INSTALLATION OF A WOOD-ANDERSON ACCELEROMETER AT OREGON STATE COLLEGE

by

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INTRODUCTION

Since there is no seismograph in Oregon and since the state is in an advantageous position geographically to study teleseisms, not being subject to local tremors, it was determined many years ago, that a station should be established at Oregon State College. Such a station will form one of a chain of stations engaged in recording seismic phenomena and may in time prove to be of special value in connection with some specific problem.

Although the state of Oregon has been relatively free from earthquake disturbance, there have been no less than fifty shocks reported during the civilized history of the state. The details of these have been, for the most part, supplied to newspapers by citizens living in the locality of the epicenter; such reports are of course only general descriptions and statements of scientific accuracy. The only professional discussions exist in two papers, one by Professor Smith of the University of Oregon in which he publishes a chronological history of thirty shocks; the other is a paper by Professor Edwin T. Hodge, dealing chiefly with the reasons why Oregon is free from seismic disturbance. To expect earthquakes here is not unreasonable, for according to both articles, Oregon is crossed by several fault lines.

The general problem of the installation of seismograph equipment can be subdivided into four smaller ones: (a) the instrument which amplifies the disturbance, (b) the optical system which magnifies the deflections upon photostat paper, (c) the recording drum upon which the paper is fastened and which must rotate as well as translate, (d) the automatic timing device which displaces the beam at intervals of one minute so that the time of occurrence of events can be determined.

THE INSTRUMENT

Essentially, the Wood-Anderson Accelerometer consists of a conducting cylinder (in this case silver) fastened tangentially to a taut tungsten ribbon which passes through small holes in two supports placed vertically over each other. The viscosity of drops of castor oil placed in the supports and the opposing force furnished by the induction in the cylinder from the field of a permanent magnet surrounding it provide the necessary damping.

A small circular mirror 5 mm. in diameter waxed to the cylinder reflects the light from the source to the photostat paper (See Fig. I). When the surroundings of the instrument move, i. e. when they receive acceleration, the silver cylinder tends to remain at rest due to its moment of inertia. Because of the restoring force exerted by the ribbon, the cylinder will move. The equation of its motion can be written

$$I\ddot{\theta} + a\dot{\theta} + k\theta + I\ddot{x}/l = 0$$

where θ is the angular displacement of the mirror from its equilibrium, "a" the damping coefficient, k the restoring force of the ribbon $\ddot{x}$ the acceleration of the earth, I the moment of inertia and l the equivalent pendulum length of the cylinder and mirror. In the construction of an accelerometer, the moment of inertia of the moving piece is made small and the restoring force fairly large, so that for a given acceleration, the angular deflection will be small. Under these circumstances, the first two terms of the equation may be neglected; it therefore reduces to

$$\theta = -\ddot{x}/kl$$

and the deflections of the mirror are seen to be proportional to the acceleration of the ground; $k = 4\pi/T^2$ where T is the free period of the mirror. This discussion of the equation is practical because experimentally short periods are not only readily obtained than long ones but are also more stable and give no trouble.

In a seismograph installation, there must be at least two instruments, one to record the north and south and the other the east and west components of the motion. The one left by Mr. Vinyard was used as he built it and a duplicate constructed. With two matched instruments, the azmuths of the waves that enter the station can be determined from the seismograms. Each instrument was covered by a box to prevent air currents from affecting the mirror.

THE ACCELEROMETER
SCALE ½

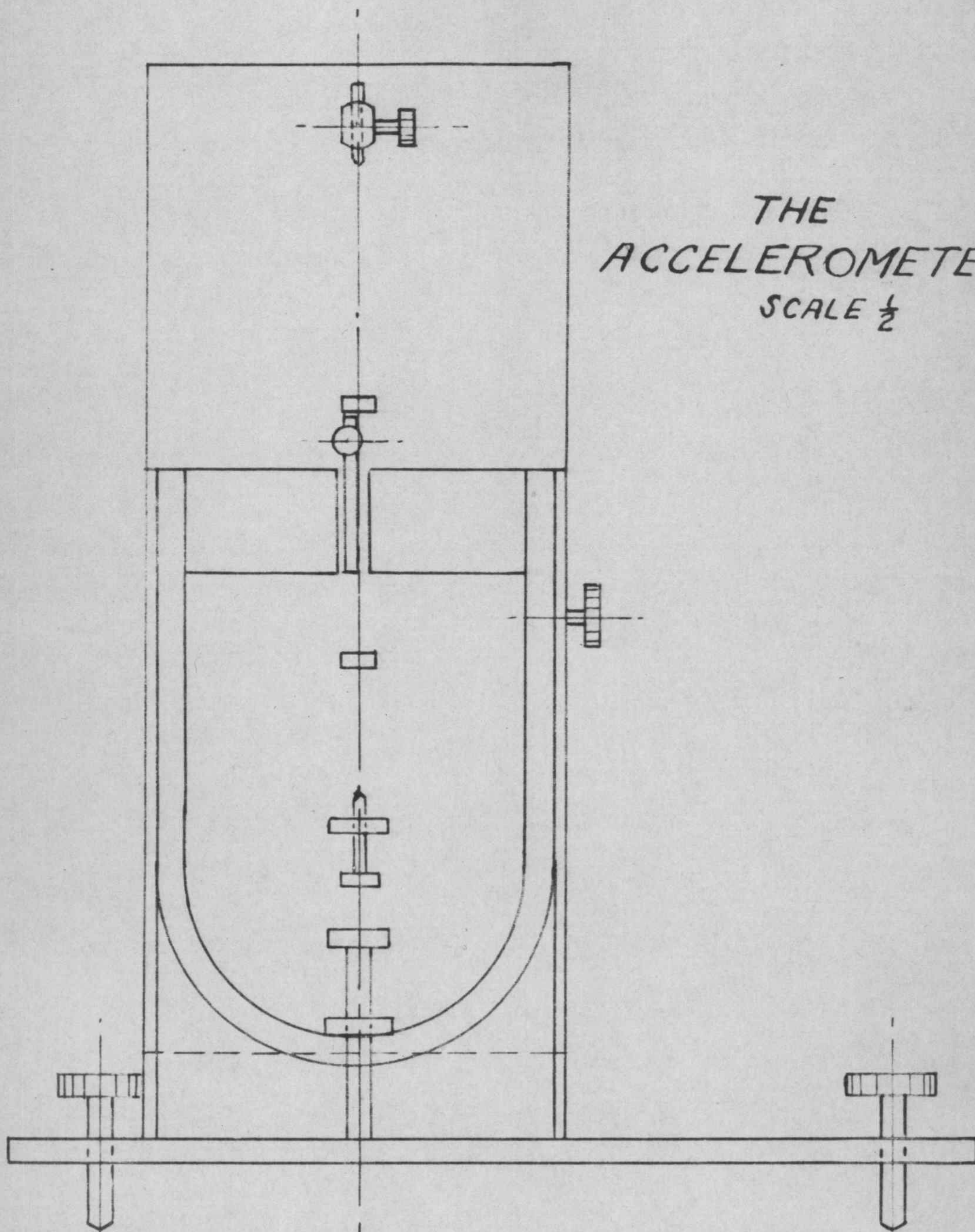
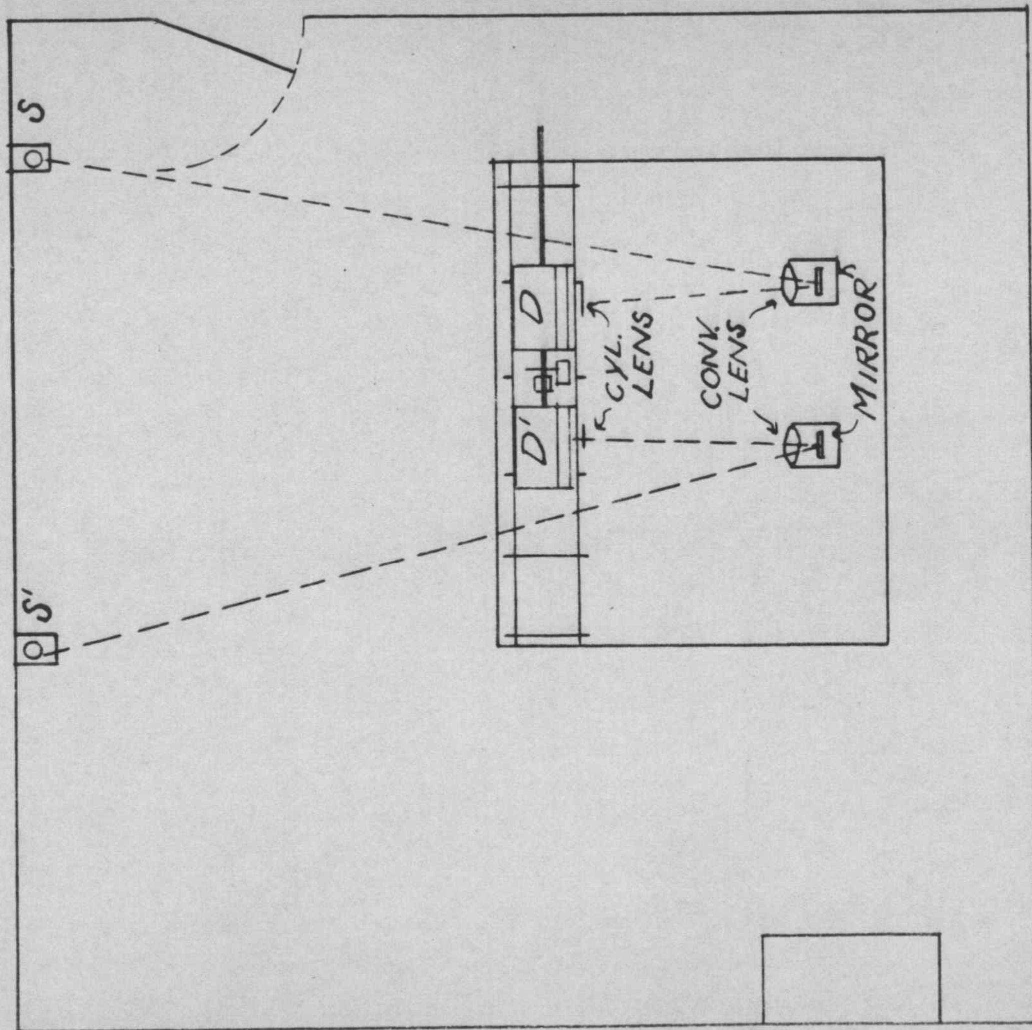


FIG. 1

THE OPTICAL SYSTEM

An optical lever is used to magnify the mirror deflections because it is frictionless. For a light source, a straight filament lamp operating on 20V is used; a four inch stove pipe with a hole cut in the proper place forms a light shield. The light after passing through a slit 2 cm. long and 0.1 cm. wide is further shielded by a horizontal tube an inch in diameter blackened on the inside. Great care must be taken to prevent stray light from reaching the wall of the room and after reflection fogging the photostat paper. The path of the light beam can be most easily seen from Figure 2, beginning at the source, S, and ending on the drum, D. The light leaves the shield as a diverging beam of rectangular cross section; after passing through the lens system is brought to a pin point focus on the drum. The drum rotates and moves 1/8" along its axis during each revolution.

The preceeding design was determined upon by the following consideration. Difficulty was encountered in bringing the light to a point due to the fact that when the filament was heated, it warped into a space curve which could not be brought into a plane by rotating the lamp. The resulting "S" curve could not be focused sharply because the cylindrical lens converged the light in one dimension only. The spot must have a radius of 0.5



SEISMOGRAPH ROOM
SHOWING OPTICAL SYSTEM
$\frac{1}{4}'' = 1'$

FIG. 2.

mm. or less since the traces are separated by only 1/8". To remove this difficulty, it was necessary to make the ratio of the image distance to the object distance small, which necessitated moving the light source some distance back from the converging lens. Of course the intensity of the light on the mirror under these conditions was much less than it would have been, had the lamp filament been straight; but, fortunately, the photostat paper used was sensitive enough to give very good traces.

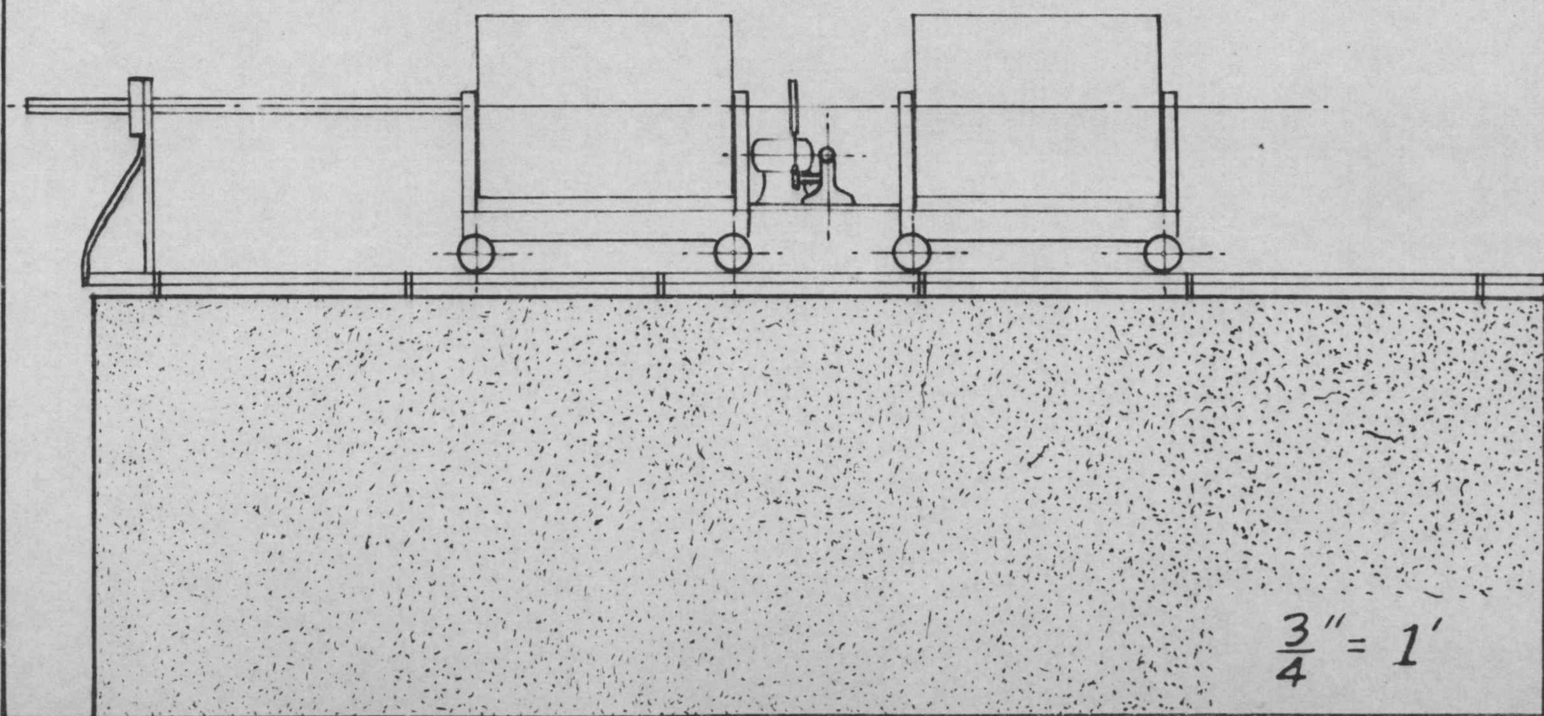
In this setup, the optical lever has a length, L, of 167 cm. and a radius, R, of the silver cylinder on the accelerometer is 0.03 cm., giving a magnification, $V = 2L/R$ or something over 10,000.

RECORDING MECHANISM

The recording mechanism used in this problem departs from usual practice. Instead of the two drums being held by a common lead screw which is supported at the two ends, they are mounted upon individual carriages, traveling upon a track. This method prevents sag and greatly reduces friction between the lead screw and its nut. The drums are carefully lined up on the same axis so that no universal joints are required in the shaft which couples them together. The whole system is rotated by means of a 1/150 horse power synchronous motor placed between the drums. A 900:1 reduction built into the end bell of the motor requires further reduction by a 48:1 worm and worm gear and 2:1 belt drive. The product of all these reductions turns the drums one and one half times in an hour, giving them a peripheral velocity of 3 cm. per minute.

The lead screw was cut with square threads, eight per inch, from a piece of 3/4" cold rolled steel. (This explains why such sharp focusing is necessary.) The lead screw runs through a "split nut" having a single tooth which can be lifted free from the thread, thus permitting the whole system to be moved along the track. The track rests upon rubber pads placed upon the pier; the rubber absorbs vibrations which might otherwise be transmitted from the motor to the accelerometers.

RECORDING MECHANISM

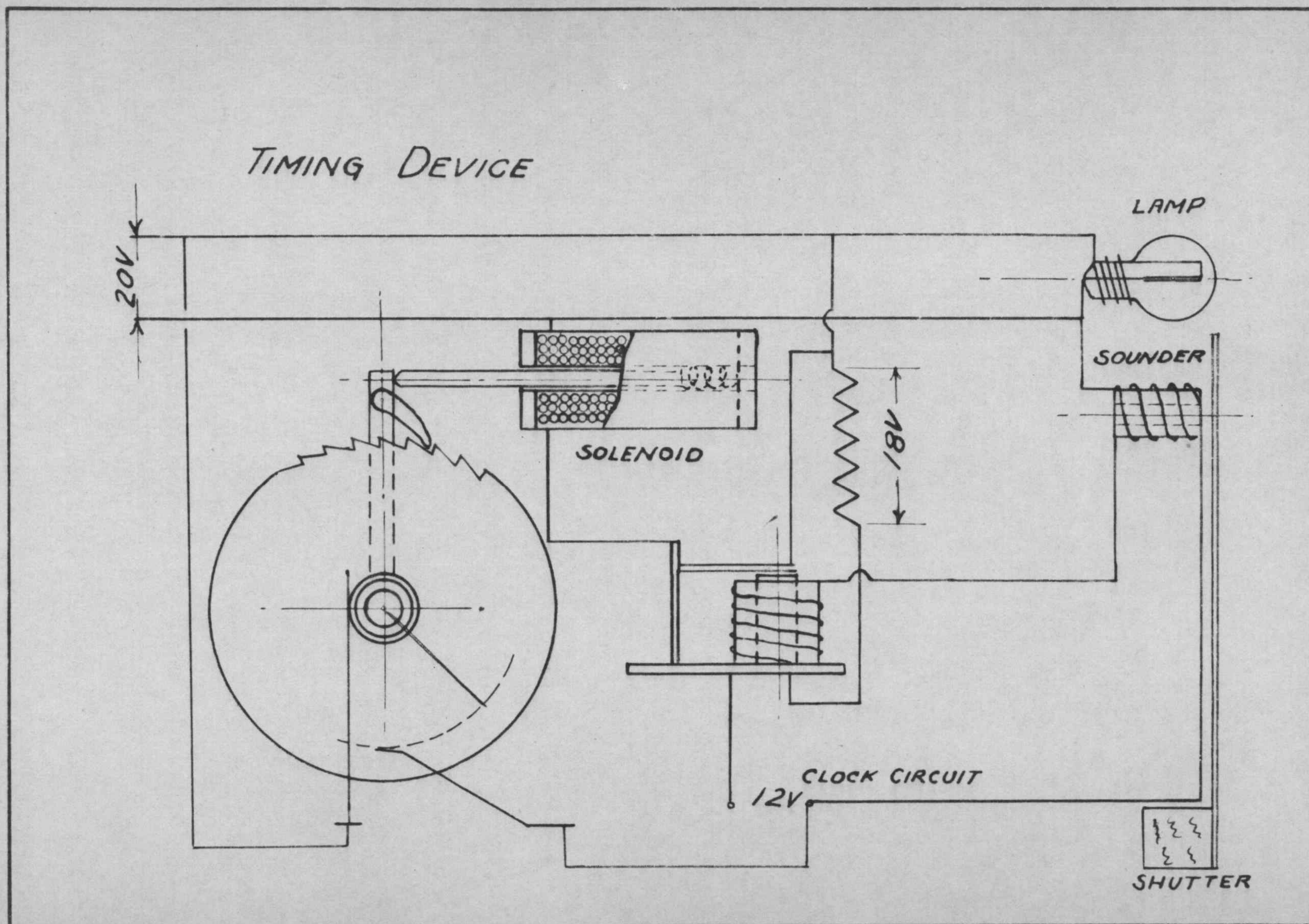


THE AUTOMATIC TIMING DEVICE

An automatic timing device must be provided if events which show on the seismogram are to be timed accurately. A master clock furnishes a difference of potential for two seconds every minute. While this potential exists, a sounder in series with the clock circuit pulls a glass shutter (at 45° to the direction of the beam) in front of the light slit and causes the beam to be displaced for two seconds. The trace between two successive displacements is three centimeters long and represents one minute of time.

Since a seismogram shows a half week's record, the counting of minute intervals for a day or two would be a very laborious task. To remedy this difficulty, something which will change the minute signal every half hour had to be devised. Since this device must be synchronized with the minute interruptions, it should likewise be operated by the master clock. Every twenty-ninth minute was chosen to be one of continuous displacement.

To achieve this, a ratchet wheel was cut with 30 teeth. The clock by means of a relay advances the wheel one tooth each minute. During the twenty-ninth minute, a a tongue on the ratchet closes the lamp circuit through the sounder and keeps the beam displaced until the next clock signal opens the circuit.


TIMING DEVICE
LAMP
20V
SOUNDER
SOLENOID
18V
CLOCK CIRCUIT
12V
SHUTTER

PROSPECT

In conclusion, it is felt that some remarks should be made concerning the future of the station now barely started. The instruments must be matched somewhat more closely and their individual constants measured. The recording is at the mercy of the external power supply which is almost certain to be interrupted if the wind reaches a force of a moderate gale. While the lamps and the beam displacing mechanism draw their currents from the battery bank, the motor that turns the recording drums is connected to an ordinary 120V, 60 cycle building circuit. It is necessary to build some kind of a device such as a tuning fork provided with contacts that will interrupt current from a storage battery 60 times a second and thus permit the motor to operate during a break in the power supply.

To make this station complete, a third instrument, giving the vertical component of a seismic disturbance must be added. Possibly the station may help to solve the puzzle as to why this Oregon area is so free from earthquakes even though surrounded on all sides by regions of great seismic activity--a condition that has been called the "hiatus of earthquake activity".

APPENDIX

STATION CONSTANTS

ACKNOWLEDGEMENT

The writer is indebted to
Professor G. V. Skelton for data used
in the calculation of these constants

STATION CONSTANTS

If a station is to work in conjunction with other stations, knowledge of its longitude, latitude, altitude, etc. is essential. For this reason, some of the constants have been worked out and appended in the hope that they will prove useful as the activity of the station broadens.

LATITUDE. When KOAC was put in operation in the Physics Building, Professor G. V. Skelton determined its geographical position to an accuracy of one foot or about 0".01 of latitude. The information on his records is as follows:

"The latitude and longitude of a point 37' E of the E wall of the Mines Building and 82' 6" N of the S wall of the Physics Building are lat. 44° 34' 2".45 N and long. 123° 16' 25".37 W."

From a drawing of the Physics Building which can be scaled to the accuracy of one foot, it was found that the SW corner of the seismograph pier lies 22' 6" N and 52' 9" E of a point whose geographical coordinates are

$$\phi_g = 44^\circ\ 34'\ 2''.45$$

$$L = 123^\circ\ 16'\ 25''.37$$

From Table IV of the "American Practical Navigator", the lengths of a degree of latitude in 44° and 45°N lat. are taken:

$$\phi_{45^\circ} = 69.054 \text{ (statute miles)}$$
$$\phi_{44^\circ} = \underline{69.042}$$
$$\text{Diff.} = 0.012$$

For lat. 44° 34', we have

$$34/60 \times 0.012 = 0.0068$$

or the length of a degree of latitude here is 69.0488 statute miles. The length of one minute of lat. is 69.0488/60 = 1.1508 statute miles and the length of one second is 1.1508/60 = 0.0192 statute miles. The number of ft. in one second of lat. in Corvallis is 0.0192 x 5280 = 101.27 ft. If $\Delta\phi_g$ is the correction for the latitude we have

$$\Delta\phi_g = 22.5/101.25 = 0''.22$$

or the geographical latitude of the SW corner of the pier is

$$\phi_g = 44^\circ\ 34'\ 2''.67$$

In most seismological calculations, it is not the geographical latitude but the geocentric latitude ϕ_s that is used. On page 332 of "Theoretical Seismology" by Macelwane and Sohon, the following equation appears

$$\phi_g - \phi_s = 695''.6635 \sin 2\phi_g - 1''.1731 \sin 4\phi_g$$
$$\phi_g = 44^\circ\ 34'$$
$$\sin 2\phi_g = 0.99989$$
$$\sin 4\phi_g = 0.03025$$
$$\phi_g - \phi_s = 695''.58 - 0''.04$$

$= 695''.54 = 11' \; 35''.54$

$\phi_s = 44^o \; 22' \; 27''.13N$

LONGITUDE. Upon entering Table IV of the "American Practical Navigator" again, the length of a degree of longitude is found to be

$$L_{44^o} = 49.840 \text{ (statute miles)}$$

$$L_{45^o} = \underline{48.995}$$

$$\text{Diff.} \; -0.845$$

For latitude $44^o \; 34'$

$34/60 \times (-0.854) = -0.478$ or

the length of a degree of longitude is 49.362 statute miles. The length of one minute is 49.362/60 = 0.8227 statute miles and the length of one second is 0.8227/60 = 0.01371. The length of one second in feet is

$0.01371 \times 5280 = 72.399$ ft.

If $\Delta L'$ is the correction in feet, the correction in seconds of arc is

$\Delta L = -52.75/72.399 = -0''.73$

The longitude of the SW corner of the pier is

$L = 123^o \; 16' \; 24''.64W$

and the time at the station is 8h 13m 5.64s behind Greenwich Civil Time.

CORRECTION TO THE SPHEROID. The data here used are taken from the international spheroid whose compression is 1/297 and mean radius a = 6378.388 km. The height in kilometers, H, of spheroid above or below a sphere whose radius is the mean radius of the spheroid is

$$H = 6378.388\ p - 6366.1977\ (\text{km.})$$

$$p = 0.99832005 \quad 0.00168349 \cos 2\phi_g - 0.00000355 \cos 4\phi_g$$

$$\cos 2\phi_g = 0.01513$$

$$\cos 4\phi_g = -0.99954$$

$$H = 1.8657\ \text{km} = 1865.7\ \text{meters}$$

STATION ALTITUDE ABOVE MEAN SEA LEVEL. The altitude, h, in feet is given by Prof. G. V. Skelton for the top of the light table in the drafting room to be

256.032 ft.

256.032 x 0.3048006 = 78.0381 meters measuring down to the top of the pier, the h in meters is found to be

$$h = 73.968\ \text{meters}$$

$$H + h = 1939.7\ \text{meters}$$

BEARING OF THE TRACK ON PIER. Unfortunately the pier does not run true north and south but from the SW corner of the pier the long side takes a direction of

S 81°E (true)

SUMMARY OF STATION CONSTANTS

Longitude	=	123° 16' 24".64W
Geographical latitude	=	44° 34' 2".67N
Geocentric latitude	=	44° 22' 27".13N
Time from Greenwich	=	8h 13m 5.64s
Altitude, h, above mean sea level (top of pier)	=	73.968 meters
Correction, H, to the spheroid	=	1865.7 meters
H + h	=	1939.7 meters
Bearing of the track	=	S 81°E (true)