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December 2, 2002

John C. Lahr
Geophysicist
US Geological Survey
National Earthquake Information Center

Thomas Boyd
Associate Professor
Department of Geophysics
Colorado School of Mines

Dear Dr. Lahr and Dr. Boyd,

Attached is the report entitled *Super Seismo 2000*, explaining in detail our design plan and assembly for the seismometer project.

Included within the report are all of our discussions, analysis, technical specifications, and assembly instructions for the seismometer. The problem at hand was to create a functional seismometer that could easily be plugged into a computer and record seismic data. The second part of the problem was to make it cost efficient, under $150 total, so that students and enthusiasts alike could afford this great tool.

My colleagues and I at Team 151° are confident that our design plan meets all of the necessary specifications and functions as to which it was designed. We hope that this report meets all of your desires and we would like to thank you for the opportunity to be part of this design process. Feel free to contact Team 151° if any concerns or comments come about.

Sincerely,

Ryan Bush, Team 151° Representative
Email: rbush@mines .edu

Super Seismo 2000

Submitted to:
Dr. John C. Lahr
Geophysicist
US Geological Survey
National Earthquake Information Center
and
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Executive Summary

Team151° was excited and proud to receive the chance to work on the Epics project this fall. We received a letter addressed to Dr. Knecht stating the problem and goals for the seismometer project from Dr. Lahr and Dr. Boyd on the 24 of August this year. Described in the letter, the project was designed to create an inexpensive seismometer that schools could affordably purchase to educate children in grade level schools.

After reading over the project specifications and goals, Team 151° decided to accept the challenge that the project put forth and set a few goals of our own. The goals of our team were to create a seismometer that is effective and efficient both technically and monetarily. It is to be a simple machine that is user friendly and capable of measuring the specified seismic activity accurately. The product should be able to withstand the tale of time and function years from now the way it is designed. To create a working machine in the appropriated time while still holding true to the overall budget was a key priority. It is important to the team that this product be created to be both simple and inexpensive so more people can become familiar with the study of seismology at a younger age. We want to set an unprecedented stage in simple seismic technology.

The final report summarizes the efforts of Team 151°'s Super Seismo 2000 design. It gives great detail into the thought process, problem solving techniques and the overall design plan for the given project. Entailed in the report is:

- Problem discussion and connection to intended consumers.
- Debates on the functionality of currently available models.
- Innovative design process and research into new seismic sensory techniques.
- Team 151°'s new and improved Super Seismo 2000.
- Sub-system Analysis of each integral portion of the Super Seismo 2000.
- Cost Analysis of the construction of the Seismometer.

Through great design and construction of this seismic sensor, all specifications were met both technically and monetarily. This particular machine has the ability to predict earthquakes of magnitude 7 or greater at distances of both 90 and 180 degrees separation. Simple voltage data passes from a digital-to-analog converter to a computer interface where graphical analysis of earths vibrations can be measured. The overall cost of the seismometer is under the budget specified in the initial problem statement. The attached report delves into great detail of the functionality of the Super Seismo 2000.

Introduction

Background

Computers have replaced the paper-drum pen recorders that were put into use years ago. Through the development of free computer software that can monitor seismic activity, more curious minds should be able to explore the natural world. Both Dr. John Lahr and Dr. Thomas Boyd have made it apparent that the IRIS Consortium Education and Outreach Committee has sponsored the development of AmaSeis, a free, PC-based program that monitors the real-time stream of data from a seismometer so that near and distant earthquakes can be easily recorded and viewed graphically. Dr. Boyd also let us know that the principal remaining barrier to more widespread, school-based earthquake recording systems is the availability of an inexpensive, yet sensitive, long-period seismic sensor that can attach to a PC's serial port via an analog-to-digital converter. The most inexpensive commercially available unit starts at $500. If this cost could be reduced to $150 or less, it would be within the range of many more budgets. With the digital-to-analog converter costing nearly $100, there is approximately $50 remaining to create a functional seismometer. At this cost it would be a good candidate for the GLOBE program.

Coming straight from their national website, GLOBE is a worldwide hands-on, primary and secondary school-based education and science program. GLOBE is a cooperative effort of schools, led in the United States by a Federal interagency program supported by NASA, NSF, EPA and the U.S. State Department, in partnership with colleges and universities, state and local school systems, and non-government organizations. Internationally, GLOBE is a partnership between the United States and 100 other countries (Globe Project). It gives kids the opportunity to explore physical earth sciences and collaborate their findings with scientists and other GLOBE students all over the world. If the seismometer were to be recommended for use by the GLOBE program, there would be simple advertising for the product as well as an abundant amount of potential customers that would view the product while doing educational research. With these general specifications and possibilities in place out team sees a great potential for creating an inexpensive seismic sensor.

Team Goals

The goal of Team 151° is to create a seismometer that is effective and efficient both technically and monetarily. It is to be a simple machine that is user friendly and capable of measuring the specified seismic activity accurately. The product should be able to withstand the tale of time and function years from now the way it is designed. To create a working machine in the appropriated time while still holding true to the overall budget is a key priority. It is important to the team that this product be created to be both simple and inexpensive so more people can become familiar with the study of seismology at a younger age.

Project Specifications

Client Specifications

We were instructed to create a sensor that is designed to record large earthquakes at any distance. This requires a good signal to noise ratio in the period range from 1 to 20 seconds. The seismometer should be able to record at least magnitude 7 earthquakes at 90 and 180 degrees distances (*Epics 2002 Charge to Students*). Economically we were allotted $150 to build the computer adaptable seismometer. With $100 going to a digital-to-analog converter, we had to create the sensor portion for roughly $50.

Group Specification

On top of the client's specifications, Team 151° also had several design goals to complete the project. We wanted to use only sturdy materials that would not warp or become misshaped over time. We wanted to use a method of seismic reading that was simple to construct and very accurate so that we did not have to waste a lot of time getting precise results. Most importantly we wanted to be innovative and not simply redesign an already functional model. We want to set an unprecedented stage in simple seismic technology.

Initial Considerations

We began this project by first looking at other functional machines that were out on the market to get an idea of what we were dealing with. We wanted to get a general understanding of how a seismometer works and the key features that make them so. The first design we came across was the Lehman model [pg. 2 portfolio]. This machine is a horizontal component sensor that connects a large boom to a stable support through a pivoted knife-edge and is held in place with a supporting wire. The model we looked at had both horizontal and vertical dampening components that were offered through both an oil pool and magnets. The actual measurements were taken with a spool of coil moving through a magnetic field. This movement in the field created electric flux which induced current that could be amplified and measured (*Lehman Seismometer*). The only problem with this very efficient set up was that it did not even come close to meeting our economic restraint. In fact it was nearly three times the cost of our budget.

We liked a few key components on the Lehman model. A horizontal boom connected to a vertical support by a knife-edge as a pivot point and a cable to support the weight. We also really liked the idea of magnetic dampening because there is no maintenance or intense measurements needed to keep the dampening functional for years. We did not like the magnet and spool of coil system to take measurements though. Inspired from the initial project letter from Dr. Boyd and John Lahr and great brainstorming sessions, Team 151° wanted to use the power of light to measure the earth's seismic waves. We believed that this method would be much simpler to incorporate effectively and would be much more efficient in the duration of the product.

Seismometer Design

Inspired by many sources, Team 151° decided to create the Super Seismo 2000 [pg. 1 portfolio]. It is a horizontal component sensor that connects a long rigid beam to a sturdy A-frame support by means of a cable and fully pivoting joint. A non-attractive metal plate that passes through a constant magnetic field dampens the boom horizontally. The magnetic field will then cause a restoring force to bring the disturbed system back to stable equilibrium, thus dampening the motion of the boom. It is dampened vertically by its own weight. The seismometer itself actually sits at an angle so that the sensor is lower in elevation relative to the pivotal connection. The tension in the string and the weight of the boom itself dampens the vertical oscillations so that appropriate data can be taken. The actual useable data is retrieved through a photocell system. A flag, that is partially covering two photocells, blocks a beam of light that is shined directly onto the photocells from and incandescent lamp. The voltage created in the two separate photocells is sent through a voltage amplified and then to a voltmeter that measures the voltage difference when the boom is swinging. This data is then run through the digital-to-analog converter, which can easily be plugged into a computer for graphical analysis.

Sub-Systems

Base

The design requires a sturdy base, which is durable, and that can be easily place on any common table. The entire project centers about the base seeing that all the components invariably are attached directly to it. We wanted to create a stable platform that would not become deformed through the longevity of the machine. The actual building material for the base is Quik-Crete that was poured around a system of rebar for support. The decision for concrete as a building material was directly related to the abilities and drawbacks of other types of material. Comparing to the Internet price listings at Lowe's, many types of metal are expensive, heavy, and would not give the project the same effectiveness. Different types of rock would also be suffice, yet many get expensive, especially with the shaping of the rock, and will not have the structural durability of concrete. It is easily obtainable and inexpensive platform to work off of compared to other materials from which the base could be made.

The overall dimensions are ten inches wide by thirty inches long and a half-inch thick [pgs. 19-21 portfolio]. The whole tope edge of the base was filleted to a quarter inch just for visual reasons. Contained within the concrete at each corner of the bottom of the base are coupling nuts [pg. 21 portfolio]. This allows bolts to be threaded in so base adjustments can be easily performed. One can simply screw in or out the nuts to adjust the base's elevation at each corner. This makes calibrating the boom's properties much easier. The bolts are one-quarter inch, and one inch long. There will also be two coupling nuts imbedded on the top of the base so that the vertical support tower can be bolted onto the base.

Table I. Base and Component Dimensions

Part	Width	Length	Height	Size
Base	10 inches	30 inches	1 ½ inches	XXX
Bolts	¼ inch	1 inch	XXX	¼ inch bolt
Coupling Nuts	¼ inch	7/8 inch	XXX	¼ inch x 7/8 inch

Vertical support System

The purpose of the tower system was essentially designed to hold the light source and boom in their respective places for proper operation of the seismometer [pg.22 portfolio]. The vertical support structure itself is a simple A-Frame that bolts easily to the base's extruding bolts and comes together at a sturdy junction at the top. There are two horizontal members that add stability and strength to the superstructure. The center of the bottom cross member also serves as the fulcrum for the boom pivotal joint. The lamp that powers the solar cells simply clips on to the top portion where the two vertical beams connect.

The connection of the two vertical members also homes the connection of the steel wire that hold the boom in its horizontal position. Two and a half feet long, the wire attaches the boom to the tower by hooks located at the top of the tower and on the boom itself. It is mounted to the superstructure inside the connection of the vertical members and is held sturdily in place [pg. 22 portfolio]. To balance the weight of the boom and the rest of the components, the vertical support tower is also connected to the back of the base with a bolt to hold the tower in place [pg. 22 portfolio]. Both wires are connected at each end by doubling over the wire and connecting them with ferrules approximately one inch from each end on the wire. The tension in the string can be adjusted with the turnbuckles that are attached in the geometric center of each cable [pg. 30 portfolio]. A simple twist of the turnbuckle will either increase or decrease the tension for perfect boom placement.

The wire itself is designed to keep the boom from oscillating in the vertical direction. The tension in the string will keep the boom from sinking any farther than it should and because the base is set at a decreasing angle. The weight of the boom itself will dampen the upward motion when the ground begins to vibrate. There is no real system in place to dampen the vertical motion of the boom, but this simple play on gravity allows the boom to always return to an equilibrium state after oscillation disturbances. The tower and wire system, along with the base, hold the measurement components of the seismometer in their correct places for accurate data collection.

Table II. Dimensions and Components of the Vertical Support System

Item	*Material*	*Connects*	*Dimensions*
Tower	Steel	Boom Wire Light	2' tall 9" wide 1/8" thick
Wire	Steel	Boom Tower	2.5' long
Turn Buckle	Steel	Wire	3" long
Ferrules	Steel	Wire	¼" long
Brackets	Steel	Tower	3" and 6" Respectively
Screws	Steel	Tower	¼" nut an bolt

Boom

The boom serves as the mobile portion of the seismometer that will show the effects of the grounds vibrations and will cause a horizontal swinging motion. The connection to the base will be in two locations. The end of the boom will be filed down to a point and placed in a small groove located at the center of the bottom most cross member of the vertical tower. A nearly frictionless pivot is necessary to ensure that the swinging of the boom represents the full amplitude of the ground waves. The second connection of the boom to the support tower will occur nearly to the end of the steel portion of the boom. At this junction a steel cable connect to a steel wire with a simple hook screw. This will hold the boom at its correct height above the base and not allow it to oscillate in the vertical direction [pgs. 23-25 portfolio].

Masses will be added to the boom so that the smallest little vibrations in even the table will not set off the data collection. The total mass added will be five pounds consisting of two and one half pound disc weights. The boom will feel only actual earth shakes so that accurate data can be taken [pg. 25 portfolio]. The mass itself will be place before the cable attachment of the boom but as close to this connection as possible so that ample torque can be provided by the least amount of mass. A bracket on top and bottom that connect that bolt together will hold the weights onto the boom at their effective location, right before the connection of the boom to the wire.

Directly after the connection of the boom and the steel support cable, a hallow aluminum rod of the same diameter will be screwed onto the end to provide one foot of length for the remaining components. Further down on the boom, directly over the location of the photocells, will be an aluminum flag that will be attached to the rod. This flag will block light coming from the lamp beam that is shown on it so that the whole photocell is no revealed to light [pgs. 3,23,26 portfolio]. This way when the boom sways more light will be allowed to the photocells causing the voltage increase that we need to calculate the appropriate data to feed into the computer. The flag will be attached directly over the point where the two separate photocells meet. This comes after the connection of the wire to the boom.

At the very end of the boom, a sheet of aluminum will be attached perpendicular to the direction of the boom [pgs. 23,24,29 portfolio]. This aluminum sheet will be the metal plate that is placed between the magnetic field that will propagate the necessary horizontal dampening to control the oscillation of the boom and invariably the collected data. This plate will have to be glued onto the end of the aluminum shaft so that there is not extra metal that would affect the magnetic field and change the dampening that we desire.

Table III. Dimensions and Components of the Boom

Item	*Material*	*Dimensions*
Boom (Steel portion)	Steel	1' Long ½" DIA
Boom (Aluminum portion)	Hollow Aluminum Rod	1' Long ½" DIA
Weights	Steel	2 1/2lbs ½" Thick 5" DIA
Flag	Aluminum	3.5" x 3.5" x 1/16"
Plate	Aluminum	5" x 7" x 1/16"
Hook Screw	Steel	1/8" DIA

Solar Cells, Light Source and Voltage Amplifier

The solar cells, light source and the voltage amplifier are the most integral parts of the seismometer design. These components produce the output, which the computer will read. We will be using two solar cells to measure the voltage from the light source. In a personal interview with Dr. Boyd, he made it obvious that measuring the difference in voltage is the only way to effectively use a simple light bulb because it is powered by an alternating current. This would give different intensities of light, which would excite just a single sensor. Thus, it would basically tell us there was ground movement when all there is was a change in intensity of light. But with two photocells, we can measure the difference between the two and no matter the intensity of the light that is coming out; the difference in voltage will be the same unless there is a vibration that has come from the earth [pgs 15, 18, 26 portfolio]. The flag will be directly above the middle of the solar cells; in this way as the boom oscillates a difference in the voltage outputs of the two solar cells will arise. We will then measure this change in voltage differences as the boom oscillates, and that will be our output reading.

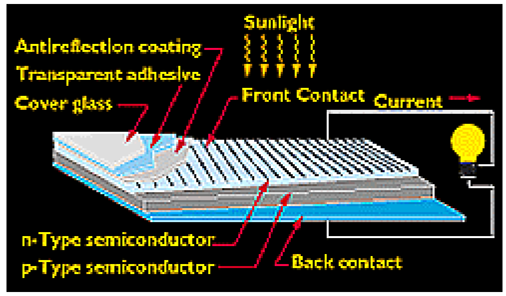

Figure 1. (Photovoltaics)

The light source for the solar cells will be an incandescent light bulb. We originally had a whole steel support structure to hold up a light fixture. But as we began shopping we found an even better way to mount the light. We were able to find a clamping fixture that runs and incandescent bulb [pg. 1 portfolio]. The fixture has no real technical planning, just a spring clamp that hold the fixture in position. It was decided that this would be the best source of light for the solar cells for three reasons:

- Incandescent light bulbs have a high intensity output in the 600 to 700 nm range of the light spectrum. This will aid in the amount of voltage output by the solar cells.
- Incandescent light bulbs are easily found at any hardware or general supply store.
- Incandescent light bulbs are very cost effective when considered against other light sources, such as fluorescent, halogen or mercury vapor light bulbs.

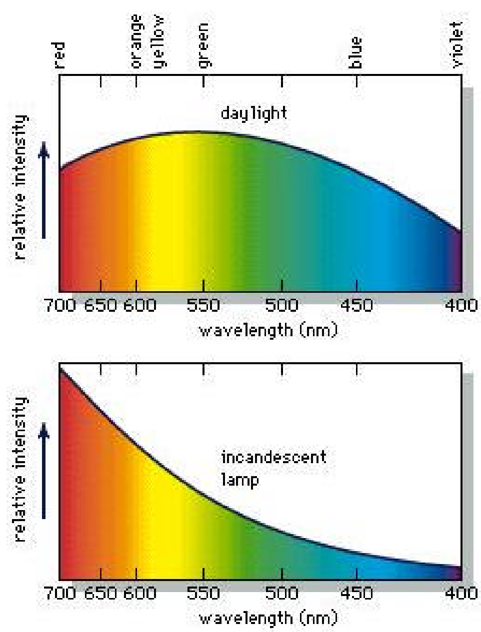

Figure 2. (Birds and Lightning)

The volt amplifier is the key piece of hardware that transfers the voltages into usable data that can be measure by the computer. The two separate photocells send their voltages to the voltage amplifier that uses simple circuitry [pgs. 27-28 portfolio] to take the two separate voltages and measure the differences between the two. This voltage is then transmitted through the voltmeter and then to the digital-to-analog converter. From here the ultimate goal of graphical analysis of the system can be achieved. We chose a solar cell component for the actual measurement aspect of the seismometer because of the ease in construction, durability, and cost effectiveness. Unlike the use of a magnet and coil design, the solar cell requires no adjustment of the voltage-producing component, only adjustment of the period of the boom. It was the optimum design for accuracy, dependency and cost relevancy.

Magnetic Dampening

The magnetic dampening will be the most effective and most precise manner of dampening the horizontal motion of the boom during vibration periods. The system will include four bar magnets that will strategically surround a metal plate attached to the end of the boom. The magnets surrounding the metal plate at the end of the boom will be placed so opposite poles face each other generating a magnetic field of attraction [pg. 16 portfolio and Figure 3 below].

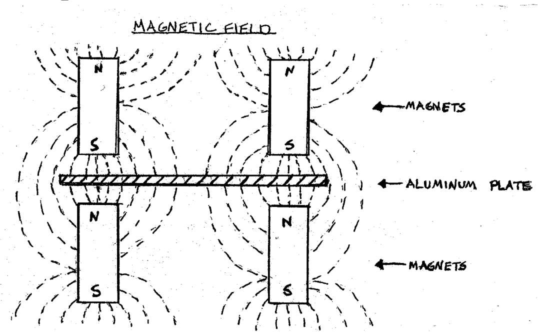

Figure 3. Magnetic Field

Atoms have magnetic dipole moments due to the motion of their electrons and spins in their respective orbitals. The alignment of magnetic dipoles parallel to an external force field will create a powerful magnetic field that will supply a force when the metal plate moves between the magnets (Tipler). This force will act as a restoring force to bring the metal plate to a resting state with respect to the bar magnets [pg. 29 portfolio]. This dampening force will bring the boom system back to equilibrium in an orderly fashion so that the next set of seismic data can be taken.

Table IV. Dimensions and Strengths of Magnetic Dampening

Material	*Description*
Aluminum Plate	5” x 7”
4 equal strength bar magnets	5 lbs. strength

Cost Analysis

Table V. Cost Analysis

Part	*Material*	*Quantity*	*Cost Per Unit*	*Cost to Group*
Concrete	Quik-Crete	1/3 Bag	$2.70 / bag	$0.90
Rebar	Rods of Rebar	3	$0.30 each	$0.90
Bolts	Steel	8	$0.10 each	$0.80
Coupling Nuts	Steel	8	$0.14 each	$1.32
A-Frame	Steel	4.5 ft.	$1.14 / ft.	$5.13
Wire	Steel	4 ft.	$0.24 / ft.	$0.96
Turn Buckle	Steel	2	$0.80 each	$1.60
Ferrules	Steel	4	$0.10 each	$0.40
Brackets	Steel	2	$1.50 each	$3.00
Hook Screws	Steel	4	$0.05 each	$0.20
Steel Rod	Steel	1 ft.	$2.50 / ft.	$2.50
Aluminum Rod	Aluminum	1 ft.	$3.63 / ft.	$3.63
Weights	Steel	2	$1.50 each	$3.00
Aluminum Flags	Aluminum	47.25 square in.	$4.00 square ft.	$1.31
Mounting Brackets with Nuts and Bolts	Steel	1	$0.30 each	$0.30
Photocells	N/A	2	$3.50 each	$7.00
Lamp and Bulb	Steel	1	$6.00 set	$6.00
Electrical Wire	N/A	3 ft.	$0.50 / ft.	$1.50
Alligator Clamps	Steel	4	$0.35 each	$1.40
Resistors	N/A	4	$0.07 each	$0.28
Socket	Op-Amp connection	1	$0.15 each	$0.15
Op-Amp	N/A	1	$0.49 each	$0.49
Circuit Boarding	N/A	1	$1.25 each	$1.25
9V Battery Connection	N/A	2	$0.15	$0.30
Bar Magnets	N/A	4	$.95 each	$3.80
Plywood	Wood	1 square ft.	$1.00 / square ft.	$1.00
Miscellaneous Nuts, Bolts, Screws	Steel	N/A	$1.97 for 150 piece assortment	$0.10

Total Cost: $49.22

The completion of this project was just shy of the monetary restraint of the project. We built a functional seismometer that records appropriate data and will last for a long period because of the quality of the building materials. We probably could have completed the project for less cost, but it would not have had the same durability or functionality. With a $50 construction limit, we left $0.78 in the bank.

Conclusion

Ultimately, the group focus was to create a working and efficient seismometer that was relatively inexpensive. In order to complete this task, we developed a system that is very efficient and capable of functioning for a long time. It meets all of the specifications both technically and monetarily and performs wonderfully. Team 151° recommends this product strongly and is very excited about the final, successful outcome. With your approval, we would love to see the production of the Super Seismo 2000.

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