Report on the Development of a Seismometer for Classroom Use

Introduction

One of the problems preventing most classrooms in the United States and around the world from obtaining a seismometer for instructional and data collection use is the great cost of most seismic instruments today. Also, the old system of paper rolls and needles to record earthquakes is both costly and requires a large storage area. Our assignment in EPICS 151 was to design an inexpensive, PC-based seismometer for classroom use as a solution to this problem.

We have developed and evaluated several different alternatives as solutions to this design problem. As part of our selection criteria, we created design parameters and constraints to decide which potential design would be the most effective at satisfying the client's needs. We conducted significant research to begin our project. GATES Design has consulted several sources to gain more knowledge of what is needed to build a seismometer. We have visited the USGS building, consulted with the client, and researched online. We have also investigated multiple styles of seismometers. After evaluating all of the potential designs we came to a conclusion as to which design would be the best for the project. We then divided the project into five separate subsystems that would be easier to manage. After formulating designs for each subsystem we checked whether we they were in compliance with the constraints and parameters.

In this report we will cover in further detail the following:

1) Alternative designs we considered
2) Our criteria for selection
3) The final design that we chose
4) Specific subsystem parameters
5) Compliance with client constraints
6) Construction, materials, and costs
7) Operation of the final unit

Alternative Designs

We investigated several different designs and focused on the horizontal and vertical suspended arm seismometers and a pendulum seismometer. What follows is brief overview of each of these types of seismometers.

<u>Horizontal Suspended Arm Seismometer</u>

The Horizontal Suspended Arm Seismometer (Figure 1) is also known as the Lehman or “garden gate” seismometer. It works on the basic principle of a pendulum with inertia so that the ground moves underneath it, and the relative motion can be determined. The design consists of a magnet at the end of a horizontal rod with another rod coming down at an angle from higher up. The magnet partially encloses a coil fixed to the base plate. The fixed end of the bottom rod typically rests on a knife-edge. The whole apparatus is tilted slightly to displace the maget (the pendulum bob) slightly from the horizontal so that gravity acts to create a true pendulum with a base position. The whole idea behind the nearly horizontal suspension is to ensure that only a very small component of the pendulum’s motion is in the vertical direction, so the period of the instrument is very long. With a long period, the pendulum is sensitive to long-period seismic waves. When ground motion occurs, the inertia of the bob leads to relative movement of the magnet and the coil (attached to the ground). The movement leads to changing magnetic flux through the wire, inducing a current that is proportional to the amplitude of ground movement. The current in the wire can be amplified and digitized, allowing for analysis via computer. So that the pendulum does not continue swinging long after the seismic movements are gone, the seismometer also has a dampening system of a cup of water through which an extension of the seismometer’s bottom arm drags. This mechanism slows the movement of the pendulum.

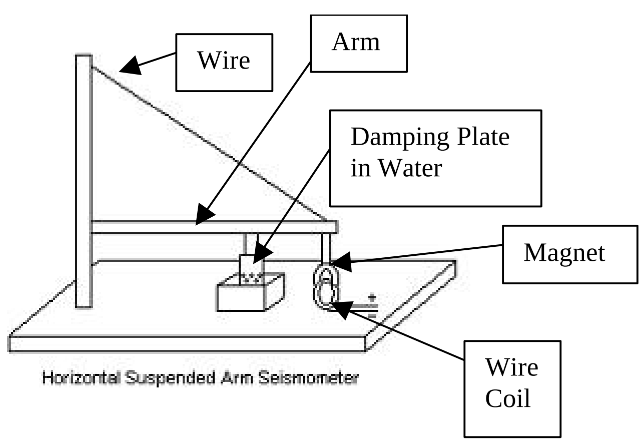

Figure 1: Horizontal Suspended Arm Seismometer

Vertical Suspended Arm Seismometer

The Vertical Suspended Arm Seismometer (Figure 2) works on basically the same principles as its horizontal counterpart, but it uses a spring in place of the angled rod or wire, and the magnet and coil are turned 90 degrees relative to the ones in the horizontal seismometer, allowing detection of vertical movement. Also, the seismometer is not tilted. Ground motion again occurs relative to the mass, but oscillation of the spring takes place rather than oscillation of a pendulum. The overall detection of movement is still measured via electrical signals from current induced in the wire by changing magnetic flux. This design also makes use of a water dampening system.

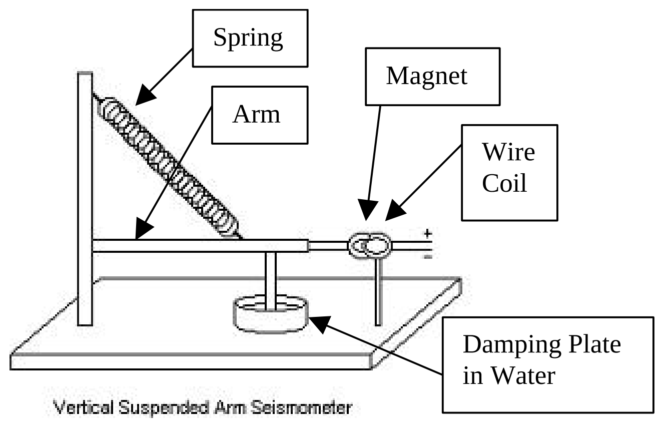

Figure 2: Vertical Suspended Arm Seismometer

Horizontal Motion Seismometer

In contrast to the Horizontal Suspended Arm design, the Horizontal Motion Seismometer (Figure 3) uses an upright pendulum with a mass and magnet on the end. Similar to the other designs, there is a coil of wire attached to the base under the magnet. For short periods of ground oscillation, it would be sufficient to have the pendulum just swing over the ground, but to achieve a long period, the pendulum would have to be far too long (approximately 100 meters for a period of 20 seconds).

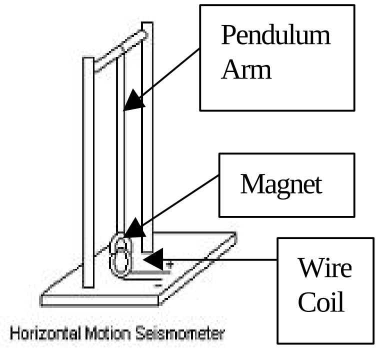

Figure 3: Horizontal Motion Seismometer

Selection Process

The Decision

In deciding which type of seismometer would be best, we looked at the factors of cost, ease of assembly, accuracy, and durability. We ranked the three designs from best to worst in each category and then added the scores in the decision matrix (Figure 4) to decide on the best design. Although the Horizontal Motion Seismometer received the best score, the pendulum is not feasible given the constraints on the period of the device, since it would require the pendulum to be about 100 meters long. Therefore, we elected to go with the Horizontal Suspended Arm Seismometer.

Table 1: Seismometer Design Decision Matrix

Decision Matrix

Design Option	***Cost***	***Ease of Assembly***	***Accuracy***	***Durability***	***Overall***	***Meets Constraints***
Horizontal Motion Seismometer	1	1	3	1	6	No
Horizontal Suspended Arm Seismometer	2	3	1	2	8	Yes
Vertical Suspended Arm Seismometer	3	2	2	3	10	Yes

Scale: 1=best, 3=worst

Subsystems

Background of Subsystem Breakdown:

The seismometer itself is composed of three primary parts: the base and cover, the superstructure, and the magnet-coil assembly. These parts each became subsystems of the project. Each of these subsystems has essentially one or two specific purposes. The base and cover lend support and protection, the superstructure furnishes a means to generate detectable motion from ground motion during a seismic event, and the magnet-coil assembly allows the motion to be turned into a signal that can be picked up, stored, and interpreted by a computer.

The other two subsystems of the project focus on the logistics of actually constructing the seismometer. The assembly subsystem contains plans for building the seismometer, combining the three main parts into a working whole. Finally, the materials and costs subsystem details the locations of availability of the various materials of the project, as well as containing an assessment of the predicted cost of the seismometer components.

Base and Cover

Technical Specifications:

The base and four sides of the cover will be wood while the remaining side of the cover will be made of plastic. The base will be two centimeters thick, twenty centimeters wide, and eighty centimeters long. There is a screw in each corner of the base to make sure it is level and balanced. Two-inch screws will be used for this. The distance from the base to the cover is forty-five centimeters. Thus, the sides are all forty-five centimeters high. Two sides are eighty centimeters wide while the other two sides are twenty centimeters wide. The cover is a five-sided structure that is removable. Since this subsystem will be made of wood and plastic, it will be very cheap to purchase. This subsystem should cost no more than fifteen dollars. This price includes wood, plastic, and the four screws, thus meeting the criteria for a cost effective, easy to assemble seismometer. See Figure 4 (Base) and Figure 5 (Cover).

Assembly:

To assemble this subsystem, all that is needed about four screws. These four go into the corners of the base for leveling. These will be a quarter inch thick and two inches long. After the vertical and horizontal boom and the sensor are assembled and attached to the base (See descriptions of superstructure and sensor), the removable plastic cover will be added. For further assembly and integration with the rest of the unit, see the assembly section.

Superstructure

Technical Specifications:

The Horizontal Suspended Arm Seismometer is also known as the Lehman or "garden gate" seismometer. It works on the basic principle of a pendulum with inertia so that the ground moves underneath it, and the relative motion can be determined. The design consists of a mass at the end of a horizontal rod with another rod coming down at an angle from higher up. Farther out than the mass is a magnet that partially encloses a coil fixed to the base plate. The fixed end of the bottom rod typically rests on a knife-edge. The whole apparatus is tilted slightly to displace the mass (the pendulum bob) slightly from the horizontal so that gravity acts to create a true pendulum with a base position. The whole idea behind the nearly horizontal suspension, though, is to ensure that only a very small component of the pendulum's motion that is in the vertical direction so that the period of the instrument is very long. With a long period, the pendulum is sensitive to long-period seismic waves. When ground motion occurs, the inertia of the bob leads to relative movement of the ground compared to the bob. The relative motion also occurs between the magnet (attached to the bob) and the coil (attached to the ground). The movement leads to changing magnetic flux through the wire, inducing a current, which is proportional to the amplitude of ground movement. The current in the wire can be amplified and digitized, allowing for analysis via computer. So that the pendulum does not continue swinging long after the seismic movements are gone, the seismometer also has a dampening system of a cup of water through which an extension of the seismometer's bottom arm drags. This mechanism rapidly slows the movement of the pendulum.

Assembly:

It is important to keep in mind the main structure of the project. The arm will be connected to a piece of wood that is standing straight up on the base held by angle brackets. A hole will be drilled in the 5cm x 5cm x 44cm piece of wood, which will hold by 2in x 2in x 60 cm piece of wood. Copper wire will be connected to the piece of wood. Also there will be two other pieces of copper wire that will be connected to the block of wood, the two pieces of wire will give extra support. Underneath the arm the dampening will be placed filled with water. See Figure 6.

Sensor

Technical Specifications:

The sensor consists of a small horseshoe magnet mounted around a coil of copper wire held in place by a spool made of cardboard. The magnet is aligned so that it can move by the coil freely in the horizontal direction. By passing a coil of wire near a magnetic field a small current is induced which can then be measured and graphed by the Amaseis software.

The magnet measures a mere 2.9cm x 1.9cm x 1.9cm. The coil is circular with a radius of 5.1cm and a width of 1.3cm. It is supported by a beam of wood that measures 5.1cm x 5.1cm x 15cm. The magnet is attached directly to the horizontal beam by means of a wood screw. The spool is also held in place by a wood screw in its center. The spool is offset from the center of the support by 1cm to provide an area for the magnet to effect.

Assembly and Operation:

The sensor is very easy to assemble. First cut the shape of figure 7A and two of 7B out of one ply cardboard, the kind that cereal boxes are made of. Then cut along the dotted lines and fold along the solid ones to form a square shaped center with flaps folded outward for gluing. Attach the center piece with white glue to the outer discs and allow to dry completely.

Second, cut the 5.1cm X 5.1cm beam to 15cm and attach it to the base with wood screws.

Third, wrap the wire around the coil until at it maximum thickness it is 1mm from the edge of the spool. Attach the spool to the support according to figure 8.

Finally, attach the magnet to the boom with a wood screw and move in to position. Calibrate as necessary.

Materials and Costs

Prices and Materials Charts:

Table 2: Sensor Material Costs

Sensor

Material	**Dimension**	**Price**
Cardboard	20cm x 30cm	NA
Copper Wire	10 ft	$2.70
Horseshoe Magnet	1.125 in x .75 in	$7.95
Wood	5cm x 5cm x 15cm (8 ft)	$1.98
Screws	1 in	$1.69
Angle Brackets	X 4	$1.28

Table 3: Base and Cover Material Costs

Base and cover

Plywood	.63cm x 20cm x 80cm	$15.00*
Plywood	.63cm x 45cm x 78cm	*
Plywood	2cm x 20cm x 80cm	*
Plywood	.63cm x 18cm x 45cm	*
Plexiglas	.3cm x 45cm x 78cm	$6.03
Fine-Threaded Screws	2 in	$1.69
Wood	1in x 2in x 8 ft	$0.98

* All pieces cut from one 4ft x 8ft piece of plywood costing $15.00

Table 4: Boom and Superstructure Material Costs

Boom and Superstructure

** Cut from same piece as wood used in sensor subsystem

Wood	5cm x 5cm x 44cm	**
Brackets	3 in	$3.00
Small plastic Container	.5 lb	NA
Tin can	5cm x 10cm	NA
Turnbuckles	X 3	$2.40

Total Price = $44.70
<$150 with filter, converter

Summary:

The total price of this project is under $150, meeting the cost criteria. We, here at GATES Design, believe that the seismometer meets all stated criteria. With individual attention to each subsystem, it can be guaranteed that the project will be a success.

Assembly

Assembly:

Figure 9 depicts an overall view of the seismometer for reference.
The first task in constructing the seismometer is to place the height-adjustment screws in the base. On the bottom of the solid wood of the base, the adjustment screws should be located at each corner, 1.25 cm from either edge. See Figure 10 for a depiction of the screws.

An optional procedure is to put a groove just wider than the solid wood of the cover running around the top of the base so as to provide a place for the cover to sit to keep it from sliding around.

Before attaching the vertical supporting rod to the base, a small circular notch should be placed on what will become the right side, 15.6-15.7 cm from the bottom of the rod.
The next step in the assembly is to attach the vertical supporting rod to the base. The square cylinder that is the support rod should be placed so that its outside edge is centered along the short side of the base and about 12 cm from the left edge. The support rod should be secured with angle brackets, as in Figure 11, on the left and right sides of the rod. Also, at the top, two eye screws should be placed in the left corners. Two more eye screws are to go on the base, on both corners of the left side of the base, just inside the boundaries of where the cover will fall **(**Figure 10). Wires, with turnbuckles in the middle, should connect the eye screws on the support rod to those on the base (Figure 9).

The damper plate can be formed by cutting a section out of a steel (tin) can and flattening it. The resulting piece should be approximately 10 cm x 15 cm. The edges should be filed to reduce sharpness. The plate should be attached via screws to the 2 in x 2 in x 60 cm of wood near the middle of its length. The damper plate faces downward (Figure 12). The magnet should attach with a screw through the middle to the right end of the 2 in x 2 in x 60 cm piece of wood. The magnet should be positioned such that it forms a “C” shape when viewed directly from the front of the seismometer (Figure 13).

Next, one more eye screw needs to go in the top of the support rod, in the middle of the right side. The 5 cm x 5 cm x 60 cm of wood should be sharpened to a point on the left side and have an eye screw inserted on the top side of the piece near the right end. This piece is the horizontal boom; the pointy end should fit into the small notch on the support rod (Figure 14), and the other end should be supported by a wire, with turnbuckle in the middle, that runs from the eye screw on the right end of the horizontal boom to the one on top of the support rod. The plastic container of water should be located and secured (eg. with hot glue) under and surrounding the damper plate (Figure 9).

Finally, the coil assembly should be on the right side of the seismometer, centered along the short side and placed so that the magnet partially encloses the coil that extends outward from the coil support. The coil assembly should be secured to the base with angle brackets on the left and right sides, as in Figure 11.

The cover is a five-sided rectangular box, secured with three screws in each side, which screw into sections of the 1 in x 2 in x 8 ft piece of wood, cut to the height of the sides, inside the edges of the box (Figure 15). One 78 cm x 45 cm face of the box should have a rectangular hole slightly smaller than the piece of Plexiglas cut in it. The Plexiglas should be screwed into the wood so that it covers the hole. The cover should fit over the seismometer assembly and sit on the base, allowing for easy removal for observation and maintenance.

Compliance with Constraints:

Due to the high strength of the magnet and the density of the coil, this sensor will be very sensitive to any movement. It should be able to detect motion within the project specifications and will be easy to amplify with the right electronics. It also poses little risk to the computer's circuitry.

The assembly subsystem is important to the requirements set forth by the client in terms of easy assembly and operation and in terms of cost. By having a subsystem dealing specifically with assembly, the idea is to create a set of instructions that will make it relatively easy to construct and maintain the seismometer. If the assembly instructions are all grouped together, it should be simpler for teachers and students to build the seismometer. Also, by focusing on a seismometer that is constructed from basic building materials, cost should be reduced as compared to machining or partially preassembling complex components.

Operation:

When first setting up the seismometer and after moving it, the adjustment screws on the base should be adjusted so that the period of the seismometer is about 20 seconds.

When the seismometer is fully constructed, the electrical leads from the sensor must be connected to the amplifier-filter circuit, which is then connected to the analog-to-digital converter. The A-D converter feeds the amplified seismic signal into the computer. The Amaseis software on the computer analyzes the seismometer input and creates a graph of the signals that resembles the output of the paper-and-drum type seismographs.

The seismometer should be periodically inspected to ensure that the area around it is free from cobwebs, excessive dust, and other obstacles to its operation. Also, the container of water will need to be refilled to replace water lost to evaporation.

Conclusion:

GATES Design has come up with plans for a horizontal suspended arm seismometer that should fit the constraints set forth by the clients. The total cost of assembly is less than $44.70, leaving the total cost of the seismograph with amplifier-filter and analog-to-digital converter under $150. The seismometer is constructed of basic materials that should be easy to obtain and relatively simple to assemble. No particular technical or assembly skills are needed, so teachers all over the world could make the seismometer with their students. One particularly good aspect of the design we came up with is the use of water in the dampening mechanism instead of oil. In a classroom setting, it is more practical to have water rather than oil in the open container of the damper in case of spills or accidents. The transparent plastic in the cover allows students to observe the working seismograph, making it a more effective tool for learning as compared to a machine shut away in a dark box.