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# Clinometric records with two long water levels in Lohja, Finland, during the total solar eclipse in 1990

**Jussi Kääriäinen**

Finnish Geodetic Institute, Ilmalankatu 1 A, 00240 Helsinki, Finland

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**Abstract.** Two water tube clinometers are installed in a deep mine in Lohja, Finland. One, lying in an E-W direction, is 177 m long and the other, lying in a N-S direction, is 62 m long. These instruments are used for tidal records and research. Because the station was on the zone of totality of the 1990 solar eclipse, the instruments offered a suitable tool for investigating whether there was any shielding effect on the direction of the vertical. During the eclipse, the resolution of the instruments was increased to 0.00001″ and 0.00004″, respectively.

Recordings and data evaluation are discussed, and the results obtained show that no gravitational shielding was found at the level of the above accuracy.

## 1. Introduction

The question as to whether the gravity of a mass particle can be reduced to the point-like centre of the mass so that the outer layers do not shield the gravity has been discussed since the early years of this century. The question can also be reformulated to ask whether the attraction of any mass could be absorbed by the intervening matter. It was Bottlinger (1912) who proposed that gravity may weaken according to the law:

$$F = F_o\, exp\,(-\int \lambda \varrho dr) \sim F_o(1 - \lambda \int \varrho dr)$$

which is also called Majorana gravitational shielding. Here $F_o$ is the attractive force when no shielding exists, $\varrho$ is the density of the shielding matter and $\lambda$ is the coefficient of absorption.

To determine the value of the $\lambda$ coefficient, much empirical research work has been done since Bottlinger deduced the value $\lambda = 3 \times 10^{-15}$ $g^{-1}cm^2$ from irregularities of the Moon's motion. Experiments have been conducted both in laboratories and using celestial events. A comprehensive bibliography is given by Gillies (1987).

One celestial method for verifying the existence of shielding utilizes the solar eclipse. During an eclipse the Moon acts like a screen between the Sun and the observer's instrument on the Earth's crust. Sensitive gravimeters record the slight increases in the intensity of the gravity vector, and accurate clinometers react to the instantaneous changes in the direction of the gravity. As shown by the calculations of Slichter (1965), the relation between the decrease dF ($\mu$gal) in the attraction towards the Sun at the moment of totality and the absorption coefficient $\lambda$ is :

$$\lambda = 1.42 \times 10^{-15} dF$$

which states that for $\lambda = 1 \times 10^{-15}$ $g^{-1}cm^2$ it is sufficient to record the gravity change with an accuracy of 0.7 $\mu$gal in a zenithal eclipse and with an accuracy of 0.15 mseca (milliseconds of arc) in the direction of the vertical when the celestial bodies are on the horizon. The results of this eclipse method, which has been used by several scientists since 1954, have been in the order of $\lambda < 1 \times 10^{-15}$ $g^{-1}cm^2$. One of the most recent results of lunar ranging experiments shows that the distance between the Moon and the Earth does not alter due to the possible shielding effect within the uncertainty of $\pm 4$ cm which gives $\lambda \leq 1.0 \times 10^{-21}$ $g^{-1}cm^2$ (Eckhardt 1990).

## 2. Experiment

The eclipse method was used again in Finland, where the total solar eclipse occurred in the early hours of 22nd July, 1990. Two water tube clinometers installed in a deep limestone mine in Lohja are used for tidal records and research (Kääriäinen 1979; Kääriäinen and Ruotsalainen 1989). Recordings are made interferometrically at both ends of the instruments. Because the station was in the zone of totality of the eclipse the water level instruments could be used to investigate whether there was any shielding effect or other anomalous tilt of the

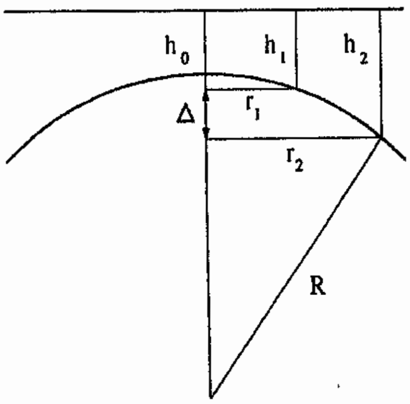


Fig.1. The relation between the height of the water surface and the radius of the interference ring.

vertical due to the eclipse. Owing to the short duration of the eclipse, the film transport was changed to be c. 5 cm/min. i.e. 60 times that of the usual recording speed. Thus the whole eclipse was exposed on the 5-m long strip and the time of the totality is seen as a 67-mm wide band on the film.

Records made with film accelerated this way started on 21st July at 14h UT and continued up to 22nd July 15h UT. The following gives some specific values concerning the eclipse at the Lohja station ; the time throughout is UT (URSA 1990):

| | |
|---|---|
| Observation site | $\varphi = 60°15.8'$ |
| | $\lambda = 24°04.9'$ |
| | H = - 117 m |
| First contact | 1h 03m 30.7s |
| Fourth contact | 2h 45m 29.4s |
| Totality | 1h 53m 35.2s |
| Duration of totality | 85.8s |
| Elevation angle of the sun (and moon) | 0.9° |
| Azimuth of the sun | 46.7° |
| Duration of the whole phenomenon | 1h 41m 58.7s |

The films are usually read hour by hour. In this experiment the data around the totality from 22h UT on 21st July to 6h UT on 22nd July with the N-S instrument and to 6h 57m with the EW instrument were treated minute by minute as follows: the minute markers were interpolated and drawn on the films on the ground of the exposed hourly time markers. The diameter of the innermost ring was measured at every minute marker using the microfilm reading device with c. 10-times magnification. Recordings were made at both ends of the instruments. Fig.1 depicts the situation at one extremity of the long tube. The curved line represents (exaggerated) the convex surface of the lens immersed in water. If the radius of the innermost pattern of the concentric Newtonian interference rings that appear changes from $r_1$ to $r_2$, the water level change is $\Delta = h_1 - h_2$. From the figure it can be seen that

$$h_1 \sim h_0 + \frac{r_1^2}{2R}$$

$$h_2 \sim h_0 + \frac{r_2^2}{2R}$$

and

$$\Delta = \frac{r_1^2 - r_2^2}{2R}$$

Further, the constant 1/2R is determined by measuring the maximum diameter, $d_m$, for the black (or white) pattern. Because the change in the diameter of the black (or white) pattern from maximum to zero corresponds to the distance

$$\frac{\lambda}{4n}$$

between the water surface and reference lens, the change from $d_1$ to $d_2$ on the film corresponds to the distance

$$\Delta = \left[\left(\frac{d_1}{d_m}\right)^2 - \left(\frac{d_2}{d_m}\right)^2\right] \times \frac{\lambda}{4n} \qquad (1)$$

between the water and lens surfaces. Here $\lambda$ is the wavelength of the light used and n is the refractive index of the water. The differences between the minute markers are then summed over the entire recording period at each end of both instruments. Note that no absolute tidal tilt is obtained this way, but the whole set of observed relative tilt values is to be compared to theoretical values.

The readings of the diameters are made with an accuracy of $\pm 0.5$ mm. When $d_m$ is around 20 mm we get for the accuracy of the difference (1)

$$\pm 8nm$$

at one end of the instrument using the mean of 10 mm for the d-values. This corresponds to $\pm 0.013$ mseca in an E-W tilt and to $\pm 0.038$ mseca in a N-S direction. To check the sum of the minute interval readings the hourly values were also read.

The tides were removed from the observations using the $\gamma$-factors of long-term averages obtained from tidal observations in Lohja. After removal of the tides, various signals still remain in the residual curves. Some of these are tides due to the nonrepresentative $\gamma$-values. However, these are not due to the eclipse, because the eclipse is not a global phenomenon but only a "scratch" on the surface and has no influence on the $\gamma$-value.

Drift and irregular fluctuations are also visible. Drift is not an unexpected phenomenon and has consistently been found in records kept in Lohja. The drift is due