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Report
on
AN INEXPENSIVE SEISMOMETER FOR THE CLASSROOM

prepared by
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December 3, 2002

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AN INEXPENSIVE SEISMOMETER FOR THE CLASSROOM

submitted
To
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Table of Contents

List of Figures and Tables

Introduction

Our team is very pleased to have been given the opportunity to design this seismometer. The purpose of this memo is to describe the specific components of our design. We understand that the main goal of this project is to design and build a seismometer sensor and transducer that can be mass-produced for $50 or less. The development of such an inexpensive seismometer will provide many benefits to the people who will use it. We believe that our design will be a wonderful learning tool for classroom use. Our chosen Lehman system has three obvious separate parts, so we subdivided our system into these three subsystems: the damping system, the magnet and coil assembly, and the structure. This memo describes the details of one individual subsystem so that you may better understand how each part of the system works and so that it is apparent how our subsystems all work together. Our designs are now completed, and reflect an excellent, inexpensive, and high quality seismometer.

Having a functional seismometer available for classroom use will give students the opportunity to learn about earthquakes by participating in the collection of scientific data. In order to be a useful classroom tool our seismometer needs to meet the following requirements and specifications:

- A period range of 15 to 30 seconds.
- A signal to noise ratio of 1 to 20 seconds
- It must be able to sense and record earthquakes of magnitude six or greater.
- Must be able to detect Love and Rayleigh waves.
- The current output of magnet and coil must be 1 mV per 4μm of earth movement.

The sensor will need to connect to an amplifier, filter circuit, analog-to- digital converter, and then to the PC via the serial port. The seismometer needs to be relatively durable and have dimensions suitable to a classroom environment.

Our Lehman system is designed to meet all of the aforementioned criteria. The different subsystems, the structure, the damping system, and the magnet and coil assembly, are all parts of the design as a whole and each enable the system to meet the criteria. The structure is composed of the base, the vertical superstructure, the stops, the weight, the boom, and the pendulum wire. The damping system is a vertical vane and a tub of oil. The third subsystem is the magnet and coil. These subsystems are all connected to form the sensor and transducer system we designed for the seismometer.

The subsystems are related in the following ways: The base supports the vertical superstructure and the boom, and the stops are mounted on the base. The boom is also connected to the pendulum wire, the weight, the magnet, and the damping vane, and has a knife-edge in order to swing in relation to the structure. The coil is located in the center of the horseshoe magnet and gains an electrical current from the motion of the boom. The damping tub is located beneath the damping vane, which dampens the motion of the boom by displacement of oil in the tub. To view this overall system, see Figure 1 at the end of this report. All of these components make up the three main subsystems, which make up the overall system. The rest of this memo will go into further detail on each of the individual subsystems.

Subsystem Analysis

Structure

Our team's design for the structure meets our client's standards because it is strong, inexpensive, and lightweight, and is a great learning tool for students to learn about earthquakes. [1] The structure also works together with the damping system and magnet and coil assembly to create a structure that meets all of the other client requirements stated in the introduction.

The following are the technical specifications for all of the components of the structure: The vertical superstructure is constructed of ¾ inch diameter black pipe, 4 two inch nipples, 2 six inch nipples, 1 five inch nipple, 2 tees, 2 flanges, and 1 union. The base is a 10 inch by 24 inch by 5/8 inch particleboard. The stops are made of 24 inch by 1/2inch plywood. The weight is 1kg of cement. The boom is a 24inch long 3/8inch diameter coarse threaded rod. [2] The pendulum is a number eight guitar string. See Figure 2 for the vertical superstructure and Figure 3 for the union and lower cross member.

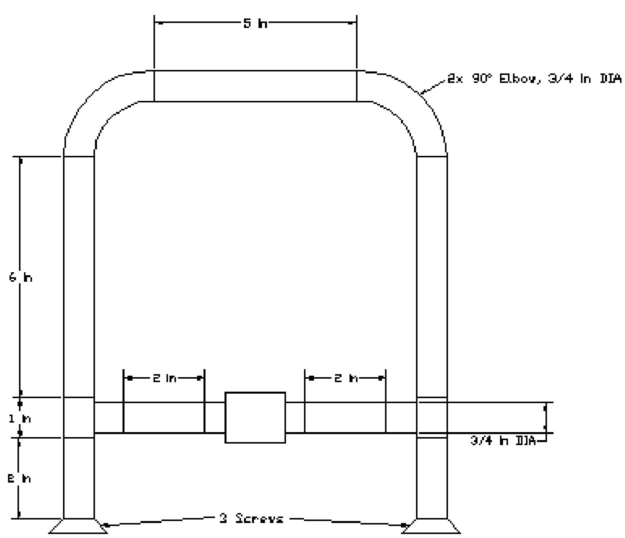


Figure 2: Vertical Superstructure

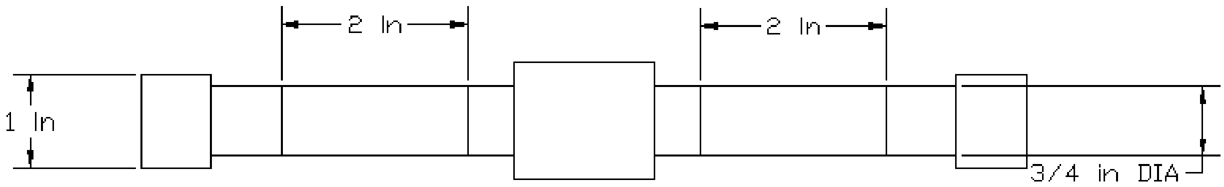


Figure 3: Union and Lower Cross-member

The structure is assembled by mounting the vertical superstructure and the stops to the base, as in Figure 1. [3] The base also supports the boom. The union and lower cross section are placed between the two vertical supports of the vertical superstructure as seen in figure 4. See Figure 4 for Structure Subsystem figure.

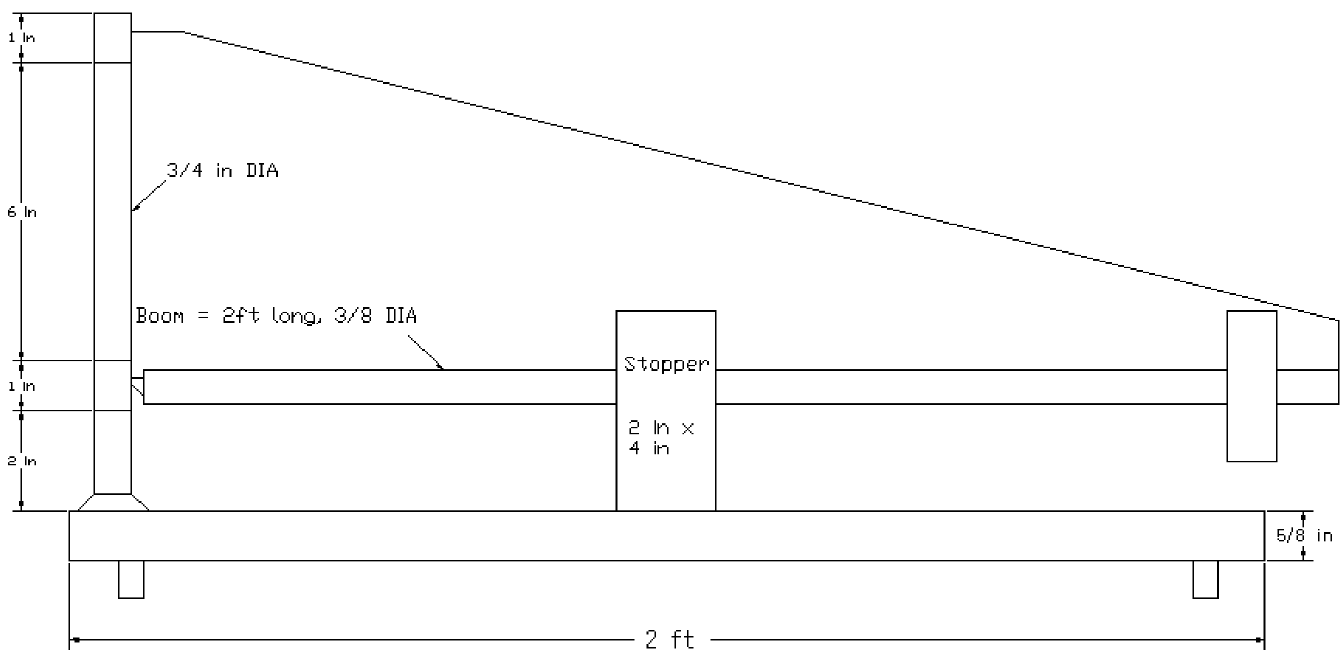


Figure 4: Structure Subsystem

The vertical superstructure supports the boom through a knife-edge and union that swings when an earthquake takes place, and finally, the boom connects to the pendulum wire, the weight, the magnet, and the damping vane. The magnet and coil assembly measures the movement of the boom and then translates it into the movement of the earth. [4] This is how the structure works. All of these components make up the three main subsystems, which make up the overall system. To view this overall system, refer back to Figure 1.

Subsystem Analysis
Damping

We chose to use the Lehman design for our subsystem. The technical aspect of the damping mechanism includes the damping vane, which will be 2 inches long by 1 inch wide by 1/8 inch thick. The tub will have a diameter of 3 inches and a height of 2 inches. To view the damping vane, see Figures 5, 6, and 7. The reason we chose these dimensions is because the damping vane can not be too big or it will not be in proportion with our overall design and the tub of oil needs to dampen the normal motion of the mechanism and only allow the seismometer to pick up the movements of the earth.

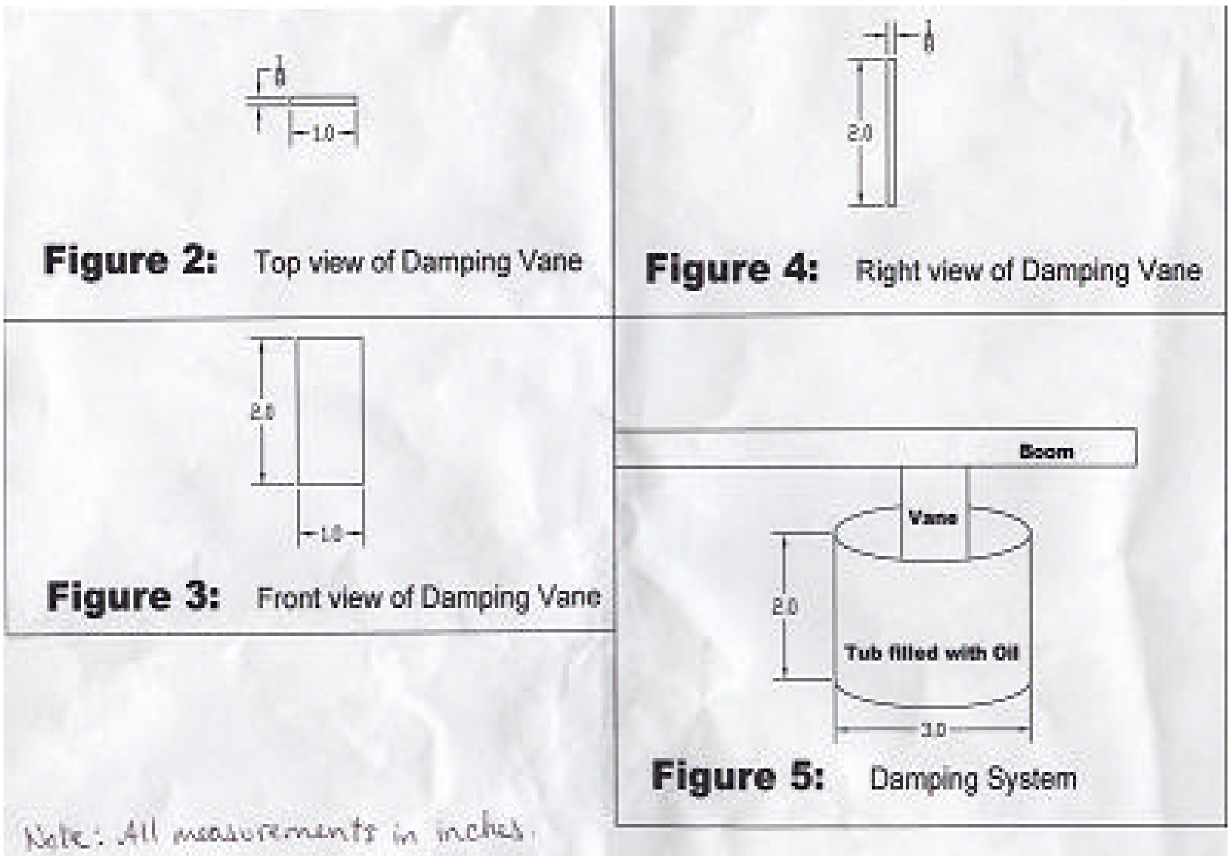


Figure 2: Top view of Damping Vane
Figure 3: Front view of Damping Vane
Figure 4: Right view of Damping Vane
Figure 5: Damping System

This particular part of the main system is very important because without it, the reading would not only be extremely large, but inaccurate [5]. The whole purpose of the damping is to allow the seismometer to pick up the movement of the ground, picking up minimal amounts of unnecessary movements [5]. The design we have come up with for our damping will comply with what our requirements are. Our damping system will be able to pick up 15 to 30 second period ranges [6]. It also will be able to sense earthquakes of magnitude six or greater. To view the damping vane and tub, see Figure 8. The assembly and operation of the damping system is quite simple. The main aspect of our damping subsystem is to have the damping vane in the tub of oil. The damping vane will be connected to the boom and also will be set into the tub of oil. The tub will be glued to the base. The oil will fill the tub about half way. Once all of this is assembled, this mechanism will reduce the motion of the boom by displacing oil in the tub. This explains why the oil in the tub is only filled up half way. This system operates by having the damping vane attached to the boom, which will go into the oil. Whenever there is ground motion, the boom will move. To avoid unreasonable movements by the boom, the vane attached to the boom will displace oil in the tub allowing the most critical motion to be recorded rather that the insignificant motion.

The damping system we chose coincides with our requirements for the following reasons. For one the period will be able to produce a period of 15 to 30 seconds [7]. Secondly the boom in our Lehman design is adjustable making it a long period instrument [8]. In addition, the damping allows us to detect Rayleigh and love waves. The assembly of the whole design is quite simple and inexpensive.

Subsystem Analysis

Magnet and Coil Assembly

The magnet and coil subsystem is the most technically demanding subsystem in our seismometer. The specs of this are limited to the size and strength of the magnet and the size and winds of the coil. Our magnet will be a horseshoe magnet sized 3 inches by 2 inches by 1 inch (see figure 9). The inner width of the horseshoe will be 13/16 inch. The magnet will have a field strength of 20 lbs of pull.

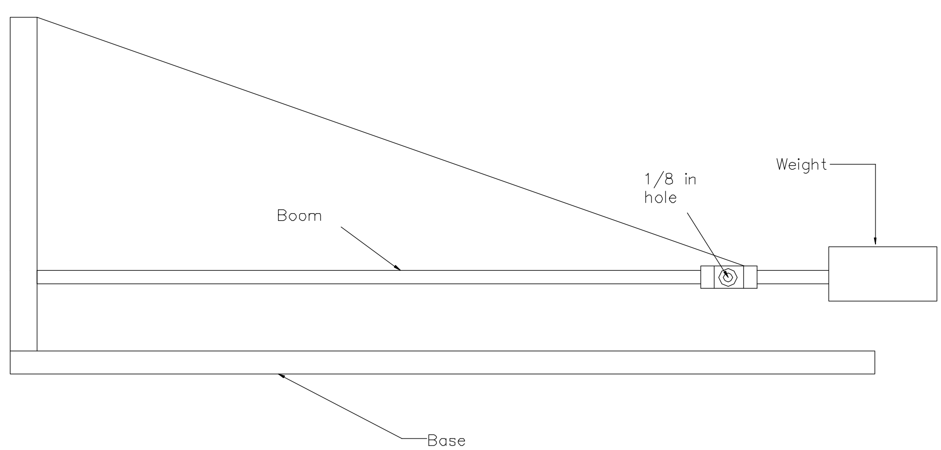


Figure 9: Magnet

The coil of our assembly will be wound with lacquer coated copper wire and will have 10, 000 winds around the inner radius. The coil will be 15/16” in diameter with an inner diameter of 3/16”. The coil will be 11/16” wide (see figure 9). The holding assembly of the coil will be built of plastic.

Figure 10: Coil

Our magnet and coil assembly will allow us to detect earthquakes of magnitude 6 [9]. This has been done by many people who have built the same seismometer with the same materials as us. This is well documented by graphs and physical evidence from reliable sources [2]. Also, our amplification will only have to be 100,000 times, which is possible for us to do and will give us a decent signal to read [3]. The magnet and coil assembly will cost us only $20, so we are right on target for our budget. If a company were ordering these in bulk, the cost will go down, so this is a very cost efficient plan. If this is what other people have had success with, then we should also have success by using their magnet and coil system. There are no industry standards to comply with, so our seismometer only needs to comply with our clients' requests, which it does. Construction requires no hazardous materials, so it will be safe for public use. (See Figure 11 for Magnet and Coil Assembly)

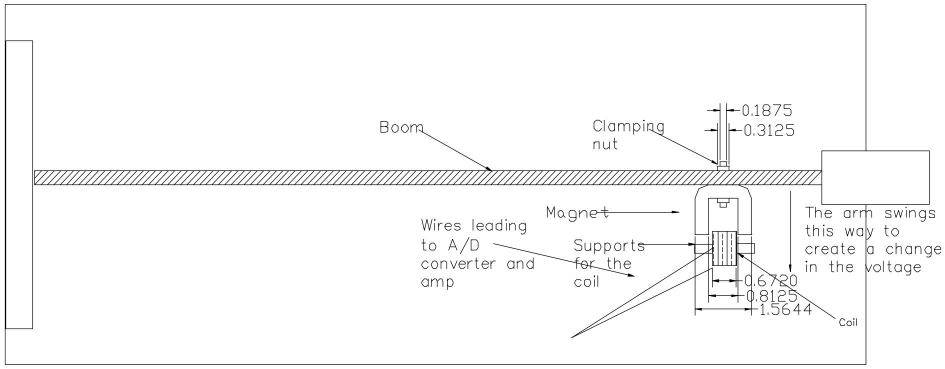


Figure 11: Magnet and Coil Assembly

The first thing to do to assemble the magnet coil subsystem is to assemble the base and the structure, (but not the boom) which is detailed by a previous subsystem analysis. The first thing to do is to drill a 1/8 inch hole centered 20 inches from the knife edge through the boom cross-wise (be sure to center the hole in the center of the boom) [fig 3]. Next line up the hole pre-drilled in the magnet to the hole you just drilled. Then, take a 1/8" threaded rod and insert it through the hole of the magnet and out the other side of the rod. Then, take two 1/8 inch hex nuts and tighten them on both sides of the rod in order to clamp the magnet to the larger rod (see figure 9). If needed, use a wrench to hold one nut while using another wrench to tighten the nuts. The magnet is now fully assembled.

To assemble the coil, first you must have a coil made. This can be done by calculating the length of the wire that you would like and then finding the dimensions of a coil that will give you the area that you need. Our coil is pre-made by a professional. The first thing to do is to measure 2 inches from the bottom of the supports and drill a 3/16 inch hole centered at the 2 inch (see Figure 10). Then, glue the wooden supports to the base so that they are lined up with the inner hole of the magnet. The inner edges of the supports should be 13/16 inch apart (see Figure 9). They should be 0.25 inch wide and 2.25 inch high. Then put some glue in the hole of the right support. Now take a 3/16 inch dowel 1 inch long and slide it through the left support first, and then through the inner hole of the coil and through the hole in the right support (see Figure 11). The dowel should now hold up the coil in a position so that the magnet will swing toward and away from it.

The magnet and coil subsystem is the transducer of the seismometer. The motion of the earth is amplified by the structure and the boom, which causes the magnet to move in relation to the coil. A changing electrical current is caused by this motion. This change in the voltage from the coil is sent to the A/D converter and amp which translates the voltage change into seismic movements. Put very simply, this seismometer translates earth movements into changes in an electrical current. The following equation shows this relationship:

Voltage = (Velocity) x (Field Strength of the magnet) x (Length of wire)

This equation gives us the change in voltage that we can expect from our seismometer. Unfortunately, we cannot figure out the strength of our magnet, but from sources on the internet, twenty pounds of pull will be enough [5]. From the presentation given by Matt Young, we can expect that our seismometer will need 100,000 times amplification. This is possible for us to create [4].

This type of design is best for several reasons. First it is simple. There are no small electronic devices to break. With a light detecting device, you have several pieces of equipment that are susceptible to temperature and moisture changes, and the key pieces are fragile, and can break quite easily. A magnet and coil is a very tough system. Everything is made out of wood or metal, making it inherently strong. Also, electrical output is not limited by any weather change and can withstand a lot more than a laser and a photovoltaic cell. Also, it is easier to set up. A laser setup must be precisely aligned, otherwise no output will be recorded. All that is required with our subsystem is to make sure that the magnet will swing onto the coil without any interference. Finally, a magnet and coil are more easily replaced or rebuilt. If you break anything on a laser setup, you are forced to go out and buy another laser or photovoltaic cell, which can be expensive. With a magnet-coil setup you can rewind a new wire on the coil, unbolt the magnet and replace it with a new one, or go down to the local hardware store to find the wood to replace the stands that support the coil. This makes it easier and cheaper to replace a magnet and coil assembly than a laser setup.

Design Options Discussion

In preparing for the building of this seismometer we decided to separate what we know the seismometer must have from what we still have to make decisions on. We agree that the seismometer must:

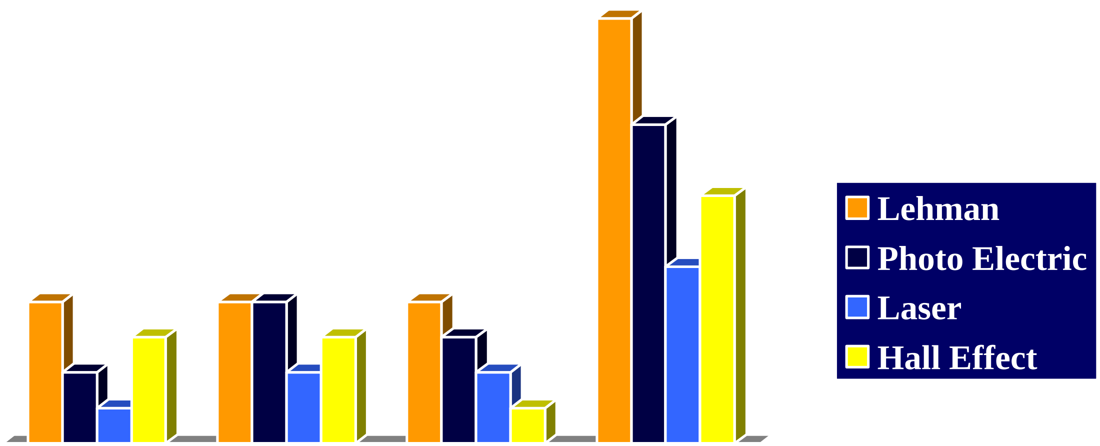
- Have a gate type structure.
- Have a magnet-coil transducer.
- Have a suspension wire.
- Have a boom.
- Have a weight or at least 5 lbs.
- Have a cover.
- Have a damping system.
- Be mounted on a base.

We only needed to decide on the type of system design, the material for the base, and the damping system. The following sections describe how we made these decisions:

Choosing a System Design: Lehman vs. Hall Effect vs. Laser vs. Photoelectric

When deciding on our system we chose to look at the Lehman, Hall Effect, Laser, and the photoelectric seismometer designs. We decided to use a modification of the Lehman design for our design. To make this decision, we made a matrix comparing cost, availability, and ease of building of each of these (see Table 1). The Lehman is the most inexpensive design because it is the most simple (see modified Lehman design, Figure 12 at end of report). It also has the highest availability because there are fewer parts than there are for the other more complicated models and these parts are easy to get.

Table 1: Systems Comparison



The Lehman is also the easiest to build because it has the simplest design with the fewest parts, compared to the other three which all require more sophisticated materials than we have easy access to. If you look at a photoelectric seismometer (Figure 13 at end of report), we would need to find a solar plate in order to get a voltage output, and then find some way to amplify, or increase the sensitivity of the plate. A Lehman seismometer only has to be adjusted for period and damping, making it much simpler to set up. Another good thing about the Lehman is that it has no sensitive or fragile pieces. A laser or photoelectric seismometers have delicate electronic pieces that would be a bad fit in a classroom with young children. Based on all of this information gathered we determined that the Lehman design best fits our purpose for this project. It had the highest availability and ease of building and the lowest cost of all of the four designs. Therefore we have decided to base our own design on the Lehman model.

Choosing Material for the Base: Wood vs. Metal vs. Plastic

We had to decide on the material we would use for our base. We considered wood, metal, and plastic to be the best options to choose from. To make this decision we made a matrix comparing the cost, availability, ease of building and resistance to weathering (see Table 2).

Table 2: Base Material Matrix

	Resistance to Weathering	Cost	Availability	Ease of Building	Total
Wood	2	4	4	4	14
Metal	4	3	4	2	13
Plastic	3	2	3	3	11

*4 is best, 1 is worst.

We determined that the wood was the least expensive of the three because wood is cheaper to buy than either metal or plastic. For availability, we decided that wood and metal were equally available, and that plastic was a little less available than those two, because metal and wood can both be bought easily in sheets at hardware stores, while plastic that fits our needs would be a little bit more difficult to find.

We decided that a wood base would be easiest to build because it is much easier to screw the rest of the seismometer onto a wood base than onto a metal or plastic base. As far as the resistance to weathering of the material, the metal and the plastic were most resistant because wood erodes with use and time, but metal and plastic do not weather nearly as much. Based on all of this information our team has decided to use a wood base.

Choosing a Damping System: Oil vs. Magnet

The final major choice our team had to make was between an oil damping system and a magnet damping system. To make our decision we made a matrix comparing the cost, availability, and ease of set up (see Table 3). We looked up information on these two damping systems and determined that the cost of the magnet was much more than the oil, and that the oil was also much more available to purchase.

Table 3: Damping System Matrix

	Cost	Availability	Setup Ease	Total
Oil	4	4	3	11
Magnet	1	1	2	4

*4 is best, 1 is worst.

By looking at the set up of the two we could see that the oil was also the easiest to set up. Therefore we chose to use the oil damping system because it is better than the magnet in all of these respects.

Conclusion

The main goal of this project is to design and build a seismometer, sensor, and transducer that can be mass-produced for $50 or less. The structure, damping system and magnet and coil assembly are all important to the overall system and allow us to meet our design goals. We believe that our design meets all of our clients' requests and will work well for classroom use. Our chosen Lehman system has three subsystems: the damping system, the magnet and coil assembly, and the structure. The structure subsystem operates when the earth has an earthquake, and then the coil and magnet assembly measures the intensity of the earthquake by the movement of the boom, attached to the vertical superstructure. When the magnet moves about the coil, an electrical current is created. This current is then sent to an amplifier to further be recorded and translated. This method will provide enough voltage so that the signal to noise ratio will be good. This design is inexpensive and within our budget, reliable, and easier to build and replace parts than any of the other design options. After reading this memo you should better understand how each part of the system works and it should be apparent how our subsystems all work together. We have had a great time building our seismometer and we are sure you will be satisfied with our product. Please contact Michelle DeBacker at mdebacke@mines.edu or 303-215-6274 with any questions you may have for our team.

References

[1] P.M. Shearer, *Introduction to Seismology*. New York, NY: Cambridge University Press, 1999.

[2] C. Lomnitz, *Fundamentals of Earthquake Prediction*. New York, NY: John Wiley & Sons, Inc., 1994.

[3] *The Encyclopedia Americana*. Danbury, CN: Grolier Inc., 2001.

[4] J. Walker, "The Amateur Scientist," in *The Scientific American*. http://psn.quake.net/lehmntxt.html (October 29, 2002).

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[6] www.seismo.com/msop/msop79/inst/inst5.html#aa50 (October 29, 2002).

[7] http://quake.eas.gatech.edu/MagWeb/CalReptAS-1.htm (November 10, 2002).

[8] J. Walker, "How to build a simple seismometer to record earthquake movement at home," *Scientific American Magazine*, July 1979, http://psn.quake.net/lehmantxt.html (November 11, 2002).

[9] P. M. Shearer, *Introduction to Seismology*, Published by: The Press of the University of Cambridge, ©1999.

Appendix

Michelle DeBacker: title page, table of contents, introduction, conclusion, structure subsystem
Robbie Bergren: Executive Summary, poster, graphics portfolio compilation, magnet and coil subsystem
Viviana Garcia: Letter of Transmittal, poster, damping subsystem
Nick Koelmel: poster, graphics portfolio compilation, structure subsystem
Brandon Trujillo: poster, graphics portfolio compilation, magnet and coil subsystem

Redactor: Michelle DeBacker