ՀՀ ԳԱԱ Տեղեկագիր, Գիտություններ Երկրի մասին, 2024, հ. 77, N 3, 15-24
Известия НАН РА Науки о Земле, 2024, т. 77, N 3, 15-24
Proceedings NAS RA, Earth Sciences, 2024, v. 77, N 3, 15-24

ԹԻՎ 3 ՀԱՏՈՐ 77 2024

DOI: 10.54503/0515-961X-2024.77.3-15

ABOUT THE LIMITATIONS OF THE SOC MODEL APPLICATION FOR EARTHQUAKES

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Received by the Editor 30.10.2024

Abstract

This article examines certain limitations of applying the Self-Organized Criticality (SOC) model to earthquakes. An analysis of earthquake distribution throughout the day reveals that in some areas, earthquake frequency strictly depends on the time of day, with more occurrences connected to the midday and midnight. This frequency also aligns with the lunar day cycle of 27.35 days. Proposed a new type of histogram illustrating the daily dependency of earthquake occurrences. It can be used for a better understanding of the seismic regime in the given territory within short time periods. It is concluded that earthquake-generating forces exhibit periodic patterns with periods of 12 and 24 hours, as well as 14 and 28 days. Since the combined tidal periodicity for spring tide is 12:25 or 24:50 per day presented in report observation is limiting the possibility to apply the trigger model of moon and sun combined forces influence to the earthquake generation process.

Key words (earthquake distribution, SOC model, daily distribution, earthquake model).

Introduction

The problem of earthquake forecasting is closely tied to their true nature. The scientific community is divided into two opposing groups: one believes earthquakes are predictable (Danijel Schorlemmer et al., 2018; Keilis-Borok 1988; Adams R.D. 1976.), while the other believes they are virtually impossible to predict (Yan Y. Kagan 1997; Mulargia F. et al. 1996). This latter view is more common, supported by the very limited success in predicting earthquakes. Although no widely accepted forecasting method exists, this does not imply that the task is inherently unsolvable. True scientific arguments for the inherent unpredictability of earthquakes need to be presented to justify such a strong claim. A detailed understanding of the mechanism of the earthquake preparation process is the key.

Some researchers have classified earthquakes as SOC phenomena, which are unpredictable by nature (Geller et al., 1997). This idea assumes that earthquake magnitude "develops" during the event, similar to avalanches. The magnitude of an avalanche does not depend on the specific trigger but rather on the amount of accumulated snow, its condition, and other environmental factors (Geller et al., 1997). This conclusion is primarily supported by laboratory experiments using an "earthquake apparatus" (e.g., Stein, 1999) that aims to replicate natural earthquake conditions.

Stein’s laboratory experiments show that brick on sandpaper, as it is positioned on Figure 1, will cover different distances **S** over the same amount of applied forces **F**. There is no correlation between the amount of applied force and the distance covered by brick.

In terms of earthquake magnitude, this means that it does not depend on the last amount of trigger forces. However, applying this conclusion to actual earthquakes remains questionable and requires further verification, as the experimental basis alone does not fully justify the widespread notion of earthquake unpredictability in the scientific community.

To test whether earthquakes genuinely represent SOC phenomena, we must first assess the adequacy of the laboratory model in relation to observed natural phenomena. The main assumption in the SOC model is that the force leading to earthquakes steadily increases, reaching a critical threshold at the earthquake's onset (Bak P., 1996.). This assumption stems from the fact that, in experiments with a brick on sandpaper, a constantly increasing force is applied until the block begins to move, with the displacement being unpredictable in relation to the force applied.

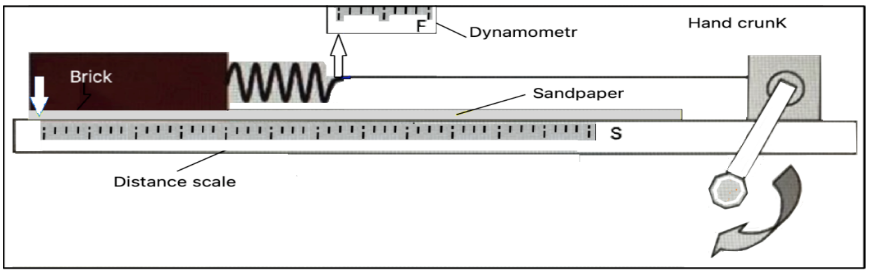

Fig.1. Earthquake simulation apparatus principal schematic view.

The variability in both the threshold force required to initiate movement and the resulting displacement led some researchers to conclude that the process is Self Organased Critically (Staine 1999). They hypothesized that the block's movement derives energy from sources beyond the last applied portion of pulling force, making it inherently unpredictable. This has drawn parallels to avalanches, where a small trigger (e.g., a single snowball) can result in a large, self-sustaining chain reaction, suggesting self-organization. However, predicting the scale of such events remains difficult due to unknown factors in the initial conditions.

In the context of earthquakes, proponents of this model argue that large earthquakes are essentially a “non-stop” small one. Since the individual small earthquakes are unpredictable, because there are too many of them, the larger events should also be unpredictable. However, the oversimplification of the phenomenon may be an obstacle to applying it to earthquakes.

One of the main differences seems to be the high friction in the real model. For instance, by putting the initial brick within a box of sand and covering it entirely to increase the friction within the system, we will obtain a completely different result. In the presented laboratory experiments, the friction in the system decreases after the brick starts moving. In contrast, during a real earthquake, because it occurs within the lithosphere, the resistance to movement after it begins is expected to increase sharply.

Data and Results

Currently, the extension of the oceanic floor due to mantle convection is regarded as the primary mechanism driving tectonic plate movement. This continuous plate motion generates forces that cause earthquakes, both at tectonic plate boundaries and within plates (intraplate). Since the spreading rate of the oceanic crust and the velocity of tectonic plate movement remain constant, it is assumed that the overall rate of stress accumulation leading to earthquakes steadily increases (Forsyth, D., & Uyeda, S., 1975).

However, this last assumption that during the earthquake preparation process, the actually applied forces are constant in magnitude and direction requires further investigation. To test this, we analyzed earthquake distribution over time. Our study focused on the Transcaucasia region, using data from the NSSP Armenia seismic catalog. For the territory of Armenia, earthquakes within a one-hour time zone interval, from 1962 up to 2007 (17833 events), regardless of magnitude, were chosen for this analysis. The time of each earthquake was converted to local time. Daytime was divided into minutes (24 x 60 = 1440 min), and the overall number of events per each minute interval of the day for the entire instrumental period of earthquake monitoring was counted (Fig. 2).

If the forces responsible for earthquake preparation were constant, we would expect a uniform distribution of earthquake occurrences throughout the day. However, our results indicated the contrary, implying variability in the forces involved.

The peak number of earthquakes occurred around midday (720 minutes), and the distribution showed a periodic nature over a 24-hour cycle, as it can be seen on fig.2. This pattern was also tested for the lunar cycle 27.35 days, as it can be seen in fig.3.

If seismic activity was independent of the lunar day, seismic events would distribute evenly across the entire interval. Our analysis revealed periodicities of approximately 14 and 28 days, suggesting that earthquake activity in the region is influenced by both solar and lunar cycles.

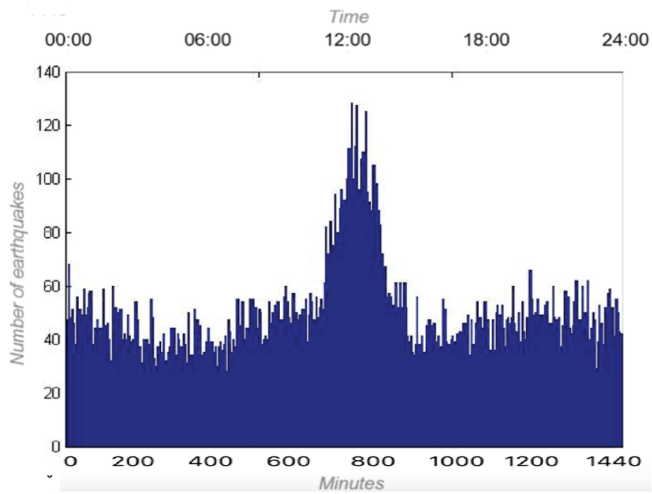

Fig.2. Earthquake distribution by the time of day in minutes for entire instrumental period 1961 2007 year for the territory of Armenia **(Kazarian, Mkrtchyan 2017)**.

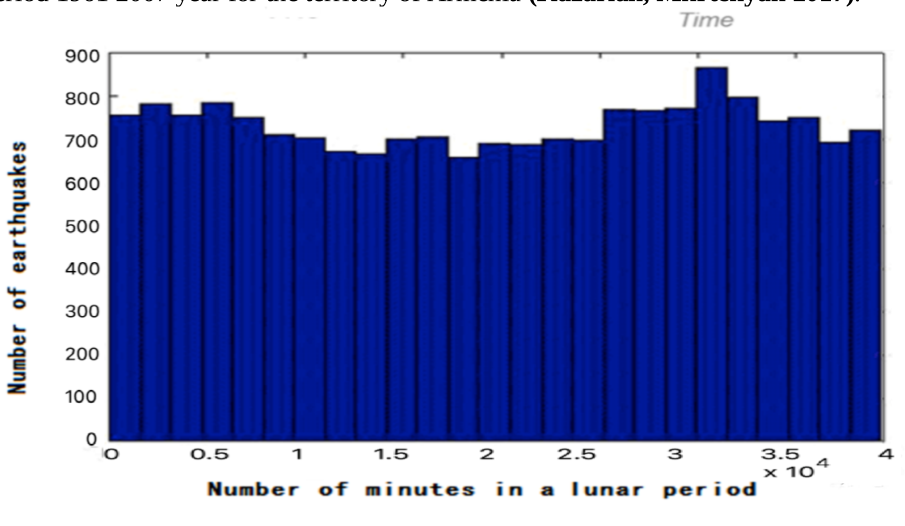

Fig.3. Earthquake distribution by the lunar day (27.35 days, 39384 minutes).

These findings suggest that, in reality, the forces responsible for earthquake preparation are periodic in nature, with intervals of 12 hours, 24 hours, 14 days, and 27.35 days. Understanding the exact implications of this periodicity requires further research. For now, we argue that the constant-force assumption in laboratory experiments has limited applicability to natural earthquake preparation processes. It's more reasonable to assume that they have periodic character according to the revealed periodicity of seismic activity. The correlation of the number of earthquakes with solar and lunar periodicity needs further investigation.

To test whether this periodicity is region-specific, we replicated the study using data from the seismic catalog on territory of Turkey. Although the seismic catalog of of Turkey (Kandilli Observatory and Earthquake Research Institute (KOERI) catalog2005–2016, 200204 events) is recorded spanning over two time zones we do obtaine similar result. (fig.4).

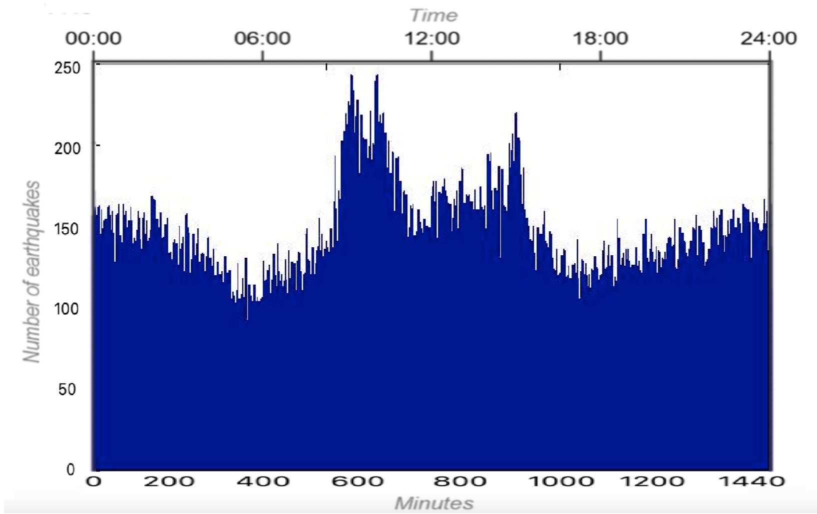

Fig.4. Earthquake distribution by the time of day in minutes for the entire instrumental period 1961-2007 year for the territory of Turkey (Kazarian, Mkrtchyan 2017).

The narrow maximums on this histogram correspond to the industrial mining activity however, after removing them, the basic line for seismicity revealed bimodal distribution with major activity by midday and midnight.

Discussion

A detailed study of earthquake frequency per minute could reveal the influence of fault orientation and structural anisotropy on daily earthquake distributions, which is the subject of our future research. Earlier, it was demonstrated (Kazarian, Mkrtchyan 2017) the correlation between the unimodal and bimodal distribution of earthquakes during the daytime and dominated focal mechanisms for the territory of Greece and Italy compared to the territory of Turkey and Armenia. However, within this report we want to concentrate on the possibility of the SOC model application for the earthquakes and the assumed triggering role of the planetary forces on the process.

Obtained results show the correlation of the number of earthquakes with planetary rotation, primarily with the period of daily rotation and the period of common rotation of Earth and Moon around the barycenter. It is important to mention that the revealed periodicities are not tidal periods since those have a period of 12 hours and 25 minutes or 24 hours and 50 minutes. Consequently, the combined amplitude of Moon and Sun tidal forces is unlikely to serve as a trigger for earthquakes.

A more detailed explanation is needed to make our point clearer. On the one hand, we observe the periodicity of earthquakes with diurnal and semidiurnal cycles, as well as the bimodal distribution during the lunar cycle (28 days). The correlation between planetary periodicity and basic seismicity appears evident. However, we argue that the combined amplitude of the Sun and Moon's tidal forces cannot be solely responsible for triggering earthquakes.

The presence of planetary periodicity (12 and 24 hours) does not imply a direct connection to combined tidal forces, as the latter have a periodicity of 12 hours and 25 minutes. If seismic activity were tied to (maximum) spring tides, it would shift by 50 minutes each day. For example, if it coincided with noon on a given day, it should shift to 12:50 the following day, 13:40 the day after, then 14:30, and so forth.

The instance of principal tidal constituents with corresponding average amplitude and periodicity are shown in Table 1. Tidal forces consist of several components most influenced presented (Coastal Dynamics. Judith Bosboom, Marcel J.F. Stive). The main lunar tide has a period of 12.42 h and the main solar tide a period of 12 h respectively ($M2$ and $S2$). The basic seismicity reveal connection to only principal solar S2 period. Although the lunar M2 constituent has more than 2 times influence in tidal daily amplitude. The seismicity relation to Lunar period reveals only on 28-day histogram, which corresponds to Mm 327.9 h and Mf 661.3 h constituency.

We also can see that Lunar-Solar declination K1 with period 23.93 h also can be blamed for initial activation of seismicity. However, as it clearly seen from the table the most influential principal lunar M2 constituent with period 12.42 h does not reflect by basic seismic activity. This brings us to the conclusion that amplitude of tidal forces unlikely can be blamed for increase of seismic activity.

Table 1: Principal tidal constituents with equilibrium amplitudes (Coastal Dynamics. Judith Bosboom, Marcel J.F. Stive).

Tidal constituents	Name	Amplitude [m]	Period [h]
Semidiurnal			
Principal lunar	M2	0.24	12.42

Principal solar	S2	0.11	12
Lunar elliptical	N2	0.046	12.66
Lunar-solar declinational	K2	0.031	11.97
Diurnal			
Lunar-solar declinational	K1	0.14	23.93
Principal lunar	O1	0.1	25.82
Principal solar	P1	0.047	24.07
Lunar elliptical	Q1	0.019	26.87
Long Period			
Fortnightly	Mf	0.042	327.9
Monthly	Mm	0.022	661.3
Semiannual	Ssa	0.019	4383

In the context of the Self-Organized Criticality (SOC) model for earthquake preparation, as demonstrated by Stain's laboratory experiments, the constant tension on the cord represents the continuous build-up of tectonic stress. Our statistical analysis of seismic data from the region suggests that the applied forces likely have a periodic nature with planetary cycles, but they do not align with the timing of maximum tidal forces.

The strongest earthquakes in the region sometimes align with new or full moon. Figure 4 illustrates the most significant earthquakes in the region from 1900 to 2023, with some coinciding with new or full moons:

1. Kahramanmaraş doublet (2023, M=7.8)
2. Manjil-Rudbar (1990, M=7.8)
3. Tabas (1978, M=7.4)
4. Amorgós (1956, M=7.7)
5. Ilgaz (1943, M=7.5)
6. Erzincan (1939, M=7.8)

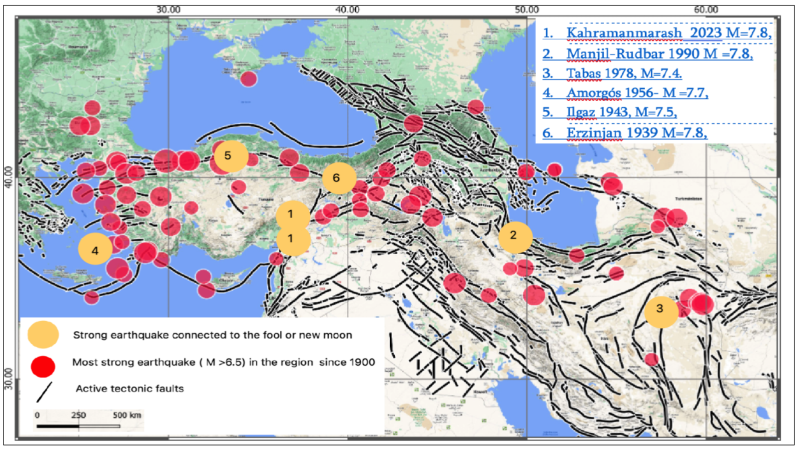

Fig.4. The strongest events in the region since 1900 according to the USGS catalog. Active tectonic faults presented by Trifonov, Karakhanyan (Trifonov, Karakhanyan 1994, 1996).

It is noteworthy that while the number of strong earthquakes coinciding with new or full moons is not large, their proportion increases with increase of the magnitude.

The histograms discussed above show that the increase in earthquake occurrences during specific periods predominantly consists of weaker events. These weaker events generally are more frequent, as described by the Gutenberg-Richter empirical Law (Beno Gutenberg and Charles F. Richter 1940).

Since the attached to the midday and midnight time earthquakes has low magnitude, we can conclude that the geological media was not in a critical state when planetary forces was assumed to act as a trigger.

According to SOC theory, the magnitude of an earthquake develops as the event unfolds after the initial trigger. If strong earthquakes are essentially “uninterrupted” sequences of weaker ones, then tidal forces are unlikely to be the triggers for such events. This restricts the potential role of tidal forces amplitude in earthquake generation. From the other side we observe the correlation of the weak earthquakes with 14 and 28 days of lunar periodicity. This, in turn, suggest that seismic activity indeed connected with planetary rotation.

Conclusion

In summary, the SOC model with triggering mechanism at the end of the earthquake preparation process's applicability is limited, at least in certain regions. Daily periodic characteristics of seismicity, which vary by region, could complement the Gutenberg-Richter law in characterizing seismic activity. We anticipate that earthquake activity's daily distribution might shift during earthquake preparation periods, potentially providing new insights into the earthquake preparation process. It is difficult to imagine that an area with an active earthquake preparation process frequently reaches a critical stage at midday/midnight or at the new or full moon. Understanding these periodic characteristics in different regions may lead to a more complete model of earthquake behavior. Our study reveal that the basic seismicity has close relation to planetary rotations, however it also shows that this connection is unlikely goes through the increase of last portion of tectonic stress implied by combination of moon and sun tidal forces.

All above mentioned bring us to the conclusion that directional component of tidal forces playing more significant role in earthquake generation process then it was assumed previously.

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ԵՐԿՐԱՇԱՐԺԵՐԻ ՀԱՄԱՐ SOC ՄՈԴԵԼԻ ՀԱՎԵԼՎԱԾԻ ՍԱՀՄԱՆԱՓԱԿՈՒՄՆԵՐԻ ՄԱՍԻՆ

Ղազարյան Արմեն, Մինասյան Գայանե, Տեր-Վարդանյան Լիլիթ, Մկրտչյան Ասատուր

Ամփոփում

Այս հոդվածում ուսումնասիրվում են ինքնակազմակերպված կրիտիկական (Self Organised Criticaly) մոդելի կիրառման որոշ սահմանափակումները երկրաշարժերի դեպքում: Օրվա ընթացքում երկրաշարժերի բաշխման վերլուծությունը ցույց է տալիս, որ երկրաշարժերի հաճախականությունը խստորեն կախված է օրվա ժամից՝ առավել հաճախականությամբ կապված լինելով կեսօրի և կեսգիշերի հետ: Այս հաճախականությունը համընկնում է նաև 27.35 օր տևողությամբ լուսնային օրվա ցիկլին: Առաջարկվում է նոր տեսակի հիստոգրամմա, որը ցուցադրում է երկրաշարժերի առաջացման օրական կախվածությունը: Այն կարող է օգտագործվել տվյալ տարածքում կարճ ժամանակահատվածներում սեյսմիկ ռեժիմի ավելի լավ ըմբռնման համար: Եզրակացվում է, որ երկրաշարժեր ստեղծող ուժերը դրսևորում են պարբերականության նմուշներ մոտավորապես 12 և 24 ժամ, ինչպես նաև 14 և 28 օր պարբերություններով: Սա սահմանափակում է երկրաշարժերի առաջացման գործընթացում Լուսնի և Արևի համատեղ ազդեցության մոդելի կիրառման հնարավորությունը:

ОБ ОГРАНИЧЕНИЯХ ПРИМЕНЕНИЯ МОДЕЛИ SOC ДЛЯ ЗЕМЛЕТРЯСЕНИЙ

Казарян Армен, Минасян Гаяне, Тер-Варданян Лилит, Мкртчян Асатур

Резюме

В данной статье рассматриваются некоторые ограничения применения модели самоорганизующихся систем достигших критического состояния (Self Organised Criticaly) к землетрясениям. Анализ суточного распределения землетрясений показывает, что частота появления землетрясений строго зависит от времени суток, связанными с полуднем и полуночью. Эта частота также соответствует циклу лунного дня, составляющему 27,35 дня. Предложен новый тип гистограммы, иллюстрирующий суточную зависимость возникновения землетрясений. Он может быть использован для лучшего понимания сейсмического режима в течение коротких временных интервалов. Сделан вывод о том, что силы, генерирующие землетрясения, проявляют периодические закономерности с периодами примерно 12 и 24 часа, а также 14 и 28 дня, что ограничивает возможность применения триггерной модели влияния Луны и Солнца на процесс генерации землетрясений.