
**Acoustics • Shock • Vibration • Signal Processing** **February 2005 Newsletter**

## Namaste

Scientists have long realized that whales communicate over vast ocean distances using infrasound.

In recent years, researchers have discovered that elephants also produce infrasonic calls. The purpose of these calls is to coordinate movements within smaller groups and larger clans. In addition, female elephants send out mating calls.

The elephants must convey these movement and breeding calls over several kilometers to reach the intended receivers. Infrasound is an effective means for achieving this because it has relatively large wavelengths. Infrasound is thus less prone to scattering and attenuation than sound in the human audible domain.

Katy Payne wrote about this research in *Silent Thunder: In the Presence of Elephants.* I enjoyed reading her book and have summarized her landmark discoveries in the first article.

Sincerely,

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## Feature Articles

**Elephant Infrasound**

**Slinky Science**

**Elephant Infrasound** by Tom Irvine

Introduction

Katy (Katharine B.) Payne is a Cornell University Bioacoustics Research Associate who has studied acoustic communication and other behavior in elephants. She wrote about her discoveries in her book *Silent Thunder: In the Presence of Elephants,* as well as in several scientific papers.

Zoo Discoveries

Payne performed her initial research with William Langbauer, Jr. and Elizabeth Thomas in the Washington Park Zoo in Portland, Oregon. They observed Asian elephants at this zoo.

Payne listened intently to the elephants' calls. Sometimes she felt a rumbling or throbbing that was accompanied by only a faint sound. At other times, she felt the throbbing but heard no sound at all.

The throbbing reminded Payne of Bach's *Passion According to St. Matthew* as played on a pipe organ.

She recalled a childhood experience:

> The organist pulled out the great stop and the air around me began to shudder and throb. The bass notes descended in a scale. The deeper they went, the slower the shuddering became. The pitch grew indistinct and muffled, yet the shuddering got stronger. I felt I could not hear. My ears were approaching the lower limit of their ability to perceive vibrations as sound.

Note that the lower frequency limit of human hearing is approximately 20 Hz, although this varies between individuals. Infrasound is considered as any sound below 20 Hz. Earthquakes, volcanoes, wind, thunder, and ocean storms are natural sources of infrasound. In addition, whales communicate via infrasound.

Payne and her colleagues borrowed some equipment to make recordings of the zoo elephants' calls. They ran the tape recorder at its slowest speed during recording. They then played the tapes back at a higher speed to raise the pitch of the sounds. This method brought the lowest sounds into the frequency range of human hearing.

Carl Hopkins later analyzed these tapes at Cornell and confirmed that they contained infrasound.

In addition, Payne noted that a slight fluttering of the skin occurs between the eyes, where the trunk meets the elephant's head. The amplitude is about 1 cm.

Field Research in Africa

For the next research phase, Payne traveled to Africa. She made field studies of elephants and their calls in Kenya, Namibia, and Zimbabwe. She performed this work with Joyce Poole, William Langbauer, Cynthia Moss, Russell Charif, Rowan Martin and others.

Payne described the various types of elephant calls as bellows, rumbles, screams, and trumpeting. Some of these sounds may be overtones of infrasound. Elephants use these sounds for greetings, warnings, distress calls, reassurance, mating, and other purposes.

In particular, elephants use their powerful infrasonic calls in long distance communication. Infrasound is effective because it has long wavelengths that travel far with little attenuation.

The intensity of these sounds can reach 104 dB, as measured 5 m from the source.

Payne and her colleagues performed tests in Etosha, Nambia, which showed that elephants hear and respond to each other's loud calls from distances as great as 4 kilometers, which is equivalent to an area of about fifty square kilometers.

During one test, Payne and a few associates sat on a tower that overlooked a water hole. Two mature male elephants, called bulls, were splashing in the muddy overflow. The researchers at the tower recorded the bull's behavior on a video with a time stamp.

As part of this experiment, a van located 2 kilometers away from the water hole with a large loudspeaker broadcast a recorded series of a female elephant's mating call. The call was inaudible to Payne and her colleagues at the tower, because only the infrasonic portion could propagate over the entire distance from the van to the tower.

The test was "double-blind" because Payne and her colleagues at the tower did not know the time at which the broadcast would occur. Neither did they know the location of the van.

At a particular instant, the bulls perked up. They paused, then left the water hole and began heading north. The elephants in fact walked directly by the van that had broadcast the mating call earlier. The elephants continued their walk past the van without stopping.

That evening, Payne and the van operators verified that the broadcasts were made at the exact time that the bulls perked up and began walking toward the distant van.

The broadcast had been played at half-power because the loudspeaker was incapable of reproducing the full volume of the female elephant's call. This allowed the researchers to extrapolate that the bulls would have heard a full power signal at twice the distance, which would have been 4 kilometers.

Elephants' Uses of Infrasound

Elephants use long distant infrasound for breeding. They also use infrasound to assemble bond groups and to coordinate movements between groups in a clan.

A bond group is headed by a matriarch who leads several mature female elephants, called cows, along with their offspring. A typical group may contain anywhere from one to three dozen individuals. The main purpose of the group is the bearing, rearing, and protection of the calves.

Bulls remain somewhat detached from these groups but may temporarily join them for mating.

During the day, elephants must move from one place to another in search of food and water. The matriarch uses calls to assemble her group when she decides to lead them to next location. These calls may contain infrasound particularly if her group has become scattered.

Furthermore, bond groups are part of a larger clan. The elephants use infrasound to coordinate the movements between groups. The groups need to remain far enough apart so that they effectively allocate scarce food and water resources. Sometimes this may mean that the groups take turns at a water hole.

On the other hand, the groups need to remain somewhat close for mutual protection against threats, particularly lions and poachers.

Infrasound is an effective tool for coordinating these movements.

## Infrasound Summary

Payne and her colleagues found that both African and Asian elephants communicate over long distances via infrasound. The infrasonic signals begin at a lower frequency of 14 Hz for each species. The infrasound has a spectrum of energy that overlaps into the audible range for humans. The upper limits for Asian and African elephants are 24 Hz and 35 Hz, respectively.

The documented distance over which the elephants communicate during the day is 2 km, but this has been extrapolated to 4 km based on a consideration of maximum sound power.

The calling area may be expanded by as much as an order of magnitude during temperature inversions in the evening and night.

Elephants may thus communicate more effectively during the evening, but the risk is that lions may detect these calls.

## Postscript

Payne's discoveries have proven to be a catalyst for bioacoustic research.

Payne studied elephant infrasound as transmitted through the air. Infrasound also generates a corresponding seismic wave. Stanford researchers are pursuing this ground-borne wave.

"We have several experiments going on right now to try to determine whether elephants perceive seismic cues via bone through their toenails and foot bones to their middle ear bones, or through vibration-detecting cells in the bottom of the foot," said Stanford's Caitlin O'Connell-Rodwell, now studying the matter in Namibia.

Other researchers using Payne's methods have discovered that rhinos and giraffes also communicate via infrasound. This list of animals may continue to grow.

**Slinky Science** by Tom Irvine

Introduction

The slinky was invented by Robert James, a naval engineer, in 1945. He was experimenting with tension springs when one of the coils fell to the floor and began to “walk.” His wife Betty had an immediate vision of for the spring as a children’s toy. She named it “slinky,” a Swedish word meaning stealthy, sleek, and sinuous.

The original slinky model has 65 feet (19.8 meters) of steel coil.

The sample slinky obtained for this science project had the following weight in terms of equivalent units

| | |
|---|---|
| 8.2 | ounces |
| 0.51 | lbm |
| 0.232 | Kg |

The slinky was suspended from a ceiling as shown in Figure 1. Weights were attached to the free end of the slinky to determine its stiffness using Hooke’s law.

The stiffness k is

$$K = F / x \tag{1}$$

Where F is the attached weight and x is the displacement relative to the equilibrium position.

The resulting spring stiffness of the sample slinky in terms of equivalent units is

| | |
|---|---|
| 0.0031 | lbf/in |
| 0.54 | N/m |

The slinky is thus very compliant.

The length of the slinky as suspended from the ceiling is 80 inches (2.03 meters).

Figure 1. Slinky Suspended from Ceiling.

Figure 2. Relative Displacement Sensor Below Free End of the Slinky

There is a small gap between the sensor head and the end of the slinky.

Hanging Slinky

The slinky was hung from the ceiling as shown in Figures 1 and 2. The resulting time history and spectral functions are shown in Figures 3 and 4, respectively.

The amplitude is uncalibrated.

The time history shows a beat effect.

The fundamental spectral peak has a frequency of 0.39 Hz.

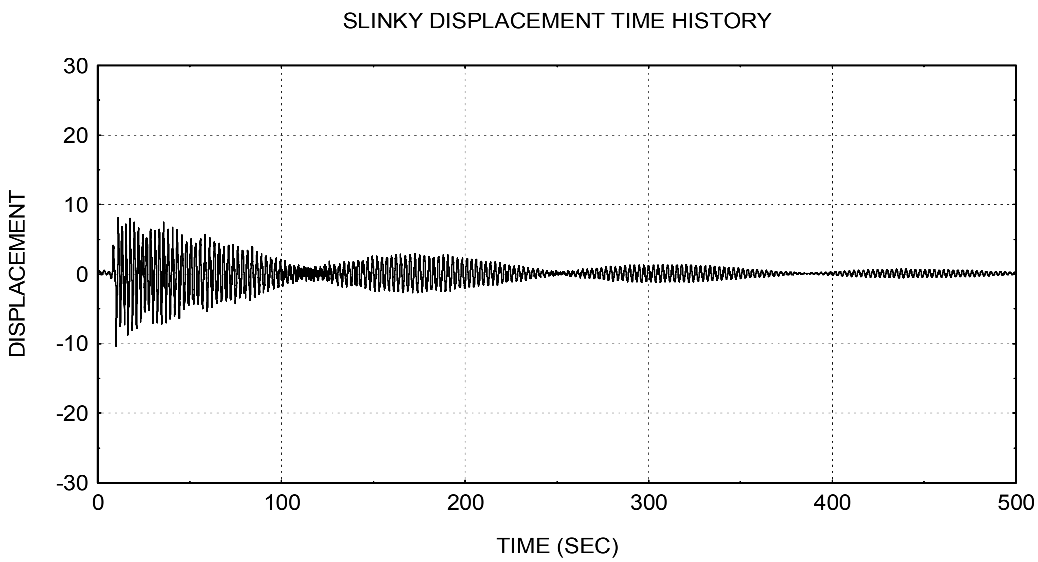


Figure 3.

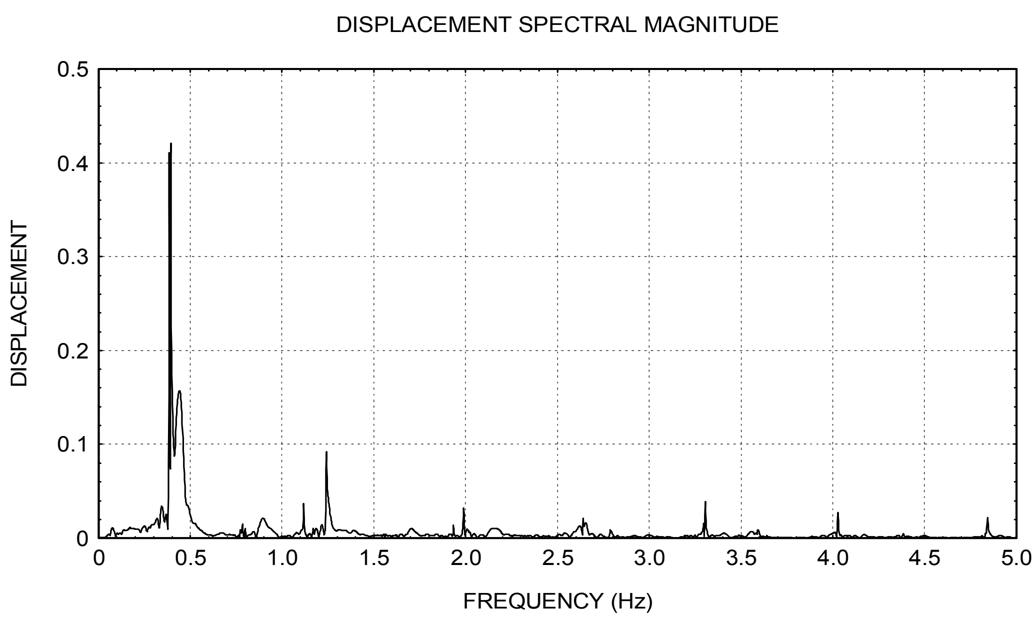


Figure 4.

## Hanging Slinky Longitudinal Vibration Mode

The natural frequency fn of a spring without an attached mass is

$$fn = \frac{1}{2\pi}\sqrt{\frac{3k}{m}} \qquad (2)$$

where k is the spring stiffness and m is the spring's mass.

$$fn = \frac{1}{2\pi}\sqrt{\frac{3\,(0.543\ \text{N/m})}{0.232\ \text{kg}}} \qquad (3)$$

The longitudinal frequency is thus

$$fn = 0.91\ \text{Hz} \qquad (4)$$

## Hanging Slinky Chain Mode

An initial thought would be to model the slinky as a simple pendulum. The slinky, however, is a flexible body. It is analogous to a suspended chain.

Daniel Bernoulli (1700-1782) determined the normal modes of a hanging chain in 1732, and it was further discussed by Euler in 1781.

The natural frequency for a suspended chain is

$$fn \approx 0.19\sqrt{\frac{g}{L}} \qquad (5)$$

where g is acceleration of gravity and L is the total length.

Now model the slinky as a suspended chain.

$$fn \approx 0.19\sqrt{\frac{9.81\ \text{m/sec\^{}2}}{2.03\ \text{m}}} \qquad (6)$$

$$fn \approx 0.42\ \text{Hz} \qquad (7)$$

## Experimental and Analytical Frequencies

Again, the spectral function in Figure 4 has its fundamental frequency at 0.39 Hz. This corresponds to the hanging chain motion. The spectral function also has a minor peak near 0.91 Hz, which corresponds to the longitudinal vibration motion.

The spectral function also contains additional peaks which represent higher longitudinal and chain modes.

Sound Effect

Figure 5.

One end of a slinky was attached to a metal plate using tape. The plate was then lifted up about 6 feet above the ground. The slinky's free end then dropped downward, striking the ground. The result was a high pitched sound effect similar to a laser burst in a science fiction movie.

The resulting sound spectral plot had its highest peak at 1130 Hz.

Angelo Campanella, an acoustics engineer, provided the following explanation:

> A traveling wave is excited when the end of the slinky hits the ground. That wave runs up and down the slinky spiral as a longitudinal wave. It might make a few trips up and down. The wire is just thick enough to radiate sound, especially at and above 1,000 Hz. The length and wave speed is enough, I suspect, to give some Doppler as well.

Walking Demonstration

Figure 6.

The ramp was nearly 72 inches long. The angle between the ramp and the floor was 17.2 degrees. This configuration was determined by some amount of trial-and-error. Whether 17.2 degrees is the optimum angle, however, is unclear.

On a good run, the slinky made 14 steps as it traveled from the top of the ramp to the floor.

The walking slinky demonstrates the conversion of potential energy to kinetic energy.