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The Acoustics of the “Clapping Circle” at Purdue University

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TESTING THE “CLAPPING CIRCLE” AT PURDUE UNIVERSITY

ACOUSTICAL SOCIETY OF AMERICA, PURDUE UNIVERSITY
Wear headphones please!

Presented by Elspeth A Wing, Steven J Herr, Alexander D Petty, Alexander K Dufour, Frederick H C Hoham, Morgan E Merrill, Donovan W Samphier, Weimin Thor, Kushagra Singh, Yutong Xue, Davin H Huston, J Stuart Bolton

What Is the Clapping Circle?

- Landscape architecture feature of Purdue Campus' Academy Park, built in 1996
- Made out of 66 concentric circles of stone tiles
- When you clap while standing in or close to the middle
 - hear a “squeak” sound

(best with headphones)

All nearby circles exhibit the same effect

So do many other parks and college campuses

Theories We heard about the Squeak

Benches

Returns In:
0.05s

Surrounding
Buildings

Returns in:
 $\geq 0.24s$

Tiles

Returns in:
0.01s-0.05s

Tested Hypothesis: Non-specular reflection from inter-tile bevels

- Rough recording of squeak shows it happening 0.01-0.06s after clap → Tile Reflections are most likely:
 - Sound would reflect away from the source when it hits the flat surface of the tiles
 - Sound may reflect towards the source from the bevels between the tiles if they act as apertures/gratings through which the sound diffracts
 - Frequency is related to the time intervals between reflection arrivals

Paths of the Reflection Wavefronts

Each circular pattern reflects sound

The repetition pitch and diffraction grating models of the squeak's reflection are related to the path lengths of each equation from the source to the receiver

$$\text{Squeak frequency, } f = \frac{1}{\Delta t}$$

Two Relevant Theories:

- **Repetition Pitch:**

- Most famously studied by Frans A Bilsen (glide)
- Refers to a tone that is heard by the human ear when it processes a broadband impulse and its periodic repetitions

- **Acoustical Diffraction Grating**

- Refers to the sound produced by summing coherent sound waves being scattered by a periodically corrugated surface
- Both theories yield the same mathematical result regarding the time-frequency relationship

From a repetition pitch article (Bilsen)

From a diffraction grating article (Declercq and Dekeyser)

Model of the Frequency: Repetition Pitch

Model of the Frequency: Classical Grating Equation

$$\alpha = \cos^{-1}\left(\frac{h_{speak}}{d_s}\right)$$

$$\beta = \cos^{-1}\left(\frac{h_{mic}}{d_m}\right)$$

$$|m|\lambda = d(\sin \alpha + \sin \beta)$$

$$m = -1, -2, -3 \dots$$

*The negative sign indicates that the diffracted ray is travelling back towards the source

Impulse Response: Equipment Setup

BK 2716
Amplifier

BK Omni-power
Speaker

Earthworks
Microphone

Behringer
UMC404
Interface

Laptop with Logic
Pro

Testing Procedure: Impulse Response

- Record claps under different conditions:
 1. Base Case
 2. Different **speaker and mic heights**
 3. Different amounts of the **circle covered with moving blankets**
 4. Circles with and **without benches**

Physical Dimensions of the Circle

Radius	9.14m
Number of tiles to the radius	66 (count)
Radial dimension of the fifteen inner tiles	0.12 m
Radial dimension of the outer 51 tiles	0.14 m

1. Base Case Measurement

0.01 – 0.05 seconds after impulse: three prominent harmonics → **squeak (glide)**

Loudest broadband impulse: **the initial clap sound**

The Base Case tested the largest circle with the speaker at 4'4" and microphone at 6'6" with now tiles covered

Second quieter impulse occurs after 0.06 seconds → **bench reflection**

Third broadband impulse is the **secondary bench reflection**

Fundamental Frequency as a Function of the Time Elapsed from the Clap:

- Looks a lot like the downward concave-up curve of the squeak in the spectrogram
- The three harmonics cover the same frequency range as the three frequency elements of the squeak area 4-3.7kHz, 2.8-2.5kHz, 1.4-1.2kHz

Comparison of Base Case to Model

Tiles 18-66 which are graphed in the plot, represent reflections arriving from 0.16 to 0.54 seconds, which is about the range of the “bridge” shape

2. Models for Different Speaker Heights

Speaker at 4'4"

The modelled frequency of the squeak flattens out as the difference between reflection distances nears the size of the tiles

2. Models for Different Speaker Heights

Speaker at 6"

The modelled frequency of summation also flattens out faster. The difference between reflection distances converges faster because the paths start out being more “flat”

2. Height of Speaker and Mic

Base Case (Speaker at 4'4")

- “slant of the squeak” is flatter for the ground level squeak
- This agrees with calculations, and is due to the reflecting paths being more “horizontal”

2. Height of Speaker and Mic

Ground Level

- “slant of the squeak” is flatter for the ground level squeak
- This agrees with calculations, and is due to the reflecting paths being more “horizontal”

3. Covering Tiles with Blankets

As more tiles are covered, the
squeak fades from left

Base Case (No Cover)

3. Covering Tiles with Blankets

As more tiles are covered, the squeak fades from left

Covered Radius: 20'3"

3. Covered Tiles

All Tiles Covered

As more tiles are covered, the squeak fades from left

No Covering vs. All Tiles Covered

Base Case (No Cover)

All Tiles Covered

While the clap and bench reflection remain, the "bridge" shape of the squeak goes away when the tiles are covered

Testing Different Circles

4. Presence or Absence of Benches

In the Wetherill circle, which does not have any benches, the second “column” goes away, but the bridge of the squeak remains

Main Circle (No Cover, has benches)

4. Presence or Absence of Benches

In the Wetherill circle, which does not have any benches, the second “column” goes away, but the bridge of the squeak remains

Wetherill Circle (No Cover, No Benches)

Why do higher harmonics outshine lower ones?

Purdue Clapping Circle

Kukulcan Pyramid : -3 is more prominent than -2 (Declercq *et al.*)

Theater of Epidaurus: -2 shows more than -1 (Declercq and Dekeyser)

Threshold for Scattering: the sound's wavelength

Location	Size of Periodic Architectural Element	Wavelength of Prominent Harmonic	Wavelength of Lower Order Less Prominent Harmonic
Purdue Clapping Circle	0.147 m	$m = -2$ $\lambda = 0.140\text{ m}$	$m = -1$ $\lambda = 0.28\text{ m}$
Hellenistic Theater of Epidaurus (Declercq and Dekeyser, 2006)	0.746 m	$m = -2$ $\lambda = \leq 0.76\text{ m}$	$m = -1$ $\lambda = \leq 1.7\text{ m}$
Kukulcan Pyramid at Chichen Itza (Declercq et al, 2004)	0.263 m	$m = -3$ $\lambda = \sim 0.23\text{ m}$	$m = -2$ $\lambda = \sim 0.51\text{ m}$

Conclusion

- Squeak is caused by the interaction of periodic reflections from the tiles that can be described as a combination of a **repetition pitch** and a **diffraction grating**
 - The spectrograms of measurements are in good agreement with the model predictions
 - The dominance of the second harmonic is corroborated by other studies that found that spatially periodic structures only scatter sound if their corrugation is less than or equal to a wavelength

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ASA Purdue Chapter Members

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Image Sources

Slide 1:

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Slide 2

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