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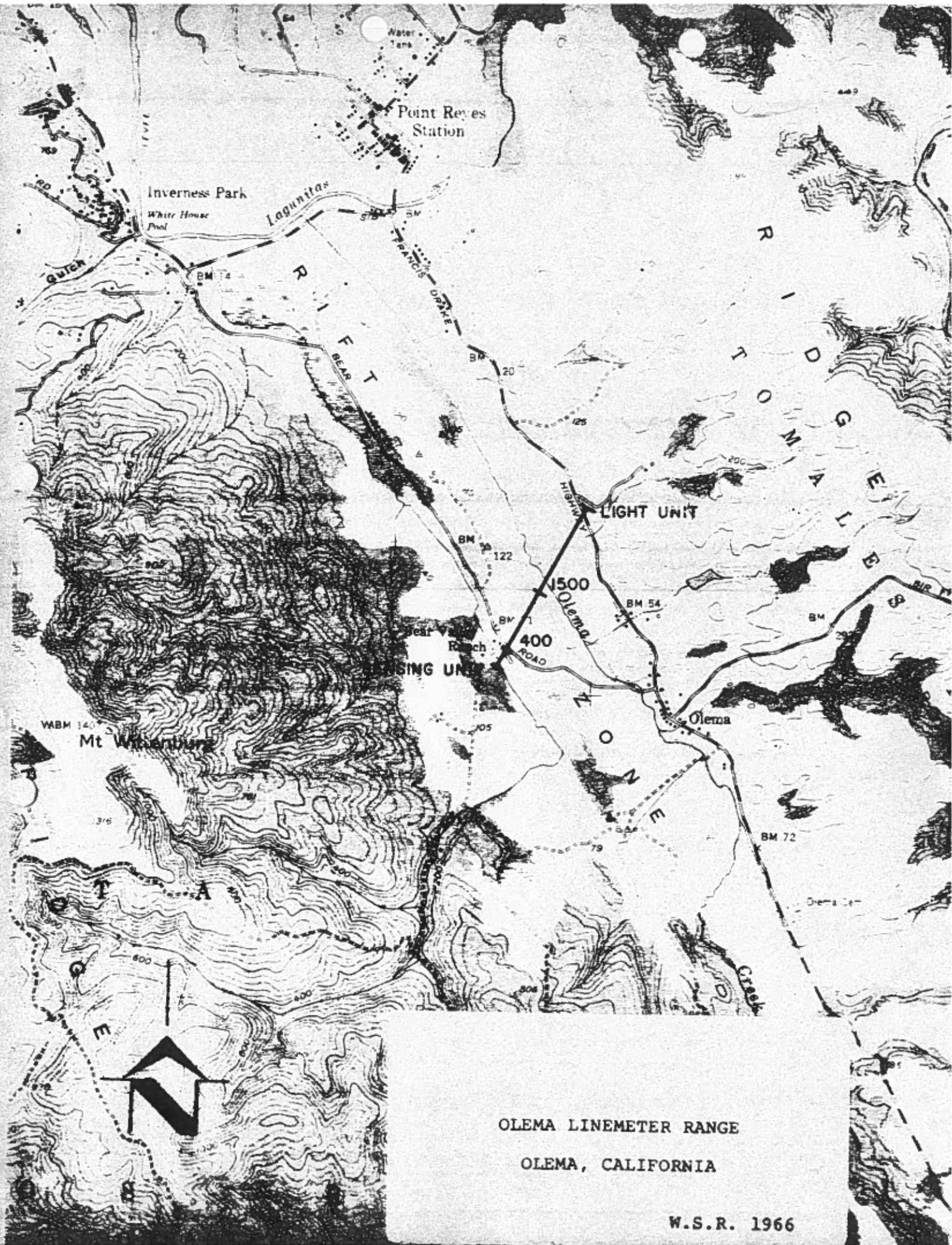
THE "OLEMA PROJECT"

An experimental survey program
using original instrumentation.

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OLEMA LINEMETER RANGE

OLEMA, CALIFORNIA

W.S.R. 1966

1. Purpose: to evaluate the "Linemeter" principle;

- a. As a method of detecting and measuring horizontal deflections of a straight line over long distances.
- b. As a method of observing and measuring the effect of climatic changes upon a light path.
- c. For application to measurement of structure and ground deflections.

The "Linemeter" system was developed in 1962 for the specific purpose of measuring horizontal deflection in a straight line of survey monuments. The requirement at that time was to detect horizontal ground movement in a site selected for a construction project.

Prior tests indicated that all conventional survey methods, including triangulation, trilateration, straight line projection, etc., were not applicable to the task of directly determining ground movements in the magnitude of 0.01 feet per mile. $\approx 2 \cdot 10^{-6}$ rad ≈ 4 arc-sec.

Before the "Linemeter" was completely developed, however, responsibility of the site study fell to others, and the completed instrument was left without a proving ground. The Olema Project was undertaken to fill this need.

2. General Description of the "Linemeter":

The system consists of four basic units:

- a. A light source capable of transmitting high intensity light for the length of the tangent under investigation.
- b. An aperture unit made up of three parts:
 - (1) A stable, laterally adjustable base.
 - (2) A reciprocating slit aperture, moving transverse to the light path.
 - (3) Aperture position transmitter, fixed to the base and continually transmitting the position of the aperture relative to the base.

- c. A light sensor and signal amplifier designed to detect light originating at the light source. Maximum light intensity at the sensor occurs when units a, b and c are aligned.
- d. A display system consisting of a display or recording instrument (Oscilloscope, Oscillograph, Oscilloscope-camera combination, or other monitoring device).

The function of the display system is to simultaneously receive aperture position data from the aperture unit, and light intensity data from the light sensor. By moving the aperture unit, the operator selects the aperture position which coincides with the point of maximum light intensity, as both data are shown simultaneously on the display instrument.

The following illustrations may serve to illustrate the system and the function of its components:

Figure 1

The directional light source and the light sensor are established at the ends of the tangent to be investigated. The aperture unit with the display system is mobile and is successively set up on points along the tangent. As the Linemeter system is for precise alignment and deflection measurement, it is assumed that previous surveys have determined that points under investigation are in alignment within the travel of the aperture unit.

Communication between the light sensor and the display system is established by direct wire, radio or modulated light transmission.

Figure 1 on next page.

Figure 1

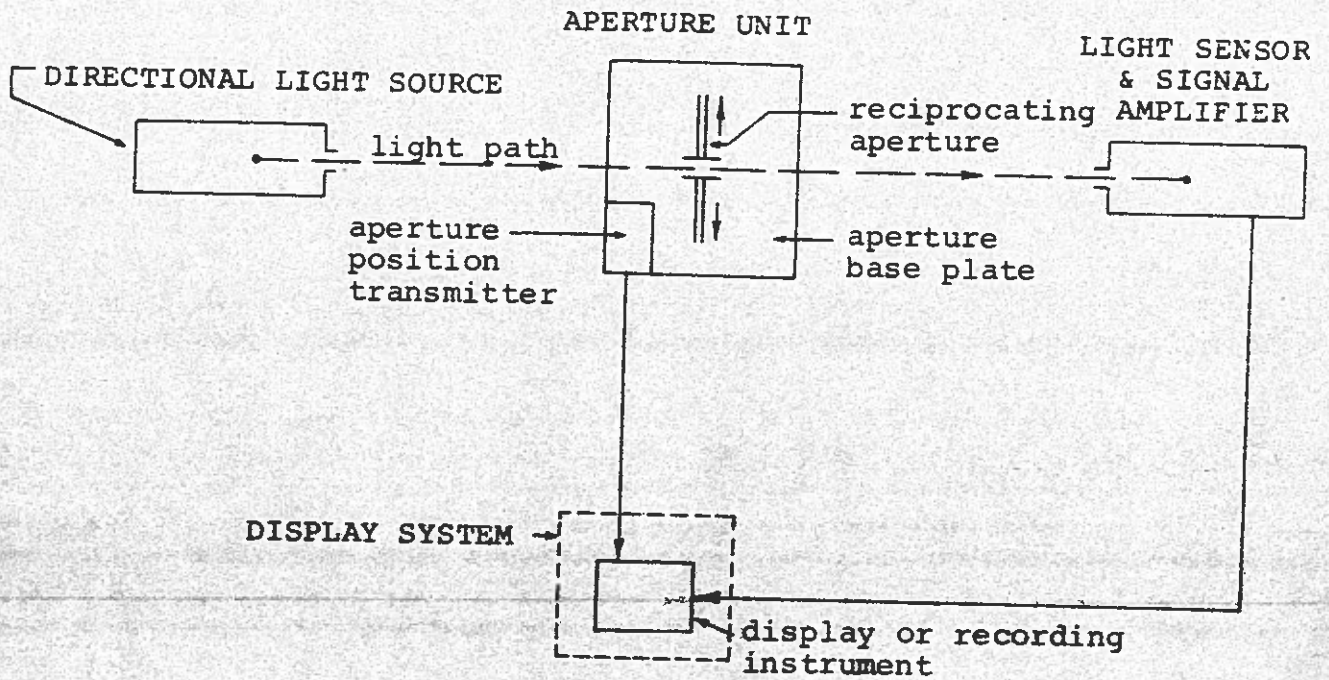


Figure 2

A view of the display oscilloscope screen showing the light intensity curve generated at the sensor by the passage of the aperture across the light path. Also shown is a random position of the aperture position mark.

Figure 2

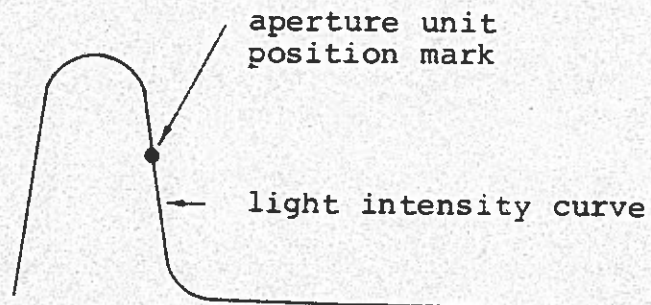
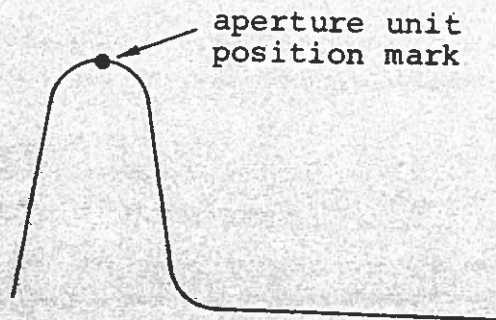


Figure 3

By moving the aperture unit, the aperture position mark has been aligned with the point of maximum light intensity. Position of the light path relative to the aperture base plate can now be read directly on the aperture position scale. Any variance from this position in subsequent re-measuring will indicate the amount and sense of deflection at the aperture station relative to the two end stations.

Figure 3



3. General Description of the Olema Range:

The Olema Range crosses the San Andreas Fault, beginning at the Point Reyes National Seashore Park Headquarters at Bear Valley Ranch, and extending 3200 feet northeasterly to a point just east of Highway 1.

The sensor station is at the westerly end, and the light station is at the easterly end. Two aperture stations are set on the line between the two end stations, approximately 400 and 1500 feet from the sensor station. All stations are on line and on grade.

Monuments for all stations are 12" diameter reinforced concrete columns, extending into the ground at least 40 inches. Instrument mountings are cast in the concrete to insure exact repositioning of instruments.

Wires for transmission of deflection data are permanently buried in the ground, and extend the length of the range, with plug-in connections at each monument.

4. General Aims of the Measuring Program:

The first aim was to conduct repetitive measurements to determine the resolution of the instrument.

The second aim was to observe short term changes in repetitive measurements, and the changes in resolution due to changing climatic conditions.

Although the San Andreas Fault exhibited a large horizontal movement at Olema during the 1906 earthquake, practically no short term motion has been observed in recent years. The third aim of the program was to conduct periodic measurements to determine if the four monuments set on the range were moving with respect to one another and, if so, how much and in what direction.

5. Measuring Procedure:

As the system is subject to interference from air turbulence, it is operable only at night on ranges longer than 800 feet.

Setup normally commences near sundown and is completed in thirty minutes. This consists of mounting the end stations (light unit and sensor unit) on the cast-in-place mounting plates, and setting the aperture unit in the permanent mounting slide of one of the two intermediate monuments. All units are connected to the data carrying wires, the light is turned on, and a test is made for adequate light signal.

Although one man can carry out the entire operation, two operators can take readings more rapidly and provide greater efficiency.

At the intermediate station selected for interrogation, one man moves the aperture unit in it's base, transverse to the light path. The other man observes the oscilloscope screen and stops the transverse motion when the oscilloscope display indicates that the center of the light path coincides with the center of the aperture unit.

At this point, the recorder notes the scale reading that indicates the position of the aperture unit relative to the permanent base. The aperture unit is then moved off to upset the reading, and then is brought back for the next reading. Ten observations are made by each man; then the aperture unit and oscilloscope are moved to the next intermediate station.

Temperature pressure and humidity readings are made at the beginning and end of each set of observations.

6. Observations

During the measuring program, which extended from March 17, 1965, to September 15, 1966, ~~four~~^{fourteen} sets of ten readings were taken at Aperture Station 400, covering nineteen observing nights. Twenty-two sets of ten readings were taken at Aperture Station 1500, covering eleven observing nights.

All observations were read directly to 0.01 inches, and estimated to 0.005 inches.

The following is a reduction of observations:

	<u>Station 400'</u>	<u>Station 1500'</u>
Deviation from the mean, maximum of all groups	0.065 in.	0.100 in.
Deviation from the mean, average of all maximums	0.032 in.	0.058 in.
Standard error of maxi- mum deviations	0.011 in.	0.020 in.

Net indicated movement of monuments for eighteen month period, relative to the line between the two end monuments:

Aperture Station 400 ----- 0.13 inches
Aperture Station 1500 ----- 0.02 inches

Gross indicated travel during eighteen month period:

Aperture Station 400 ----- 0.26 inches
Aperture Station 1500 ----- 0.16 inches

7. Conclusions:

- a. Resolution of the instrument, as indicated by short term repeatability, is sufficient to attain measurement of lateral deflection with an accuracy of 1:1,000,000. This is in free air, using an incandescent light source. It is apparent that similar measurements carried out through a tube to minimize air turbulence would yield better results.

Application of a Laser light source would increase the range, but probably would not yield better results.

- b. Although analysis of the climatic effect is inconclusive, it is apparent that atmospheric variations introduce variations in readings. It was observed that, as the temperature decreased with the later hours, the curve generated by the light became more regular, and the readings more consistent. Conversely, in some instances during the summer, no readable curve could be generated until later in the night. This indicates the condition well known to professional surveyors - differentially heated layers of air refract the line of sight. It also indicates a method by which the displacement due to refraction may be measured, and possibly a method by which quantitative factors can be developed for correction of high precision survey lines.
- c. The results of the survey indicate that the monuments of the Olema Range underwent changes in their relationship. These changes were generally slight, and would not be measurable by conventional survey methods.

Although the project was not concerned with activity of the Fault, the measurements obtained indicate that use of the Linemeter could result in detection and measurement of extremely small fault movement. Movement in a structure, such as a dam, could thus be measured, and movement trends could be detected well in advance of conventional methods.