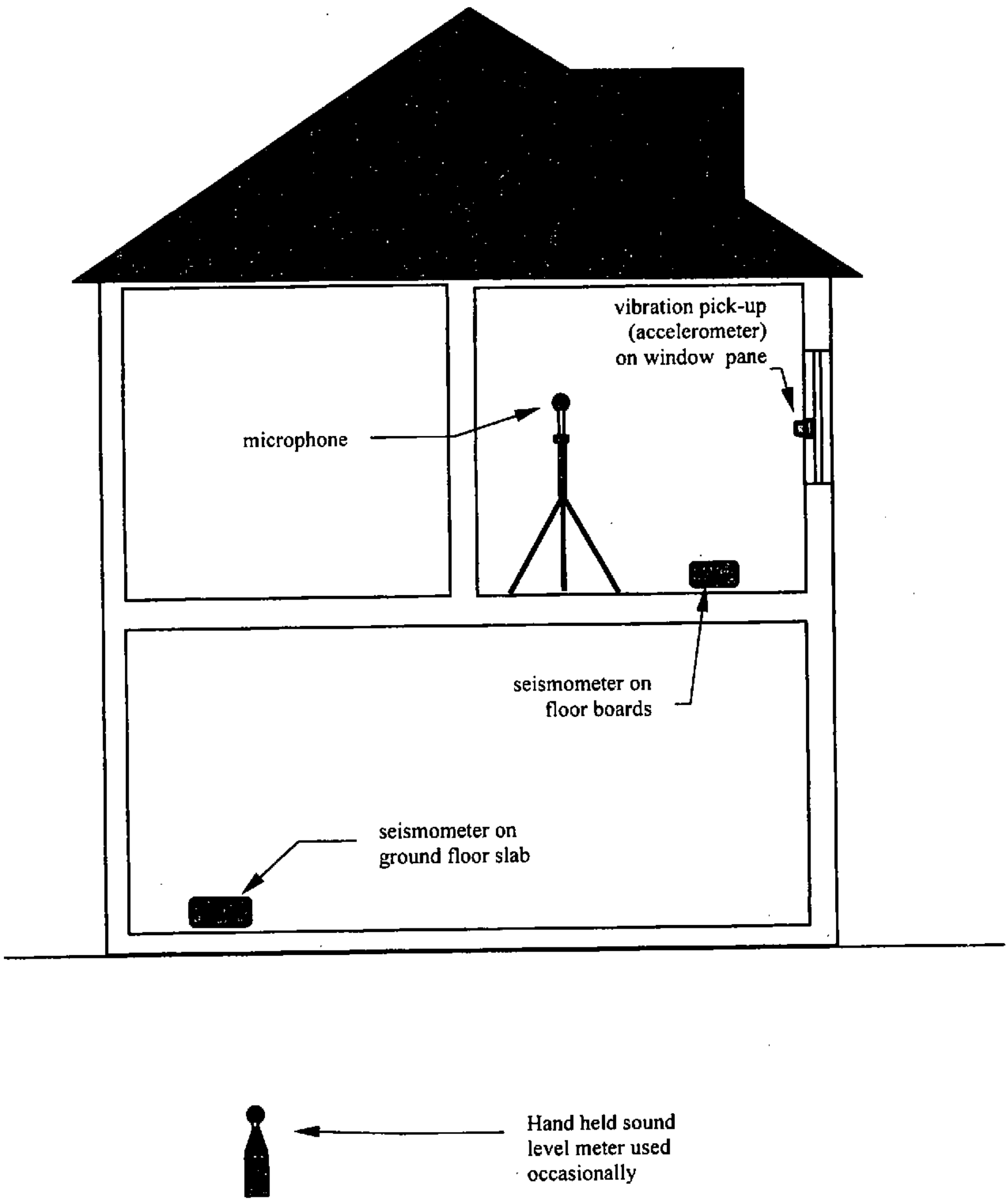


Figure 2 IDENTIFICATION OF EXTERNAL AND INTERNAL NOISE/VIBRATION SOURCES AND TRANSMISSION PATHS

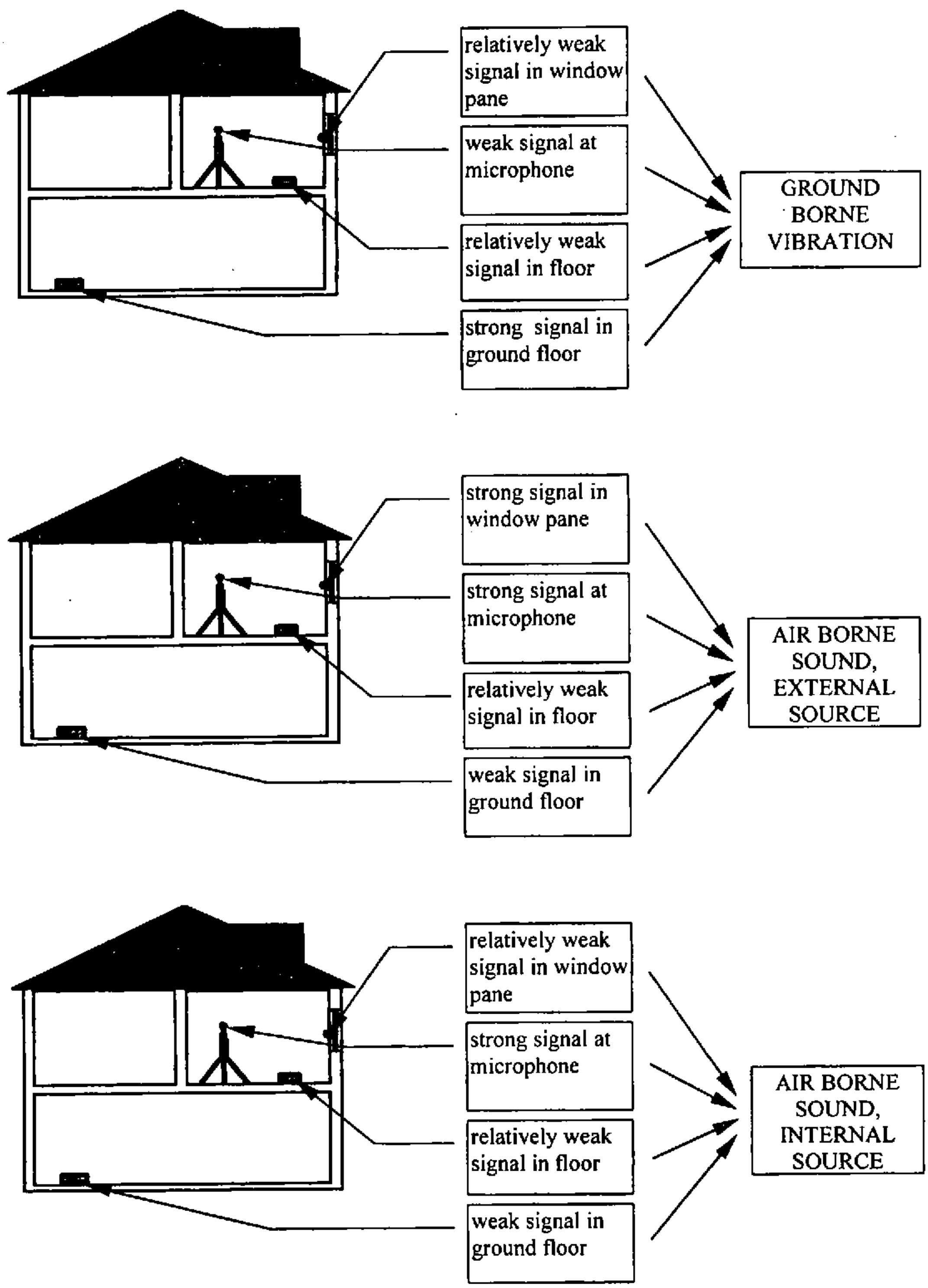


Figure 3 ***CASE STUDY A:*** *SOUND LEVELS AT HOUSEHOLD NEAREST TO INDUSTRIAL SITE DURING SHUTDOWN EXPERIMENT, SHORTLY PRIOR TO TOTAL SHUTDOWN. RESIDENTS DESCRIBED HEARING A 'PULSATING NOISE' AT THIS TIME. FANS WHICH WERE LATER SELECTED FOR NOISE CONTROL IMPLEMENTATION WERE ACTIVE.*

(a) *time history, showing 12.5 Hz pulsing;*
(b) *narrow band spectrum, showing peaks at 12.5 Hz and 38 Hz;*
(c) *third octave band spectrum compared with DIN 45680 night-time limits.*

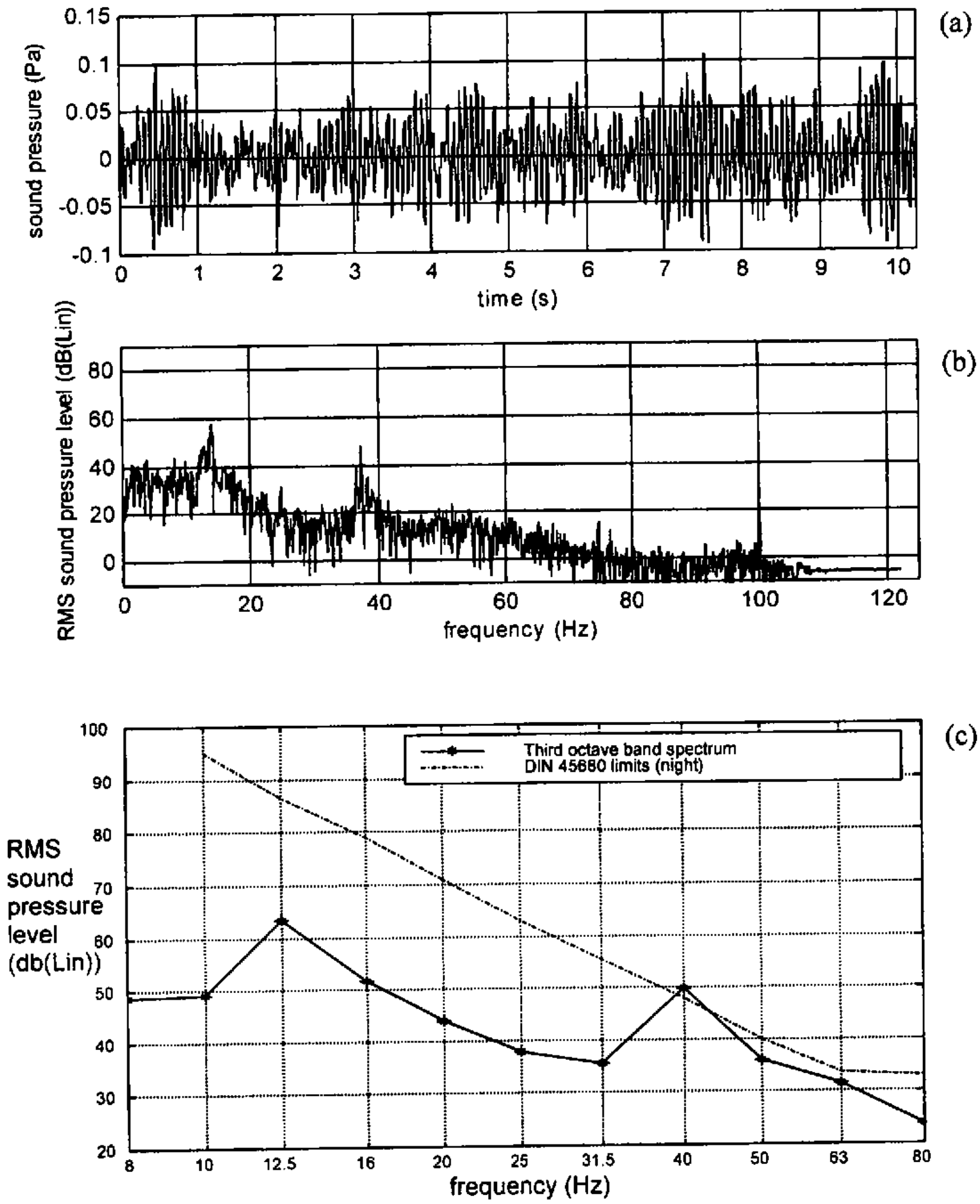


Figure 4 ***CASE STUDY A:*** *SOUND LEVELS AT HOUSEHOLD NEAREST TO INDUSTRIAL SITE DURING SHUTDOWN EXPERIMENT, SHORTLY AFTER TOTAL SHUTDOWN. RESIDENTS STATED THAT DISTURBING NOISE HAD STOPPED. FANS THAT WERE LATER SELECTED FOR NOISE CONTROL IMPLEMENTATION HAD BEEN SWITCHED OFF BY THIS TIME.*

(a) *time history, 12.5 Hz pulsing is absent;*
(b) *narrow band spectrum, 12.5 Hz and 38 Hz peaks are absent;*
(c) *third octave band spectrum compared with DIN 45680 night-time limits.*

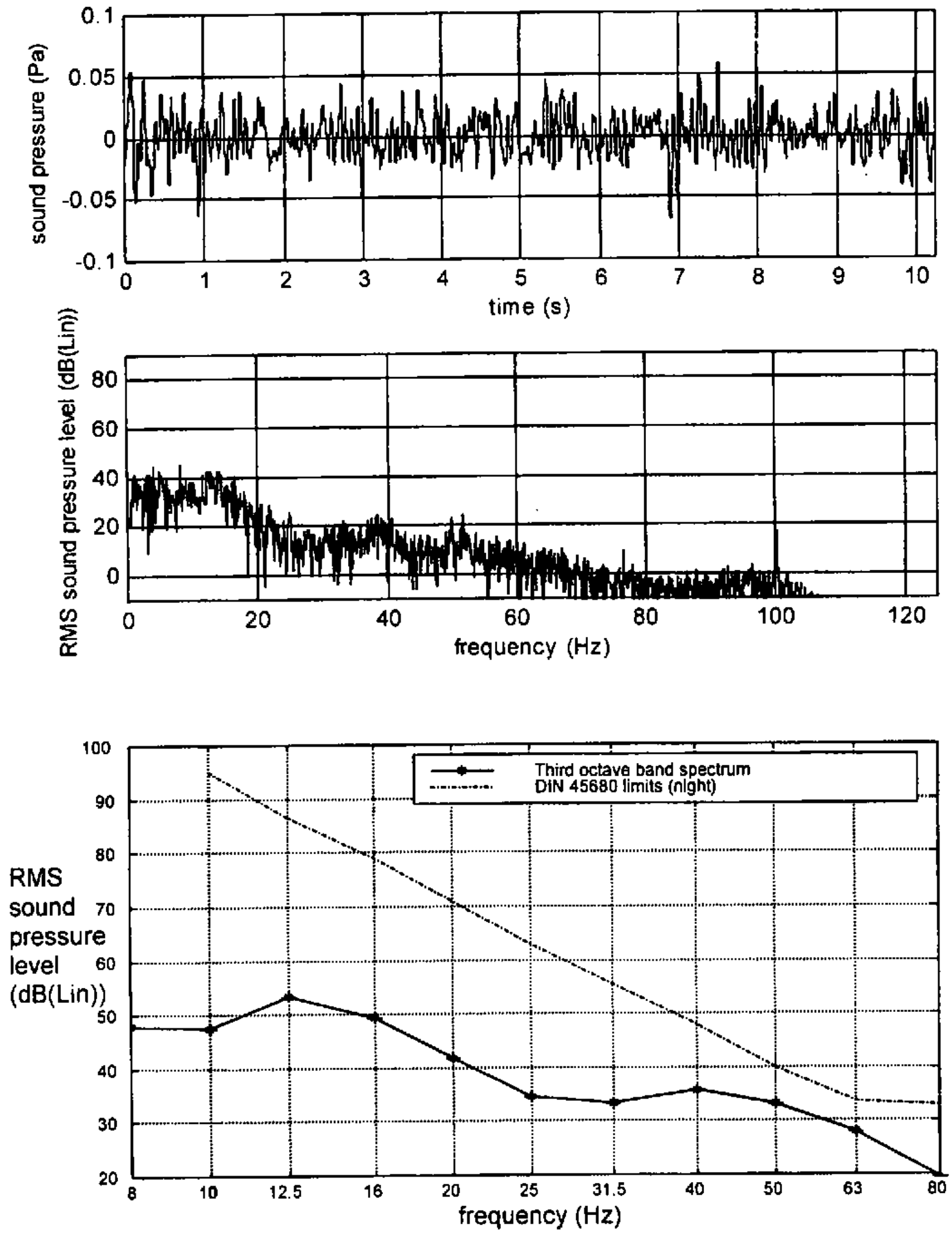


Figure 5 ***CASE STUDY B:*** *TYPICAL SOUND LEVELS AT A HOUSE NEAR TO AN INDUSTRIAL SITE, WHERE THE RESIDENTS COMPLAINED ABOUT A LOW FREQUENCY 'THROBBING'.*

(a) *time history;*
(b) *narrow band spectrum, showing prominent peaks at 48.1 Hz and 49.3 Hz;*
(c) *third octave band spectrum compared with DIN 45680 night-time limits.*

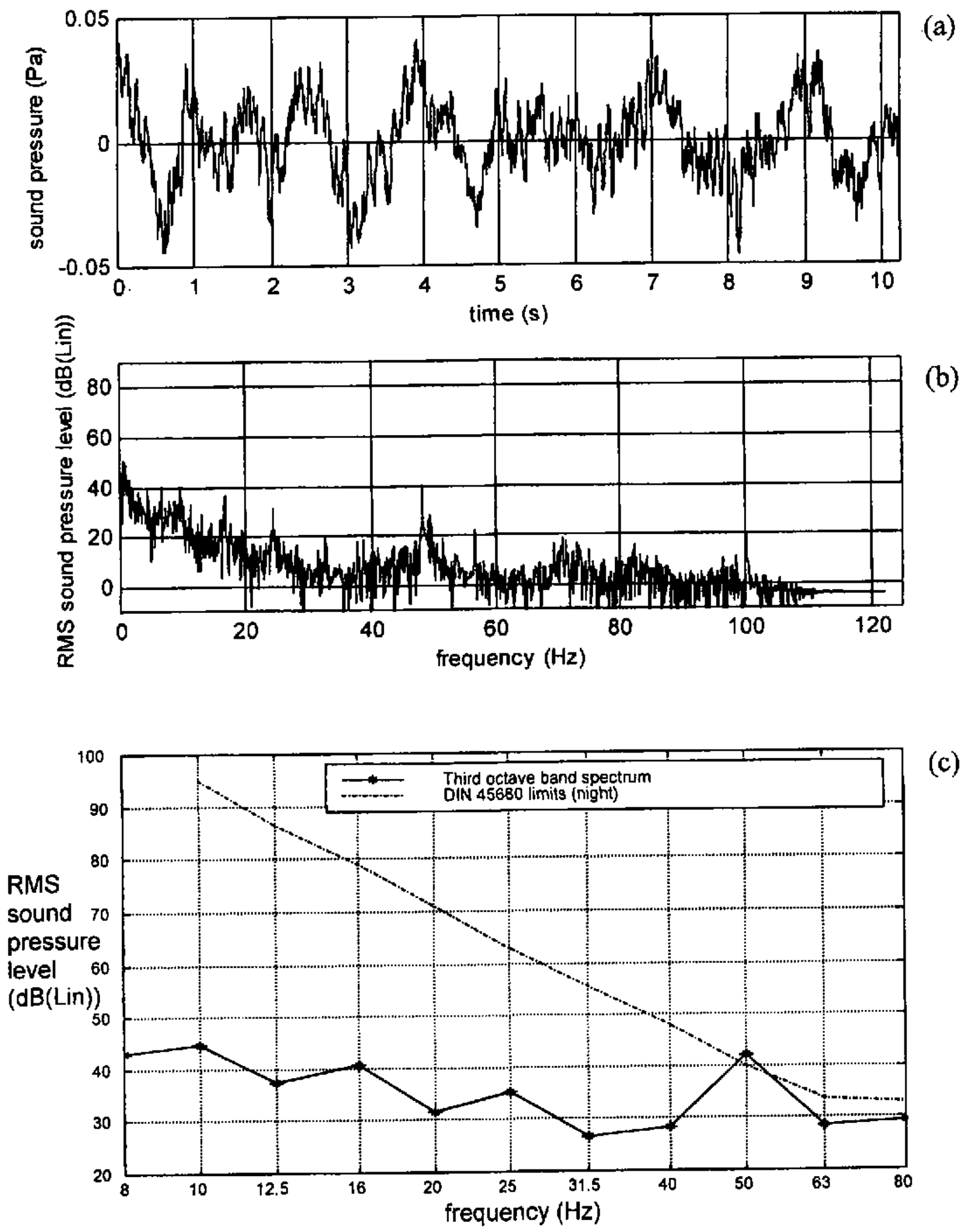
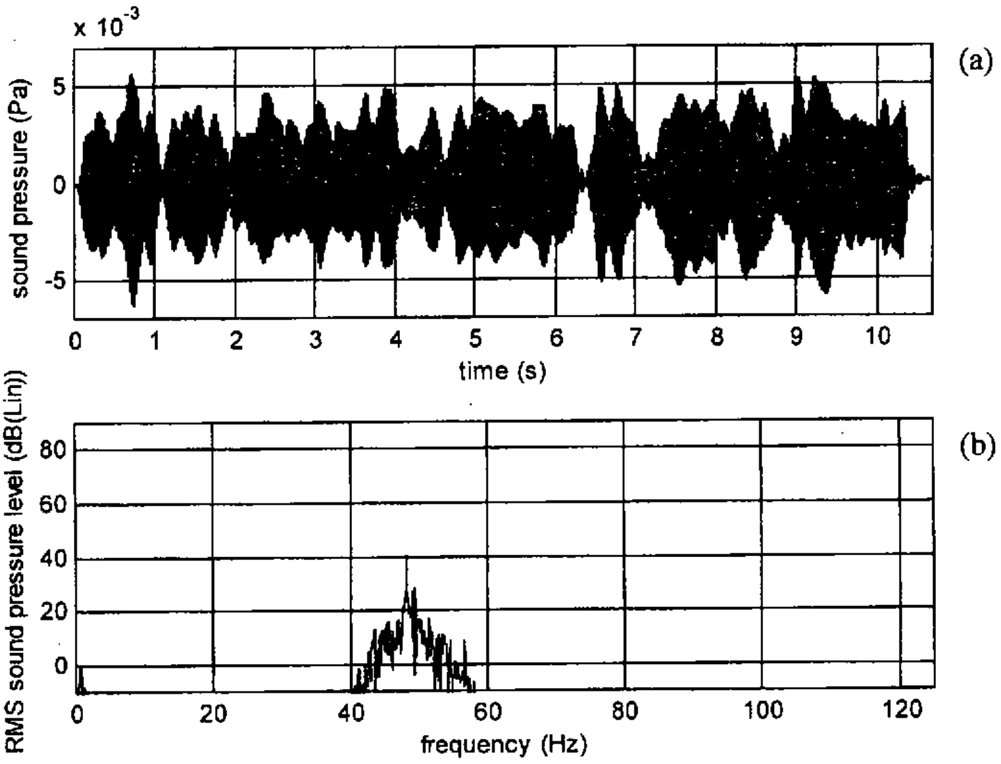


Figure 6 ***CASE STUDY B:*** *THIS FIGURE SHOWS THE SAME 10 SECOND EVENT RECORD AS PRESENTED IN FIGURE 5, AFTER THE APPLICATION OF A DIGITAL BUTTERWORTH BAND-PASS FILTER.*

(a) time-domain filtered record for the 50 Hz third octave band;
(b) filtered narrow band spectrum, showing prominent peaks at 48.1 Hz and 49.3 Hz.



NOTE THE FLUCTUATIONS AT A RATE OF AROUND 1 CYCLE PER SECOND; THIS BEATING MAY EXPLAIN THE 'THROBBING' NOISE PERCEIVED BY THE RESIDENTS.