A case history of low frequency air-borne sound produced by a weir in the river Reno

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A CASE HISTORY OF LOW FREQUENCY AIR-BORNE SOUND PRODUCED BY A WEIR IN THE RIVER RENO.

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INTRODUCTION

Marzabotto is a small village in the north of Italy, near the city of Bologna. The town lies at the bottom of a broad valley where the river Reno flows. In 1985 strange vibrations of glass windows and doors started to disturb the rest and sleep of the population. Local newspapers wrote about the awakening of the ghosts of ancient Etruscans, a population that lived in this area in olden times.

In order to discover the source of such vibrations, the authorities of the village first called researchers of the National Institute of Geophysics who made measurements of vibration in different parts of the village and identified the waterfall of a weir, recently built to control the flow of the river Reno, as the source of the phenomena. The spectrum of the vibrations was characterized by a frequency of 8 Hz.

The presence of such vibrations far away from the weir, at distances of about 4 - 5 Km and in raised positions with respect to the valley floor, brought up the idea that transmission of the phenomena could be by air as well as by ground. Local authorities decided to start new investigations and entrusted the work to the Institute of Technical Physics and the Institute of Hydraulics of the University of Bologna. It was decided to begin a campaign of systematic measurements of noise and vibration in order to understand the origin of the phenomena.

EXPERIMENTAL INVESTIGATIONS

The first measurements of noise were aimed at investigating the possible presence in the village of air-borne sound sources able to produce the vibrations. Many noise sources in the industrial area of the village were checked: the results excluded such a presence. Later on , measurements were made near the weir in order to describe the phenomenon. It was immediately clear that the weir was the source of the vibrations and that the trasmission was by air. Moreover, it was evident thet the phenomenon was strictly related to the discharge of the river, which changes according to the needs of a hydroelectric power plant situated uphill. In some flow rate conditions the sound field produced by the weir was so high that it was almost possible to feel the vibrations of the air on the body; at the same time another evident fact was the appearance, at regular intervals, of compression and expansion lines on the water fall, particularly visible when sunlight strikes the water at grazing incidence. All these observations brought out the idea that the water falling from the weir 2m high and 60m wide excites the column of air under the waterfall, wich sounds like a long organ pipe.

Experimentally it was decided to make sound field measurements correlated to the discharge of the river: in this respect it was agreed with the hydroelectric power plant administration to produce an artificial flood.

The acoustic field was measured with a 1" B&K microphone; the amplified signals were stored in a 7003 B&K tape recorder and later analysed with an ONO-SOKKY CF 920. The discharge was continuously recorded using a hydrometer. Figures 1 and 2 show some experimental results: the presence of a pure tone in the spectrum at low frequency is evident. At the same time it is also clear that the value of this frequency decreases as the discharge increases. In order to investigate the resonance modes of the air enclosed under the fall, measurements were made inside. The results showed a standing wave with a node in the middle of the weir and a boundary condition at the end of the air column not well defined. In fact, it is important to note that the weir is open at its edges but, at about 4 meters, there are wide reflecting surfaces made by concrete walls, which impose maximum values of sound pressure levels.

HYPOTHESES FOR INTERPRETATION OF THE PHENOMENA

As has previously been observed, the main idea is that the volume of the air beneath the waterfall acts as in a long organ pipe. In this respect the first resonance frequencies of the system have been computed keeping in mind that a part of the lateral wall of the "pipe" is water and therefore has a finite value of the impedance related to the discharge of the river.

The resonance frequencies of the system

Figure 3 shows a section of the weir and the meaning of the geometric symbols: the values of the resonance frequencies of the system are given by this equation:

$$f_a = c_o \sqrt{n^2/(2l)^2 - \varrho_o/(2\pi)^2 \cdot (H_o^2 + L^2)/(M\Omega_c)} \qquad \text{(Hz)} \qquad (1)$$

where:
c_o =sound velocity in the air (m/s),
ϱ_o =density of the air (kg/m^3),
M=mass of water per meter (kg/m),
Ω_c =area of the waterfall section (m^2),
l=length of the weir (m),
n=number of the mode: n=1,2,3,4,.......

According to this formula, figure 4 shows the values of the resonance frequencies of the system as a function of the discharge; the same figure also indicates the experimental values of the frequencies of the pure tones related to the measured values of the discharge. It is worth observing how these experimental values decrease as the discharge increases and how they suddenly change, from one mode to another, at certain values of the discharge: this result shows that excitation of the system is strongly related to the flow of the river.

Hypotheses for the excitation

Still not clear is how these resonance frequencies are excited by the flowrate; so far we have only two hypotheses.

The first hypothesis is as follows: the air under the weir is continuously removed by the water leaving the fall and replaced by fresh air coming in through the open lateral edges, which act as lips of a flue organ pipe. The stream of air strikes the lips and breaks up into a series of vortices which excite the resonance frequencies of the system.

The second hypothesis is that the water vortices, primed on the sharp edge at the weir inlet, induce vibrations in the waterfall which, in its turn, excite the resonance frequencies of the air under the fall.

CONCLUSIONS

On the basis of this interpretation of the phenomena, a very simple solution was suggested to remove the causes of the vibrations in windows and doors in the village. The 60 m-wide stream of the river at the weir entrance has been divided into three different-sized parts, by placing, just before the fall, two big concrete blocks in the water in such a way that the length of the air column under the weir is shortened, the resonance frequencies drastically increased and, as a result, the disturbing phenomena completely disappeared.

Investigations are still progressing to try to better understand and clarify the real mechanism of the excitation of the system, the final aim being to give indications for the correct design of these important structures which control the flow of a river.

Fig.1 – Frequency Spectrum

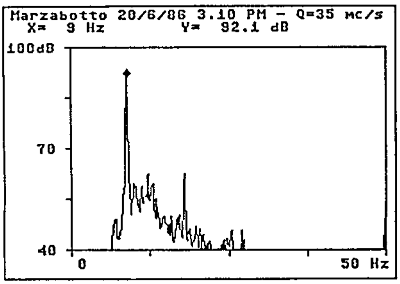

Fig.2 – Frequency Spectrum

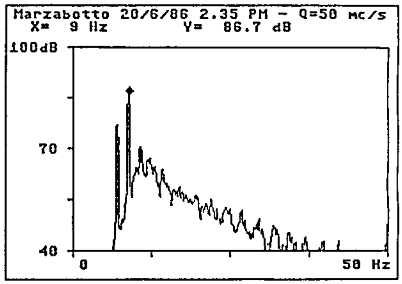

Fig.3 – Waterfall Section

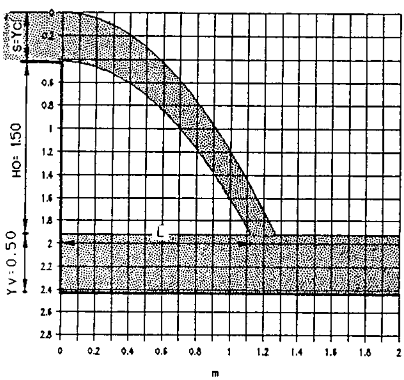

Fig.4 – Theoretical Cavity Resonancies