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P1 6 We Will Rock You (But Not That Much): Estimating the Seismic Energy of a Rock Concert Crowd

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Abstract

This paper estimates the number of people required to generate, through rhythmic stomping, the same amount of energy as a small earthquake. Using Queen's iconic '*We Will Rock You*' as a model, we approximate the kinetic energy released per stomp and compare it with the seismic energy of a magnitude 3.0 earthquake. We find that 295 million people would need to stomp in unison for the duration of the song to simulate a minor earthquake.

Introduction

Live concerts are known for their ability to make the ground shake. Reports of measurable ground vibrations lead to speculation about whether a sufficiently large and synchronized audience could mimic a minor earthquake. In this paper, we explore the question quantitatively: How many people stomping in rhythm to Queen's '*We Will Rock You*' are required to generate the same amount of energy as a small earthquake?

Earthquake magnitude and seismic energy are empirically related by seismological studies such as those by Charles F. Richter in 1935 [1]. This relationship allows us to compare human-scale mechanical energy with natural seismic events. By calculating the energy released by a magnitude 3.0 earthquake (a minor earthquake but still felt by people [2], such as the earthquake that hit New York August 2nd this year, that was described as a 'very brief tremor, just a slight swaying for a moment' [3]), and comparing this to the

kinetic energy of an average human stomp, we estimate how many people would need to engage in the '*We Will Rock You*' rhythmic pattern to simulate a minor earthquake.

Theory and Results

The total seismic energy, E , associated with an earthquake of moment magnitude, M_w , can be estimated using [4]:

$$\log_{10}E = 5.24 + 1.44M_w. \quad (1)$$

So for an earthquake of moment magnitude 3.0, the total seismic energy is $E = 3.63 \times 10^9$ J. The kinetic energy per stomp can then be calculated using:

$$E_{\text{stomp}} = \frac{1}{2}mv^2, \quad (2)$$

where m is the effective mass, and v is the velocity at which the mass is moving. Taking the average mass of a person's leg as 15 kg [5], and the average speed at which a person stomps their foot to be 1 ms^{-1} [6], we obtain a kinetic energy, $E_{\text{stomp}} = 7.5$ J. The number of stomps required

is found by taking the ratio of the two energies:

$$N_{\text{stomp}} = \frac{E}{E_{\text{stomp}}}, \quad (3)$$

assuming the conversion rate of kinetic energy to seismic energy is perfect, we find the number of stomps required to be $N_{\text{stomp}} = 4.84 \times 10^8$.

Finally the number of people required to generate energy equivalent to that of a small earthquake can be calculated using:

$$N_{\text{people}} = \frac{N_{\text{stomp}}}{N_{\text{spp}}}, \quad (4)$$

where N_{spp} is the number of stomps per person, in this case $N_{\text{spp}} = 164$ [7]. This number was determined by analysing the song, which features the repeating 'stomp-stomp-clap' rhythmic pattern 82 times, thus the song includes 164 stomps. Therefore, the number of people required to engage in Queen's '*We Will Rock You*' rhythmic pattern, in order to simulate a magnitude 3.0 earthquake, is estimated to be 2.95×10^6 , which is ~ 20 times the band's largest crowd (150,000 [8]).

However, in reality the conversion rate of kinetic energy to seismic energy is far from perfect. Now assuming the conversion rate is just 1% for a more precise estimation, by following the same method as above, we estimate a required crowd size of 2.95×10^8 people. This is now nearly 2000 times the size of the rock band's largest recorded crowd.

Discussion

In this paper, the assumption is initially made that all kinetic energy released by a person stomping their foot is perfectly converted into seismic energy. In reality, the majority of this kinetic energy is absorbed by the persons body, shoes and the floor itself, dissipating as heat, sound, and local vibration as opposed to traveling through the ground as seismic waves. Therefore, we then assume only a very small fraction of the released kinetic energy propagates as seismic waves, and a more realistic estimate is made by taking 1% of the kinetic energy per stomp to

be converted into seismic energy. Although this is still much greater than what is actually converted, this is a much more realistic estimate.

The assumption of perfect synchronization of, what we find to be, 295 million people is also made. In reality, we would see discrepancies in people's rhythms, resulting in partial cancellations of the total power generated, reducing the total energy transmitted to the ground as seismic waves. Furthermore, this number of people would occupy an enormous area. Assuming an average of 0.5 m^2 per person in a dense crowd, 295 million people would cover roughly 150 km^2 , greater than the area of a large city such as Manchester [9]. For a seismic event, however, the energy must be concentrated over a much smaller area to have a measurable effect, meaning the energy from such a dispersed crowd would be even less effective at generating a coherent seismic wave.

The assumed 1% conversion of kinetic energy to seismic energy was chosen as a conservative upper bound based on experimental studies of human-induced ground vibrations, which typically find less than 1% of mechanical energy couples efficiently into the ground [6]

Thus, the number of people required to engage in the classic 'stomp-stomp-clap' rhythm of Queen's '*We Will Rock You*' would be even greater than the 295 million estimated in this paper.

Conclusion

Using mechanical physics and seismological scaling laws, we estimate that around 2.95×10^8 people stomping in unison to Queen's '*We Will Rock You*' generates energy that is equivalent to the seismic energy of a magnitude 3.0 earthquake, $3.63 \times 10^9 \text{ J}$. This is ~ 2000 times the size of Queen's largest recorded crowd, so, while stomping to the rhythm of '*We Will Rock You*' can certainly shake a stadium, the Earth remains unperturbed on a geological scale.

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