A METHOD FOR DETERMINING THE TRAVEL TIMES OF ARTIFICIAL SEISMIC WAVES

by

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A THESIS

submitted to

OREGON STATE COLLEGE

in partial fulfillment of
the requirements for the
degree of

MASTER OF SCIENCE

June 1952

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Date thesis is presented August 2, 1951

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ACKNOWLEDGEMENTS

The author wishes to express his appreciation and thanks to Dr. H. R. Vinyard, Associate Professor of Physics, Oregon State College, for his assistance and encouragement in carrying out this project.

Special thanks are due to Mr. J. Strickland, for his assistance and suggestions concerning the electronics equipment; to Mr. R. P. Merritt for his assistance and instruction in the handling of the dynamite.

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INTRODUCTION

The velocities of shock waves in the surface materials of the earth are comparable to sound velocities in similar solids, amounting to several thousand feet per second. In consequence measurement of the travel times of surface waves taken over short distances requires the observation of very short time intervals with reasonable accuracy.

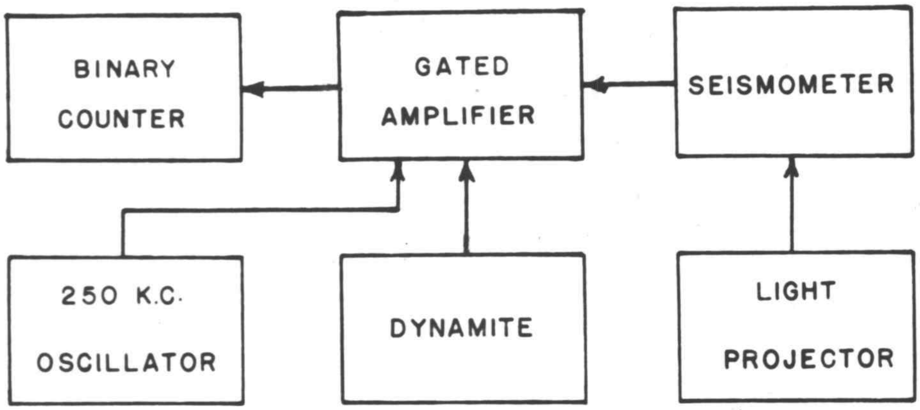
In seismic exploration the determination of travel times of waves artifically induced by explosive charges has been generally accomplished by a photo-mechanical arrangement. In this system a light beam is reflected from the mirror of a seismometer, and is then focused upon a rapidly rotating drum with photosensitive paper attached to its surface. A knowledge of the speed and the radius of the drum permits the calculation of time intervals indicated on the paper. To obtain a good degree of accuracy in measuring the travel times of waves over distances ranging to a few hundred feet, the highest permissible drum speed must be used. The uncertainty of this method is ordinarily of the order of 0.005 seconds.

A new method for recording time intervals utilizes electronic circuits, which greatly reduce the time inaccuracies of the mechanical system. In this application of electronic methods, the two events which begin and end the elapsed time must be converted to electric voltage pulses for starting and stopping an electronic scaler. The time reference base is provided by an accurate quartz crystal frequency-controlled oscillator. In the work described here, the starting pulse resulted from the breaking of a wire contact by the dynamite explosion which started the shock wave; the terminating pulse was generated when the shock wave reached a Slichter seismometer, the mirror of which directed a beam of light upon a photocell.

GEOLOGICAL FEATURES OF THE REGION NEAR THE STATION

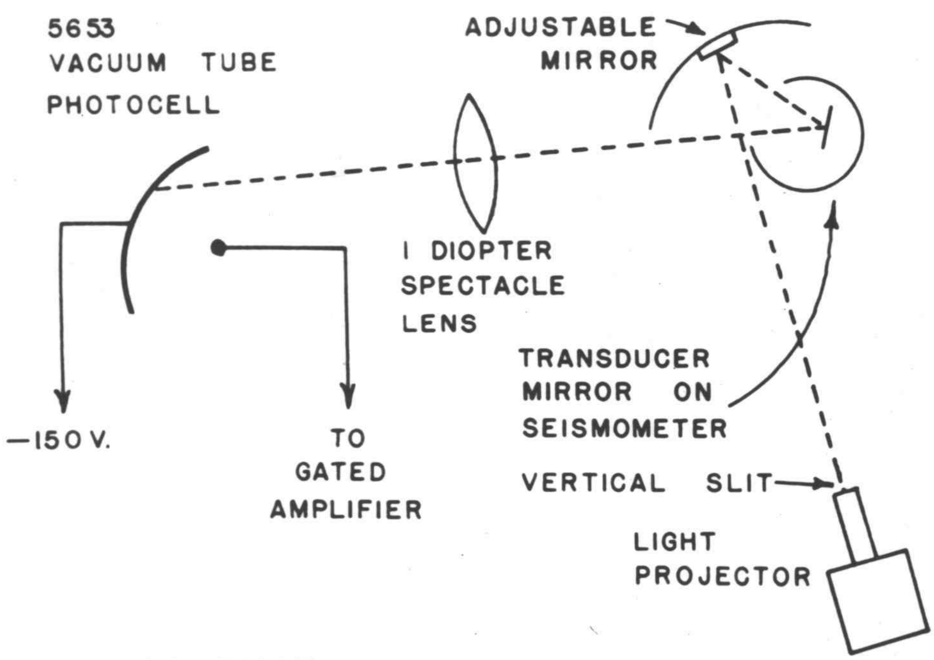
A geologic fault lies near the Oregon State College seismograph station, with its nearest point approximately 600 feet east of the station. The mean fault line runs approximately 17 degrees east of north thus making an angle of 73 degrees with the E-W line through the station.

As indicated by surface evidence the fault is nearly vertical, and is a discontinuity between sandstone and basalt. The surface indications are very noticeable in the bed of a small creek that runs along the fault line. On the east side of the creek the sandstone is exposed, and is nearly vertical with a slight dip to the west. On the west



BLOCK DIAGRAM OF APPARATUS

FIGURE 1



SCHEMATIC OF OPTICAL SYSTEM

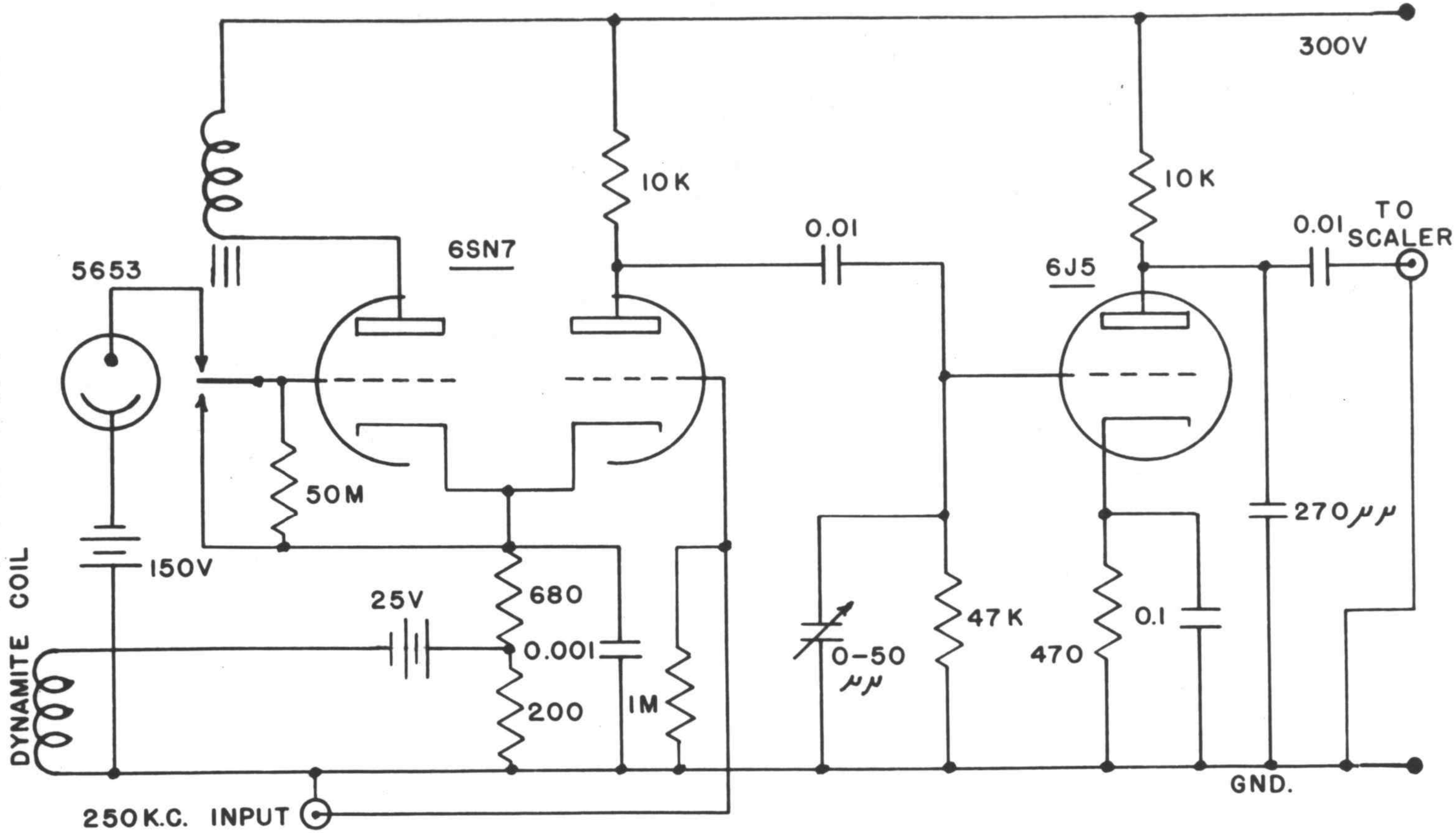
FIGURE 2

bank, and farther west, basalt rocks and boulders lie on the surface.

PROBLEM OF DETERMINING TRAVEL TIME

The region near the fault was chosen for the location of the blasts because the travel time would be concerned with two different materials. The question of how to measure the travel time of the blast waves was the first major problem.

By necessity this experiment was performed in the surface layer (2, p.391). This layer may be as much as 150 feet thick, but in this instance thicknesses as small as one foot were also involved. In the surface layer the velocity of blast waves is of the order of 2,000 feet per second, while the velocity in the underlying layers is upwards of 6,000 feet per second. The path lengths over which the travel times were to be determined were small, so that with a velocity of the order of 2,000 feet per second the time intervals for these distances were of the order of fractions of a second. Thus, the accurate measurement of a very small time interval was necessary. Using the electronic equipment shown in the block diagram (Fig. 1), the total travel time was measured in terms of 4 microsecond intervals.



GATED AMPLIFIER

FIGURE 3

APPARATUS

The oscillator used was a BC-221-M heterodyne frequency meter which provided accurately calibrated 250 kilocycle pulses of about 1.5 volts amplitude. The accuracy of this instrument, as accepted by the Federal Communications Commission for the measurement of radio frequencies, is 0.05 percent. The frequency used was at one of the crystal check points, so that by calibrating the crystal's 20th harmonic against Radio Station WWV of the National Bureau of Standards in Washington, D. C., the accuracy of the 4 microsecond time intervals is believed to be much greater than 0.05 percent.

The gated amplifier was used to start and stop the counting of the time intervals from the time of the blast to the arrival of the resulting wave at the seismometer. This amplifier had a voltage gain of about 30, which was necessary in order to amplify the oscillator output voltage to the 50 volts peak required by the counter.

The scaling units were built by R. P. Merritt for W. R. Jewell's Ph.D. thesis. These units are a modification of the "Model 200 Pulse Counter" developed by W. A. Higinbotham, (1, pp.706-715).

The seismometer was a Slichter 3 component unit with an optical-mechanical transducer which has a period of one second and a static magnification of 25,000. Only the vertical component was utilized in these measurements.

The cable from the dynamite to the gated amplifier was a signal corps field wire W-110-B consisting of a pair of conductors, each composed of 4 steel and 3 copper wires, with tar impregnated cloth insulation.

The light source was a Spencer Lens Company 2"x2" lantern slide projector with a 150 watt lamp.

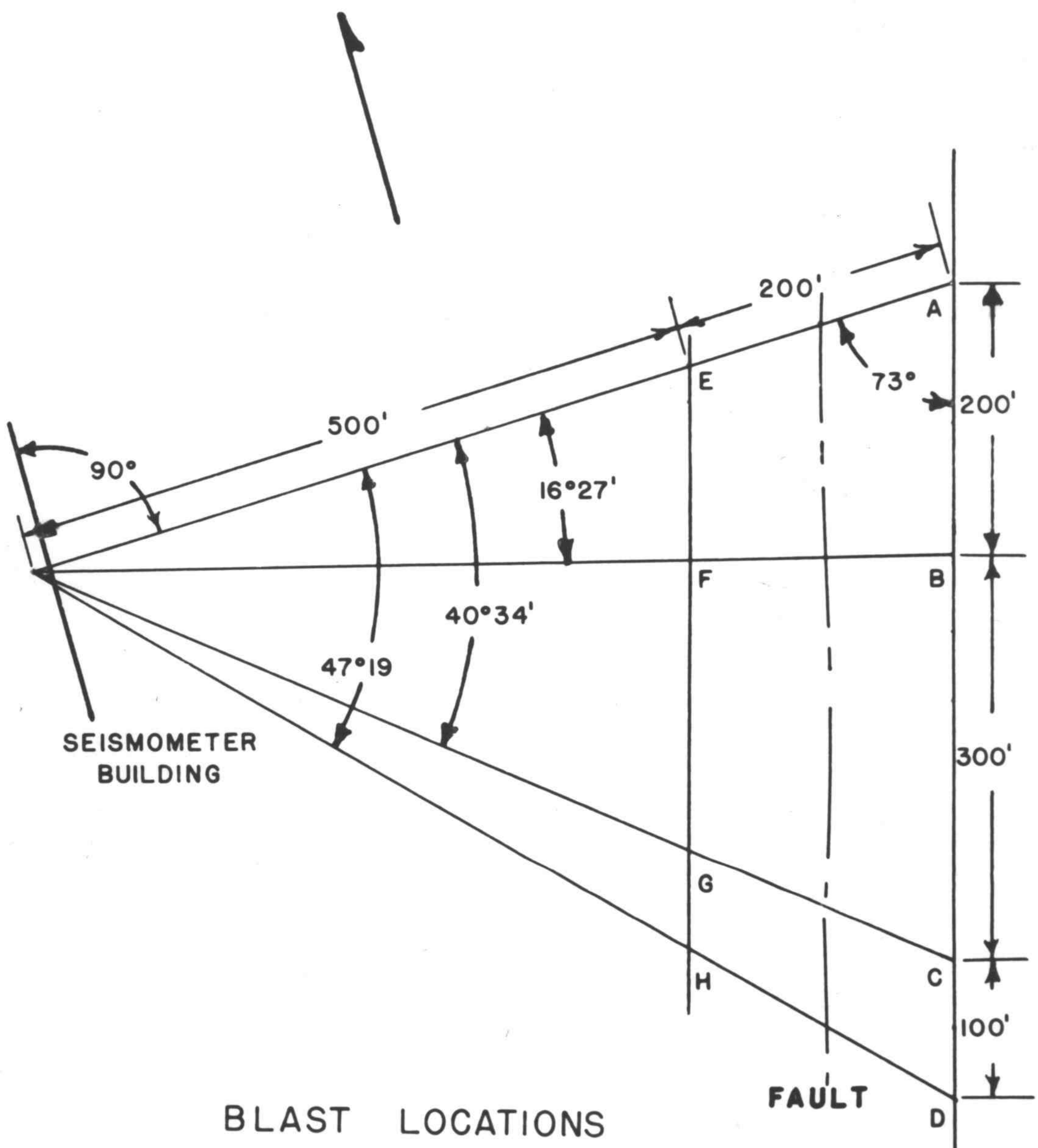
AMPLIFIER CIRCUIT

This unit, as shown in Fig. 3, consists of a type 5653 vacuum photocell and three electrically identical medium mu triode amplifier elements, two of them in a type 6SN7 tube with the third in a 6J5 tube. The second section of the twin triode tube is used in a high frequency resistance coupled amplifier of relatively low gain. Its grid is fed with the 250 kilocycle oscillator voltage. The single triode which follows is used in another amplifier with a resistance coupled output to the counter. The gain of this amplifier, which is greater than needed, is reduced by a small capacitance loading to give the desired voltage.

Gating is accomplished by sequential removal and application of a positive bias voltage on the common cathode circuit of the gate and first amplifier section. Prior to the blast this voltage is developed across 200 ohms of the 880 ohm cathode resistance by the flow of a current in the field wire wrapped around the dynamite. One micro-second is required to discharge the wire after the blast has stopped the flow of current, whereupon removal of the cut-off bias causes the first amplifier to start operating. The loop of wire from the gated amplifier to the blast site will henceforth be referred to as the triggering circuit.

During the time before the amplifier is turned off, light reflected from the mirror of the seismometer falls upon the photocell. This applies a negative potential to the grid of the first half of the 6SN7; thus no current flows in this section. The 6SN7 cathodes are tied together at the pins, so that any current through either section developes bias for both cathodes. Before the blast the cathode potential is plus 23 volts; thus neither half conducts current. At the instant of the blast the triggering circuit is broken, and the cathode bias is removed. The first amplifier stage then passes the 250 kilocycle voltage into the final amplifier, which is ready to operate at any time.

When the shock wave reaches the seismometer and the light is moved off the photocell the grid-to-cathode potential of the gating section rises to zero. The resulting current through this section of the gating tube has two results: first, it reinstates the positive cathode bias on the first amplifier, thus stopping passage of the 250



BLAST LOCATIONS

FIGURE 4

kilocycle wave pulses through the amplifier and into the counter; second, it closes a relay in the plate circuit of the gating section which locks the grid-to-cathode potential at zero, and thus insures closure of the gate even when the light beam returns to the photocell.

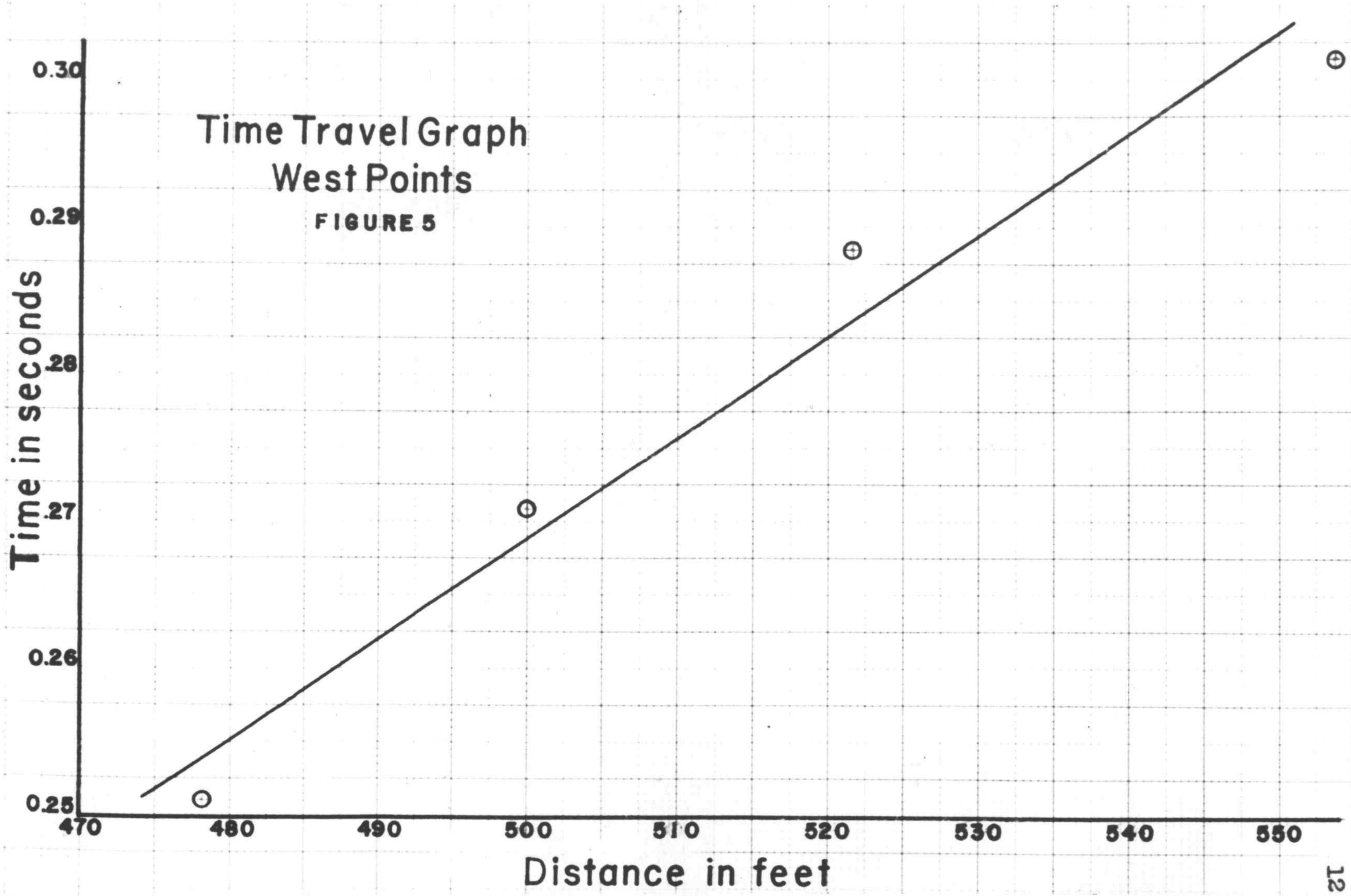
PROCEDURE

Having determined the direction of the fault which continued with small deviations for several hundred feet, two parallel lines were laid out with the fault nearly midway between and approximately 100 feet from either line. A base line was then established from the seismometer station, located about 600 feet west of the fault, to the two lines near the fault. To make sure that the base line was perpendicular to the parallel lines the proper bearing was obtained from a transit which was located on the roof of the station directly above the seismometer.

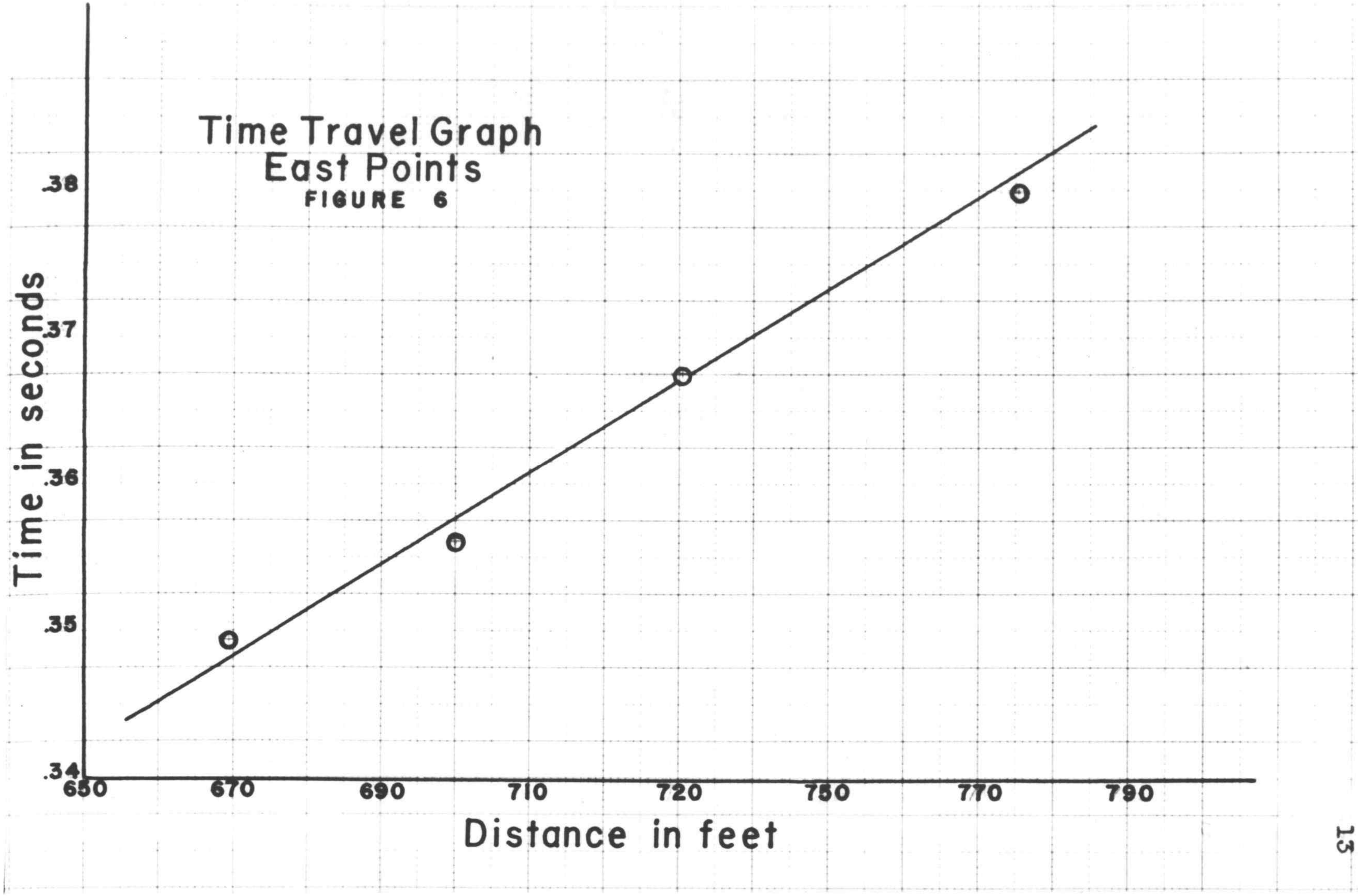
Starting at the intersection with the base line, markers were placed along the east line at equal intervals as determined by a 100 foot steel tape. Markers were also placed on the west line, not at equal intervals, but at points determined by the intersections of radial lines from the seismometer station to the east line markers. To locate these west line intersections two transits were employed, one at the seismometer station and the other at the junction of the base line with the west line. By means of a procedure called "wiggling in" the rodman responded to signals from both transitmen to locate the position of the intersecting lines of sight. When this was completed, each point on the east line had a corresponding point on the west line as shown in Fig. 4.

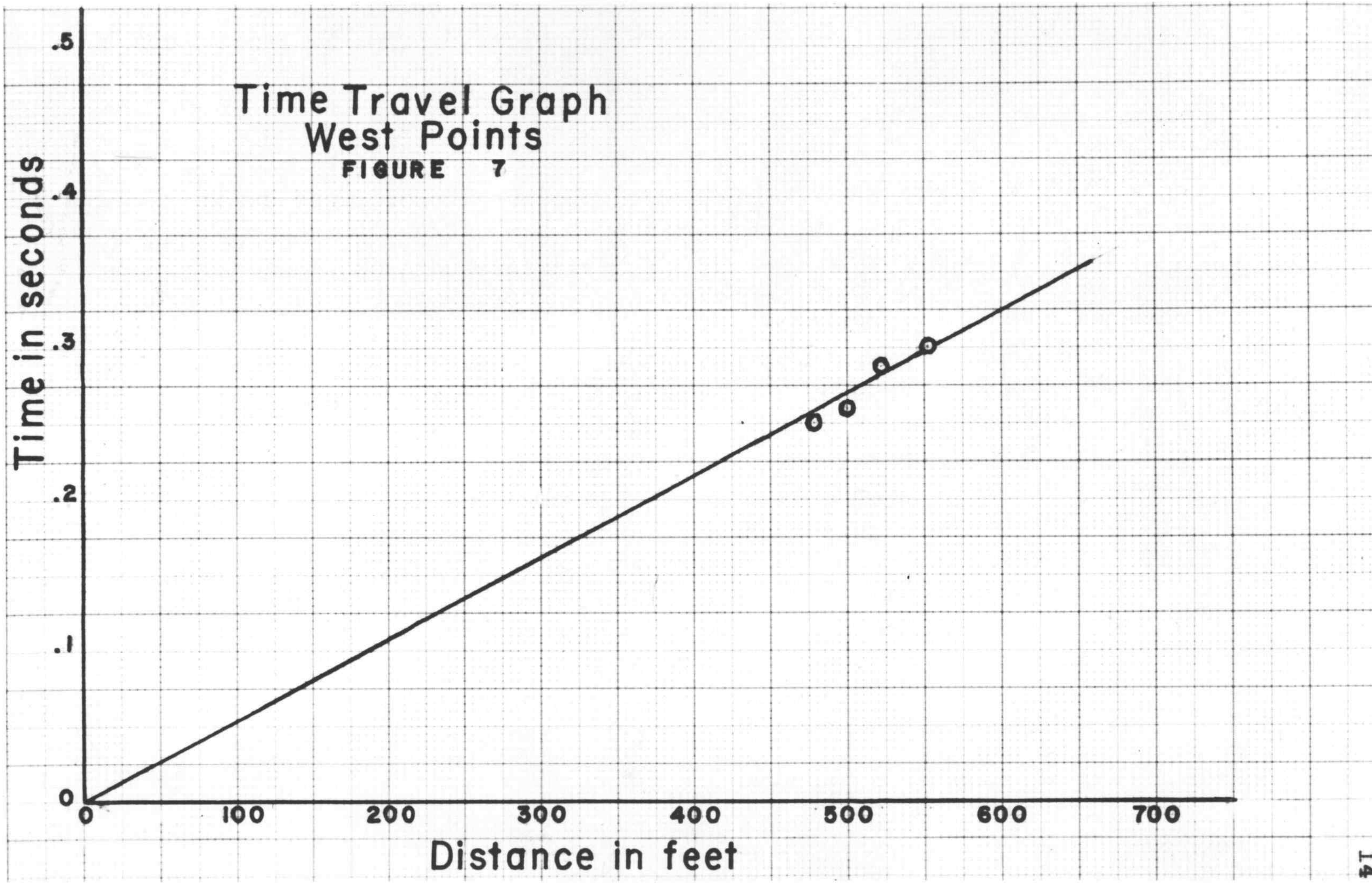
At each location five sticks of forty percent dynamite were placed in a small hole at a depth of 8.5 feet. The charges were fired with electric caps by a 90 volt battery placed a safe distance away.

To obtain the data required two men, one at the station to reset the apparatus and record the counts, the other outside to prime the charges and set them off. The outside man also rewrapped the triggering circuit wire from the station around each charge. The wire was maintained at constant length by splicing short wires on the ends and wrapping these around the charge. An ammeter was placed in the line near the blast point as an indicator. When the operator at the station was ready the circuit was broken several times as a signal for the outside man to fire the shot.



Time Travel Graph
West Points
FIGURE 5


Time Travel Graph
East Points
FIGURE 6
Time in seconds
.38
.37
.36
.35
.34
650
670
690
710
720
750
770
790
Distance in feet


Time Travel Graph
West Points
FIGURE 7
Time in seconds
.5
.4
.3
.2
.1
0
0
100
200
300
400
500
600
700
Distance in feet

DATA

SHOT	DISTANCE IN FEET	COUNTS	TIME IN SECONDS
A	700.00	89045	0.356180
B	669.44	87369	0.349476
C	730.32	91913	0.367652
D	775.45	94995	0.379980
E	500.00	67749	0.270996
F	478.17	62751	0.251004
G	521.66	72123	0.288492
H	553.90	75351	0.301404

RESULTS

The blasts were set off in the surface layer, in which the velocity range is 1,000-6,000 feet per second (3, p.212). The waves from the blasts travel at varying velocities in the above range due to the fact that the surface layer is inhomogeneous (2, p.392), (3, p.60).

As indicated by the slope of the curves, the waves from the west points have a local velocity of 1,458.3 feet per second (Fig. 5), while those from the east points have a local velocity of 3,211.3 feet per second (Fig. 6), if assumed to travel directly to the seismometer. These velocities fall within the range given for surface layers (2, p.391), (3 p.61), (4, p.212). The curve obtained by plotting the west points from the origin has a slope corresponding to a wave velocity of 1,846.1 feet per second, (Fig. 7). This is the average velocity for the waves from the west blasts; a similar plot for the east points cannot be made because of the uncertainty of what takes place at the discontinuity.

Since the first wave to reach the seismometer turns off the amplifier there may be several reflected waves that would not be detected. An average velocity of about 3,600 feet per second is obtained by calculating the time required for the wave to travel from the fault to the seismometer, and by use of the remaining time the velocity for the rest of the distance to the east points was computed, and found to be very close to the indicated local velocity at these points.

CONCLUSIONS

Since the indicated travel times are of the right order of magnitude, it is the opinion of the author that this method is practical. This method could be used to measure accurately travel times in any homogeneous layer.

The waves which first reached the seismometer apparently traveled only in the surface layer, as was shown by the computations of travel times from the east points to the fault and from there to the station. The indicated velocity for the east side falls in the lower part of the range for sandstone (3, p.212). In digging the holes for the east blasts, unconsolidated sandstone was encountered very near the surface; this would account for the higher velocity on the east side.

In the seismometer there is an incalculable time delay in the swing of the mirror. The maximum amplitude of the slit image on the photocell was of the order of 3 millimeters, while the width of the image was about 5 millimeters. A 5 millimeter slit was placed directly in front of the photocell to insure the tripping of this circuit.

The seismometer, being very sensitive, was in almost constant motion at an amplitude of 0.5 millimeter or less. The photocell circuit would trip when the image was very near 2 millimeters off the photocell. There was no available way to determine exactly where the image was at the instant the wave reached the seismometer, consequently this delay cannot be calculated. Although this delay would be small it detracts from the accuracy of the method.

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