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A3_2 Ding Dong! Ding Dong! My Hearing is Gone!

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Abstract

This paper discusses how loud Big Ben would have to chime to be heard at 50 dB , a quiet office volume, on the University of Leicester campus. We found that the required volume is 153 dB, louder than the 130 dB which deafens people indefinitely. We also discuss the adverse effects of a sound being this loud. We calculated that the sound drops below the deafening threshold at 14.2 m from Big Ben. Between 14.2 m and 45 m away from the source, the sound would cause pain, beyond 45 m there would be no effect on the ears of those hearing it.

Introduction

Big Ben has been iconic since its 1859 completion, its tower standing at 96 m tall. It is known as a tourist destination and counts us down into the new year. In this paper we show how much louder it would have to ring to be heard in Leicester, and the effect that would have on those in London.

Method

Sound is a wave, propagating by the compression and rarefaction of whichever medium it moves through, commonly air. In air, the speed of sound is commonly quoted as 343 ms^{-1}. Sound falls off as an inverse square law [1] as seen in equation (1).

$$I = \frac{P_{av}}{4\pi r^2} \tag{1}$$

In equation (1), I refers to the intensity of the sound, P_{av} is the average power and r is the distance between the origin of the sound and where it is being measured. Equation (2) gives the logarithmic nature of the sound intensity level, β, in decibels. I_0 refers to the threshold of hearing which is 10^{-12} Wm^2.

$$\beta = 10\log_{10}(\frac{I}{I_0}) \tag{2}$$

By substituting equation (1) into equation (2) and rearranging to make P_{av} the subject, equation (3) is made.

$$P_{av} = 4\pi r^2 I_0 10^{\frac{\beta}{10}} \tag{3}$$

Now we have an equation to find the average power, this can be substituted back into equation (1) in order to find the intensity of the chimes. This can then be used in equation (2) to calculate how loud Big Ben needs to chime to be heard in Leicester.

Findings

Currently, Big Ben chimes at 118 dB [2] meaning it has an average power, P_{av}, of 7.92 W. Using this value we worked out that the current sound from Big Ben would arrive in Leicester at 14.9 dB. This is significantly quieter than an average library noise level, 40 dB [1]. We then assumed that β is 50 dB in Leicester, which is approximately the number of decibels needed to be audible. We calculated the average power needed for the chimes to be heard, by following the equations and methods previously explained. The distance between Big Ben and the Charles Wilson Building was found to be $142,000$ m [3]. The average power needed for the chimes to be heard was calculated as $25,400$ W. This was substituted into equation (3), along with the distance from the source being 1 m to work out the sound intensity in decibels. The volume of the chime leaving Big Ben would need to be 153 dB to be heard in Leicester.

The volume of sound needed to cause sudden hearing loss is 130 dB [4]. Given that we calculated the sound to be 153 dB, people within a certain distance of Big Ben would be deafened. It would also harm many more as any sound over 120 dB is considered painful [1]. To work out these distances, we rearranged equation (3) for r, as seen below in equation (4).

$$r = \sqrt{\frac{P_{av}}{4\pi I_{ref} 10^{\frac{\beta}{10}}}} \tag{4}$$

By taking the average power as $25,400$ W, using β_{deaf} to be 130 dB and β_{pain} to be 120 dB it is possible to find the distance from the source that causes deafness and pain. We found r_{deaf} to be 14.2 m and r_{pain} to be 45.0 m. We then calculated the area of the circles with both these radii. By multiplying the areas by the population density of Westminster, $11,025.9$ km^{-2} [5], we calculated the number of people who go deaf and are in pain due to the sound. We calculated that approximately 7 people would be within the deafening radius and hence go irreversibly deaf when the bell rings, whilst causing significant pain to a further 63 people.

Assumptions

We have assumed that there is no interference from additional sound waves as this would affect the volume of the chimes. We have also assumed a 2D scenario with Big Ben at one point and the University of Leicester at the other. This assumption was required as the distance between the two points is not flat. We assumed that between consecutive chimes, 7 people enter, are deafened, leave, and a new 7 people enter the affected area, the same applies for those in pain.

The population density used is not necessarily accurate, as it is likely that more people will be within 14.2 m of Big Ben as it is a popular tourist destination and the population of Westminster is not equally spaced out. To counter this, we have assumed a 2D scenario, but in reality the world is 3D. The height of Big Ben is larger than the radius of both hearing damage and deafening. This would mean it is unlikely any damage would actually be caused.

Conclusion

Big Ben's current sound arrives in Leicester at 14.9 dB, approximately 25 dB quieter than a library [1]. We calculated that Big Ben needs to chime at 153 dB to reach Leicester at an audible volume. This deafens approximately 7 people after each chime within a 14.2 m radius, and causes pain to an additional 63 people within a 45 m radius of Big Ben. In reality, no one's hearing would be damaged as the world is 3D. Taking into account the height of Big Ben, those on the floor would be out of range of the 45 m radius.

References

[1] P. A. Tipler, *Physics For Scientists and Engineers* (W.H Freeman and Company, New York, 2008), 6th Edition, Chapter 15, pages 495 - 532.

[2] `https://tinyurl.com/bigbendb` [Accessed 14th October]

[3] `https://tinyurl.com/ycg6ys9j` [Accessed 14th October 2020]

[4] `https://tinyurl.com/dbpain1` [Accessed 14th October 2020]

[5] `https://tinyurl.com/popdenslondon` [Accessed 14th October 2020]