

Influence of Partial Solar Eclipse 2016 on the surface gravity acceleration using photogate sensor on Kater's reversible pendulum

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Abstract. This study was conducted to determine the Earth's surface gravitational acceleration (g) prior to, during, and after a partial solar eclipse. Data was collected in Basic Physics Laboratory Universitas Pendidikan Indonesia, Bandung with coordinates S $6^{\circ}51'48''$, E $107^{\circ}35'40''$ for three days on March 8 – 10, 2016, in time interval measurement from 6 a.m. to 9 a.m. This research used a standard pendulum, Kater's reversible pendulum, which deviated less than 3° so that the motion can be regarded harmonics oscillation. The period of pendulum oscillation motion is measured by a light sensor (photogate sensor) with accuracy until 10^{-13} seconds. The data analysis shows that there is small difference value of gravity acceleration at the Earth's surface from three days of observation, i.e. in the order of 10^{-3} ms^{-2} . It means, there is a changes in the Earth's surface gravitational acceleration (g) due to the partial solar eclipse but not significant.

1. Introduction

Gravity is a force between two objects of mass that makes the objects attracts each other. Mathematically, Newton reveals that the gravitational force (F) is proportional to the product of the mass (m) of both objects and inversely proportional to the square of the distance (r) between these objects [1].

$$F \approx \frac{m_1 m_2}{r^2} \quad (1)$$

Gravitation phenomenon of small objects was difficult to observe because it produces very small gravitational force. But in a wider review, the phenomenon of gravity can be observed as the celestial objects and satellites moving on its path, e.g. earth, moon, and sun in the solar system [2, 3].

The research about changes in the gravitational field or gravity acceleration (g) of the Earth's surface during the solar eclipse has been done by some scientists. In 1954, Maurice Allais observed the effects of the solar eclipse on the Earth's gravitational field and he found that the solar eclipse can affect the Earth's gravitational field. Wang et al used Lacoste-Romberg gravimeter to report anomaly of the Earth's



gravitational field $(7.0 \pm 2.7) \times 10^{-8} \text{ ms}^{-2}$ as a result of a total solar eclipse in 1997 in China [4]. Using the same tools, Yang and Wang reported the decrease of gravitational field during a solar eclipse (contact 1 to contact 4) at $7 \sim 8 \mu\text{gal}$ [5]. The different results found by Zainuddin, which reported an increase in the gravitational field of the Earth's surface as a result from two event solar eclipse i.e. total solar eclipse 2009 in China with an increase amounted to 18.92%, and a annular solar eclipse 2010 in Maldives with an increase of 7.51% and 8.59% [6]. Based on the research, Wang and Zainuddin found a different conclusion on the effect of solar eclipse to the Earth's surface gravity field.

Research that conducted by Zainuddin uses harmonic oscillations in a simple pendulum which vulnerable of disturbance, such as conic motion of the pendulum and air resistance that could interfere harmonic oscillatory motion of the pendulum. Moreover, the determination the period of oscillation was using a stop watch that is error-prone. In this study, measurement of the Earth's surface gravitational field done using the same concept with Zainuddin research but with different measurement methods, i.e. using Kater's reversible pendulum as oscillate object and a light sensor (photogate sensor) to measure the time period of oscillation.

2. Methods

Total solar eclipse that happen on March 9, 2016 passes through several areas of Indonesia such as Palembang, Bengkulu, Belitung, Palangkaraya, Palu, Ternate and the surrounding areas. Data is collected in Bandung with coordinates $6^{\circ}51'48''\text{S}$, $107^{\circ}35'40''\text{E}$ as one of the areas that receive partial solar eclipse with 85% of the Sun's surface covered by Moon. Data taken during three consecutive days, i.e. on March 8, 9 and 10, 2016 at 06:00 am until 9:00 am which is the time span partial solar eclipse in Bandung.

The gravitational field of the Earth's surface is determined by oscillatory motion of Kater's reversible pendulum that deviated less than 3° , so that the movement considered as a simple harmonic oscillatory motion. In Kater's reversible pendulum experiment, the period measure with two different pendulum position, i.e. at 06:00 - 07:30 am for the initial position with the mass of pendulum object is above and at 07:30 - 09:00 am for the reversed position of pendulum from the initial position. The value of the gravitational field of the Earth's surface using Kater's reversible pendulum is determined by the equation:

$$g = \frac{8\pi^2 \ell}{T_1^2 + T_2^2} \quad (2)$$

Where ℓ is length of Kater's reversible pendulum, T_1 is period of pendulum oscillation for initial position and T_2 is period of pendulum for reversed position.

Period of Pendulum oscillation measure using a light sensor (photogate sensor) with accuracy of 10^{-13} seconds which is connected to a computer so that each oscillation period immediately recorded and stored on the computer. Set of a research instrument shown in figure 1.

3. Result and discussion

The results measurement and analysis shows that the average period of pendulum oscillation for T_1 , T_2 , and g shown in Table 1. Changes in the Earth's gravitational field surface for each day of observation can be seen in figure 2.

Table 1. The average period of pendulum and the gravitational field of the Earth's surface

Days/Date	Period of pendulum		g (m/s ²)
	Average of T ₁ (s)	Average of T ₂ (s)	
Tuesday/ 08-03-2016	1,9351292848587	1,9774475097680	10,3226858769144
Wednesday/ 09-03-2016	1,9348869323730	1,9772186279300	10,3251718134668
Thursday/ 10-03-2016	1,9351766705514	1,9772253483534	10,3236234000278

Figure 2 show visible pattern of changes in the gravitational field of the Earth's surface during three days of observation. On the day of solar eclipse (Wednesday, March 9, 2016) changes in the gravity field more fluctuate than the other two days. These results indicate that there are anomalies of the gravitational field of the Earth's surface due to solar eclipse.

When the solar eclipse happened, moon's position is between Earth and the Sun so that the gravity force resultant of the Earth and the objects in it will tend to be heading out of Earth. Thus it predicts that the value of gravitational field of the Earth's surface will decrease. However, the research showed the opposite result, the gravitational field of the Earth's surface that occurred is increase despite the increase was not significant. This is due to the sudden change several environmental parameters during the solar eclipse, such as an increase in the mass distribution of the atmosphere surrounding the research site due to changes in atmospheric temperature when the moon covers the sun (the density of the atmosphere increases), changes in air pressure, disturbance of seismic due to movements mass underground and changes in geomagnetic [7,8]. The changes of environmental parameters during solar eclipse is also indicated on anomalous gravitational field changes the Earth's surface that is more fluctuate as shown in figure 2 (b).

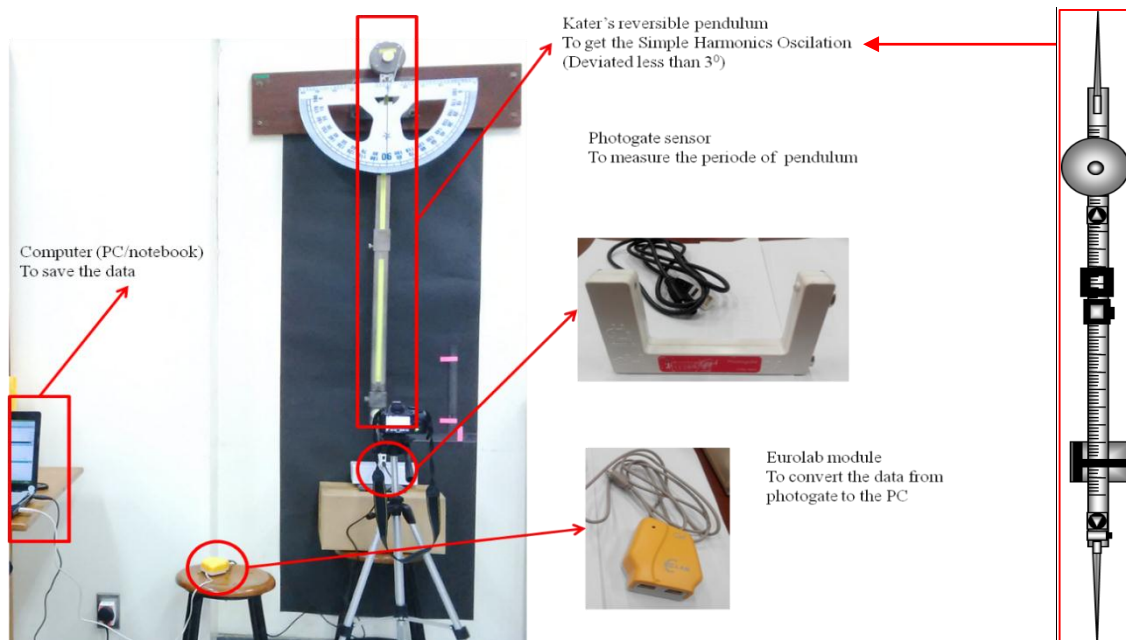


Figure 1. Set of a research instrument

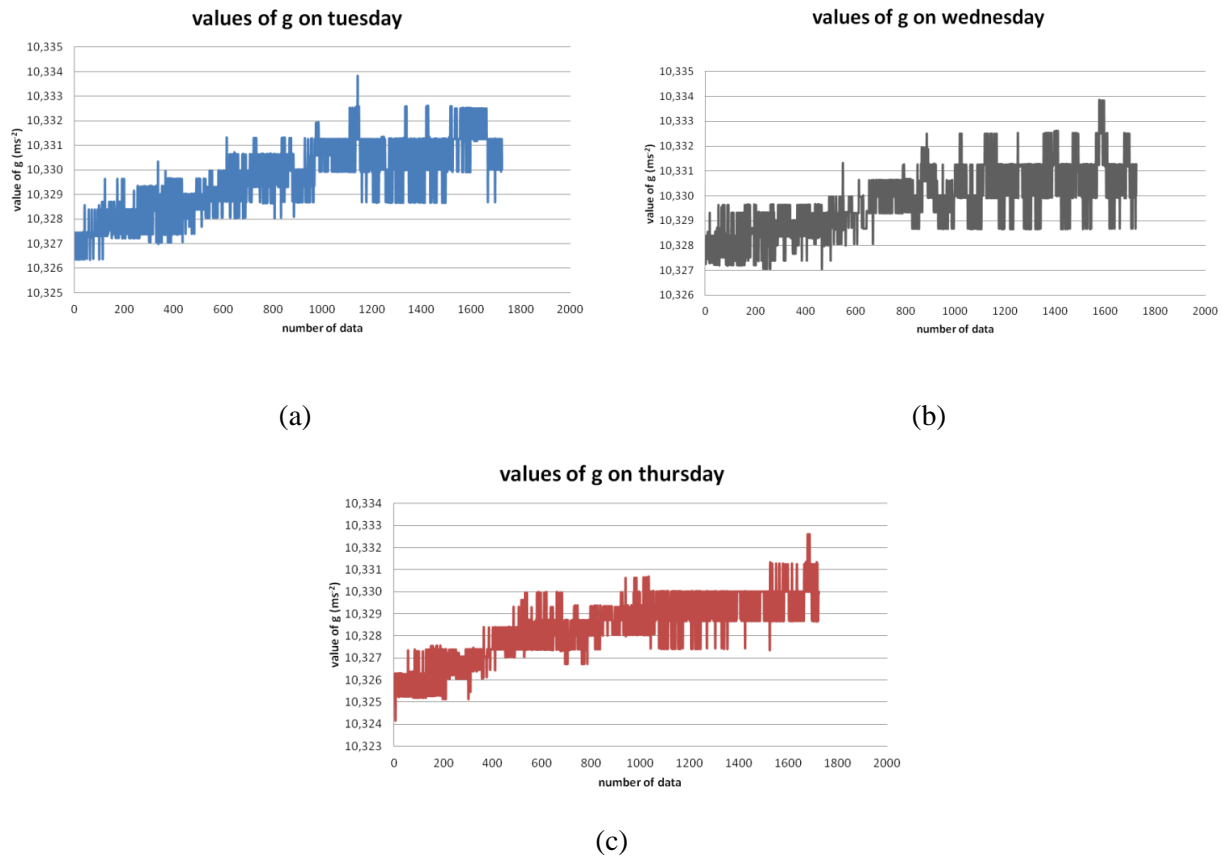


Figure 2. Changes in the gravitational field of the Earth's surface: (a) on Tuesday; (b) on Wednesday; (c) Thursday

4. Conclusion

The research concluded that there is an increase in the gravitational field of the Earth's surface during the solar eclipse although the increasing value is not significant. Nevertheless, it needs further comprehensive studies on the effect of the solar eclipse to the Earth's surface gravitational field, taking into account various parameters that change as a result of the solar eclipse.

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