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# A Possible Relationship between Gravitational Variations and Earthquakes in Central Italy

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***ABSTRACT:*** *An earthquake is not simply a sudden movement of the earth's crust, but the final product of a process that may have begun much earlier. In an area subject to tectonic stress, there can be precursory phenomena since this is where crustal deformation accumulates. A variation in gravity, measured instrumentally to the sixth decimal place, is one of the possible candidates to analyse measurable signals that precede, accompany and follow a seismic tremor. To verify the relationship between the number of earthquakes, the energy released, and the variations in gravity, the sequence in Central Italy was examined, above all that of January 2017. Data from a gravimeter located about 270 kilometres from the epicentral areas have been modelled as Standard Deviation, obtained from gravity measurements (400) carried out on the respective days. This indicator, of a statistical and mathematical nature, indicates the degree of dispersion with respect to its mean value, taken as the average value of these gravity measurements, and shows a positive correlation with the number of daily earthquakes and the energy released by the seismic sequence of January 2017.*

***Keywords:*** *Seismic sequence of Central Italy, gravitational deflections, gravitational waves.*

## I. INTRODUCTION

The energy released by an earthquake in the hypocentre in the form of elastic waves propagates across the terrestrial shell in all directions, causing, locally or globally, changes in density of the materials in the fluid phase of the crust and the asthenosphere. Their remixing determines both density variations and micro-variations in gravity. The gravitational variations generated by earthquakes depend, in turn, on the energy released by the earthquake and the distance separating the hypocentre from the monitoring station. The greater the distance, the greater the arrival time of the micro-disruption of gravity, and vice versa. The potential link between earthquakes and gravitational variations is the object of studies that have intensified since the 1980s [1][2][3][4][5][6]and have recently been confirmed by Montagner et al.[7].If, on the one hand, for strong earthquakes a link has been found between earthquakes and micro-gravitational variations, on the other, micro-variations in gravity and crustal deformations have been observed to precede earthquakes, includingthose of high energy [8][9][10][11], and in other cases, to be accompanied by alterations in the geomagnetic background and acoustic emissions [12]. The long uninterrupted seismic sequence in Central Italy (Fig.1) began on 24 August 2016 with an earthquake of magnitude Mw 6.0, which occurred in the province of Rieti (I) at 01:36:32 (UTC), and resulted in more than 300 victims, causing the collapse of numerous buildings in 131 locations and inflicting substantial damage on Italy's historical and artistic heritage. The earthquakes of 24 August were followed by an uninterrupted daily seismic swarm, exceeding 52,700 shocks on 3 February 2017, (INGV) and reaching Mw 6.5 in the case of the earthquake on 30 October 2016. The long sequence of earthquakes was compared with variations in gravity detected by a gravimeter that exploits all the potential of the simple pendulum, constructed using advanced technologies by Dr. Mario Campion. This instrument runs 24/7, and is located in the city of Rovigo, Italy (Latitude +45.07 N. and Longitude -11.778 E), far from the region affected by the seismic sequence of central Italy, which is about 270 kilometres away.

## II. MONITORING STATION

For the gravimetric measurement, the zone near Venice was particularly suitable since the Adriatic Sea has a basin of an ideal shape to assess tidal forces. In fact, its oblong form lying along the meridian means that rises in sea level follow a movement in tune with the passage along the meridian of both the Moon and the Sun [13].

## III. GRAVIMETRIC MEASUREMENTS

The gravimeter has a device which is independent from barometric pressure variations and a pendulum with low expansion rods to limit errors due to thermal dilatation. The oscillator with a position finder able to produce a very precise synchronism signal has no electromagnetic interference and is connected to an electronic clock which is precise to the eighth-ninth significant figure. This system is controlled by a calculator. In one day, about 52 values of the Earth's gravitational field are obtained and data continue to be collected between one measurement and the next thanks to being recorded on a disk. The relative error over 1000 measurements is 0.000000089.

## IV. INSTRUMENTS

The instrument used in this case for monitoring the gravitational field differs significantly from those normally used, which are essentially of three types:

- the first is a spring gravimeter with constant length;
- the second is able to measure the absolute gravity, also known as free-fall gravimeter;
- and the third one which works with the sensing element electromagnetic balance. The instrument created by Dr. Mario Campion differs significantly from these three types, and may have advantages in terms of measurement compared to them. It basically refers to a gravimeter which makes the most of the potential of the simple pendulum, as long as its functionality is optimized with advanced technologies. The tool measures the average value of gravity in a defined time interval, by timing with extreme precision the time that the oscillator needs to perform 1,000 or 100 or 10 oscillations, then dividing the value by the number of oscillations itself. When determining the extent of g with 1,000 oscillations, the figure is averaged over nearly half an hour, and at the end of the day, a graph is created with about 50 intervals on the abscissa and 50 on the ordinate, with related values. The variations of the average period are inversely proportional to the variations of gravity g, in the range within which the instrument carried out the measurement, as resulting from the formula of the simple pendulum. When working with 100 or 10 oscillations, the measures are obtained by intervals ten or hundred times shorter, so that the analysis of the phenomena are very detailed. According to Dr. Mario Campion, another great advantage of this instrument is that it is able to sum all the gravity values that have acted on the oscillator, one after the other. So that the entire trend of the force of gravity, as detected by the oscillator, comes into the evaluation of its average value, also performing a compression of the data, whose limited amount can be easily used. Considering the 100 measures, the starting interval begins to be perceivable, but in any case it will only take up about thirty percent of the overall interval. Considering the 10 measures, the measuring interval is reduced to ten percent, and in any case much wider than other measuring systems of g. To complete the description of the device, consider that it is controlled by a computer which manages the operating cycle automatically. The graphs drawn on a daily basis have changes in the average period as an index of g, and are much larger than the considered values of gravity measured by spring or free-fall gravimeters. In our case, the period may vary from 5 or 6 millionths, and these variations are much larger than the values of g measured with other gravimeters. This amplification could be the result of this measurement method, which concerns the amount of repeated values, and also the consequence of the use of a sensor with an angular horizontal momentum, which is perpendicular to both the plane of oscillation and the direction of g. The graphs do not show daily and on a regular basis the curve of tidal forces, but over a complete cycle, they point out two significant events which clearly interpret the tidal forces, drawing graphs of similarity with those of the tidal forces, always with great amplification of the phenomenon.

## V. METHODS AND DATA

To verify whether the Italian seismic sequence occurred between August 2016 and January 2017, the authors analyzed the data on gravimeter monitoring products through Dr. Mario Campion. These data were compared with data on seismic activity recorded in Central Italy between 24 August 2016 and 18 January 2017, 24/7, by United States Geological Survey (*https://www.usgs.gov/*) and IstitutoNazionale di Geofisica e Vulcanologia (*www.ingv.it/*).

## VI. DISCUSSION

Before examining the seismic sequence of Central Italy and its possible relationship with micro-variations in gravity detected on a local scale, let us take a look, by way of example, at some cases of earthquakes studied in recent years.The first case concerns the earthquake in Japan occurred on March 11, 2011 [14]. During the catastrophic earthquake in Japan, the gravimeter recorded the event with low-frequency signals which are open to important interpretations. The unit was operating with 10 measures on 10 oscillations and, therefore, obtaining average values of the gravity on 15 seconds inserted into 135 seconds intervals. So, the analysis of the event was detailed, namely, with a total of 650 daily measurements. The graph shows the registration of an interval of 6 hours and fully grasps the event, with a continuous recording from 6 am to 2 minutes before 12 am. The peak on the graph has a value of about 55 microseconds, but we know that it is a value averaged over 15 seconds, and we do not know if the instrument could record it on its maximum value. This Figure (Fig.2) shows the same event, extended over time, with a total of 19 measurement intervals on the abscissa. We see that the phenomenon shows the decrease in gravity of 40 millionths of g and is damped with half-wave only. We can consider it a phenomenon of the gravitational nature because we believe the whole wave lasted about 13 minutes, so with a frequency not comparable to that of the seismic waves. The data from the INGV report that the shock occurred at 6:46:24, Italian time, whereas the expanded graph shows that it was detected by the gravimeter at 07:05: 00 with a delay of 1241 seconds, traveling at a speed of about 7 km per second. An important detail is the symmetry in the variations of gravity, both in correspondence of the peak and in later surveys illustrating the variations of gravity happening at regular times. This last feature certainlyopens up newquestions.The second case concerns the earthquake in Russia that occurred on August 14, 2012 (Fig.3). The duration was obtained from 4 successive measurements. Like other earthquakes, this graph also shows that it was a gravitational wave, deducible from the fact that it was obtained using multiple consecutive measurements, and this unquestionably represents an interesting novelty in the scientific panorama. Another important element evidenced by the gravimeter graphs is the fact that the plots show the behaviour of gravity before and after the seismic event. Thus, from a study of the graphs, we can detect any disturbances in the terrestrial crust before a seismic event, as well as any deflections of gravity after the earthquake itself. Both the first and the second case represent examples of gravitational variations associated with strong earthquakes at a considerable distance from the Rovigo station (Italy). The situation is different when we consider earthquakes with a magnitude equal to or greater than 6 on the Richter Scale that have occurred in Italy relatively close to the Rovigo monitoring station. The only recent case was the Emilia earthquakes of 2012. The area of the Po Valley affected by the earthquakes of 20 and 29 May 2012 (http://iside.rm.ingv.it) is approx. 60km from the gravimeter. The peak accelerations, corresponding to the strongest shocks on 20 and 29 May 2012, were respectively 0.31g and 0.29g. The appearance of the gravitational deflections coincided, from a temporal point of view, with average gravimetric variations of approximately 30µGal around the epicentre areas, concurrent with the mainshock[15].

## VII. EARTHQUAKES OF THE CENTRAL ITALY SEQUENCE ON 26 AND 30 OCTOBER 2016.

The seismic sequence in Central Italy culminated, between 26 and 30 October 2016, in two strong earthquakes with a magnitude of Mw 5.9 (lat. 42.91, long. 13.13 at a depth of 8km) and Mw 6.5 (lat. 42.83, long. 13.11 at a depth of 9km), which occurred respectively in the provinces of Macerata and Perugia (INGV). The strong shocks were followed by a seismic swarm that intensified the number of shocks in the sequence, which had begun on 2 August 2016. Both the aftershocks were recorded by the gravimeter with gravitational deflections close to the two mainshocks. In the first case (Fig.4), the gravitational oscillations began 26' before the sharp increase in gravity (off the gravimeter scale), corresponding to the Mw5.4 mainshock at 19:10:36. After the significant variation in gravity, the level returned to the values preceding the earthquake. For two hours, the oscillations continued until the new Mw 5.9 shock at 21:10:05 and the subsequent deflection of approximately 8 milligal with gravity on the increase.Also in the second case (Fig.5), the Mw 6.5 earthquake was preceded by oscillations lasting around 30' with gravity on the increase, followed by an abrupt increase (end of instrument scale) corresponding to the main shock. The gravity pattern was characterized by a return wave, as in the cases studied of earthquakes with a magnitude greater than Mw6. Like the previous earthquake of 26 October, after the mainshock, the gravity deflection was around 8 milligal.

## VIII. STANDARD DEVIATION

To check the reliability of the measurements carried out by the gravimeter, the standard deviation was calculated from the gravity measurements (400) made throughout the day. This indicator, of a statistical and mathematical nature, indicates the degree of dispersion – in our case the value of gravity being measured – with respect to its mean value, taken as the average value of these gravity measurements. The period taken into consideration comprises the entire month of January 2017, where the 31 days of the month appear on the abscissa,while the value of the standard deviation is marked on the ordinate for each of them. The values obtained were compared with the number of earthquakes in the seismic sequence for the same time interval (1-31 January 2017). The figure shows a correspondence between the standard deviation values of the daily gravity measurements and the increase in the number of earthquakes from 17 to 19 January in excess of magnitude Mw2. Comparing the Standard Deviation gravity values in January 2017 with the daily number and the seismic energy of the earthquakes in Central Italy (Fig.6) reveals a positive correlation between the two variables.

## IX. CONCLUSIONS

In all the earthquakes studied with a magnitude of Mw5, starting from 2009, both in Italy and abroad, a wave with a maximum appears, followed by a more modest downwards peak. This behaviour of the micro-variations in gravity might be showing that the corresponding earthquakes, in addition to producing different types of seismic wave, also generate a temporary local variation in gravity, of an undulating nature, consisting of an entire period as a consequence of the passage of the seismic waves. The gravity pattern found during earthquakes with a magnitude greater than 6 has been deduced from subsequent measurements and, for this reason, it is reasonable to assume that it is the measure of a gravitational wave and not a seismic one. On the other hand, the variation in gravity in the form of a wave should be consequent to the compression and consequent depletion of soilproduced by the great energy dissipated by the train of arriving seismic waves, remixing the density of the fluid materials of the crust – the upper mantle, thereby inducing micro-variations in gravity. The standard deviation pattern considered for the month of January 2017, in relation to the number of earthquakes in Central Italy and corresponding roughly to the daily seismic moment, indicates a potential relationship between the two physical phenomena that could be confirmed by future interdisciplinary studies.

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## FIGURES

**Fig.1.** Index Map. (1) Monitoring area, (2) Seismic sequence area of Central Italy.

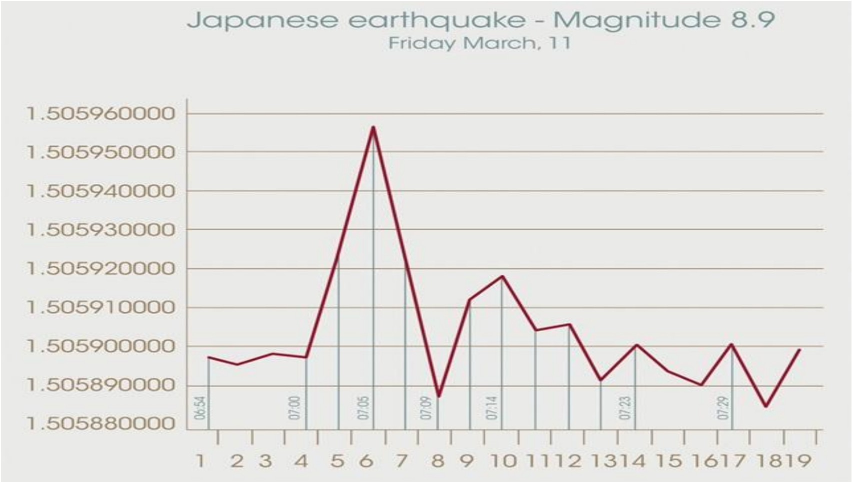

**Fig.2.** Gravity pattern during the Japan earthquake of 11 March 2011. The peaks on the graph correspond to the main seismic events. The most pronounced (hh:mm 07:05) corresponded to the mainshock of magnitude M9.0.

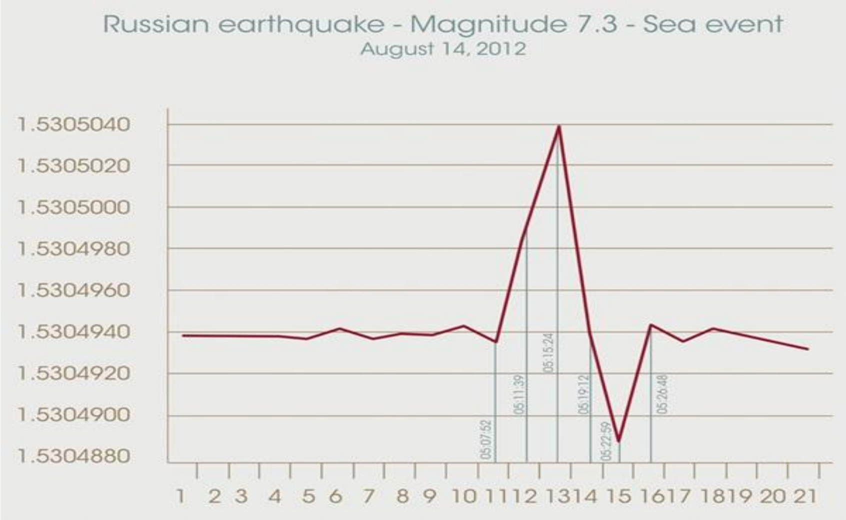

**Fig.3.** Gravity pattern before, during and after the mainshock of the earthquake on 14 August 2014. Also in this case, the peak coincides with the earthquake with the greatest energy.

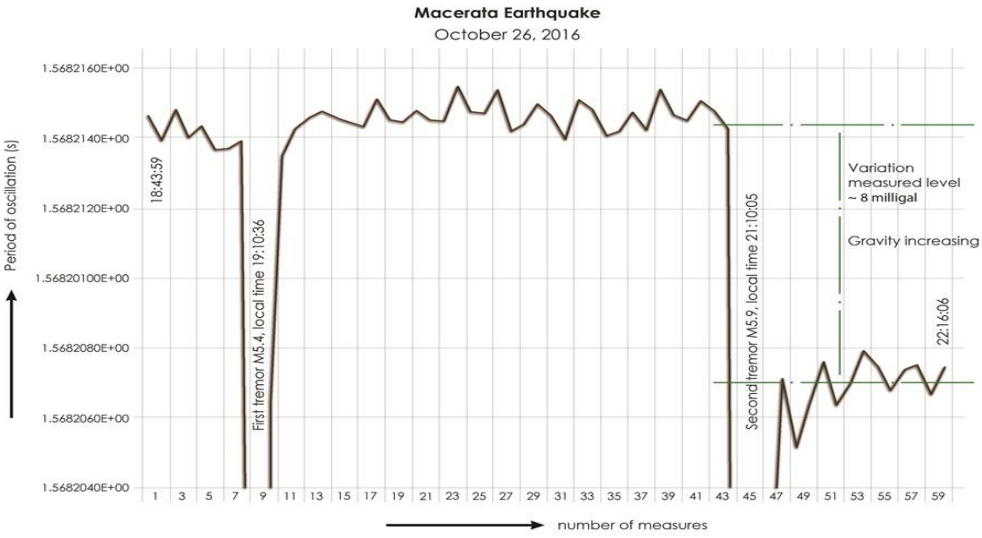

**Fig.4.** Gravity pattern, before, during and after the Macerata earthquake of 26 October 2016 (M5.9), showing a deflection of approximately 8 milligal.

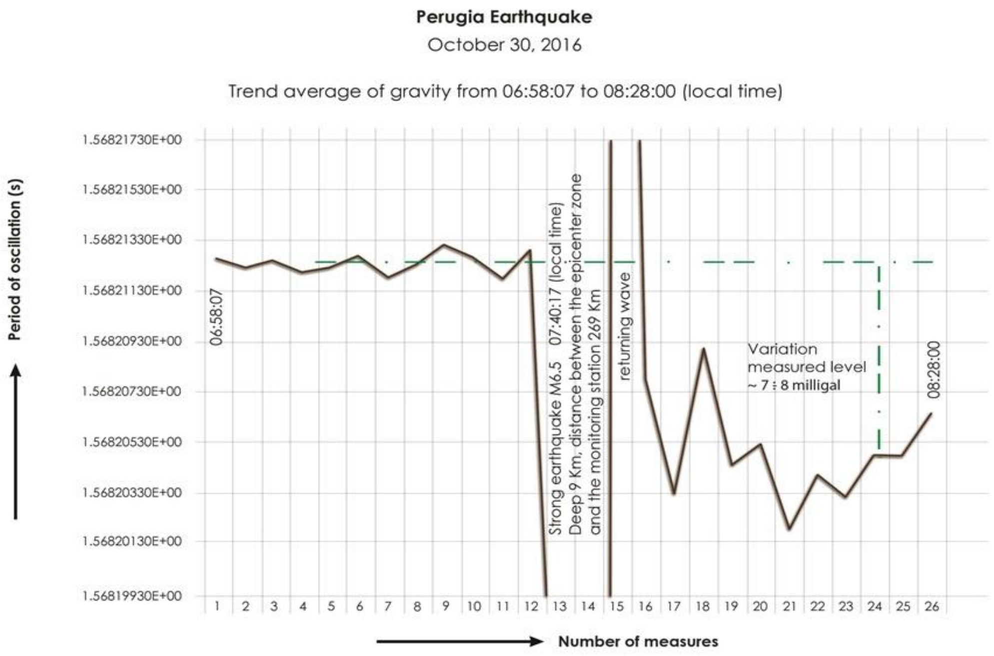

**Fig.5.** Gravity pattern, before, during and after the Perugia earthquake of 30 October 2016 (M6.5), showing a deflection of approximately 8 milligal.

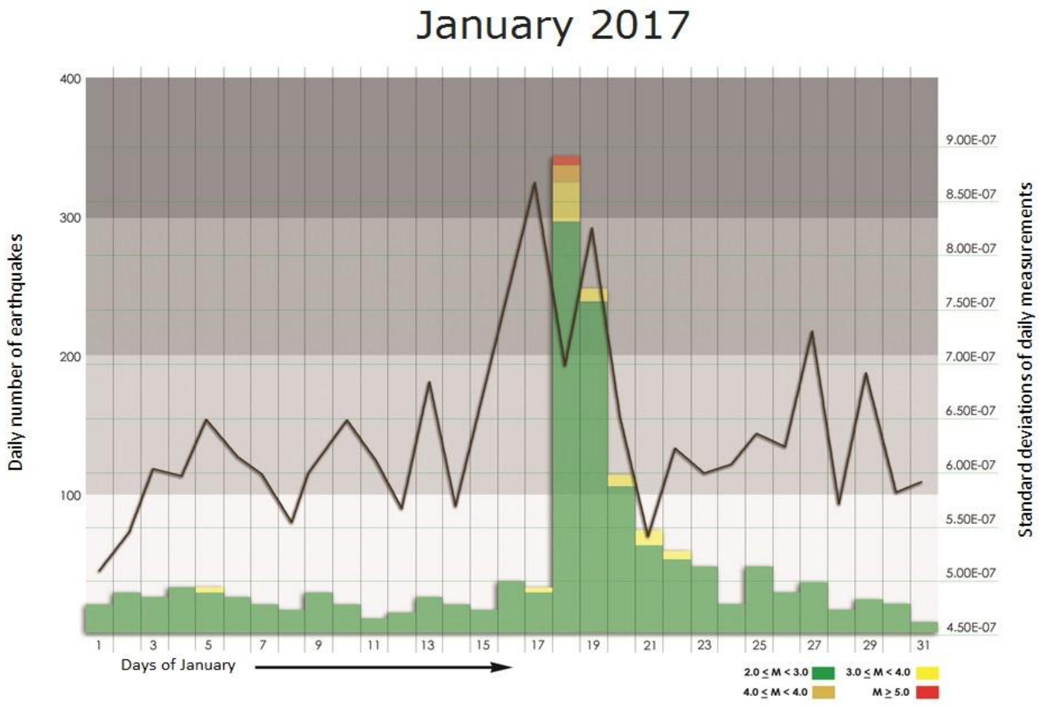

**Fig.6.** Comparison of the standard deviation in daily gravity values in January 2017 with the number of earthquakes in Central Italy during the same period (redrawn and amended from http://iside.rm.ingv.it/).