Modeling Geophysical Waves with Gelatin

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Geophysicists use the properties of waves to discover information about rock layers in Earth. The purpose of this experiment was to begin modeling how different types of waves move through materials. Gelatin was used instead of rock because its much slower wave speed facilitated video analysis. A gelatin slab was struck and the resulting waves were analyzed by tracking grid lines using LoggerPro software. Two mixtures of gelatin were tested. In the first mixture, which had a higher proportion of water in the ratio, the speed of a compressional wave through the gelatin was found to be 31 ± 1 cm/sec. And in the second mixture, which was more concentrated, a compressional wave had a speed of 39 ± 6 cm/sec. When comparing the speeds in the two different gelatin mixtures, as well as comparing them to rock, it makes sense that in the stiffer materials the wave moves faster. The attenuation of waves in each mixture was also found; with mixture 1 having a damping distance of 54 ± 9 cm and mixture 2 having a damping distance of 5 ± 1 cm. The next important step is to repeat the experiment again with different mixtures to confirm the data, as well as testing other concentrations of gelatin. The ultimate goal would be to compare and confirm the data with the properties and concepts used in seismic studies.

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INTRODUCTION

By studying the way vibrations, or waves, propagate through Earth, scientists have gathered information about the layers of Earth. They have discovered where and what materials the main layers are, going all the way to the inner core, as well as the more specific stratigraphy near the surface of Earth. When rocks slip against each other, causing an earthquake, vibrations move outwards through Earth. Scientists observed propagating earthquake waves on different sides of the planet from where an earthquake occurred and realized waves change as they move through the planet. This indicates that there are different layers within Earth, of different thicknesses and materials, which cause waves to change direction and speed. Scientists use earthquake waves to study Earth's layers, but they also have devised methods using artificially induced waves to study the layers. The purpose of this experiment is to examine different types of waves as they move through varied materials and compare with the knowledge of seismic waves moving through rock layers in Earth.

THEORY

Even though scientists are not able to travel all the way to the center of Earth, using the properties of waves, they are able to make inferences about layers many kilometers below our feet. Waves cannot actually be seen moving through most rocks because they move too quickly, on the order of km/sec, as the rocks are very stiff, but it is possible to measure wave velocities by actually observing the propagation of waves through the material.

The speed of waves in materials can also be represented by

$$v = \sqrt{\frac{p}{\rho}}, \tag{1}$$

where ρ is the mass density of the material and p is essentially the coefficient of stiffness. For stiffer materials, as they have higher coefficients of stiffness, the faster the wave will move through the material.

While the purpose of this experiment was to get information related to wave movement through Earth, it was decided that an easier way to study wave movement was not through rocks but through a substance where the waves could be more easily mapped and then compared to rock wave data. Gelatin was chosen as a stand-in for rocks because it was easy to make, relatively cheap and the speed of waves through it was slower and thus able to be observed.

By knowing distances x on the material and times t at which the wave reaches those distances using high speed video, the speed of the wave can be determined using

$$v = \frac{x}{t}. \tag{2}$$

By graphing distance versus time data, the slope of the line created will be the speed of the wave.

It can also be assumed that there will be some attenuation of the wave as it moves through the material. If at one time the rate of change of the amplitude with distance x is proportional to the amplitude A, then

$$\frac{dA}{dx} \propto A. \tag{3}$$

Eq. 3 can be rewritten as

$$\frac{dA}{dx} = -\frac{1}{x_0}A, \tag{4}$$

where x_0 represents the damping distance. Through integration, Eq. 4 becomes

$$A = A_0 e^{-\frac{x}{x_0}} \tag{5}$$

to show that the damping will be exponential.

PROCEDURE

Waves in the Gelatin

Knox Gelatine was used as the wave medium. The first step was to find the best way to shake the gelatin. A gelatin slab stuck to the surface it was on and thus gave surface waves instead of body waves, as desired. It was found that the best way to minimize one side moving differently than the rest was to place the gelatin slab in water. This helped because the gelatin floated along the bottom of the container because of buoyancy.

Making of the Gelatin

A large, Rubbermaid tub was used to create a rectangular gelatin slab, approximately 3 by 9 by 13 inches. Two different mixtures of gelatin were used to test if there was a difference in wave characteristics. The first mixture used the recipe off the Knox gelatin box, with a ratio of 1 packet of Knox gelatin to 3/4 cup of warm water and 1/4 cup of cold water. The second mixture had a ratio of 1 packet of Knox gelatin to 2/3 cup of warm water and 2/9 cup of cold water. The best way to remove the sample was to place the Rubbermaid container in heated water so that it became unstuck from the sides and flip it over onto a pan, then draw grid lines of 3.7 cm spacing.

Recording Waves in the Gelatin

The gelatin sample was placed in a tub of water and a high speed camera was aimed straight down on the gelatin. It was found that the best way to see mostly body waves and less surface and edge waves was to press the sample up against the side of the tub using a plexiglass plate and create waves using my hand. The high speed camera recorded videos of the gelatin being hit at 210 frames per second. Videos were taken of different gelatin slabs of the same size using the same standard recipe ratio on the Knox box. These videos were analyzed using LoggerPro software by tracing multiple intercepts of the grid along the same horizontal line over the same time. The speed and damping of the wave was found.

RESULTS AND ANALYSIS

The observations of the gelatin slab in water when it was contained against the side of the container demonstrated that mostly body waves were present. Even without the high speed camera, the wave could be seen quickly propagating through the gelatin. The gelatin slab that

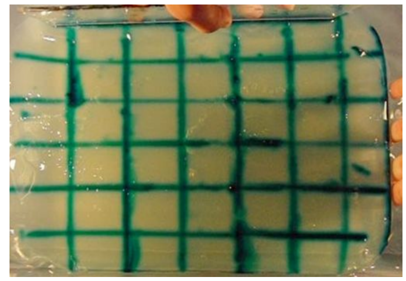

FIG. 1: Photo showing the gelatin slab with the grid marker and no wave propagating through.

was analyzed can be seen in Fig. 1. Then high speed videos were taken of the gelatin and analyzed.

First, mixture 1 was analyzed. The position of different lines along the gelatin at certain times were mapped out. The data was then graphed to show the movement of each vertical line across the gelatin. It can be seen in

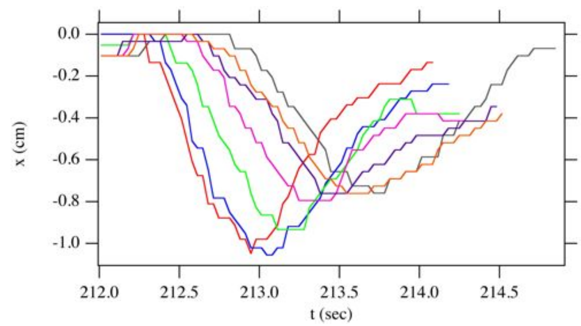

FIG. 2: Graph showing the movement of each vertical line in mixture 1 gelatin as the wave propagated through.

Fig. 2. Each line on the graph represents the movement of a vertical line on the gelatin over time. The data for each line has been adjusted so that they all start at zero to make it clearer to read. It can be seen that the first lines to show, thus happening sooner in time, have higher amplitudes as the wave is just beginning to propagate. Then as the wave moves through the gelatin, reaching other lines, the amplitude becomes slightly less.

Then using the concept of Eq. 2, distance versus time was graphed and the slope of the line was found. The distances were known because the spacing of the lines was a known distance of 3.7 ± 0.1 cm. The times were found by mapping the low points for each data set in Fig. 2, as those represented the times at which the vertical lines reached their maximum displacement from the propagating wave. The graph can be seen in Fig. 3. The speed of

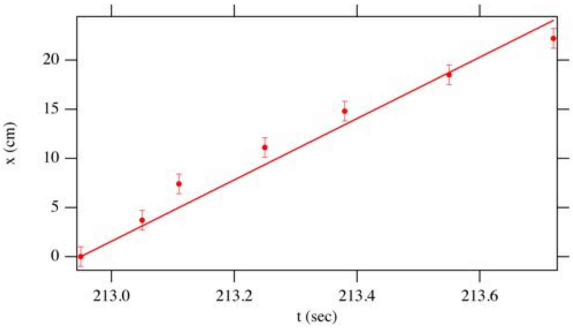

FIG. 3: Graph showing distance versus time of the wave propagating through mixture 1 gelatin with the slope of the fit line being the speed of the wave.

the wave was found to be 31 ± 1 cm/sec. Compared with the speed of compressional waves in rocks, which move at kilometers per second, this is much slower [4].

The data was also analyzed for damping, as waves attenuate somewhat as they propagate through material. The rate of damping, which is the decay rate of the exponential, represented in Eq. 5, was found by graphing the amplitude of the wave as it passed through the gelatin versus distance between grid lines. This is shown

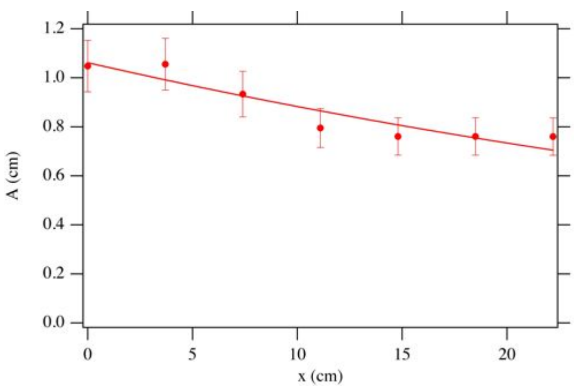

FIG. 4: Graph showing amplitude of the wave versus time at one time, with an exponential fit line representing the damping, in mixture 1 gelatin.

in Fig. 4. The damping distance at one point in time was then found by taking the inverse of the exponential decay rate. It was found to be 54 ± 9 cm. This essentially means that the wave moving through gelatin mixture 1 will damp out after moving about 54 cm.

Then, mixture 2 was analyzed in the same way as mixture 1. Fig. 5 shows the position of the grid lines at different times as the wave propagated. Then the speed of the waves in mixture 2 gelatin was found the same way. This can be seen in Fig. 6. The speed in mixture 2 was found to be 39 ± 6 cm/sec. As with mixture 1, this speed is much slower than the speed of compressional waves in

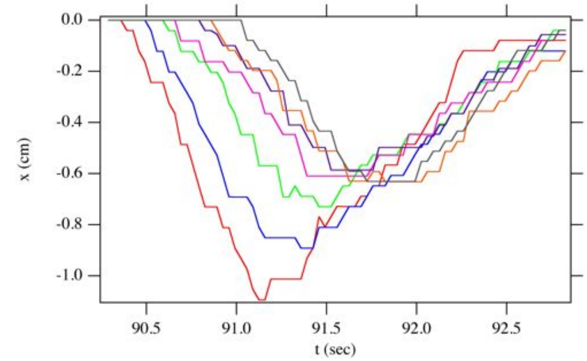

FIG. 5: Graph showing the movement of each vertical line in mixture 2 gelatin as the wave propagated through.

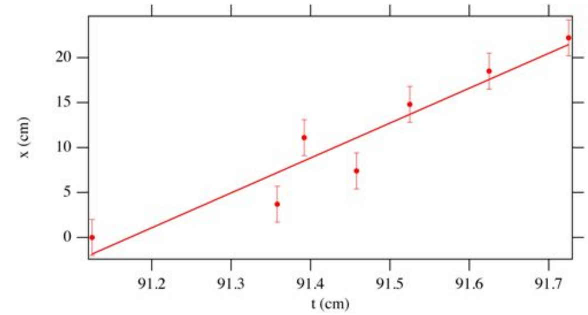

FIG. 6: Graph showing distance versus time of the wave propagating through mixture 2 gelatin with the slope of the fit line being the speed of the wave.

rock. However, the speed in mixture 2 can be seen to be faster than in mixture 1. This is most likely because the mixture is more stiff, just like rock is even stiffer than both the gelatin mixtures.

The damping was found for mixture 2 in the same was, by graphing how much the grid lines offset, or the amplitude, versus distance between the grid lines. This can be seen for mixture 2 gelatin in Fig. 7. The damping

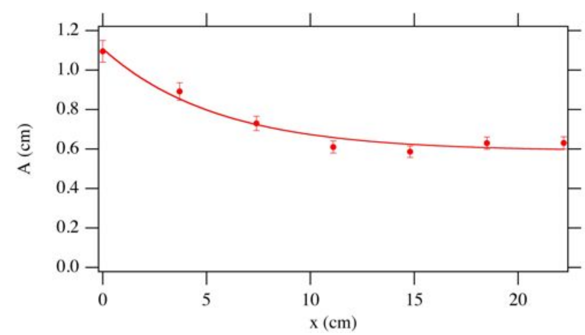

FIG. 7: Graph showing amplitude of the wave versus time at one time, with an exponential fit line representing the damping, in mixture 2 gelatin.

was found to be 5 ± 1 cm. It can be seen that there is a large difference between the damping in mixture 1 and

2. In mixture 2, the wave travels less distance before it is damped out. Although this seems like a large difference and must be tested further to confirm it, it makes sense that the damping distance would be less in mixture 2 because it is a stiffer material and the wave would attenuate quicker.

From the speed and density of the gelatin, the stiffness of the gelatin can be calculated. The density of each mixture was found. Then using the speeds of the wave in the two mixtures and Eq. 1, the stiffness coefficient for each mixture was calculated. The stiffness coefficient for mixture 1 was 980 ± 10 dyn/cm^2 and for mixture 2 it was 1457 ± 15 dyn/cm^2. It makes sense that mixture 2, the more concentrated mixture, would be the stiffer material; this is why the waves move faster through it. To compare to the stiffness of rocks, the stiffness of an average igneous rock would be 5×10^{11} dyn/cm^2. This can be seen to be much larger than the stiffness of either of the gelatin mixtures.

FUTURE WORK

As this project was just the beginning of research on seismic waves in gelatin, there is a lot of future work that can be done. The next step with this experiment is to repeat the compressional waves through the gelatin slab using the same mixtures in order to confirm the current data. Different mixtures, with different gelatin mix concentrations, could be tested as well.

Another interesting experiment that could be done would be to model shear waves in the gelatin, specifically to see how the movement of shears waves changes when traveling from solid to liquid back to solid. An attempt was made to create shear waves in the gelatin using a board with nails sticking out to move against the gelatin perpendicularly. The technique needs to be refined to not only find a good way to observe and measure the shear wave propagating through, but also to make sure the nails do not rip the gelatin. Once shear waves have been successfully seen and measured through the gelatin, it would be interesting to set up a gelatin slab with water in the middle to see how the liquid changed the wave as it moved through.

CONCLUSION

Seismic waves, both natural and artificial are helpful in identifying properties about the rock layers in Earth. The motivation of this project was to explore different types of waves in different types of materials and compare the results to the behavior of actual seismic waves in rock. Gelatin was used first to model this because the waves move slow enough to be visible. While waves in rocks move on the order of km/sec, it was found that the speed of compressional waves in gelatin was on the order of cm/sec. In a gelatin mixture with a higher ratio of water, waves moved at a speed 31 ± 1 cm/sec and damping of 54 ± 9 cm. The damping distance of the gelatin mixtures were also found. Mixture 1 being 54 ± 9 cm and mixture 2 being 5 ± 1 cm. It makes sense that the more concentrated, stiffer gelatin mixture would have faster wave speeds and that those waves would damp out more quickly. The large difference in damping distances is something that needs to be better explored to make sure this difference is actually this large.

The waves studied in the gelatin were assumed to be pure compressional body waves; however, this is most likely not the case, as the pressures on different sides of the gelatin slab were different, thus causing the wave to affect the edges differently. The waves studied were a good start to future modeling of pure body waves. There is also still a lot of interesting experiments to explore with seismic waves in materials. Another interesting step would be to create shear waves in the gelatin and analyze different setups using some liquids in between solids to see how that affected how the wave propagated through. This could be a model to simulate the interior layers of Earth, with some solid and some liquid.

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