Proceedings of the Institute of Acoustics

MEASUREMENTS OF ENVIRONMENTAL LOW-FREQUENCY NOISE

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1. INTRODUCTION

The present paper describes the methodology and some of the results of our recent experimental investigations into environmental low-frequency noise, also called the low-frequency hum (see, e.g., "The Independent" of 22 June 1994). This phenomenon has been known in the UK for at least two decades [1-3]. However, in many aspects its nature and even the existence itself is still questionable. Although a current number of complaints about low-frequency noise (around 500 a year) represents just a small fraction of a total number of noise complaints, the phenomenon deserves careful consideration. In particular, the questions are to be answered whether the low-frequency noise objectively exists and, if so, what are its main physical mechanisms and sources.

The latest measurements of environmental low-frequency noise have been carried out by the Building Research Establishment (BRE) and the Sound Research Laboratories (SRL) on behalf of Department of the Environment [2,3]. The results of these investigations have been generally negative: neither noise itself, nor its sources have been identified. However, it has been mentioned in this survey that in a relatively small number of cases "there was some evidence to suggest that a low level low frequency noise may occasionally be present that could be related to the noise complained of".

We believe that environmental low-frequency noise may be caused by different physical mechanisms. In our previous theoretical work [4,5] the hypothesis has been examined that one of such mechanisms can be related to the structure-borne sound caused by ground vibrations propagating to buildings as surface Rayleigh waves. In particular, we analysed the possibility of surface wave sources being buried underground gas or petrol pipes in which sound waves propagating in a pipe-line as in a waveguide might be caused by different reasons, e.g., by pipe-line compressor stations or by turbulent flows of gas or liquid. It has been demonstrated that Rayleigh waves can be effectively generated if the velocities of sound c_0 inside the pipes (450 m/s for methane) are higher than Rayleigh wave velocity c_R in the ground (typically c_R = 200-600 m/s). The physical nature of this phenomenon is similar to that of sound boom from supersonic jets or to that of recently predicted Rayleigh ground wave boom from superfast trains [6]. Especially large resonance increase occurs for c_0 slightly higher than c_R. The central frequencies of generated Rayleigh wave vibration spectra depend on depth of the pipe and are in the low-frequency range (5-20 Hz). Given (arbitrarily) the level of sound propagating in gas pipes is 100 dB, the amplitudes of generated ground vibration velocity for pipes buried at a depth from one to two meters may achieve about 70 dB (relative to the reference level of 10^{-9} m/s). These vibrations may cause annoyance both because of a direct impact and due to generated structure-borne noise.

2. METHODOLOGY OF EXPERIMENTAL INVESTIGATIONS

Experimental investigations into environmental low-frequency noise and vibration were carried out in four locations over the East Midlands, using the addresses provided by the members of the Low Frequency Noise Sufferers Association (LFNSA). The main aims of these investigations, which have been supported by the Royal Society, were to obtain experimental evidence of the existence of environmental low-frequency noise and to check the above mentioned theoretical hypothesis that under certain circumstances underground gas pipes may be one of its sources.

The experiments comprising high resolution measurements of noise and vibration spectra were carried out inside and outside the complaint's houses, as well as near buried gas distribution lines in the surrounding areas. The equipment included portable FFT spectrum analyser which was used in combination with high-sensitive electrete microphone (for noise measurements) and with accelerometers (for measurements of vibration). The measured spectra have been memorised in the FFT spectrum analyser which had an output to a computer.

Initial noise and vibration measurements were performed inside the houses: in living rooms, bedrooms, and utility rooms. Afterwards, they were repeated outside the houses: within boundaries of the properties and in relatively remote locations, especially in the vicinity of underground gas distribution lines. Special attention has been paid to measuring ground vibration spectra and examining their relationships with measured noise.

3. EXPERIMENTAL RESULTS

In two properties out of four the environmental low- frequency noise has been detected. In what follows we discuss only these positive cases.

In the first property, located in a very quiet rural area (near Melton Mowbray, Leicestershire), the noise spectra measured inside the house in the frequency range 0-100 Hz showed three very distinctive narrow peaks at frequencies 24.5 Hz, 49 Hz and 73.5 Hz (see Figure 1). These resembled the first three Fourier harmonics of the main frequency 24.5 Hz. This noise, which we could clearly hear (probably because of the presence of higher harmonics at 49 and 73.5 Hz), was exactly the noise complained of. The amplitudes of the spectral peaks were respectively 46 dB, 43 dB and 34 dB of the linear scale. That is approximately by 15 dB higher than background noise at corresponding frequencies.

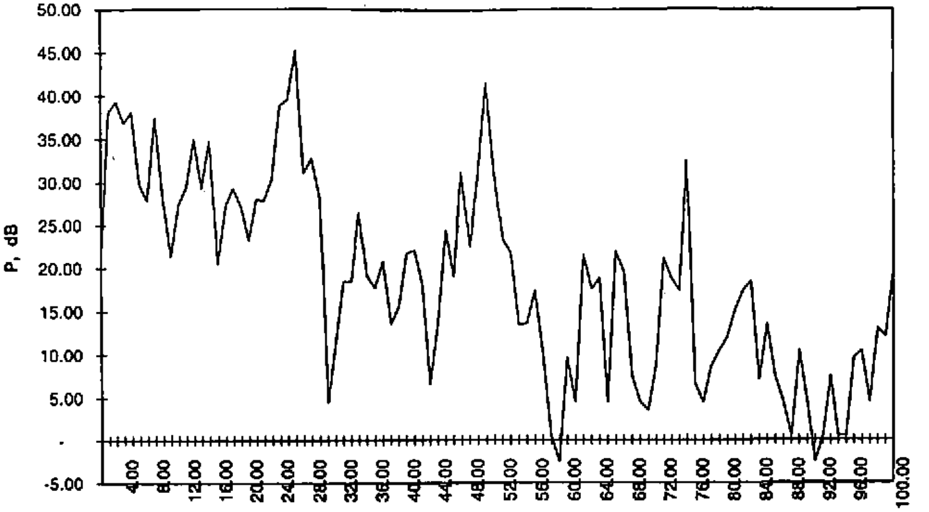

Figure 1. Noise spectrum inside the house (first case)

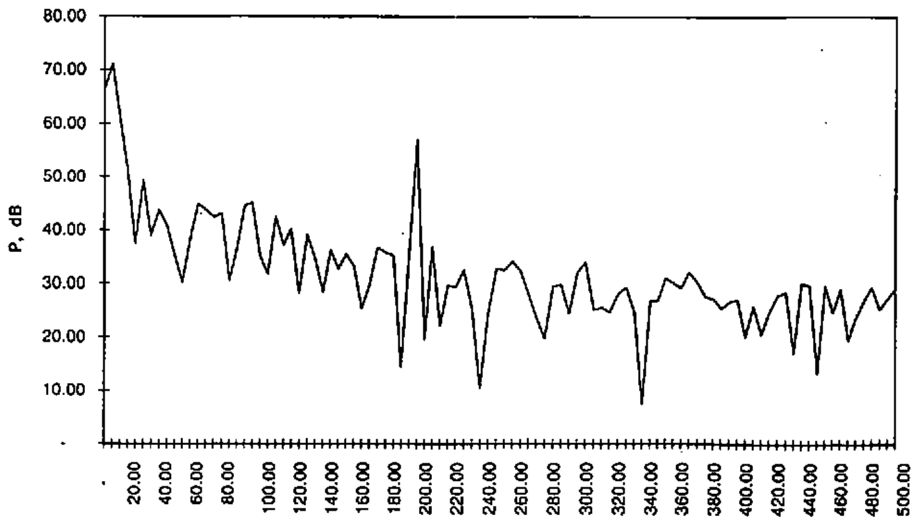

Figure 2. Noise spectrum near the electric sub-station

Measurements of ground vibration spectra near the house as well as around the suspected underground gas pipes in the nearby area showed the absence of any vibrations above the background level. Attempts undertaken to locate the source of air-borne noise by driving around gave no results, partly because the noise was not steady and occasionally disappeared. Spectral measurements taken near some of the local utility installations, e.g., the electric sub-station (Figure 2), could not be related to the noise measured in the house.

Thus, in the above mentioned case there was no experimental evidence that the low-frequency noise complained of was caused by ground vibrations generated by underground gas pipes. Moreover, according to the theoretically calculated spectra of ground vibrations from underground pipes, which are broad and smooth [3], it was unlikely to expect generation of the associated structure-borne noise at three distinctive harmonics. The presence of these three harmonics in the spectra of measured noise allows us to suggest that in the particular case under consideration the source responsible for the noise represented a vibrating body oscillating with high amplitudes at the main frequency of 24.5 Hz. Then the appearance of higher harmonics in noise spectra could be attributed to nonlinear distortions of the body vibration.

In the second case of the positive indication of the low-frequency noise, the property was also in a quiet rural location (near Bunny, Nottinghamshire). In this last case it was possible not only to detect low-frequency noise inside and outside the house, but also to identify and locate the source of the noise. Since this case gives a good illustration of the methodology of measurements, we describe it in more detail.

The noise spectrum inside the house can be seen in Figure 3 for the frequency range 0-100 Hz (this spectrum and the ones described below have been measured with higher frequency resolution: 0.25 Hz). One can see two distinctive peaks above the background noise level: at 19.5 Hz and 27 Hz. The corresponding amplitudes are 42 dB and 36 dB of the linear scale. Measurement outside the house (Figure 4) showed only one of the peaks left: at 19.5 Hz. Thus, the maximum at 27 Hz measured inside the house was caused probably by excitation of one of the room resonances. Note that the amplitude of the peak at 19.5 Hz outside the house is around 48 dB, i.e., the sound level inside the house is only by 6 dB lower than outside.

Spectra of ground vibrations measured outside the house indicated no vibrations above the background level. In particular there were no any increase of vibration amplitudes in the frequency range around 19.5 Hz. Thus, it was clear that the noise complained of is the air-borne noise.

Driving around the area and measuring the noise spectra outside the car enabled us to locate the source by observing the increase in amplitude at the frequency of interest (19.5 Hz). It has been found that the source was located on the territory of the nearby industrial works, i.e., approximately in 2 miles from the complaint's house.

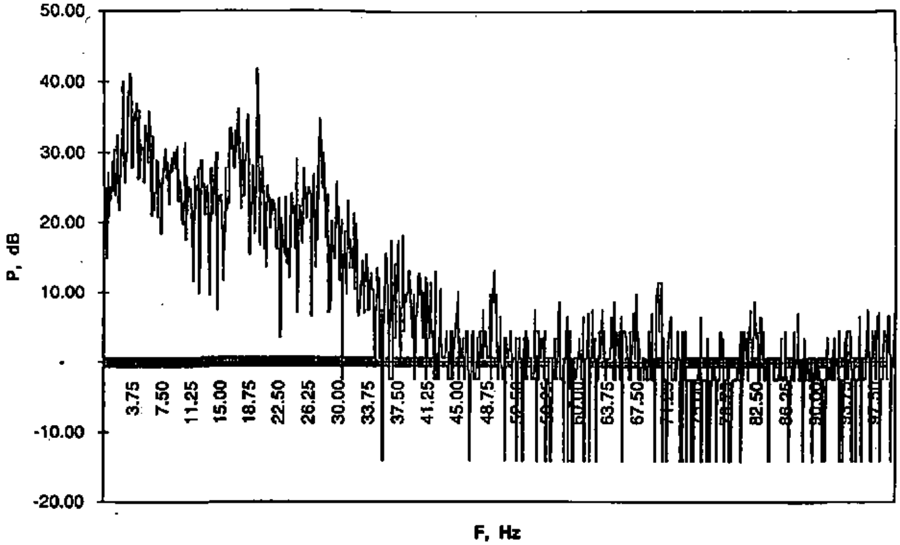

Figure 3. Noise spectrum inside the house (second case)

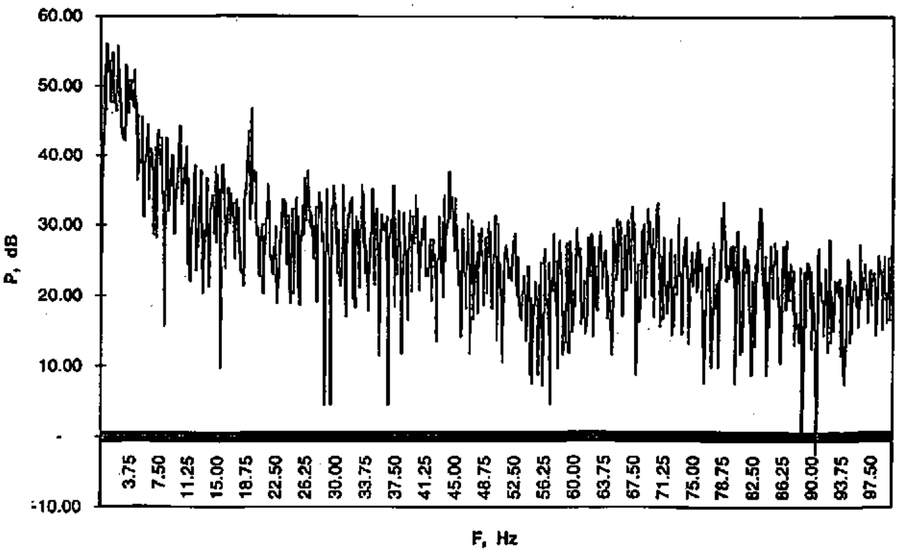

Figure 4. Noise spectrum outside the house (second case)

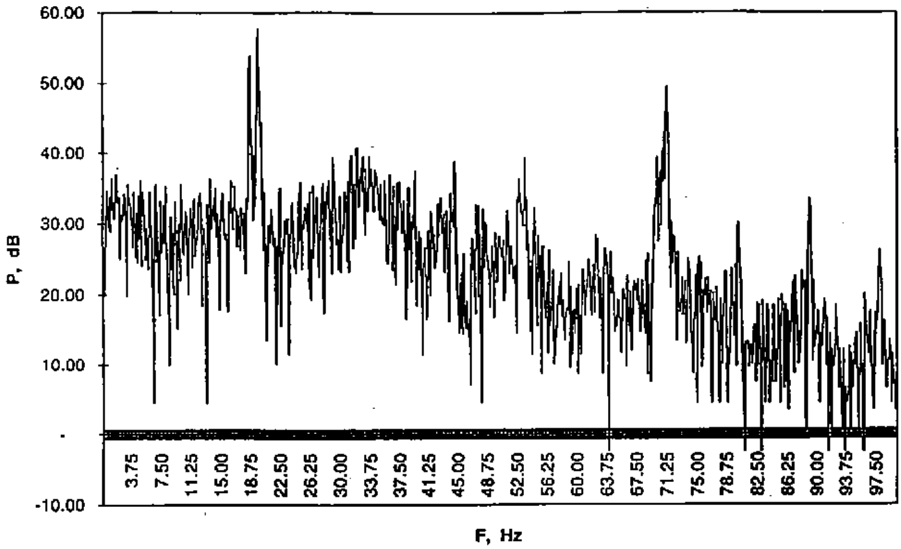

Figure 5. Noise spectrum measured on the road

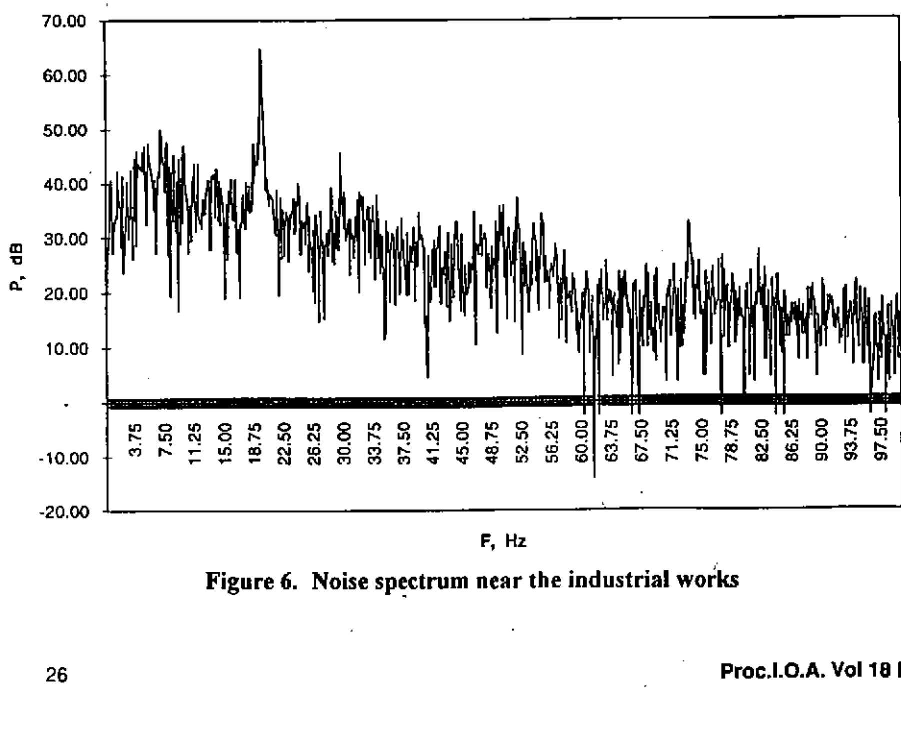

Figure 6. Noise spectrum near the industrial works

Figure 5 shows the noise spectrum measured on the road leading to the above mentioned industrial works. Note that the amplitude of the now split peak with the central frequency of 19.5 Hz is up to 58 dB (i.e., by 10 dB higher than near the house). The additional significant peak around 70 Hz, which has not been present in the spectra measured near the complaint's house, was probably caused by a side local source which was out of our attention. Finally, the noise spectrum measured near the territory of the industrial works is shown in Figure 6. It can be seen that the amplitude of the peak at 19.5 Hz is now 65 dB. Thus, the source responsible for the low-frequency noise complained of might be one of the installations located in the territory of the industrial works, e.g., manufacturing rigs or chimneys. The more definite identification of the source was not possible without access to the territory.

4. DISCUSSION

The above described experimental investigations of environmental low-frequency noise have demonstrated the following.

In two locations out of four (50% of cases under investigation) the low frequency noise complained of *has been detected*. Spectra of noise in both cases were absolutely different. Therefore, they should be associated with different noise sources. This confirms our point of view that the nature of environmental low-frequency noise can not be reduced to one general mechanism of a national or global scale. There is a variety of sources and mechanisms of environmental low-frequency noise depending on particular circumstances.

The presence of environmental ground vibrations above the background level has not been observed in any location. Thus, at least during this series of experiments, there was no evidence of underground gas pipes being a source of low frequency noise. The reason for this could be low amplitudes of sound generated inside the pipes, for example because of gas flow speed being insufficiently high to cause efficient excitation of sound by turbulence. This does not mean, however, that this mechanism should be excluded from further consideration.

The measured spectra of the air-borne low-frequency noise consisted of a few low-level tonal components with the amplitudes inside houses up to 50 dB of the linear scale. This level is generally below the averaged threshold of human sensitivity (A-weighting curve). Therefore, only people characterised by high sensitivity to low-frequency sound and living in quite rural locations can be affected. Nevertheless, even though a number of such people is relatively small, these cause quite specific physiological and legal aspects related to individual perception of noise, in particular the increased annoyance of tonal components [7]. We did not touch these aspects in the present work, concentrating on physical mechanisms of the low-frequency noise. However, in our opinion, the measurement techniques and the corresponding legal aspects of this problem could become a subject of special discussion.

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5. CONCLUSIONS

1. The environmental low-frequency noise (or hum) does exist.

2. There is a variety of mechanisms and sources of environmental low-frequency noise, rather than one general mechanism of a national or global scale.

3. At least during this series of experiments, there was no evidence of underground gas pipes being a source of environmental low-frequency noise.

4. The measured spectra of the air-borne low-frequency noise comprise a few low-level tonal components which are generally below the averaged threshold of human sensitivity.

5. Even though a number of people sensitive to environmental low-frequency noise is relatively small, the technical, physiological and legal aspects of the problem deserve special discussion.

ACKNOWLEDGEMENT

The author is grateful to the Royal Society for financial support of this investigation.

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