# The 2025 M7.7 Myanmar Earthquake and its effect on Thailand


Yoshio Okamoto

yossi.okamoto@gmail.com

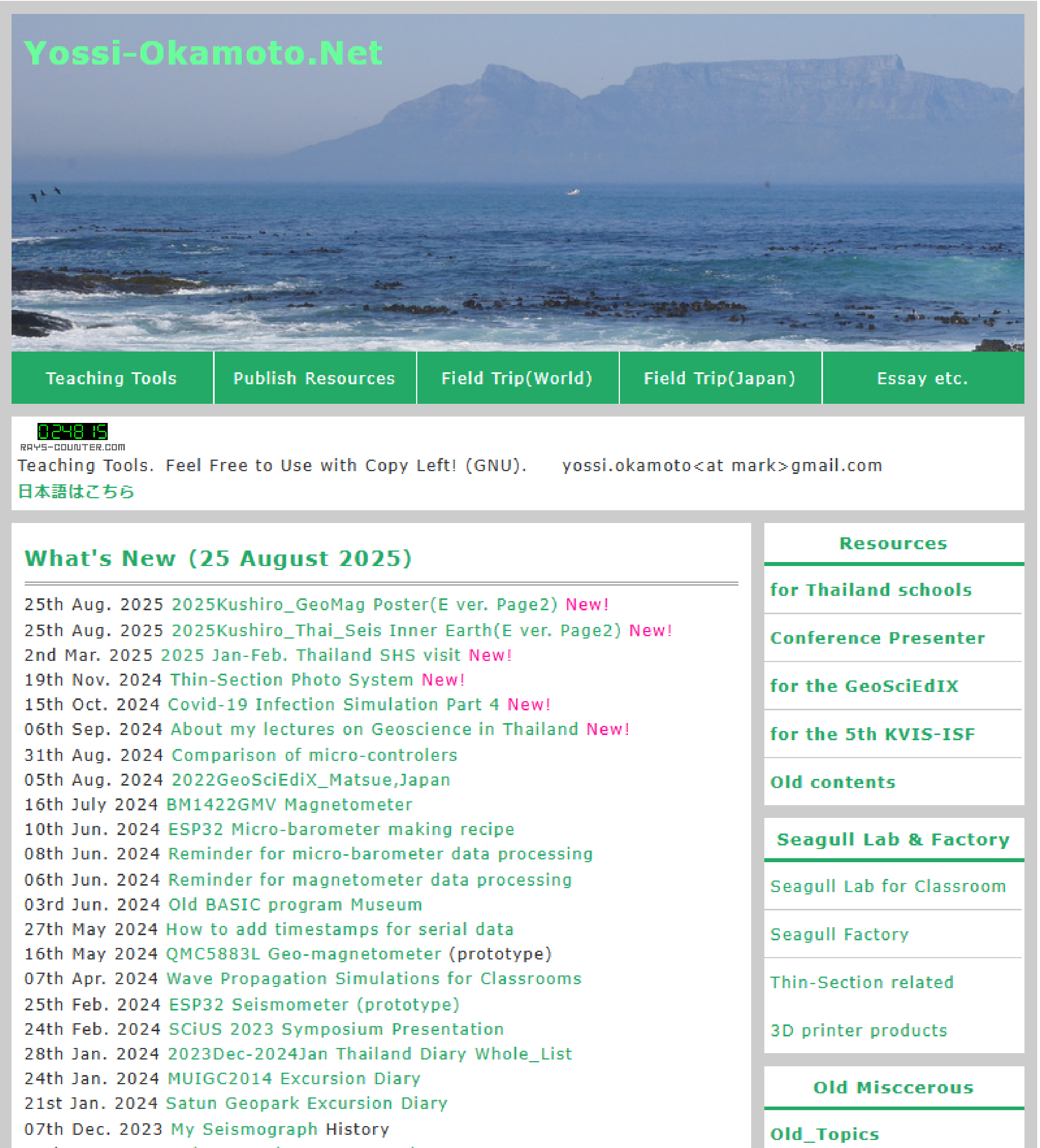
http://yossi-okamoto.net/


Chiang Mai Univ. DS 3th Dec.2025

**Silpakorn University 9th Dec.2025**

# Who ar

- Earth Science high-school
- Associate professor and pa
  Osaka-Kyoiku University
- Geo Science class at KVIS, Loei/NST, Chiang Mai Univ Silpakorn Univ. DS
- School Seismograph Syste Mukdahan, PCSHS Loei, PC DS, Phayao Univ. DS, Silpa
- 3D seismicity maps, tsunar
- Polarized microscope unit classroom
- 3D printing (2019- )
- Linux Programming (awk, (



# Today's Outline

- What is the 2025 Myanmar earthquake?
- Myanmar earthquake recorded by our seismographs
- Why was Bangkok so strongly shaken?

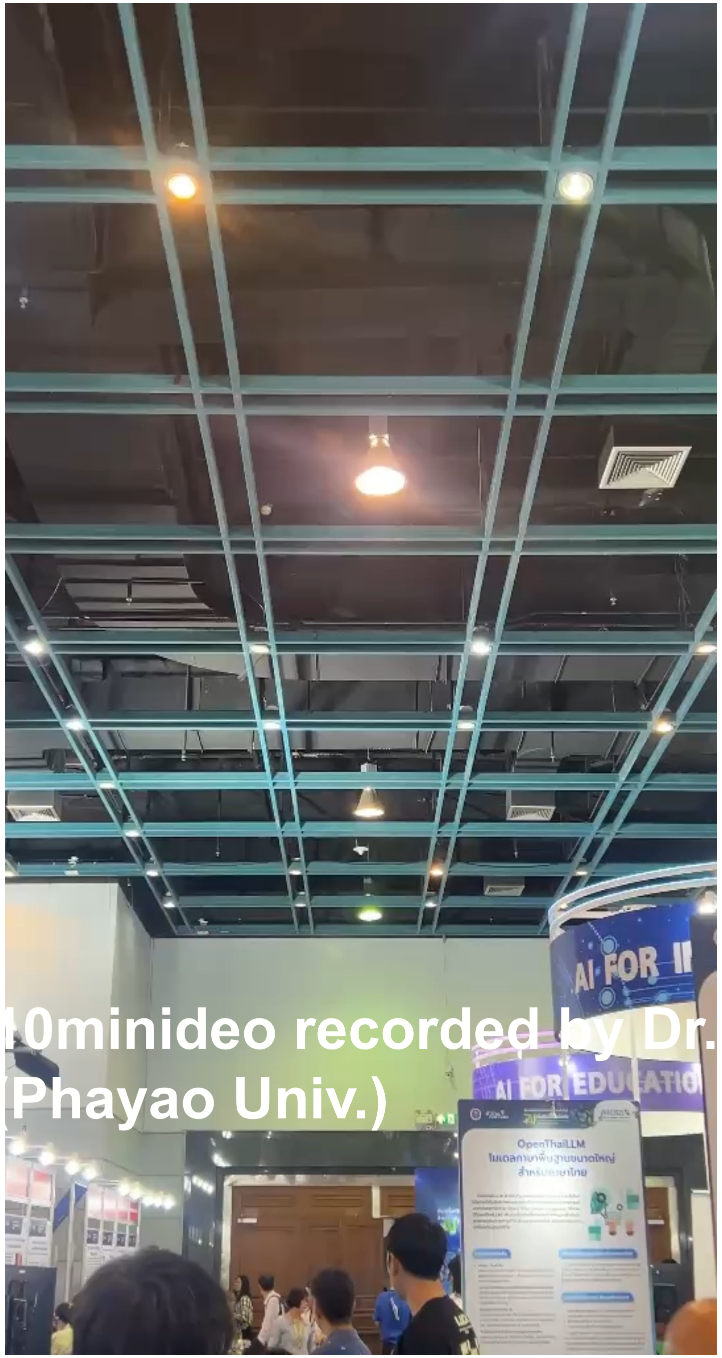
- The boring statistics? About earthquakes

-> Why is it so difficult to predict future earthquakes?

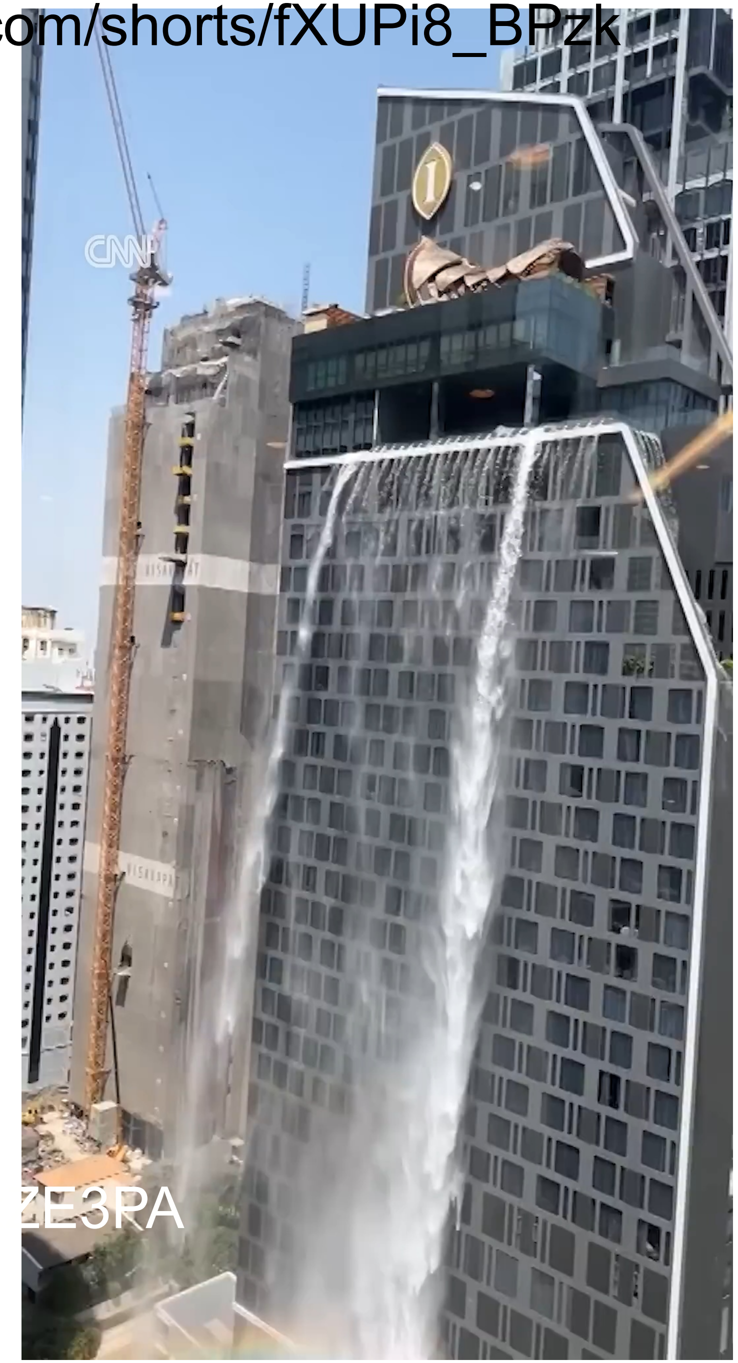

PCSHS Mukdahan,Thailand 2025


The waves just arrived at PCSHS
Mukdahan 28Mar.2025

https://www.youtube.com/shorts/fXUPi8_BPzk



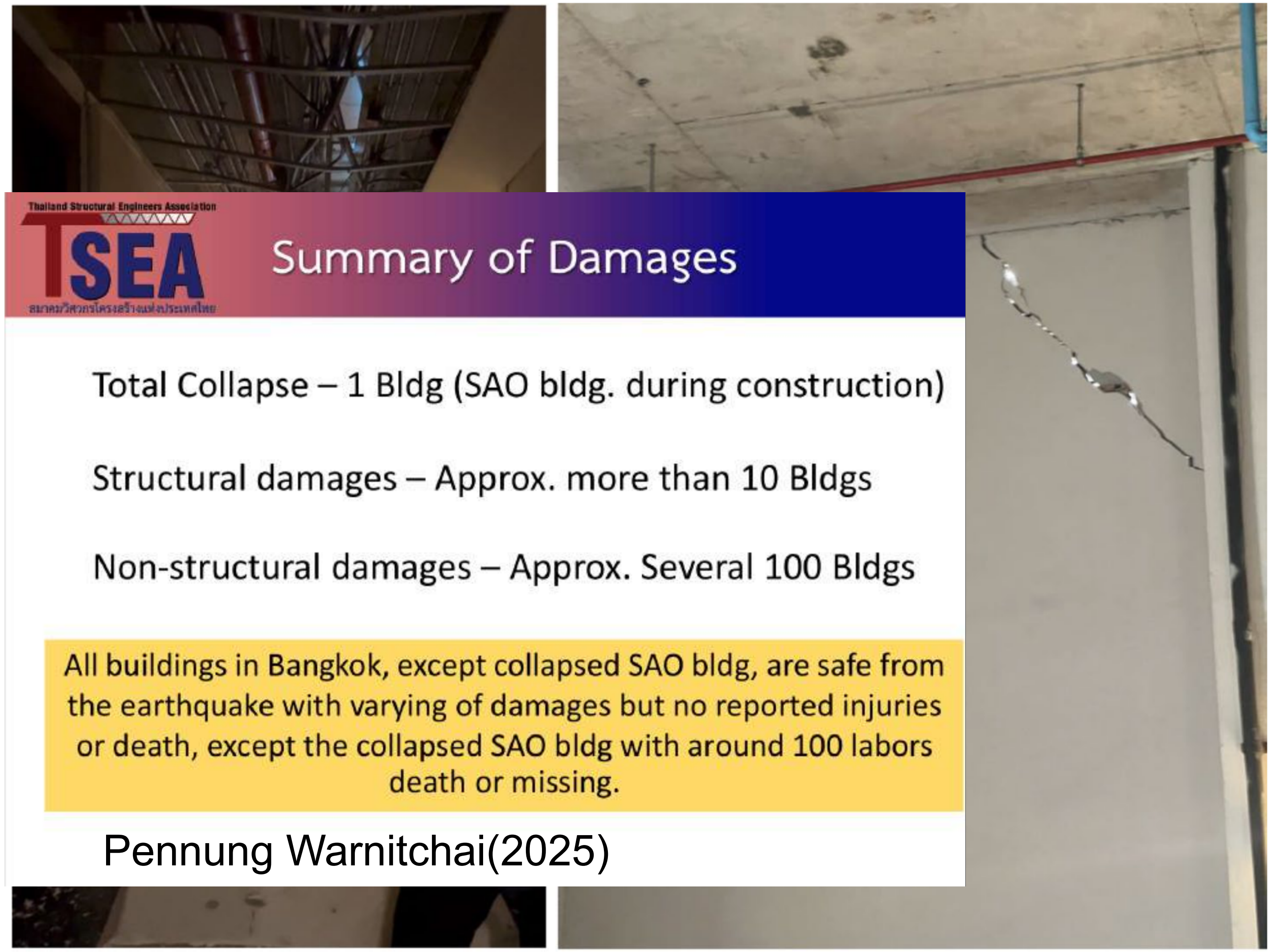




0minideo recorded by Dr. chawal
(Phayao Univ.)

ww.youtube.com/shorts/BW ZE3PA


Fig. 15 Severe damage observed at shear wall including vertical bar buckling and concre the lower stories of a 25-story building due to lack of seismic detailing with horizontal rei of about 300 mm spacing

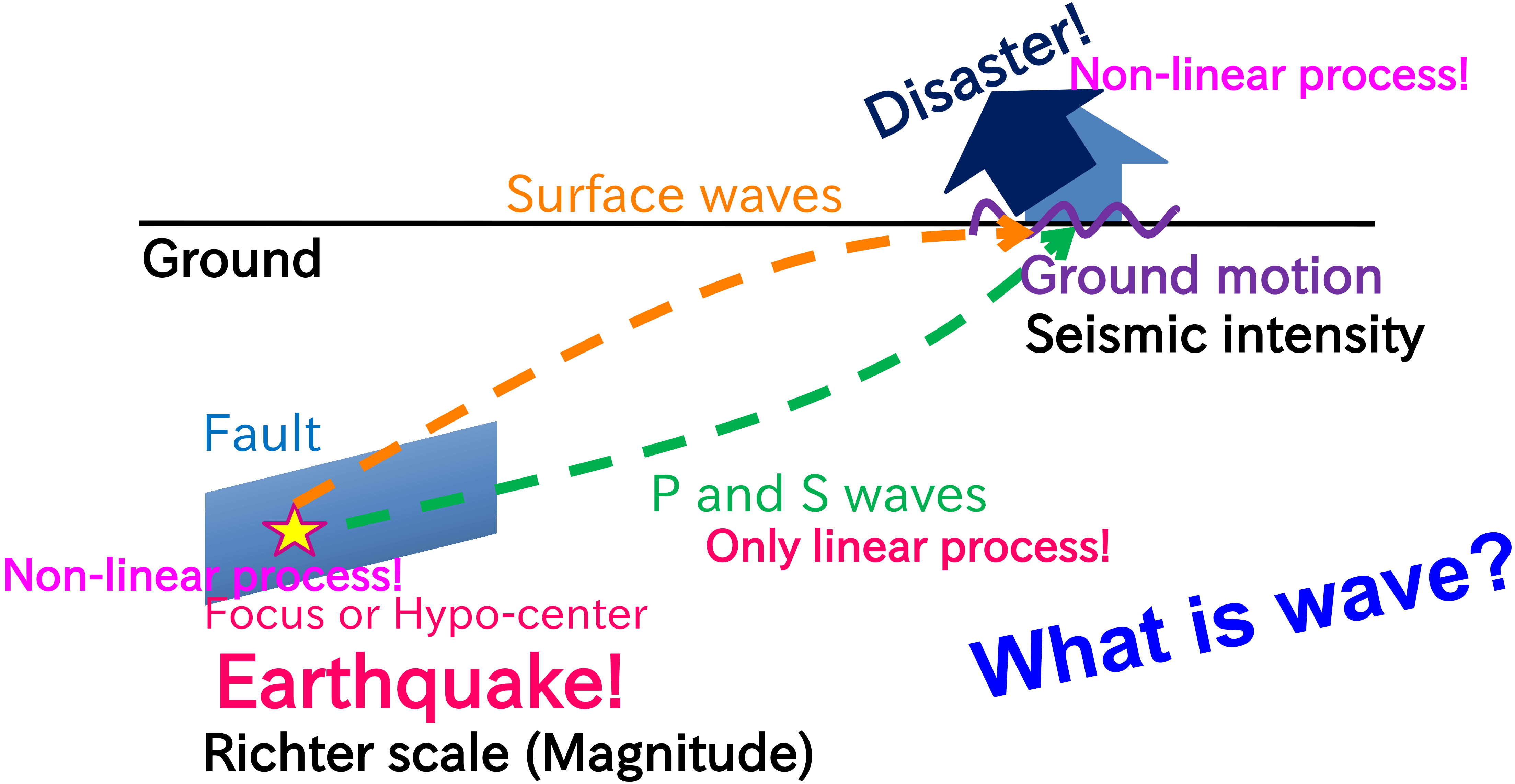



a) b)

Fig. 16 a) A partial failure of suspended ceiling in a high-rise building was commonly observed damages due to lack of horizontal bracing, b) non-structural damage to a large infill wall was also widely reported, indicating out of plane failure pattern from the boundary frame

Teraphan Ornthammarath et.al.2025

# Earthquake: cause and result

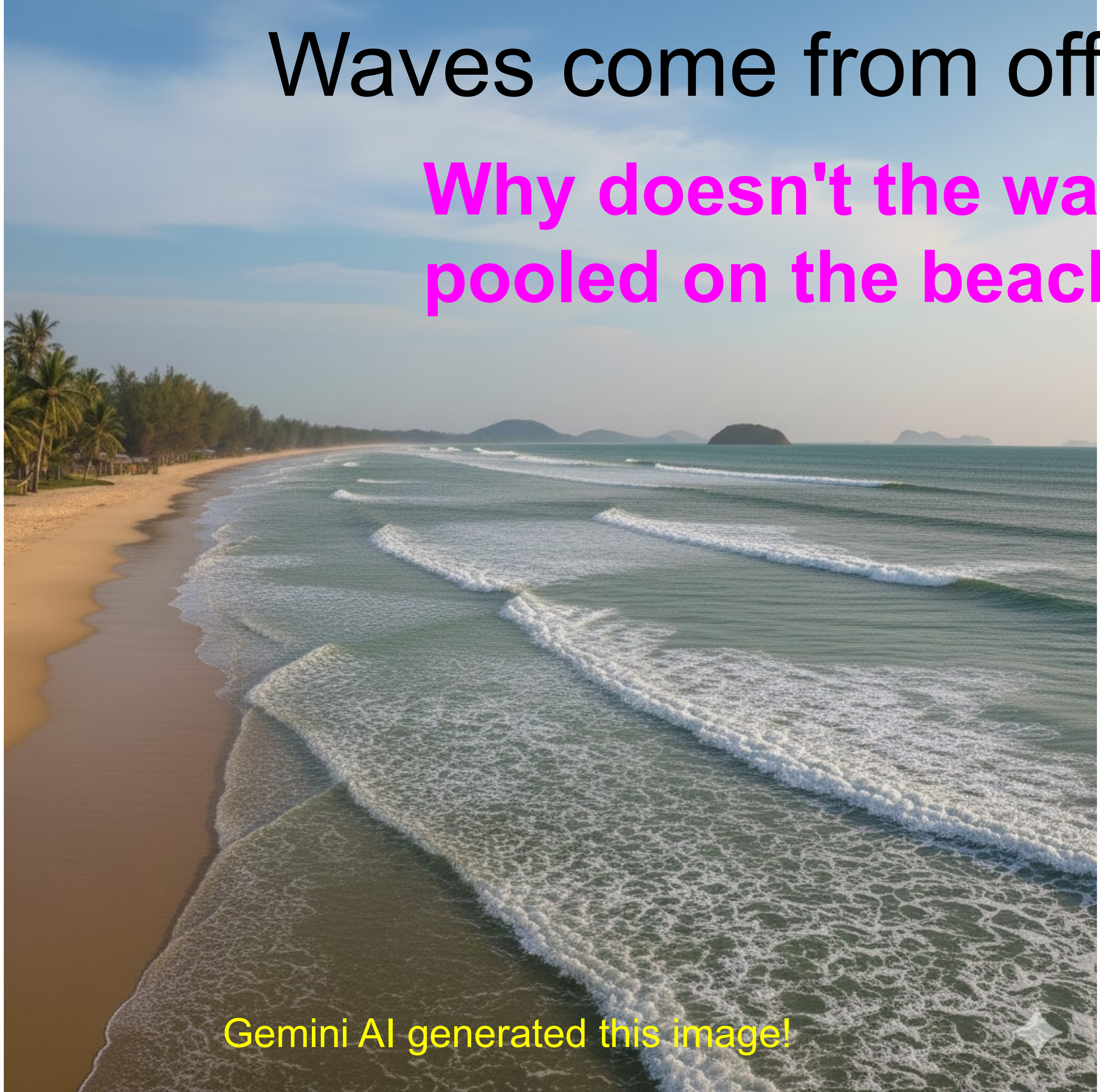


You are a primary school teacher,
and bring your students to the beach-----

A student asks you suddenly----

# Waves come from offshore---------

**Why doesn't the water stay pooled on the beach?**



Gemini AI generated this image!

**ChatGPT generated this image!**

# Typical answers from my university students---

- Water seeps underground at the beach and returns to the sea as groundwater.
- As a surfer, I know that there is an offshore current at the beach that flows out to sea.
- Surface water flows toward the beach, but bottom water flows toward the open sea.

# What is wave?

**It’s not the mass(matter) that moves!**

**It's the change in matter (state) that moves!!**

**Changes in density, position, form etc.**

**Types or examples of waves?**

**Sound, ray, radio waves, ----- Seismic wave!**

We can explain the strong shaking using Wave Physics

# Cause of the strong shaking in Bangkok

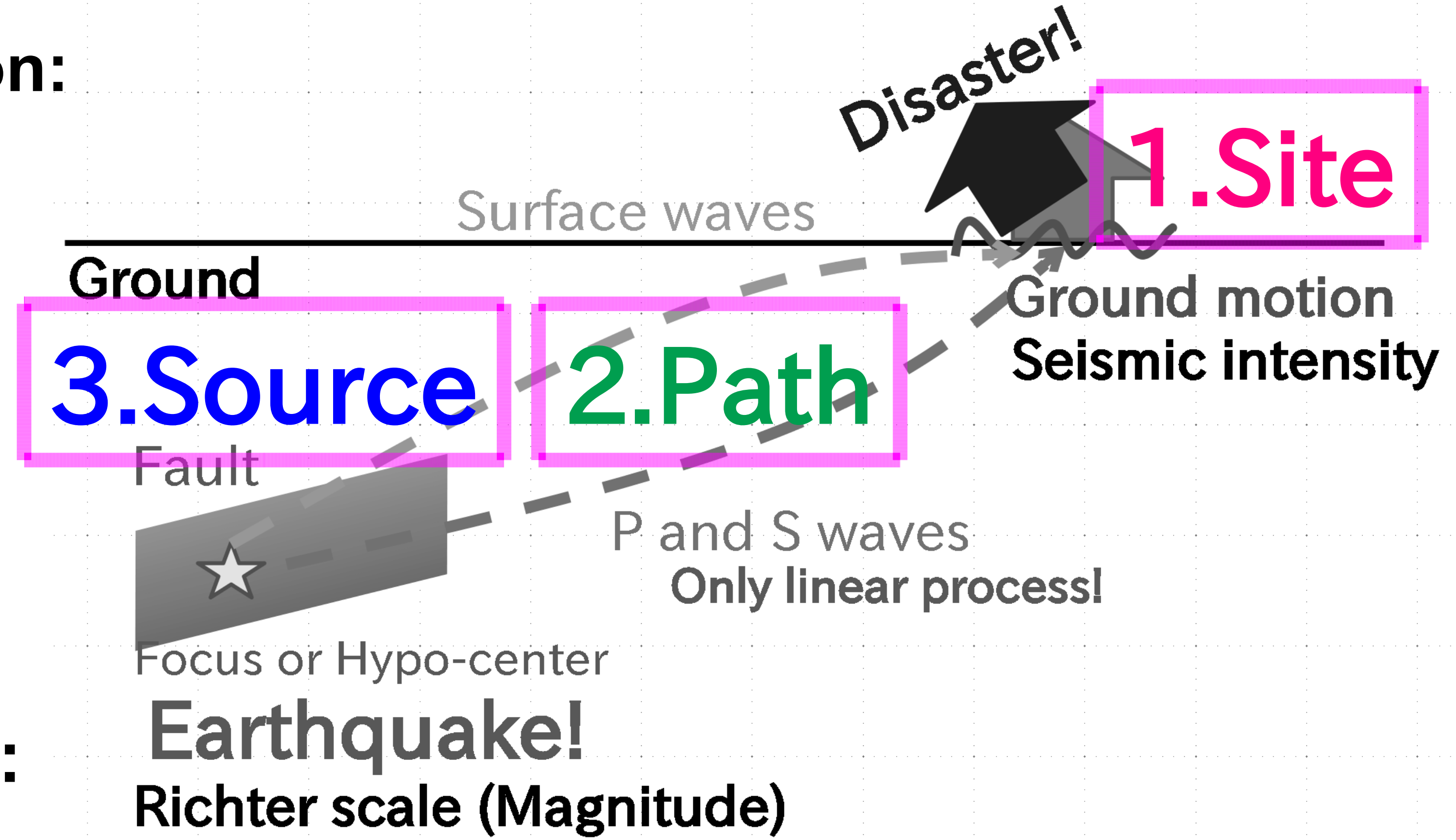
- I) **Thick soft sediments** amplify the shaking
- ii) The long-period waves **survive at long distances**.
- iii) **Resonance** of the buildings at the free oscillation periods
- iv) **Directivity** of S-wave radiation pattern
- v) **Supershear rupture**?

## Why Strong Shaking Was Observed in Bangkok, Thailand (Approx. 1,000 km from the Epicenter)?

**1. Site-Specific Amplification: The Bangkok Basin Effect**

**2. Path: Low Attenuation Rate (Long-Distance Wave Propagation)**

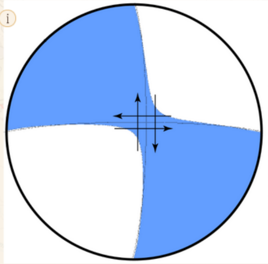
**3. Source Characteristics: Supershear Rupture**



# From USGS Web Site



## 28 March 2025, M 7.7 Mandalay, Burma (Myanmar) Earthquake



Focal mechanism of the 28 March 2025, **M** 7.7 Mandalay earthquake determined from W-phase inversion (Duputel et al, 2012). See Appendix for a tutorial on focal mechanisms. Arrows show the direction of motion for each of the nodal plate (fault).

The 28 March 2025, **M** 7.7 earthquake (yellow star) near Mandalay, Burma (Myanmar), occurred in a region of the Sagaing fault that had not seen notable seismicity (**M** 5.5 and larger) since 1900. The focal mechanism of the mainshock combined with the distribution of aftershocks indicate that faulting occurred on the Sagaing fault.

USGS Event Summary

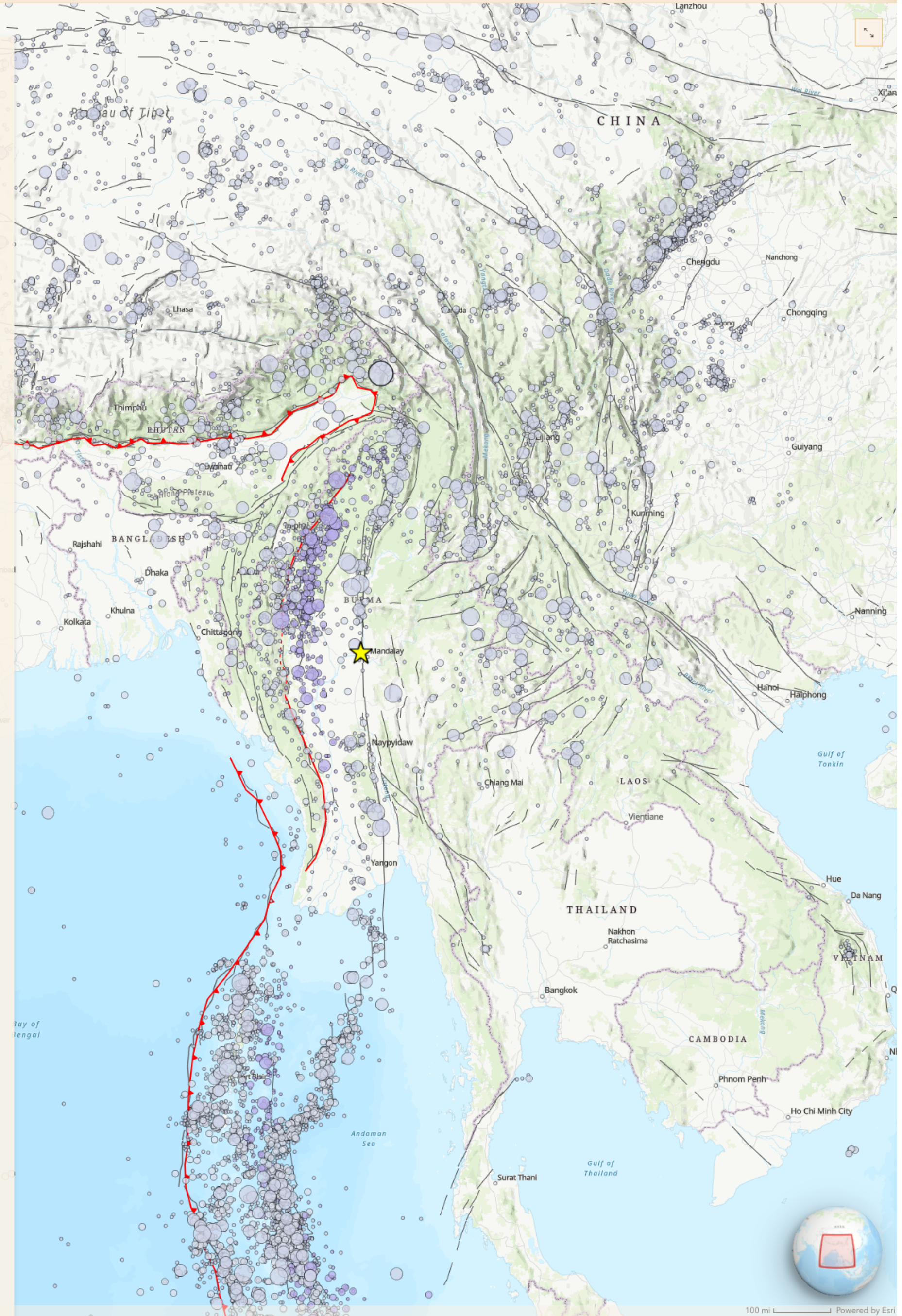
The full range of USGS earthquake information products related to this earthquake are found by clicking here.

*Click below to view the locations of the mainshock and **M** 4.5 and larger aftershocks located by the United States Geological Survey (USGS).*

USGS mainshock and aftershocks

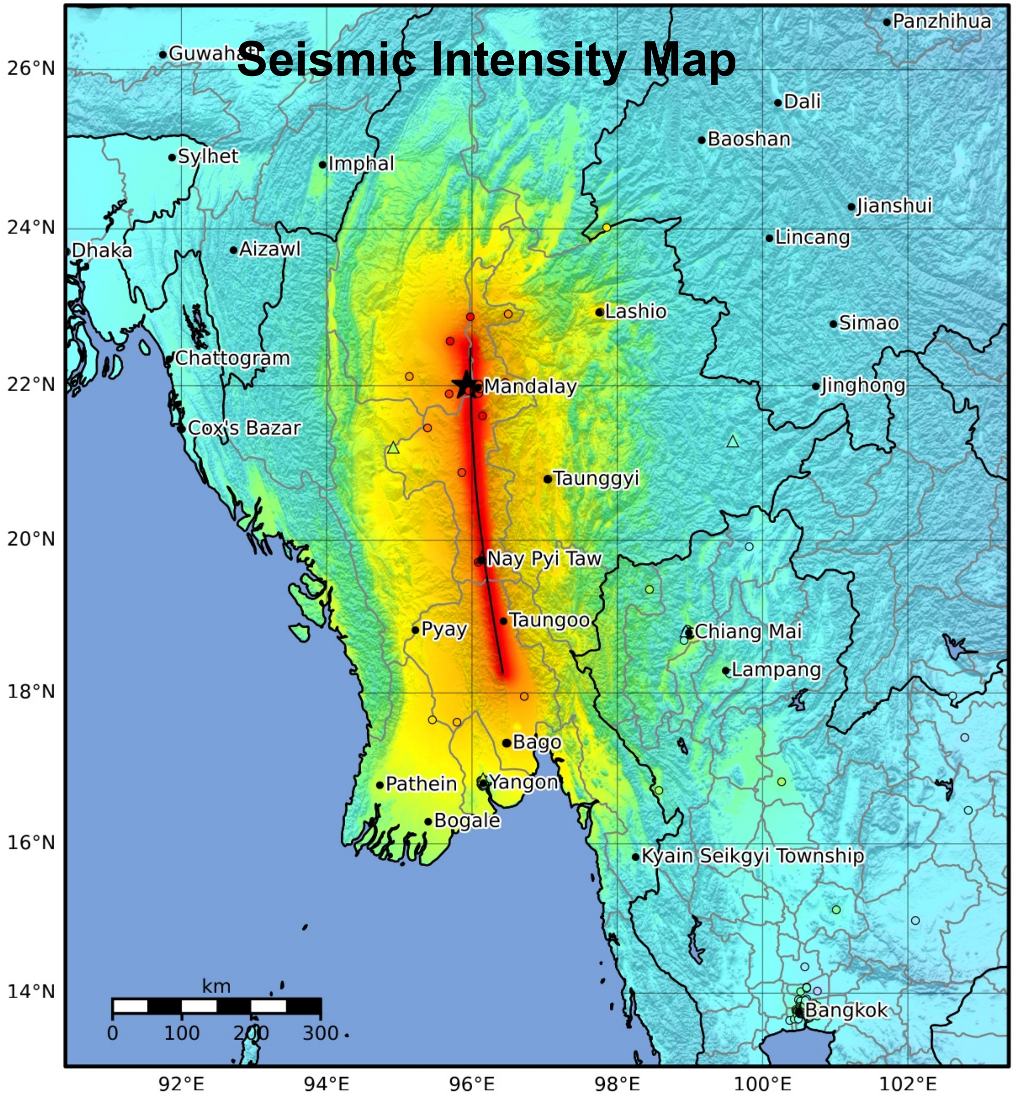
This general region has experienced similar large strike-slip earthquakes with six other **M** 7 and larger earthquakes occurring within about 150 miles (250 km) of the March 28, 2025 earthquake since 1900.

*Click on "M 7 and larger earthquakes" to view the largest events in this broad region of southeast Asia.*




Macroseismic Intensity Map USGS
ShakeMap: 2025 Mandalay, Burma (Myanmar) Earthquake
Mar 28, 2025 06:20:52 UTC M7.7 N22.00 E95.92 Depth: 10.0km ID:us7000pn9s

# Seismic Intensity Map

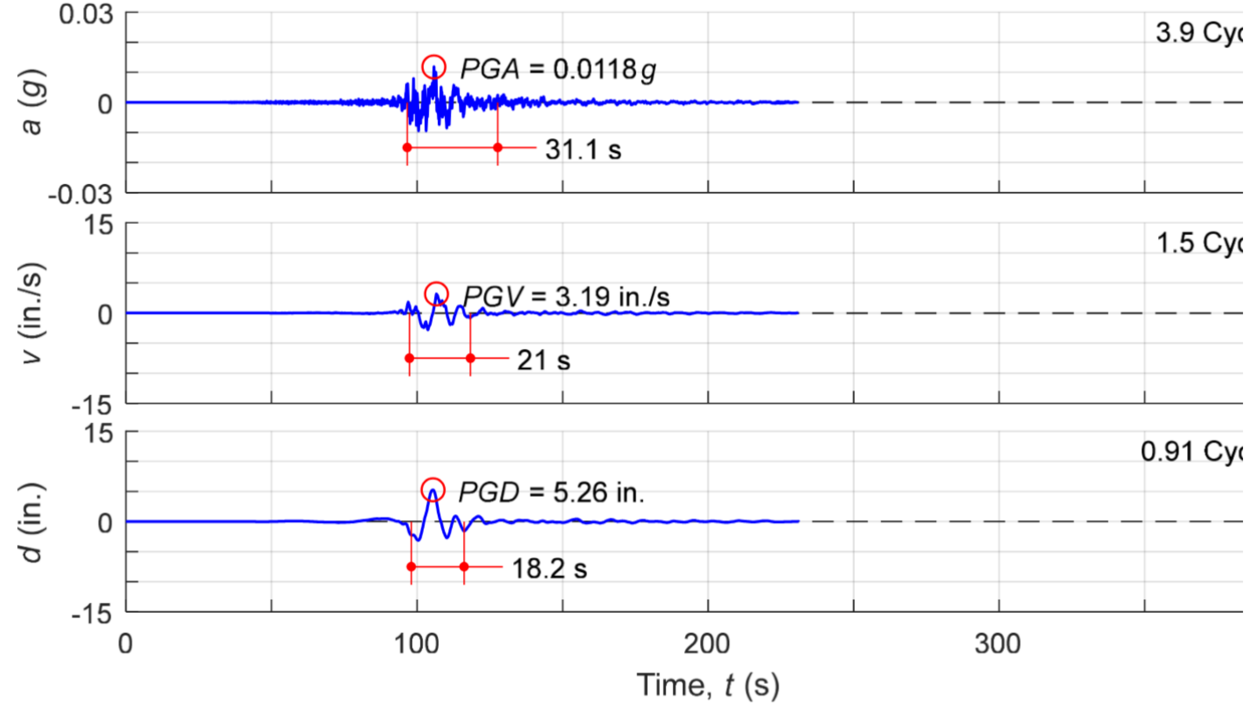



| SHAKING | Not felt | Weak | Light | Moderate | Strong | Very strong | Severe | Violent | Extreme |
|---|---|---|---|---|---|---|---|---|---|
| DAMAGE | None | None | None | Very light | Light | Moderate | Moderate/heavy | Heavy | Very heavy |
| PGA(%g) | <0.0464 | 0.297 | 2.76 | 6.2 | 11.5 | 21.5 | 40.1 | 74.7 | >139 |
| PGV(cm/s) | <0.0215 | 0.135 | 1.41 | 4.65 | 9.64 | 20 | 41.4 | 85.8 | >178 |
| INTENSITY | I | II-III | IV | V | VI | VII | VIII | IX | X+ |

Scale based on Worden et al. (2012) — Version 21: Processed 2025-04-16T05:13:29Z

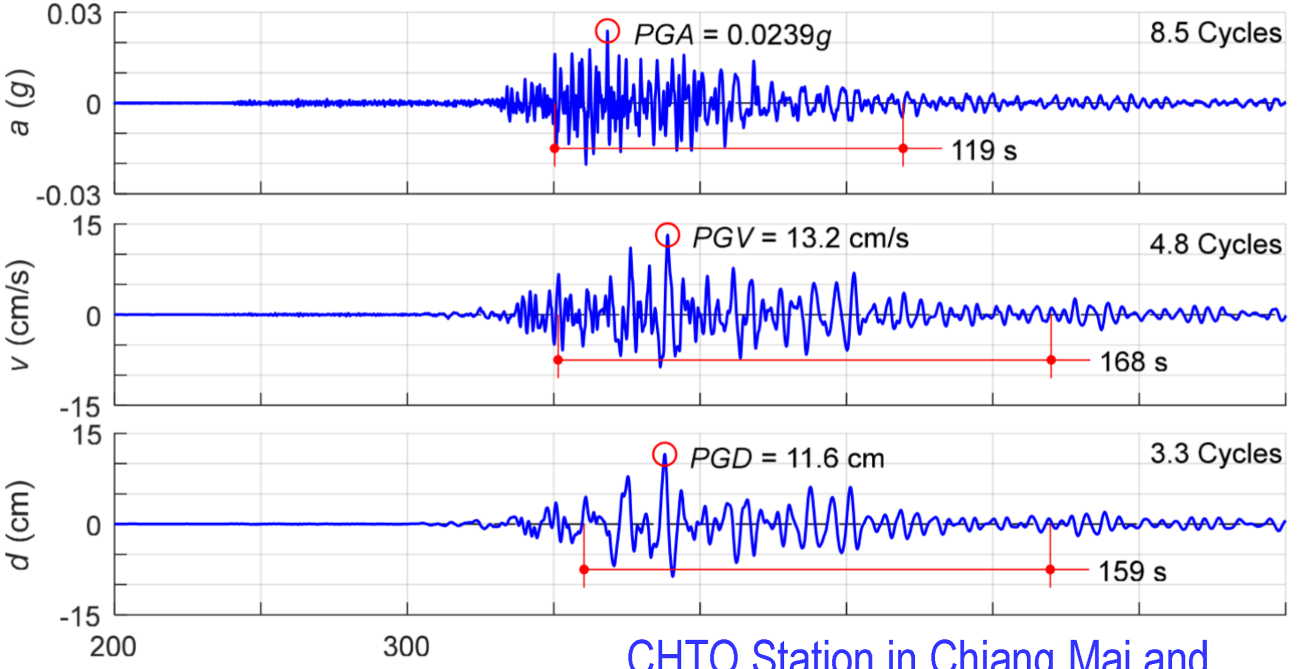
△ Seismic Instrument ○ Reported Intensity ★ Epicenter ▭ Rupture

# Maximum-Horizontal Ground Motion Histories — CHTO (Rock)





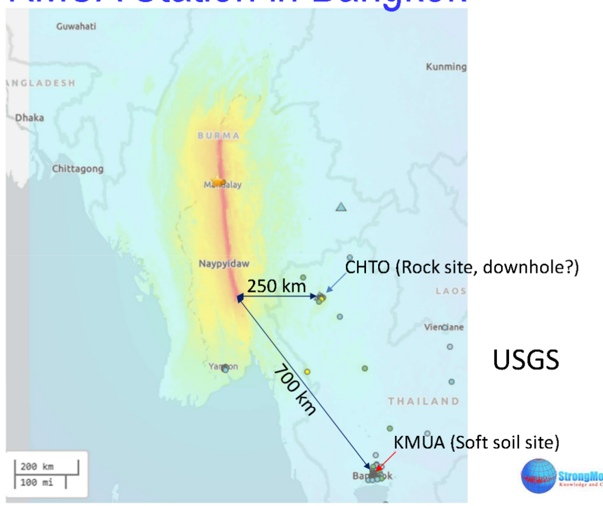

# Maximum-Horizontal Ground Motion Histories — KMUA (Soft Soil)



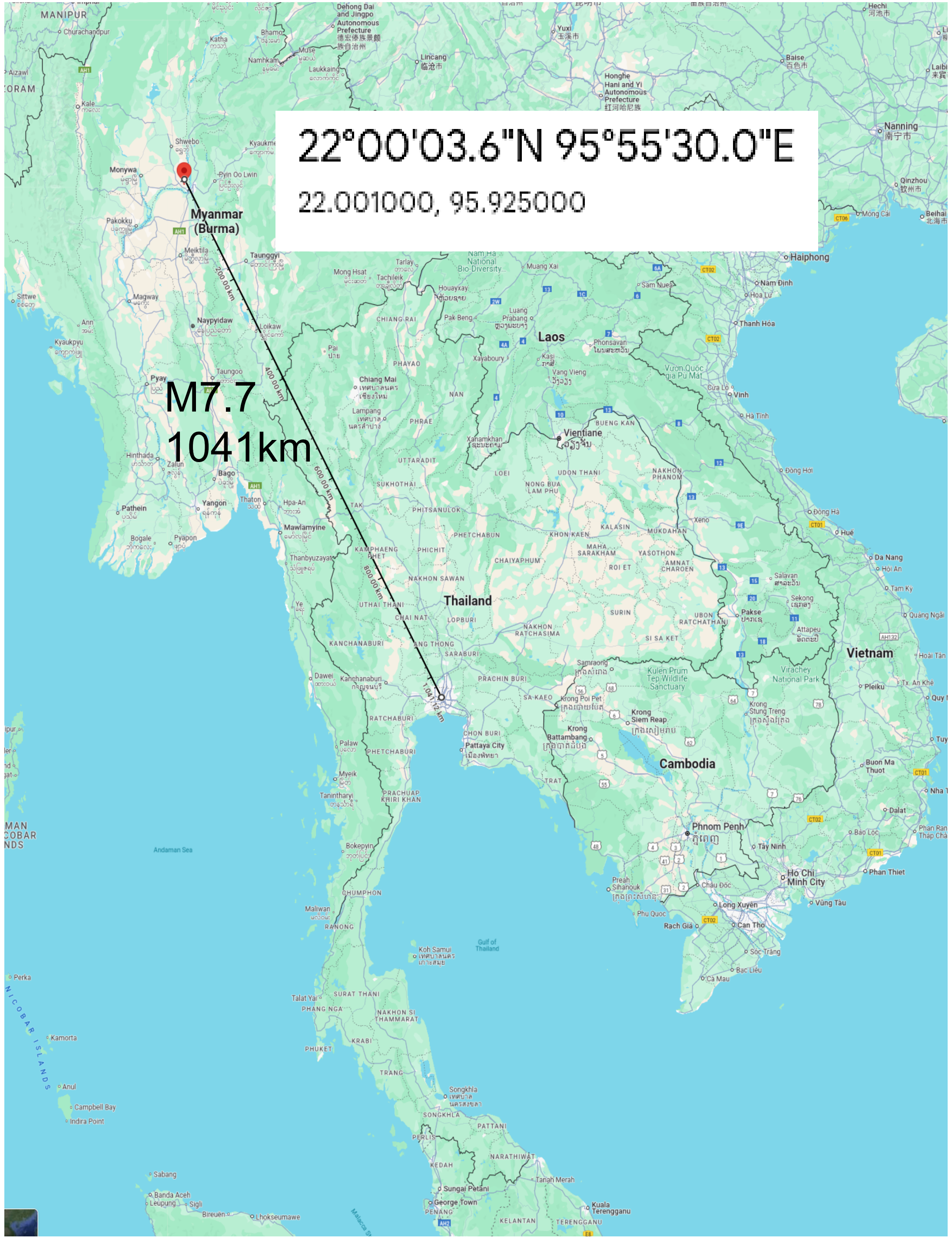


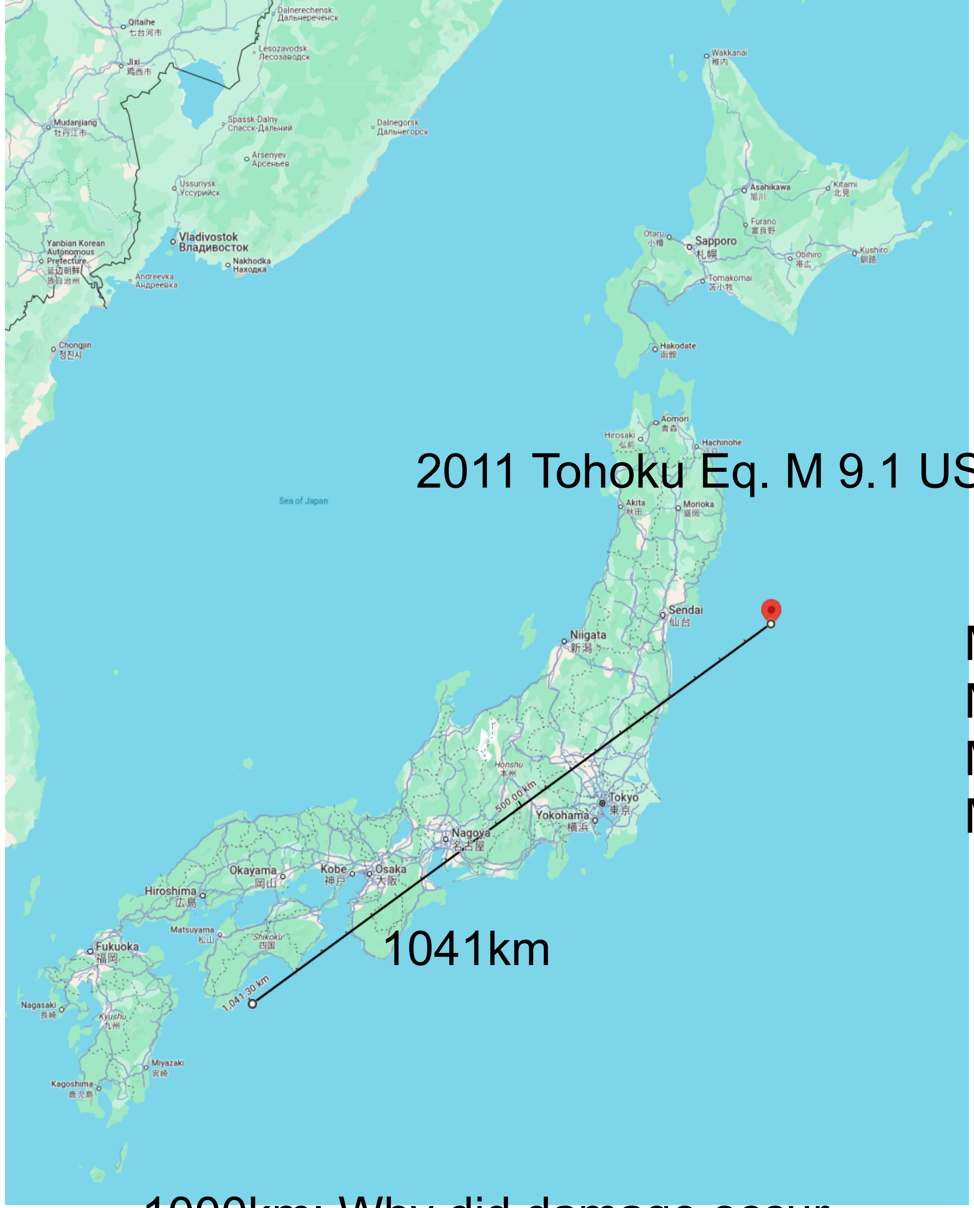

**Praveen K. Malhotra (2025)**

CHTO Station in Chiang Mai and KMUA Station in Bangkok




USGS



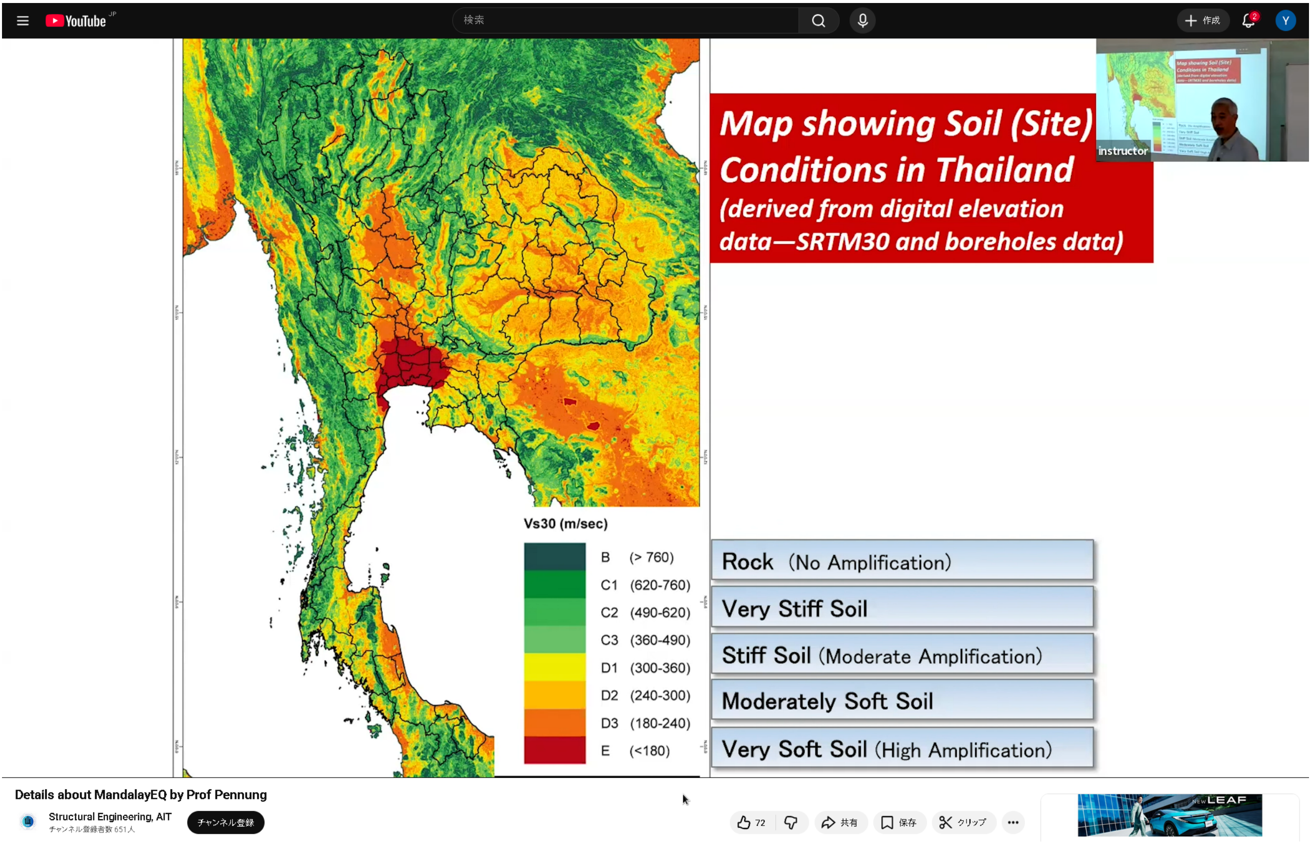




M 7.7 vs. M 9.1
M +1.0 = E 32x
M +2.0 = E ???
M +0.2 = E ??

1000km: Why did damage occur despite the epicenter being so far away And the size is so small?

Pennung Warnitchai
Professor of Structural Engineering
Asian Institute of Technology (AIT)

https://www.youtube.com/watch?

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# Far-field ground motion characteristics of the Bangkok Basin, Thailand, in the 2025 Mw 7.7 Mandalay earthquake: initial insights

Original Article | Open access | Published: 13 October 2025

(2025) Cite this article

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Teraphan Ornthammarath, Pennung Warnitchai, Yoshihisa Maruyama, Patinya Pornsopin & Fumio Yamazaki


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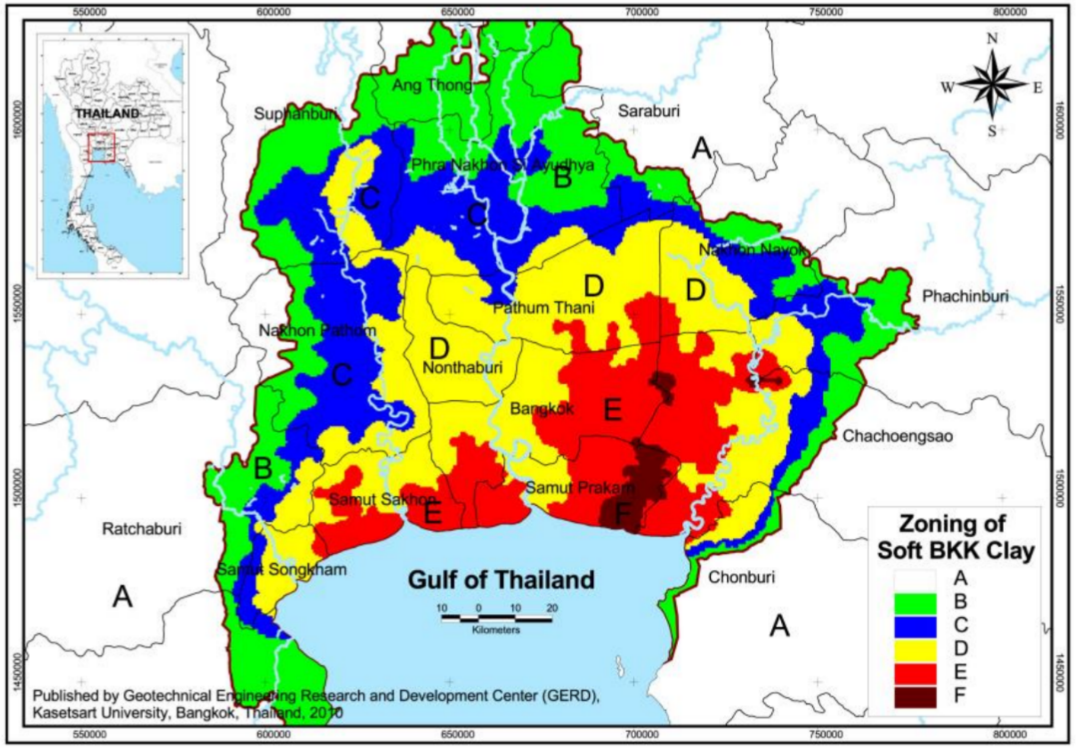
## Abstract


The 2025 Mw 7.7 Mandalay earthquake occurred on 28 March 2025 along the Sagaing Fault causing severe damage to building structures in Myanmar and large vibrations could be felt in nearby countries. This was the first time in modern history in continental Southeast Asia that an earthquake with magnitude greater than 7.5 was caused by one of the major active faults. The ground motion from the mainshock was recorded by twenty-seven accelerometers across northern and western Thailand. Five of these seismic stations located in the Bangkok basin provided valuable insights into far-field ground motion characteristics for this region, where recorded accelerations are limited. In this work, the recorded ground-motion parameters are assessed and compared with the NGA-West2 Ground Motion Models (GMMs). It was found that the recorded ground motion from the 2025 Mw 7.7 Mandalay earthquake generally provides positive residuals at a long distance, indicating a lower attenuation rate for the observed data than those estimated in the GMMs. The observed acceleration in the deep sedimentary basin indicates significant amplification in long spectral periods, primarily attributed to the thick soft soil layers of the Bangkok basin. This amplification effect is consistent with previous studies highlighting the seismic response of the basin to distant large-magnitude events. The findings underscore the importance of incorporating site-specific amplification in seismic hazard assessments for Bangkok, especially for long-period structures.




soft clay > 18 m.
Wn > 100 %
LL > 100 %
PI > 60 %
$\gamma_t$ < 1.45 t/m$^3$

soft clay 14-18 m.
Wn 80-100 %
LL 80-100 %
PI 50-60 %
$\gamma_t$ 1.45-1.55 t/m$^3$

soft clay 10-14 m.
Wn 60-80 %
LL 60-80 %
PI 30-50 %
$\gamma_t$ 1.55-1.65 t/m$^3$

soft clay 0-3 m.
Wn 0-20 %
LL 0-20 %
PI 5-10 %
$\gamma_t$ 1.85-2.15 t/m$^3$
A

soft clay 3-6 m.
Wn 20-40 %
LL 20-40 %
PI 10-20 %
$\gamma_t$ 1.75-1.85 t/m$^3$
B

soft clay 6-10 m.
Wn 40-60 %
LL 40-60 %
PI 20-30 %
$\gamma_t$ 1.65-1.75 t/m$^3$

Fig.15 Zoning of Soft Bangkok Clay

Warakorn Mairaing and Cherdpun Amonkul (2010)

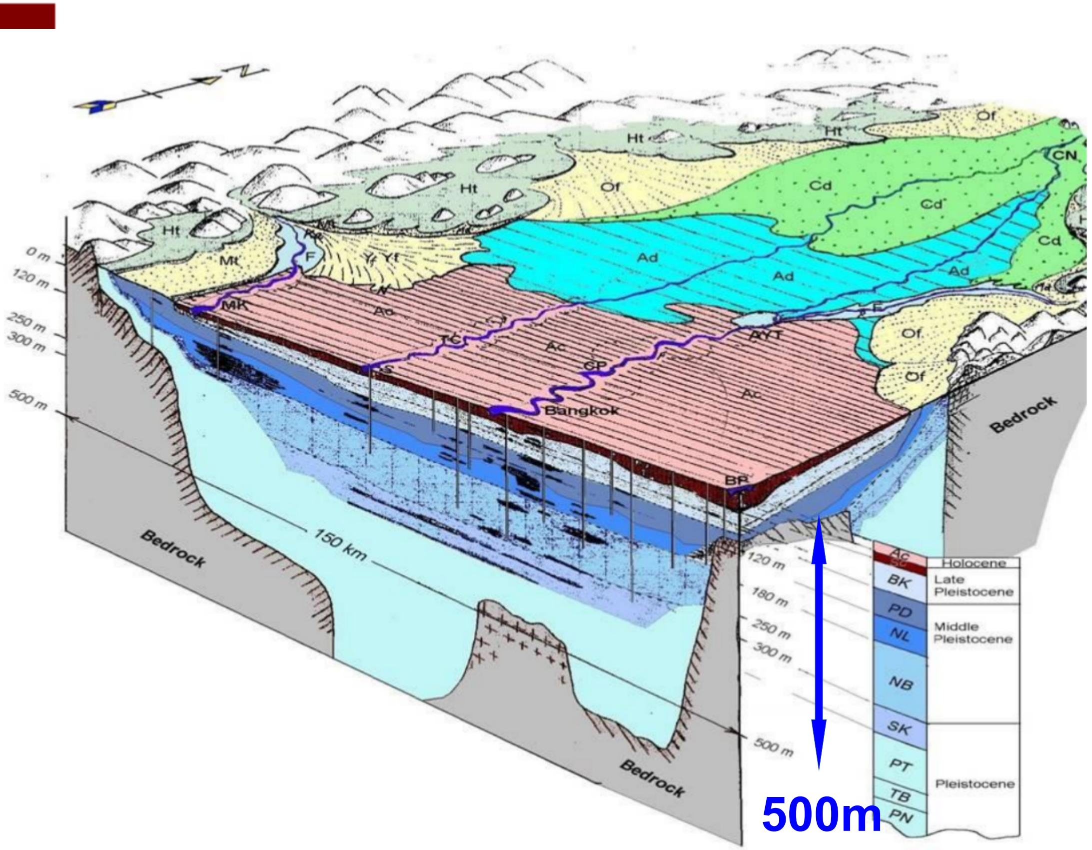



Fig.7 Schematic cross-section of lower Chao Phraya Basin (JICA, 1999)

https://www.gerd.eng.ku.ac.th/Paper/Paper_Other/Mairaing/%28EIT-Japan%29Soft%20Bangkok%20Clay%20Zoning.pdf

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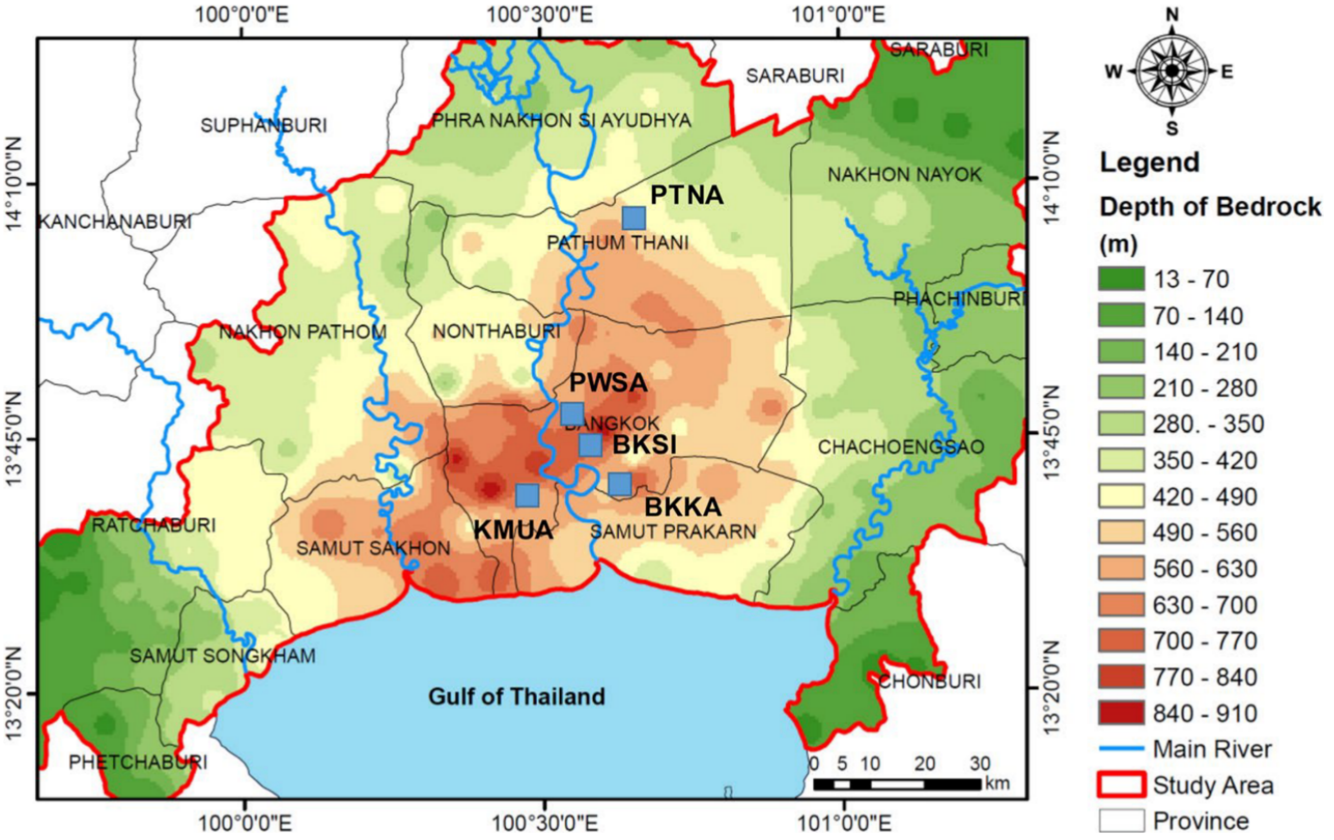


**Fig. 3** Map showing five seismic stations located in the Bangkok basin and the depth to the bedrock (modified from Jirasakjamroonsri et al. 2018)

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Highlights the greater seismic demand imposed by the **horizontal ground motion.**

The **rapid build-up in the horizontal direction** is attributed to the appearance of a strong phase (likely surface waves) around 110 seconds.

The **deep, soft sedimentary layers in the center of the basin** significantly amplified and retained the earthquake's total energy.

The **basin effect**, leading to energy amplification, is less pronounced closer to the basin's edge. The amplitude of surface waves for PTNA was also noticed to be the lowest among all Bangkok stations after 350 seconds

Bulletin of Earthquake Engineering

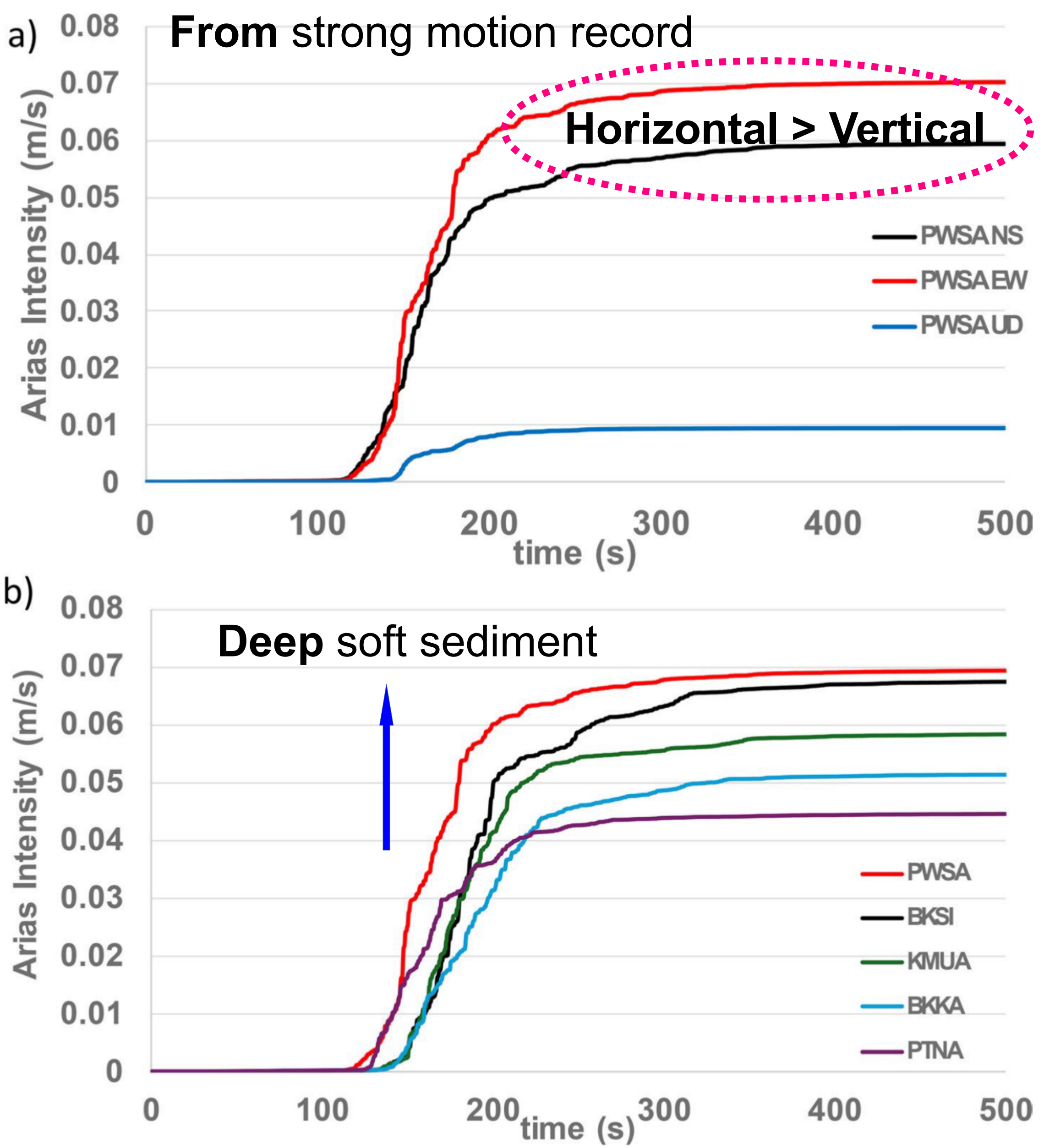
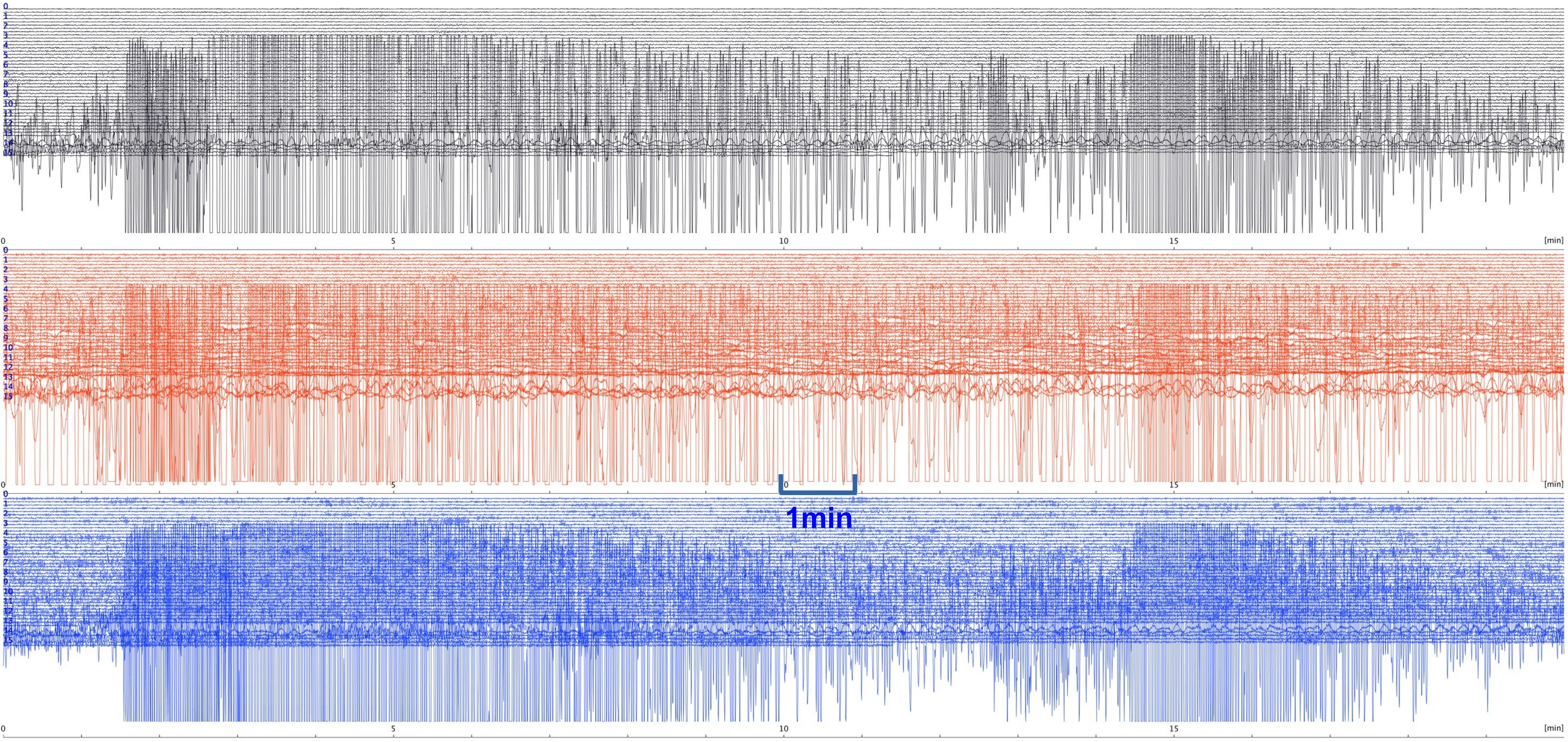



**Fig. 11 a**) Arias Intensity of ground motion at the PWSA station during the Mw 7.7, 2025 Mandalay earthquake, and **b**) comparison of the orientation-independent intensities among different 5 stations located in the Bangkok basin

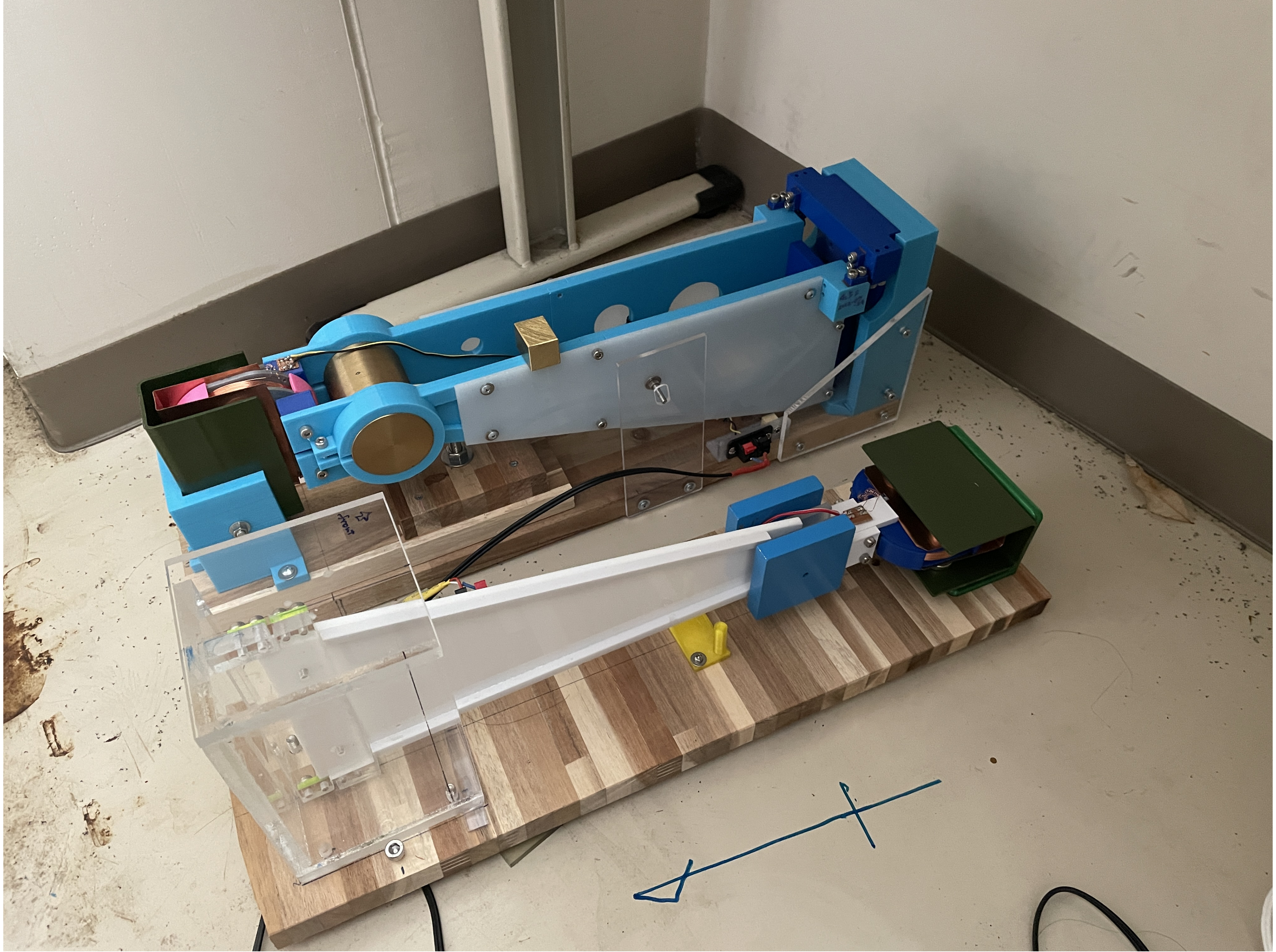
Our seismographs in Thailand

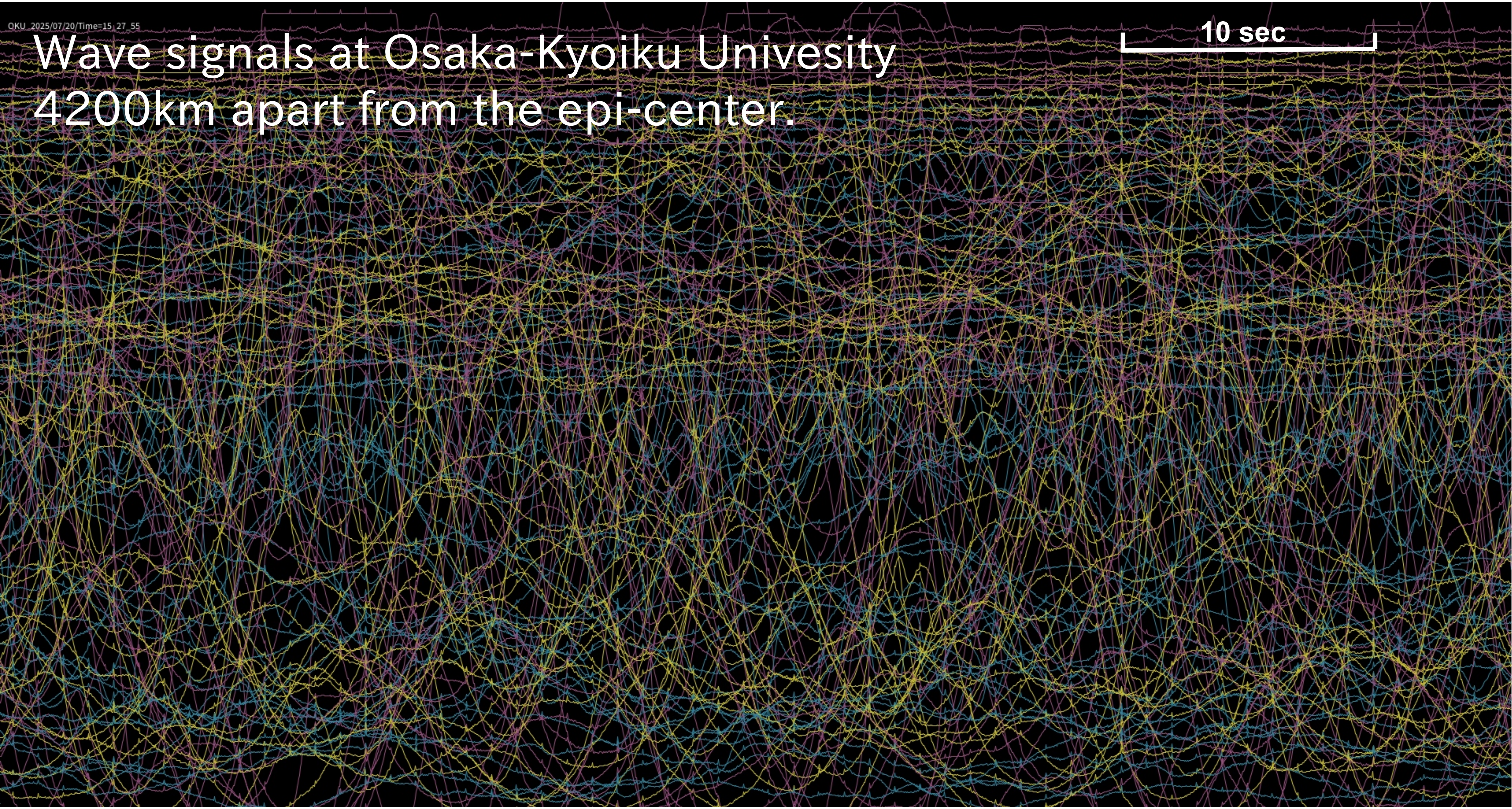
Prof. Ohm and our seismographs at Silpakorn Univ. Physics Labo.

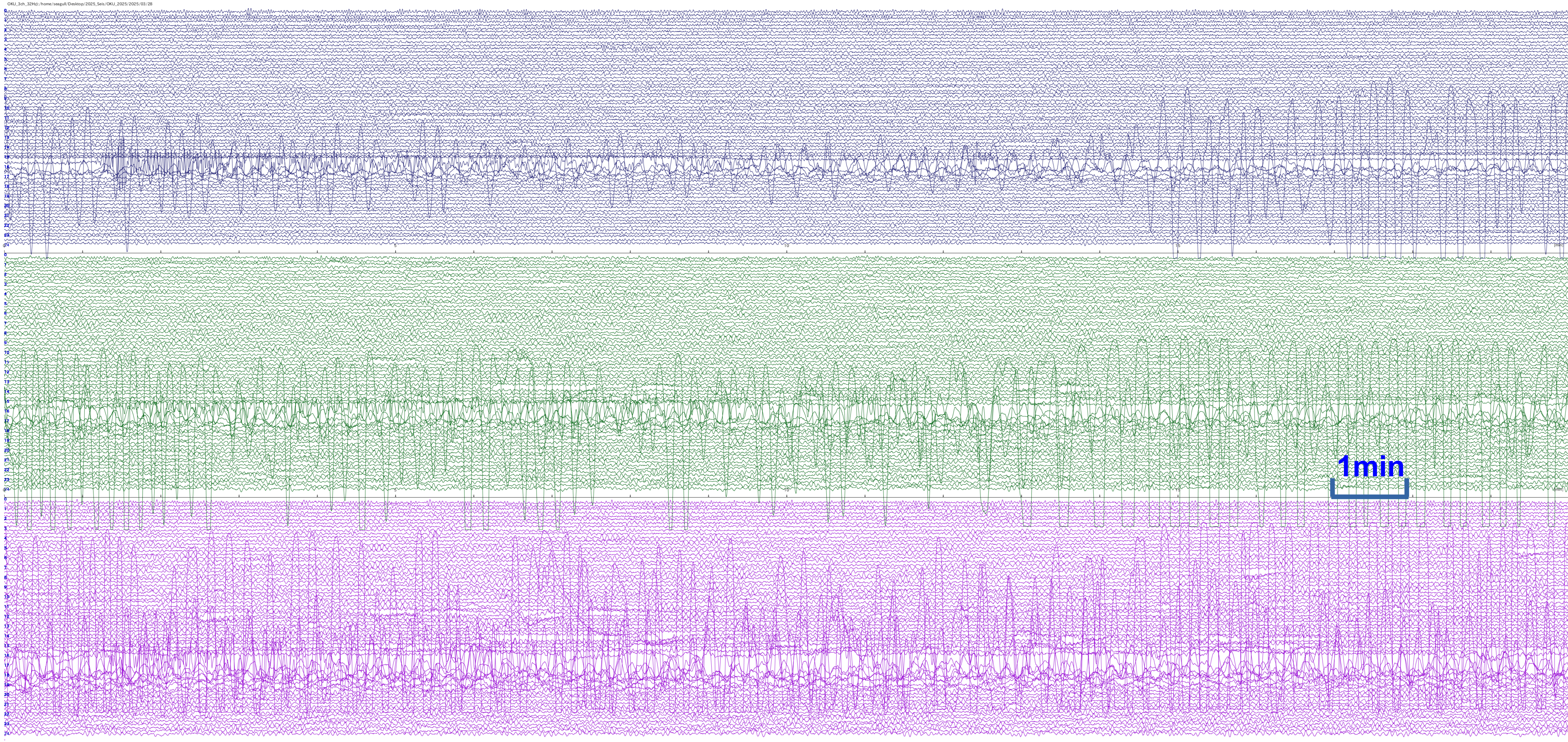
SU_3ch_32Hz):/home/seagull/Desktop/2025_Seis/SU_2025/03/28



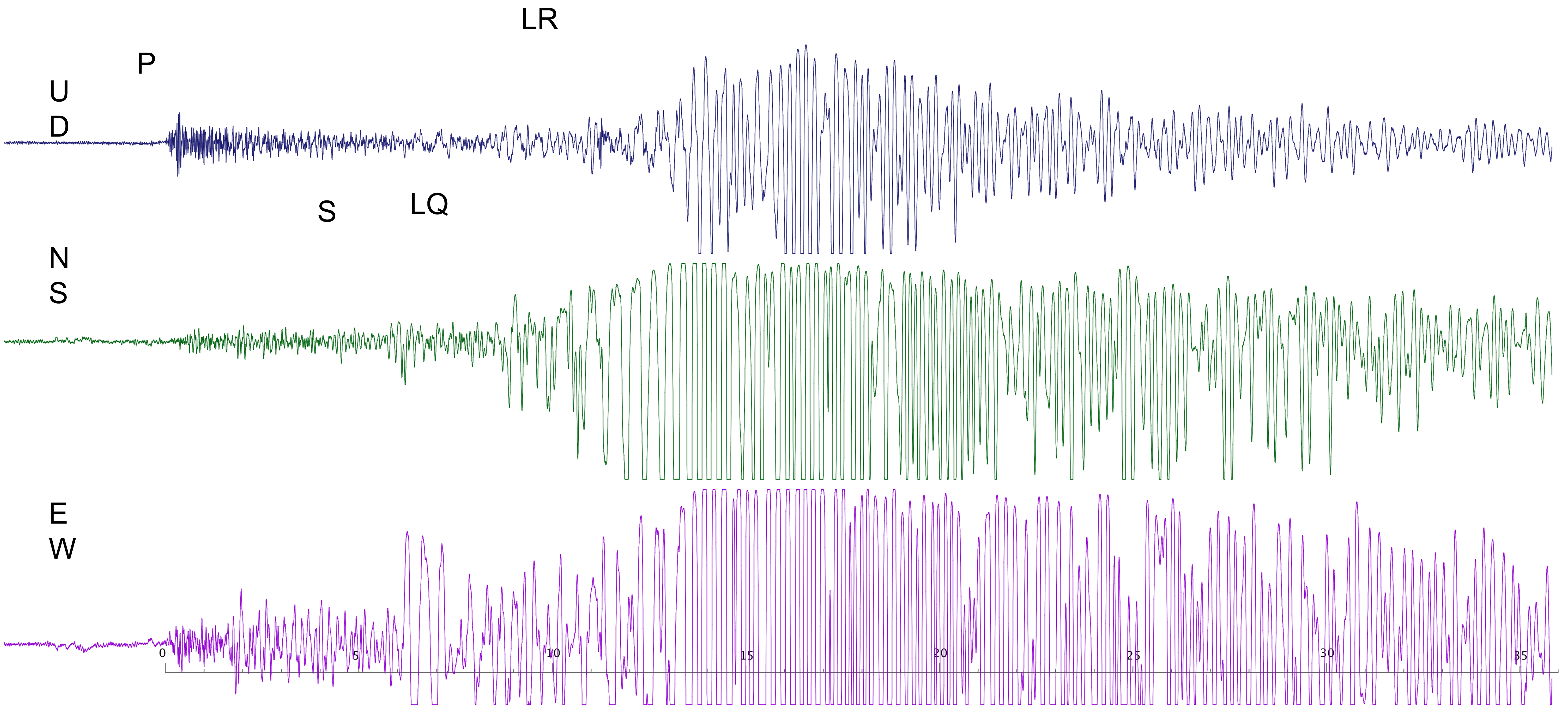

Our seismographs in Osaka-Kyoiku Univ.

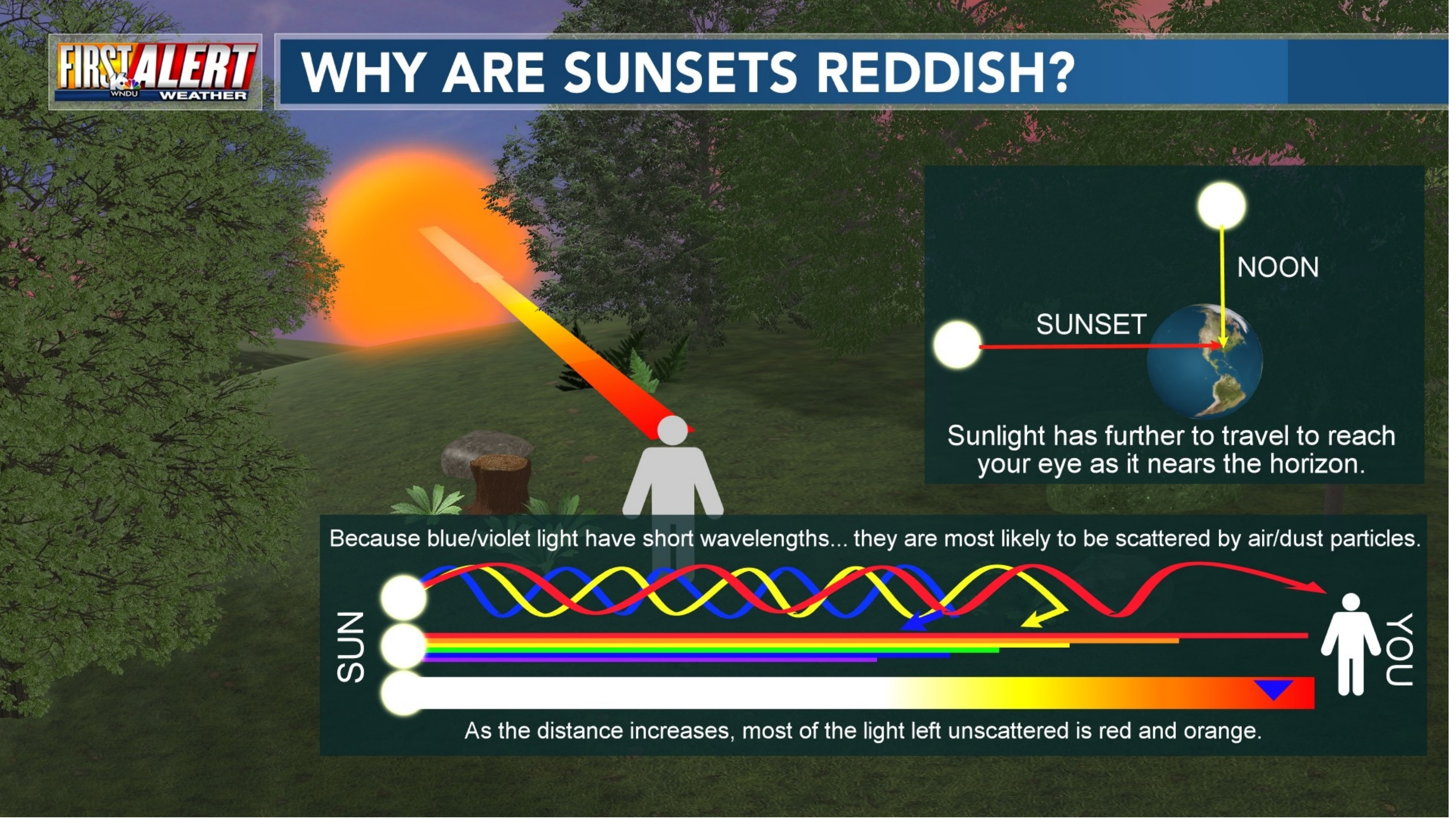



OKU_2025/07/20/Time=15_27_55
Wave signals at Osaka-Kyoiku Univesity
4200km apart from the epi-center.
10 sec


OKU_3ch_32Hz):/home/seagull/Desktop/2025_Seis/OKU_2025/2025/03/28
1min

/home/seagull/Desktop/2025_Seis/OKU_2025/2025/03/28.txt    M 7.7 - 2025 Mandalay, Burma (Myanmar) Earthquake




FIRST ALERT WEATHER
WNDU
WHY ARE SUNSETS REDDISH?
NOON
SUNSET
Sunlight has further to travel to reach your eye as it nears the horizon.
Because blue/violet light have short wavelengths... they are most likely to be scattered by air/dust particles.
SUN
YOU
As the distance increases, most of the light left unscattered is red and orange.


10minideo recorded by Dr.C[illegible]achawal
(Phayao Univ.)

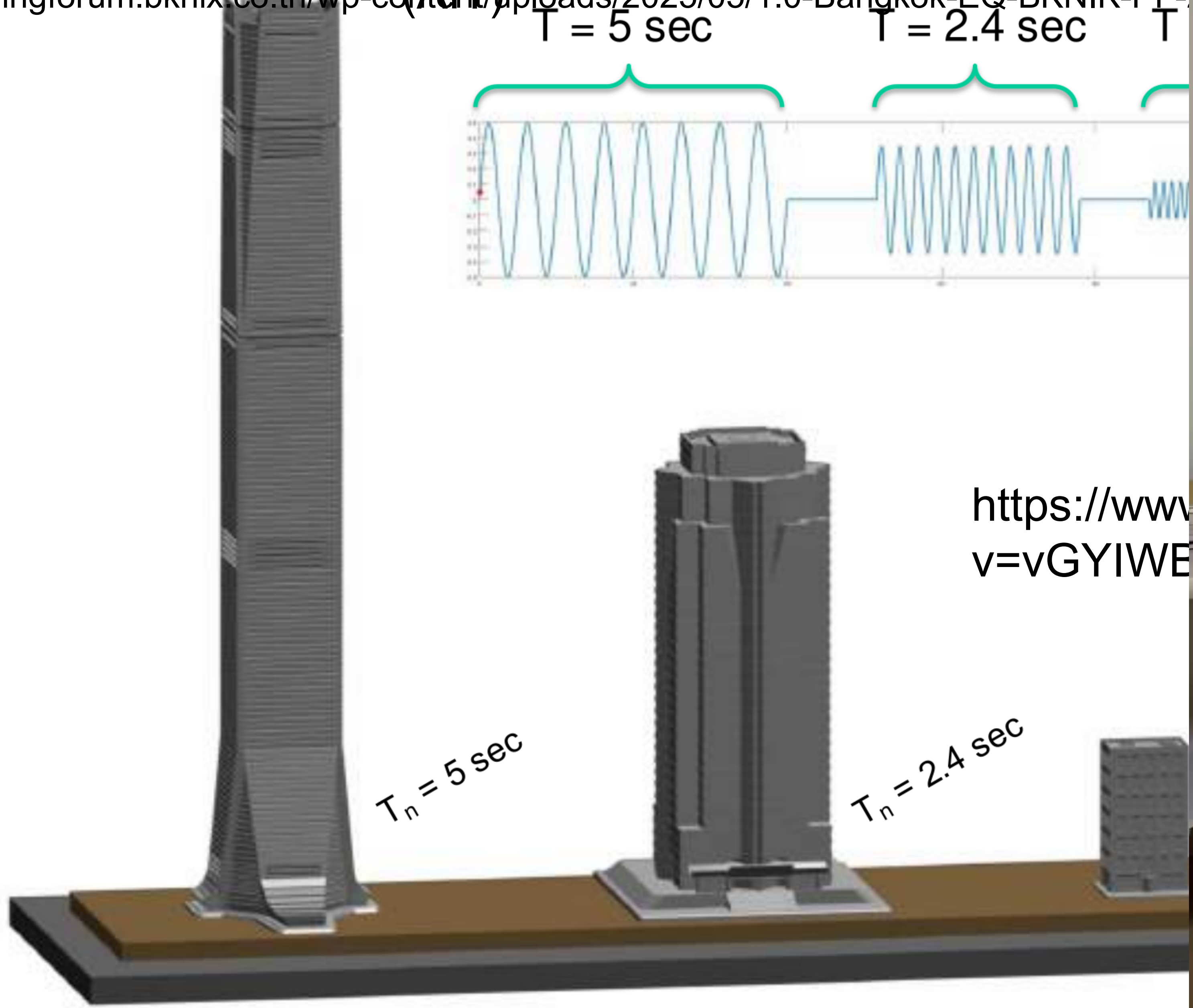

https://www.youtube.com/shorts/fXUPi8_BPzk

/www.youtube.com/shorts/BWuk[illegible]xZE3PA

# Resonance Effect

By Pennung Warnitchai, Professor of A
(AIT)

https://peeringforum.bknix.co.th/wp-content/uploads/2025/05/1.0-Bangkok-EQ-BKNIK-PF-2




https://www
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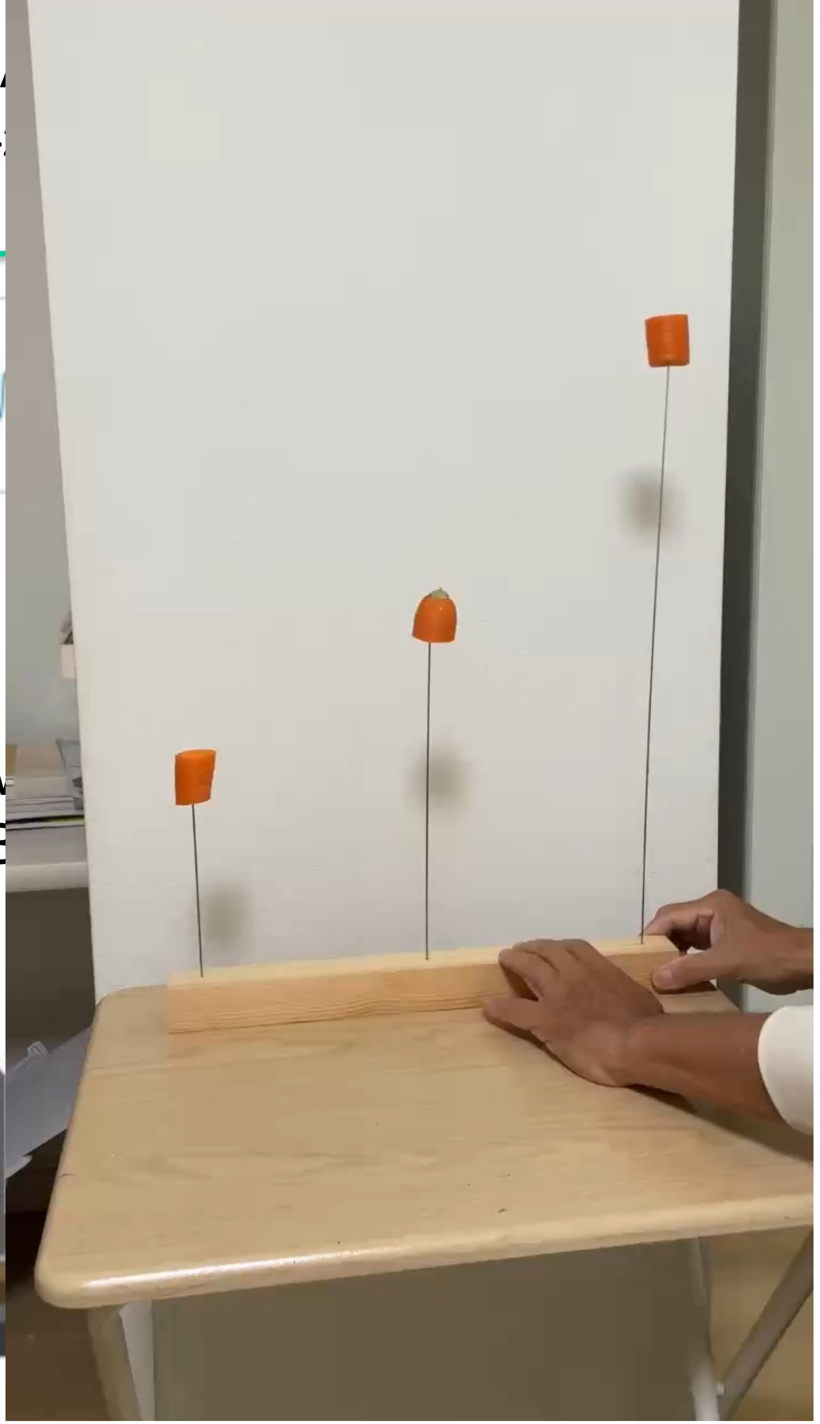


Takemura, S., Furumura, T. & Saito, T. Distortion of the apparent S-wave radiation pattern in the high-frequency wavefield: Tottori-Ken Seibu, Japan, earthquake of 2000. Geophysical Journal International 178, 950–961 (2009).

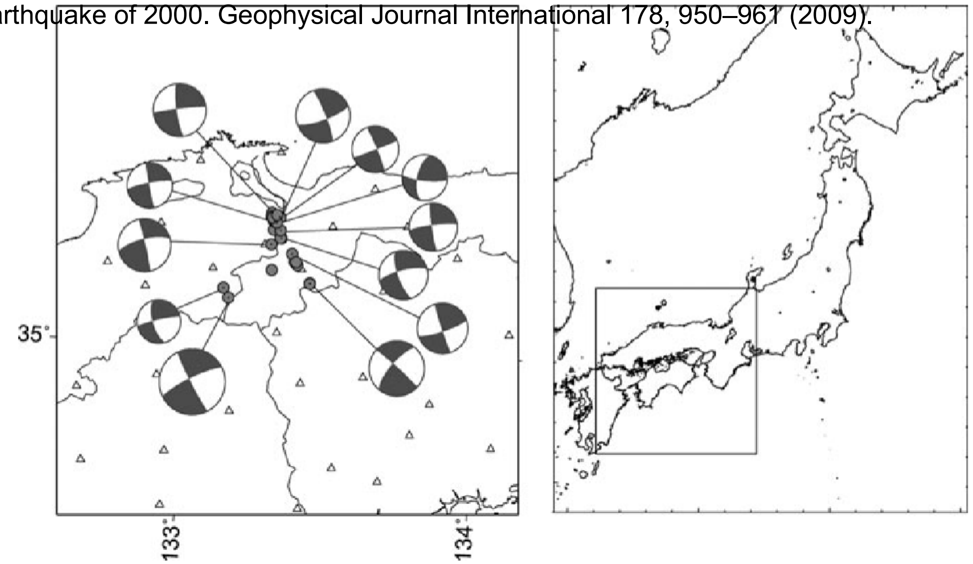



**Figure 3.** Map showing the epicentre of the 2000 Tottori-Ken Seibu, Japan, Mw 6.6 earthquake that occurred in southwestern Japan, and the distribution of 29 aftershocks used in the present study. The CMT solutions of largest 12 events are also shown.

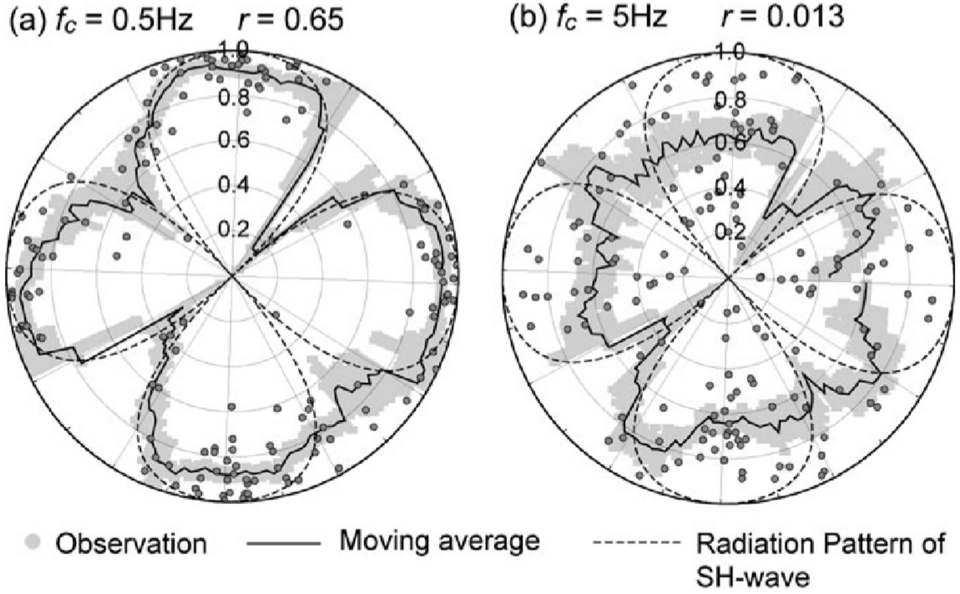



**Figure 4.** Distribution of the maximum *S*-wave amplitude in transverse (T) motion as a function of azimuth from the fault strike, at frequencies of (a) 0.5 Hz and (b) 5 Hz. The grey dots are the amplitudes of the observed *S*-waves in T motion relative to the rms of the horizontal motion for 152 waveforms of 29 aftershocks. The solid lines illustrate their moving average, and the grey areas show the standard deviation. The theoretical radiation pattern for the *SH* wave is shown by the broken lines.



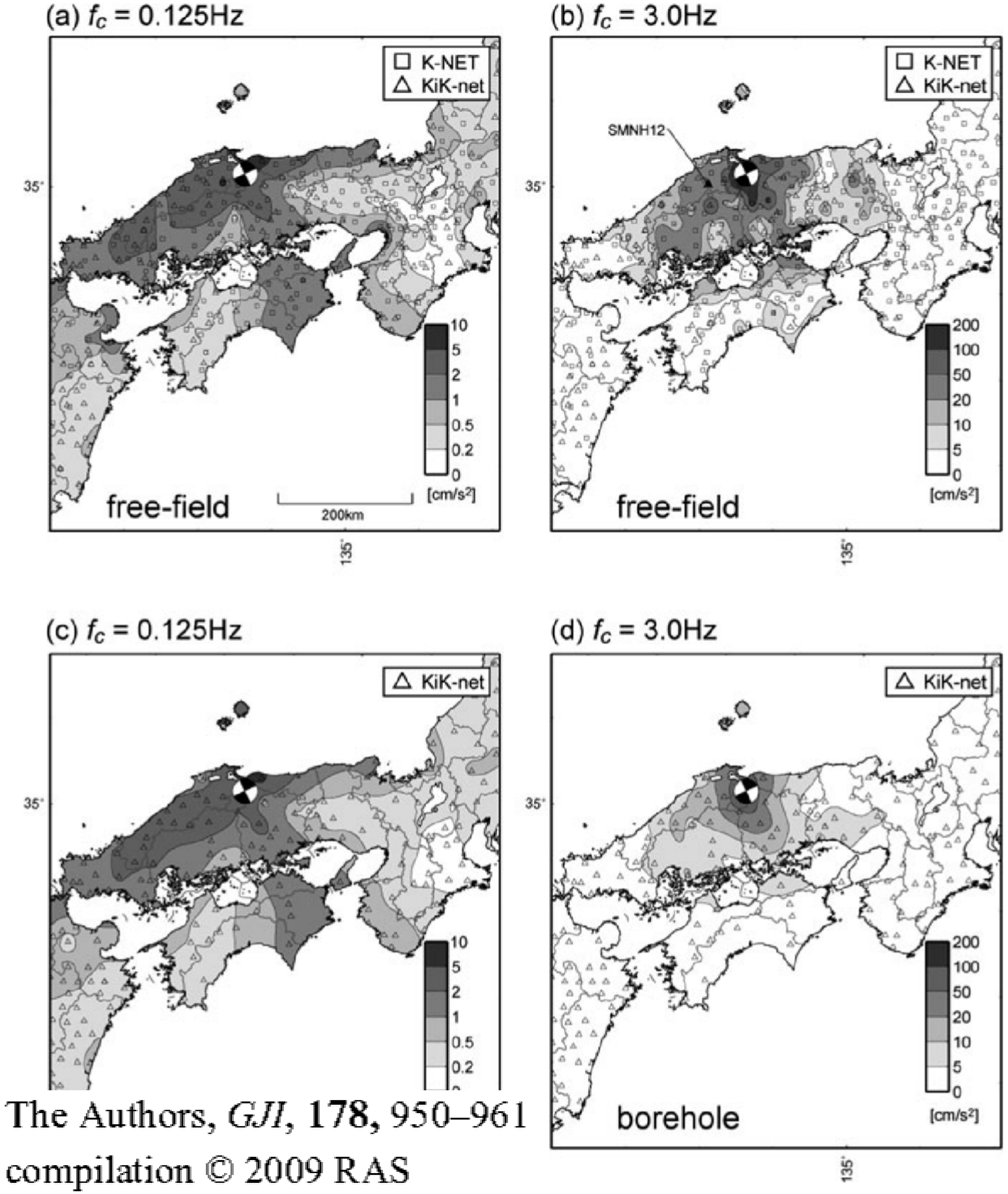





**Figure 1.** Distribution of the PGA in terms of the tangential component ground motion from the mainshock of the 2000 Tottori-Ken Seibu, Japan, earthquake at frequencies of (a) 0.125 Hz and (b) 3.0 Hz derived from the waveform of 523 free-field (K-NET and KiK-net) stations, and 220 borehole (KiK-net) station records at frequencies of (c) 0.125 Hz and (d) 3 Hz.

Sreeram Reddy Kotha et. al.(2019)

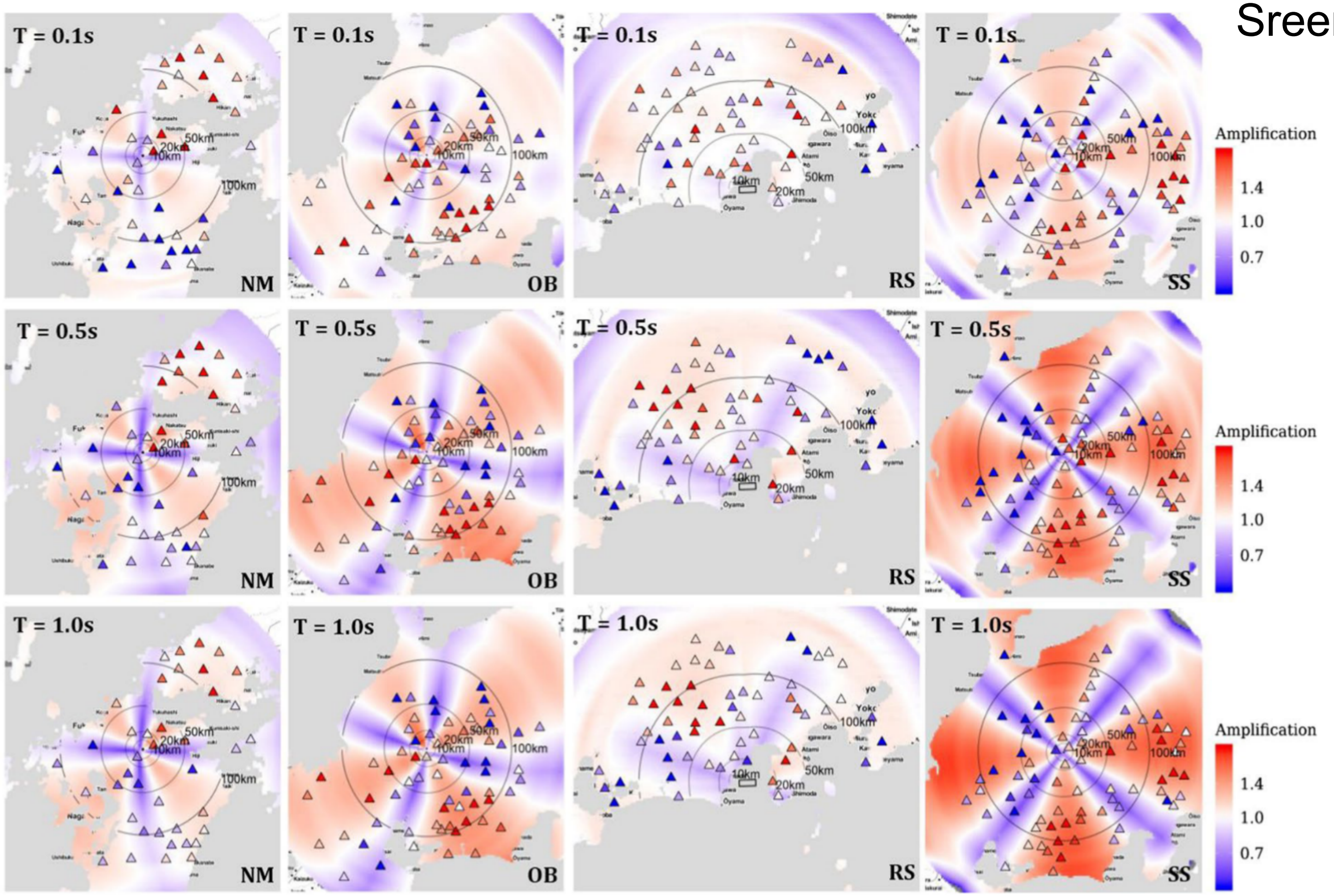
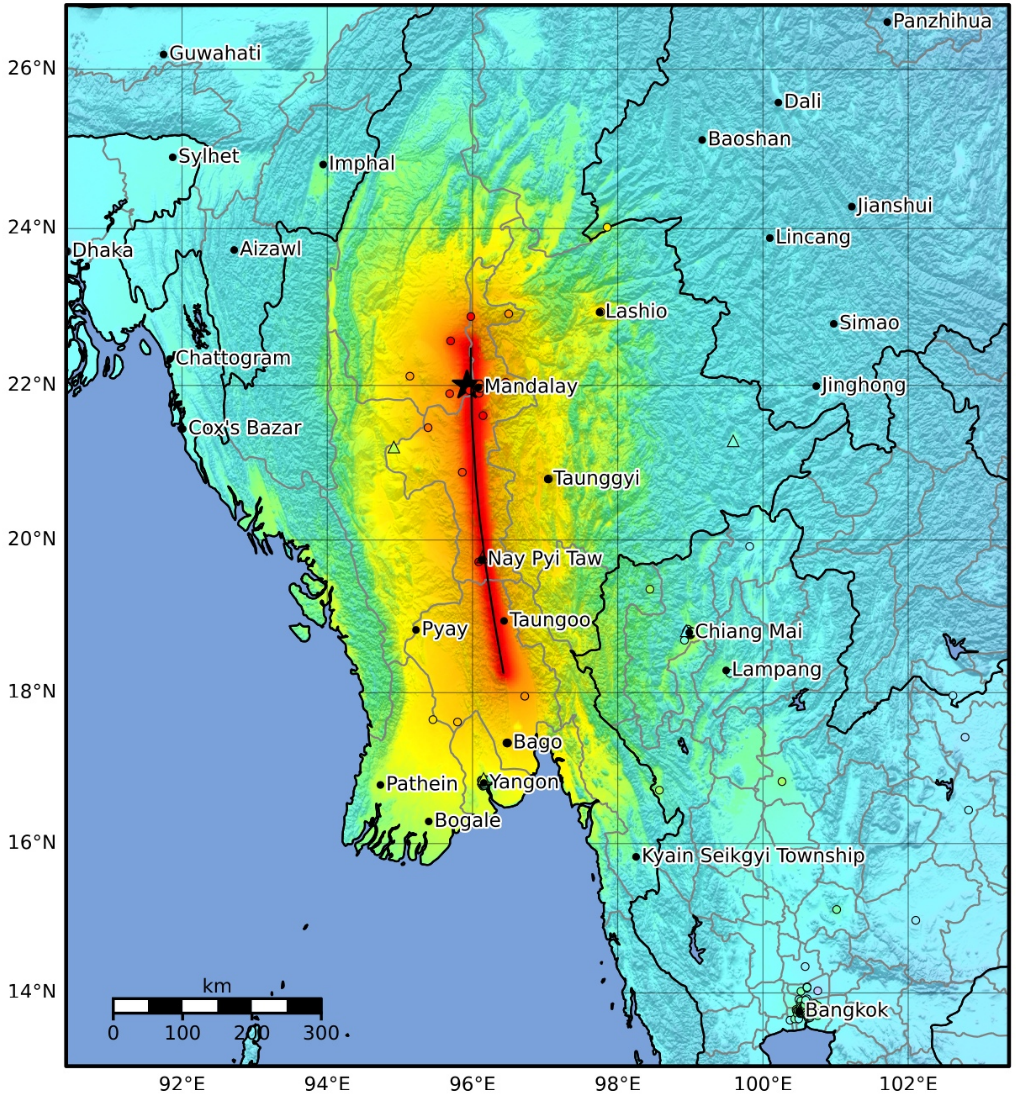



**Figure 5.** Period-, distance- and style-of-faulting dependent anisotropic ground-shaking amplification predictions for four events in Japan (NM: Normal, OB: Oblique, RS: Reverse, and SS: Strike-slip from left to right panels), for periods T = 0.1, 0.5 and 1 s (top-to-bottom panels). Each panel shows the R ≤ 200 km region (with 10, 20, 50,100 km contour lines) around the rupture trace, with color coding to reflect anisotropic increases (red)/decreases (blue) in ground-shaking with respect to the isotropic predictions, as a result of including the S-wave radiation pattern in empirical ground-shaking predictions. Overlying markers indicate the locations of recording sites, which are also color coded to reflect systematically higher (red) or lower (blue) than median isotropic ground-shaking model predictions. Wherever the background colors coincide with marker colors, the prediction model captures the observed anisotropic spatial variability of the ground-shaking reasonably well.

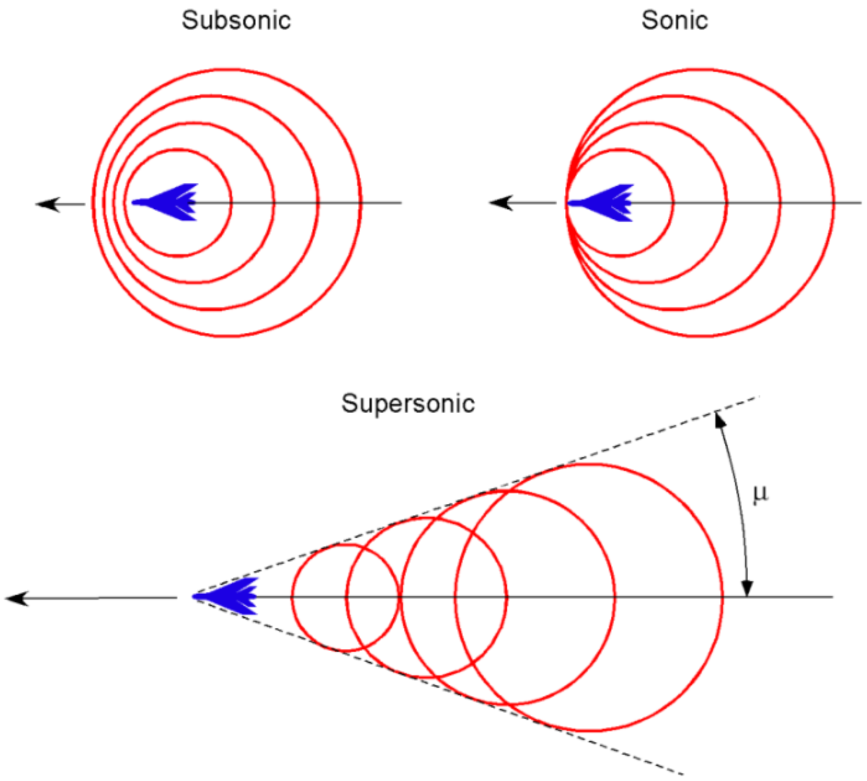
Macroseismic Intensity Map USGS
ShakeMap: 2025 Mandalay, Burma (Myanmar) Earthquake
Mar 28, 2025 06:20:52 UTC M7.7 N22.00 E95.92 Depth: 10.0km ID:us7000pn9s




| SHAKING | Not felt | Weak | Light | Moderate | Strong | Very strong | Severe | Violent | Extreme |
|---|---|---|---|---|---|---|---|---|---|
| DAMAGE | None | None | None | Very light | Light | Moderate | Moderate/heavy | Heavy | Very heavy |
| PGA(%g) | <0.0464 | 0.297 | 2.76 | 6.2 | 11.5 | 21.5 | 40.1 | 74.7 | >139 |
| PGV(cm/s) | <0.0215 | 0.135 | 1.41 | 4.65 | 9.64 | 20 | 41.4 | 85.8 | >178 |
| INTENSITY | I | II-III | IV | V | VI | VII | VIII | IX | X+ |

Scale based on Worden et al. (2012) Version 21: Processed 2025-04-16T05:13:29Z

△ Seismic Instrument ○ Reported Intensity ★ Epicenter ▭ Rupture




*As an airplane approaches the speed of sound, pressure waves merge ahead of it, and at supersonic speeds, a Mach cone forms at the nose.*

# Supersonic Shock Wave

https://eaglepubs.erau.edu/introductiontoaerospaceflightvehicles/chapter/supersonic-flight-vehicles/

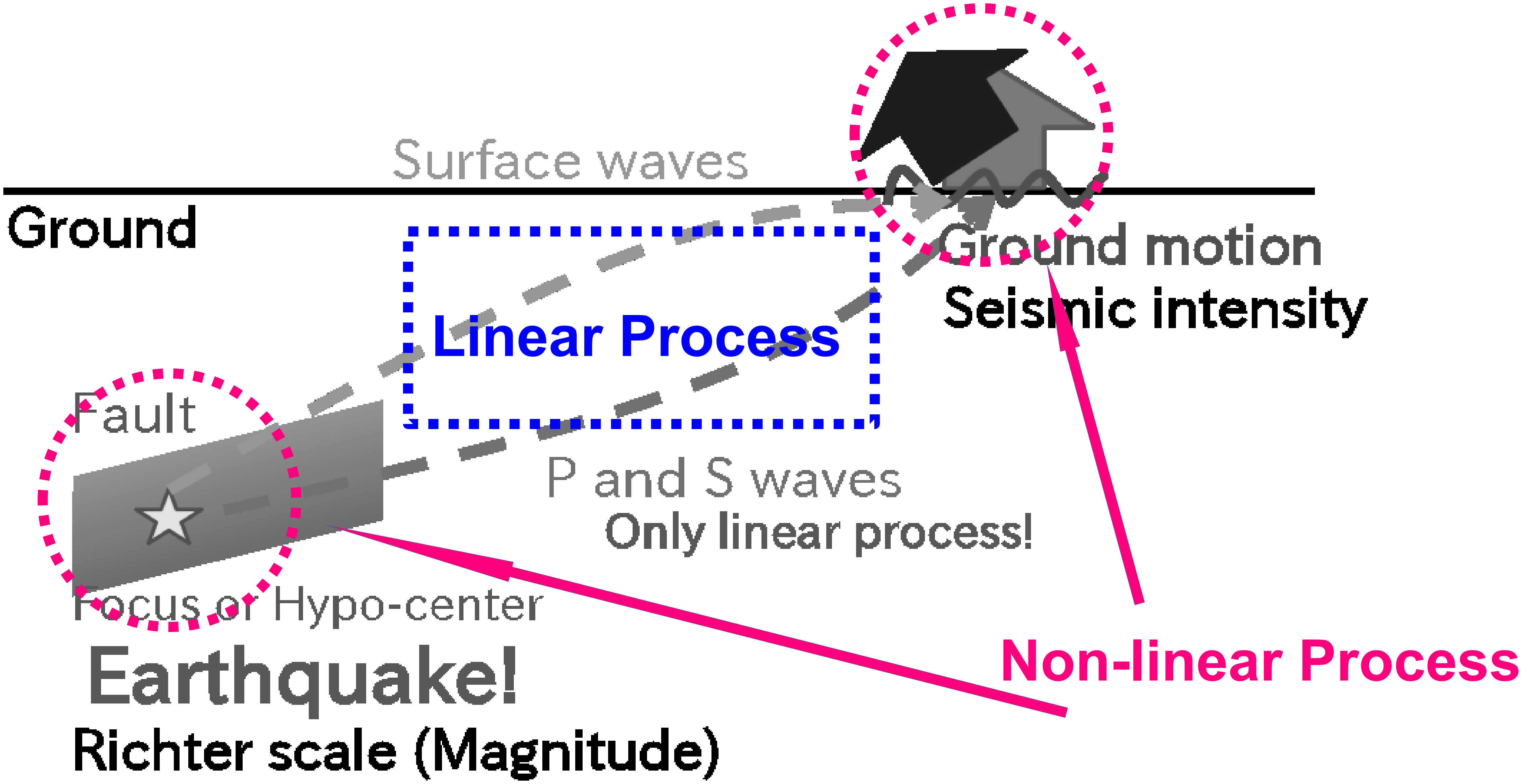
# Supershear Rupture

https://www.youtube.com/shorts/Wk9QVPk_IpQ

# Wave Physics

- I) The strong shaking at Bangkok is explained by a simple wave physics: propagation, resonance, dispersion, super-sonic etc.
- ii) But the collapse of building is essentially non-linear process. → so this forecast is very difficult.
- iii) Also, the earthquake cause is complicated non-linear process. → the difficulty of earthquake forecast.
- Many students try to challenge this unsolved target!!

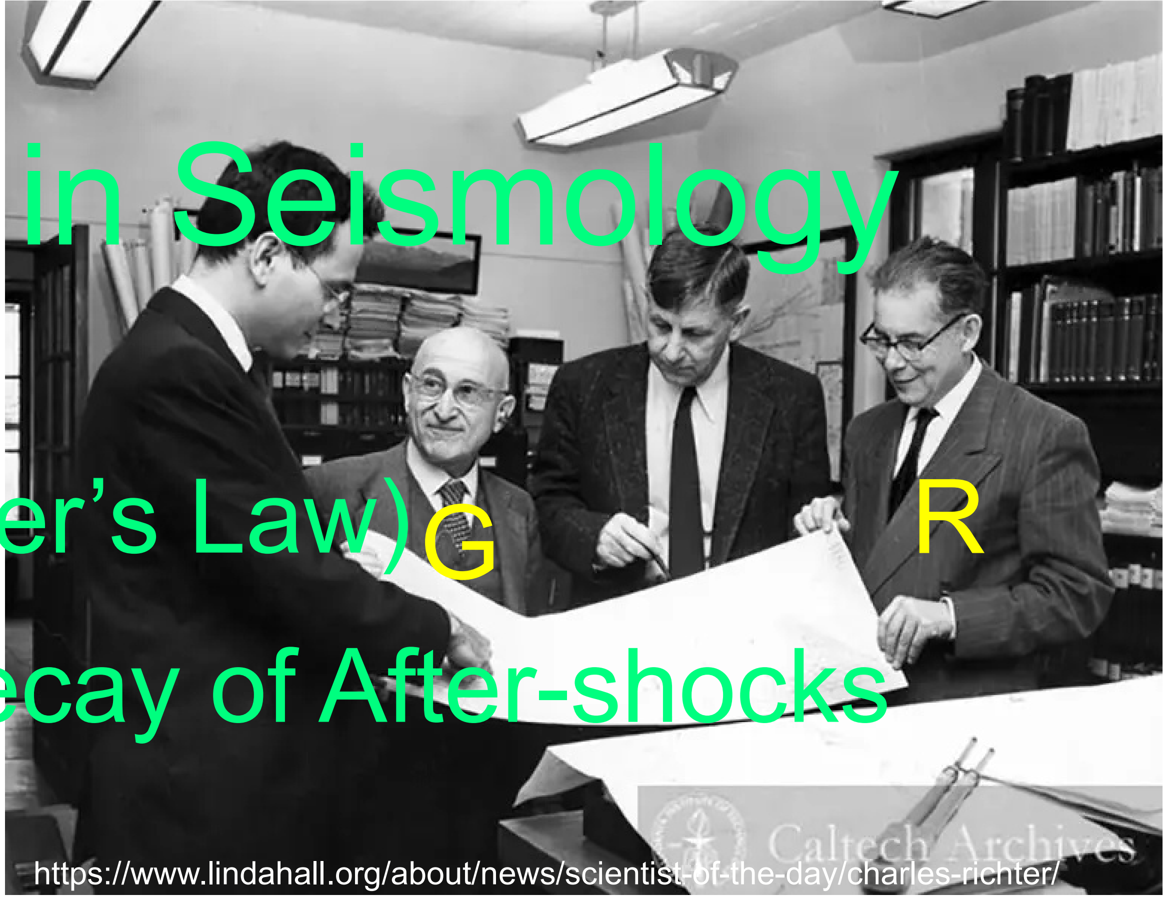
# Wave Physics and Rupture



# Go to “Boring” Statistics!

# Two Empirical Laws in Seismology

- G-R Law (Gutenberg-Richter's Law)
- Omori Law: Exponential Decay of After-shocks



https://www.lindahall.org/about/news/scientist-of-the-day/charles-richter/

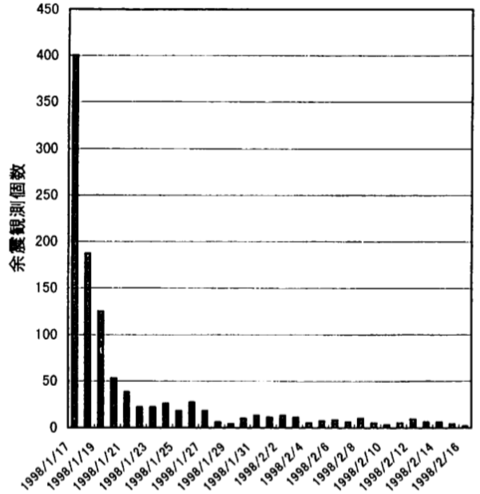



図１　表１のデータをグラフに示したもの（２／18以降は省略）

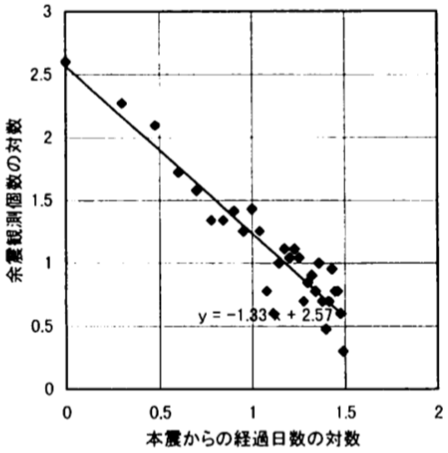


図２　図１のグラフの両軸を対数に代えたもの

**Log-Log Plot -> Line: Power Law**

Okamoto,1999

# The Gutenberg-Richter's Law

Earthquake-size: Magnitude(Size)

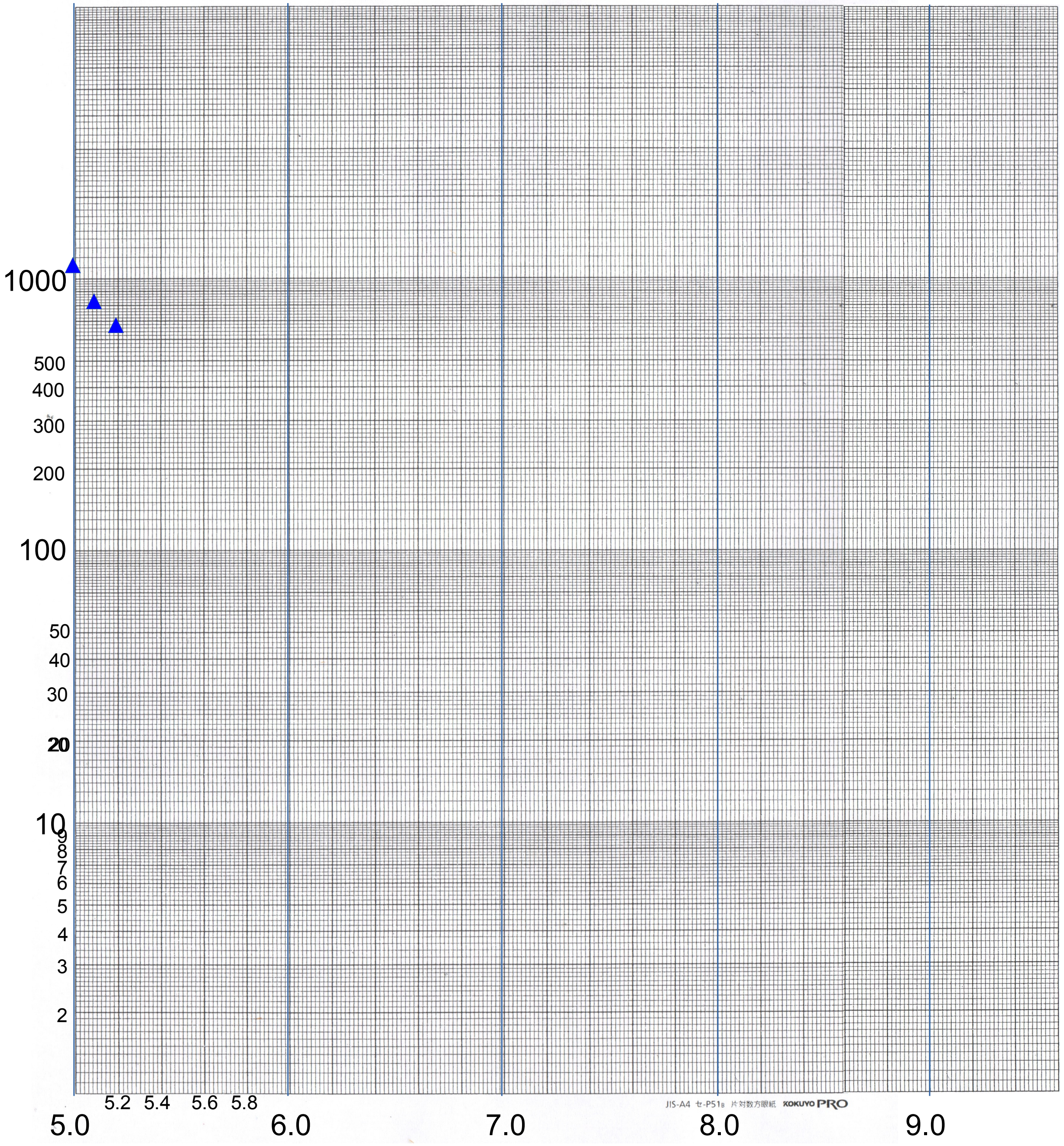
Number of earthquakes (Frequency)

Examples of South-East Asia and Japan

Lets’ Try!

# The Gutenberg-Richter's Law

- Earthquake-size: Magnitude(Size)
- Number of earthquakes (Frequency)
- Examples of South-East Asia and Japan
- Lets’ Try!

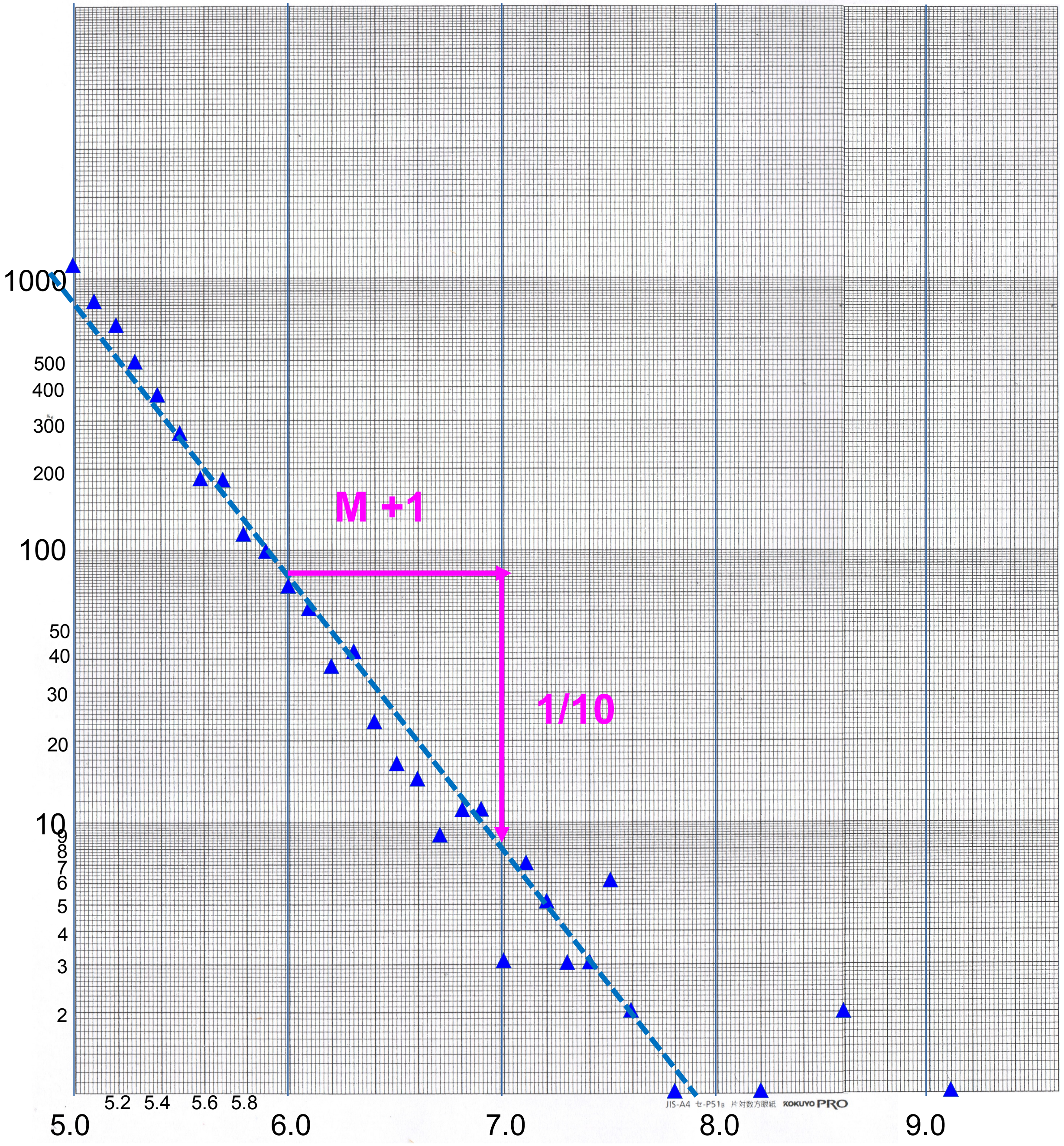



SE Asia2000-2019 85-130-0-30

| 5.0 | 5.1 | 5.2 | 5.3 | 5.4 | 5.5 | 5.6 | 5.7 | 5.8 | 5.9 |
|---|---|---|---|---|---|---|---|---|---|
| 1113 | 806 | 676 | 495 | 375 | 272 | 188 | 188 | 112 | 98 |
| **6.0** | **6.1** | **6.2** | **6.3** | **6.4** | **6.5** | **6.6** | **6.7** | **6.8** | **6.9** |
| 72 | 61 | 37 | 42 | 23 | 16 | 14 | 9 | 11 | 11 |
| **7.0** | **7.1** | **7.2** | **7.3** | **7.4** | **7.5** | **7.6** | **7.7** | **7.8** | **7.9** |
| 3 | 7 | 5 | 3 | 3 | 6 | 2 | | 1 | |
| **8.0** | **8.1** | **8.2** | **8.3** | **8.4** | **8.5** | **8.6** | **8.7** | **8.8** | **8.9** |
| | | 1 | | | | 2 | | | |
| **9.0** | **9.1** | | | | | | | | |
| | 1 | | | | | | | | |

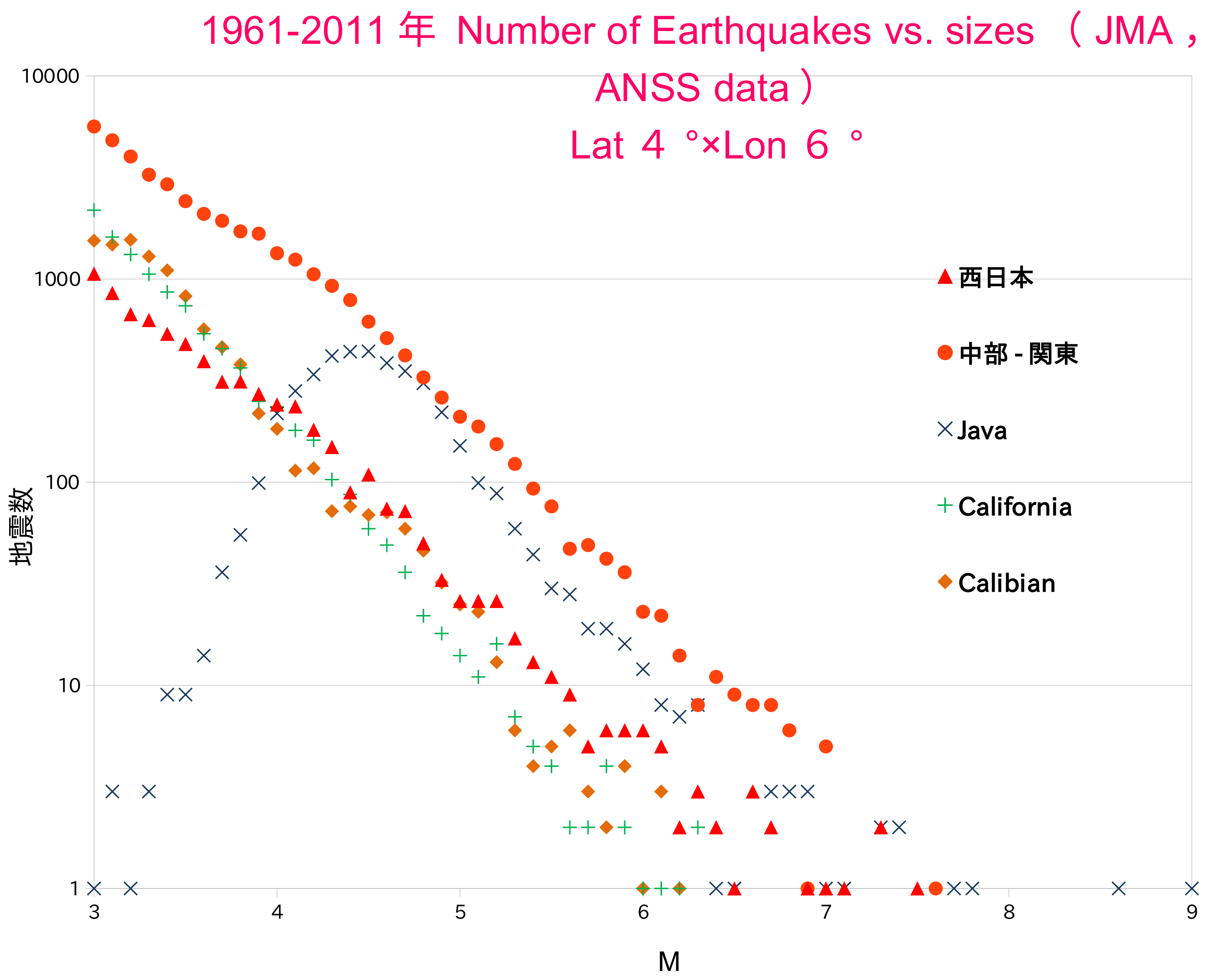
| *Japan 2000-2019* | *125-150-25-50* |
|---|---|

| 5.0 | 5.1 | 5.2 | 5.3 | 5.4 | 5.5 | 5.6 | 5.7 | 5.8 | 5.9 |
|---|---|---|---|---|---|---|---|---|---|
| 455 | 314 | 241 | 171 | 126 | 115 | 79 | 78 | 59 | 49 |
| **6.0** | **6.1** | **6.2** | **6.3** | **6.4** | **6.5** | **6.6** | **6.7** | **6.8** | **6.9** |
| 31 | 33 | 29 | 22 | 8 | 10 | 4 | 6 | 3 | 5 |
| **7.0** | **7.1** | **7.2** | **7.3** | **7.4** | **7.5** | **7.6** | **7.7** | **7.8** | **7.9** |
| 3 | 2 | | 2 | 1 | | | 2 | 1 | 1 |
| **8.0** | **8.1** | **8.2** | **8.3** | **8.4** | **8.5** | **8.6** | **8.7** | **8.8** | **8.9** |
| | | 1 | | | | 2 | | | |
| **9.0** | **9.1** | | | | | | | | |
| | 1 | | | | | | | | |

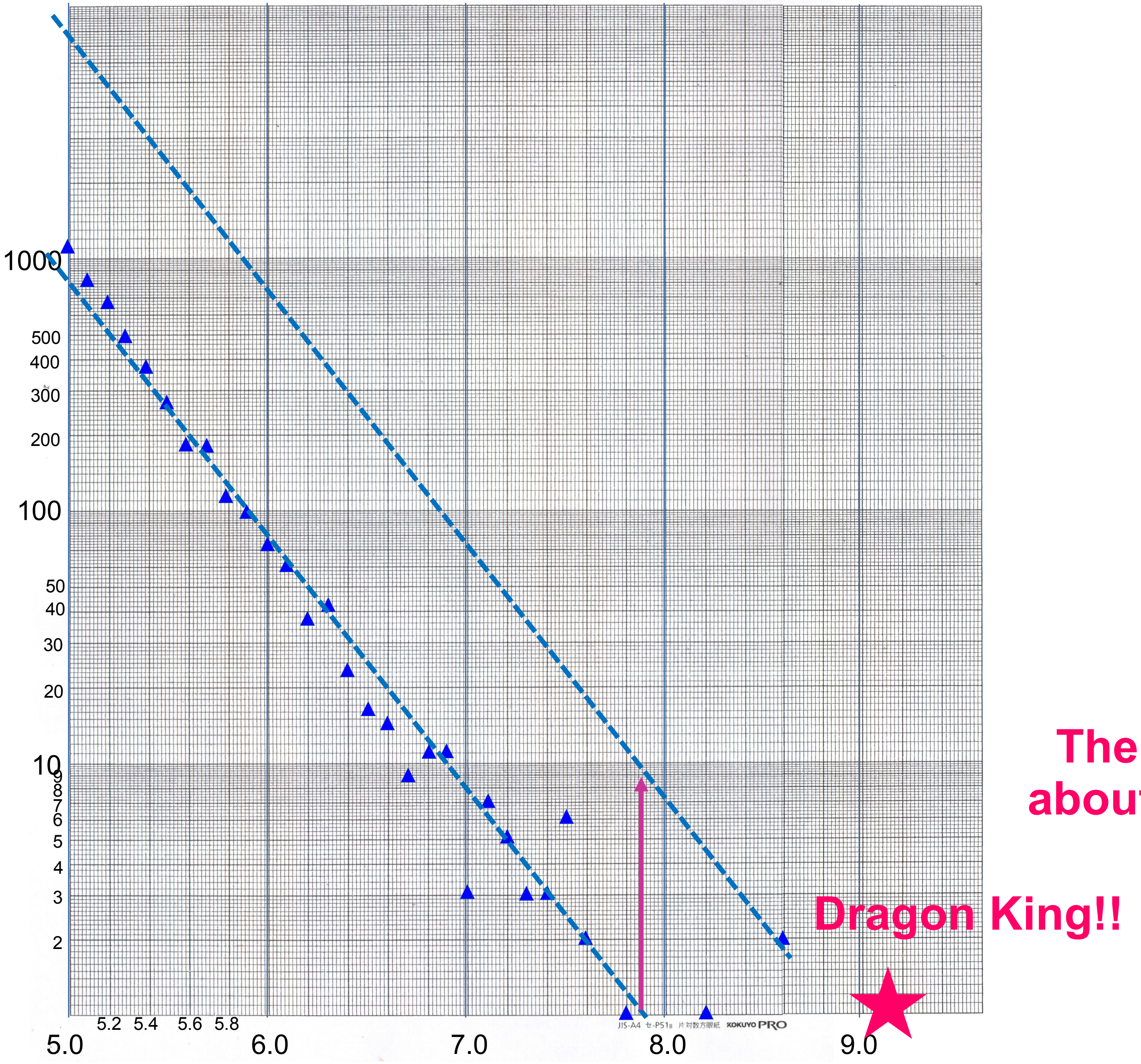



## Small Earthquakes: Many

## Big Earthquakes: a little




# Everywhere!
# Every time!




There are two ideas about out-ranged data

# Why G-R Law?

- Go-Game Model (Ohtsuka,1971)
- Sand-Pile Model (Bak, et.al.,1987 )
- Spring-Block Model ( Burridge and Knopoff,1967, Carlson and Langer,1989)

# Go-Game Model (Ohtsuka,1971)

地　　震　　第 2 輯
第 24 巻 (1971) 215-227 頁

# Q-2　地震の起り方のシミュレーション
## 第二部　地震の規模別頻度分布

熊本大学理学部物理学教室　大　塚　道　男
(昭和 46 年 6 月 30 日受理)

## A Simulation of Earthquake Occurrence
## Part 2. Magnitude-Frequency Relation of Earthquakes

MICHIO OTSUKA
Department of Physics, Faculty of Science, Kumamoto University
(Received June 30, 1971)

At what stage of earthquake phenomena is the total amount of energy to be liberated by a particular event determined? Is it scheduled since long before the occurrence of that event, just before its outbreak or just after termination of disturbance?

Through detailed study of the operation of a simulator treated in the first part of this paper, the author was led to be interested in the plausibilty of the last case.

The basic idea is that the elastic stress energy spread over vast volume of rock medium cannot be liberated at an instant but must be released as a result of sequential progression of rupture which may be controlled by numerous factors such as stress concentration strength, inhomogeneity, distribution of flaws etc. in the medium.

The implication is that the amount of energy which is going to be liberated by a particular earthquake can only be told on the probabilistic ground until all energy release processes of that event are brought to termination. The observed magnitude-frequency relations of earthquakes are in general agreement with this argument.

### § 1.　は じ め に

さきに大塚 (1971, a) は，地震発生に関するいろいろな属性が，一つの機械的モデルを想定することによつて計算機の上にうまく simulate 出来ることを示した．たとえば，地震エネルギーの放出の模様，地震発生の時間的間隔，震源域の拡大などについて自然地震の発生に見られるさまざまな特徴が可成り巧みに再現されることを見た．この中で“地震の規模別頻度分布”の simulation についても成功の見通しがあることを示唆したが計算機のメモリーと計算時間の経済から結論を保留した．

本論文の目的は，“地震の規模別頻度分布”に焦点を絞り，その成り立ちのメカニズムをさぐる所にある．

さて，本題に入るに先立つて筆者が simulation をあつかつた論文 (大塚 (1971, a)，以下論文

昭和 46 年 5 月 20 日地震学会で発表





作させればよい．このことは原理的には正しいが効率から考えると著しく損である．われわれの simulator が有効に働らくためには構成ブロック数を格段に増す必要があり，その上計算時間も甚しく増大する必要であると思われるからである．

そこで，地震の規模を支配している要因と思われる連鎖反応の機構だけを simulator から抽出することによつて別のモデルを作り，このモデルについて検討を加えることにする．次の一節は，その新らしいモデルを紹介するために費やそう．

### § 2.　碁石モデル

Fig. 1 を参照して，まず碁板の中央に一つの白石が置かれている状態を考える (A)．この白石を囲む点は $a$, $b$, $c$, $d$ の四点である．今これらのそれぞれについて一回ずつ一つのサイコロを振る権利が与えられ，もし 6 の目が出れば，それに対応する点に白石をおく．6 以外の目が出れば黒石をおくと約束する．今仮りに $a$ に対応して 6 の目が，その他三回は 6 以外の目が出たとすると石の配置は (B) のようになるであろう．次のステップでは更に新らしい白石のまわり，すなわち $e$, $f$, $g$ でサイコロを振る権利が与えられる．その結果，$g$ に対応して 6 の目が，他は 6 以外の目が出たとすると石の配置は (C) のごとくなる．第 3 ステップでサイコロを振る権利は $h$, $i$ に与えられる．その結果，もし 6 の目が一回も出なかつたとすると石の配置は (D) のようになる．白石三ケは完全に黒石に包囲されてしまつたから第 4 ステップではサイコロを振る権利がない．この状態で一回のゲームは終る．上の例の場合の得点は囲まれた白石の数，すなわち 3 点である．ここであらためて (A) の状態からゲームをくり返す．

さて，このようなゲームを何回も繰り返すうちに得点の頻度分布がはつきりして来るであろう．それはどんなものだろうか．

碁石モデルを simulator と対比してみるに，白石が一つ置かれることは一つの辷りが起つたことに対応し，黒石が置かれることは辷りの波及がそこで喰い止められたことを意味する．

当然のことであるが，simulator の中である辷りが発生し，それがどの程度成長するかは，その構成要素たるバネの強さ，摩擦力の大きさ，過去に経験した辷りの履歴等をすべ

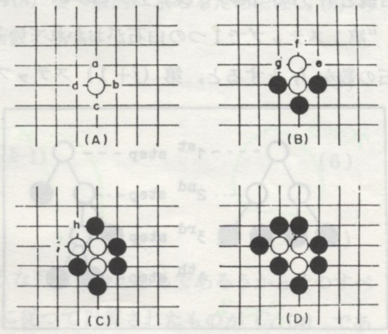



Fig. 1.　An example showing how “Go game model” simulates the progression of rupture in the medium. Each progression of rupture is assumed to be determined by probabilistic processes.

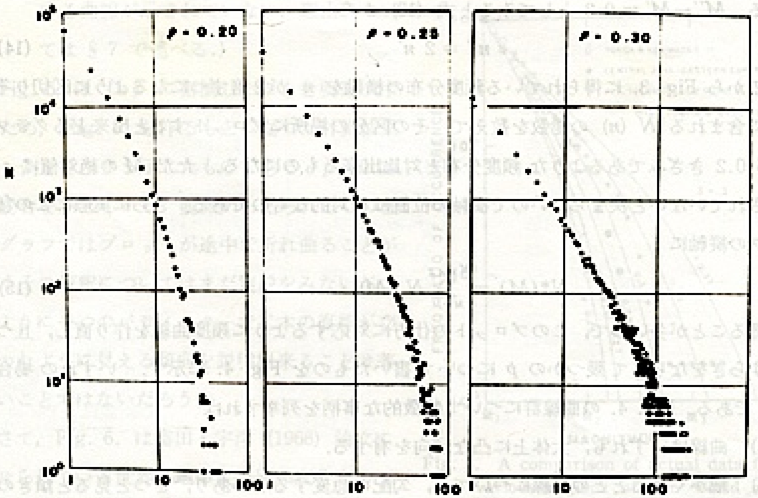



Fig. 3. The calculated output of "Go game model" for various values of $p$, a parameter which controls the probability of rupture propagation.

程として捉えたことの正しさを示している．しかも試行回数が桁違いに多いのに比して計算時間は著しく短かい．

この議論を一歩進めて，われわれの解を地震の規模別頻度分布と対比してみたい．そのためには Fig. 3. の横軸の目盛り方を少し変更して地震のマグニチュードに対比出来るものにせねばならない．そこでふたたび論文（1）の立場をとつて，一つの白石（すなわち一つのブロックの辷り）から発生する地震エネルギー $\varepsilon$ は一定であるとすると $n$ ケの白石の塊から得られる地震エネルギー E は

$$E = n\varepsilon \tag{9}$$

で与えられる．故に

$$\log E = \log n + \log \varepsilon \tag{10}$$

である．またエネルギー $E$ と地震のマグニチュード $M$ の間には

$$\log E = 1.5\ M + 11.8 \tag{11}$$

の関係があるから式（10）と（11）から $E$ を消去すると

$$\log n = 1.5\ M + (11.8 - \log \varepsilon) \tag{12}$$

を得る．今 $M'$ に対する $n$ を $n'$，$M''$ に対する $n$ を $n''$ とすると式（12）から

$$\log (n''/n') = 1.5\ (M'' - M') \tag{13}$$





する曲線が示されていない．理由については §7 で述べる.)

Fig. 5. は（b）に指摘したことを明確にするため，Fig. 4. を作るもとになつた計算結果の一例をそのまま示したものである．$p = 0.32$ の場合を示している．観測からえられるこの種のグラフではプロットが途中で折れ曲ることが多くその解釈についてはまだ定説をみないがこのように一つのパラメーターで二本の直線が交わつたように見える傾向を説明出来ることは著しいことではないだろうか．

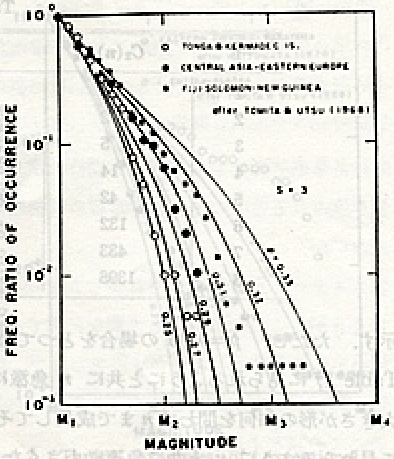



Fig. 6. A comparison of actual data from various regions of the world with the result of "Go game model". Note that plots in each symbol are in fair agreement with general trends of theoretical curves of any parameter. This type of frequency distribution is onmed "type A" in the text.

さて，Fig. 6. は富田・宇津（1968）論文に載せられている世界各地の規模別頻度分布のデータから三例を拝借して碁石モデルの頻度曲線に重ねたものである．各記号はそれぞれ地域別を表わすが，各々がいずれかの $p$ に対応する曲線でよく説明されるのが認められる．富田・宇津の論文に挙げられている例のうち一部を除いた殆んどはこの型に属しているように見える．また，ここに一々述べるいとまがないが地震の規模別頻度分布は概してこの型式をもつているのではないだろうか．とすれば，地震の規模別頻度分布の大部分は碁石モデルのパラメーター $p$ を適当に選ぶと説明出来ることになる．観測データに式（1）をあてはめたのではプロット全体の傾向を説明出来ないことに注意してほしい．

さて，こうした目で地震の規模別頻度分布を調べてゆくと中には $p$ の選び方だけではどうにもならず計算結果から大幅に外れるものがある．$M$ の大きい部分で計算から大きく右へ張り出すものである（Fig. 7. 参照）．そこで Fig. 6 のように $p$ の選び方で何とか説明のつく頻度曲線の型をA型，Fig. 7. のような型をB型と仮称して以下の節でそれぞれの成り立ちを考察してみたい．

## §6. A型頻度分布

式（4）によつて $P_s(n)$ のふるまいは $C_s(n)$ と $(pq^{s-1})^n$ によつてきまる．今 $s=2$ の場合について $C_2(n)$，$(pq)^n$ および $P_2(n)$ を $n=1\sim8$ につき計算したものを Table 1. に

# 2.1 Go-game Model (Rules)

(Okamoto,2003)

http://seagull.stars.ne.jp/2003_Canada/web/index.html

"Go-game" is a popular stone puzzle game in Japan imported from ancient China.
"Go-game model" was originated by M. Ohtsuka in 1971 to investigate the background of "Gutenberg-Richter's Law", which is a famous relation between earthquake sizes and frequencies.

-Preparation:
* A lattice printed-paper.
* A pencil: Maker's logo shows hit.
(The probability of hits is 2/6 (p.p=0.33), see Fig.1).
This article uses "p.p" as a propagation probability.)

-Procedures:
1) A cell is chosen randomly with a star<*>
 (start point of a fault break) (Fig. 2-a)
2) Four nearest neighbors are numbered (Fig. 2-a).
3) Dice trial; hit plots O and blank plots X.
 O means a break propagates while X means doesn't (Fig.2-b).
4) Sites surrounding O without any marks are numbered for next trial (Fig. 2-c).
5) The process is iterated until all sites are surrounded with X (end of an "earthquake").
6) If our virtual earthquake "finished", then an next earthquake will start. <Return to 1)>
7) After some practice time, the results of all students are gathered and summed on a blackboard, then are plotted on a log-log graph.


Fig.1 A lattice paper and pencils
(Left shows hit, right shows blank).

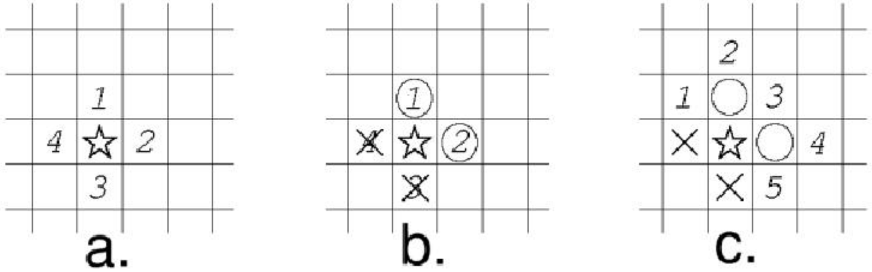



Fig.2: Rules of Go-game model.

**Simulation Rules:**

1. **Start:** Mark a random square with a star (⋆).
2. **Test:** Check the 4 neighbors (Probability p≈1/3).
    - **Hit:** Mark **O** (Continue).
    - **Miss:** Mark **X** (Stop).
3. **Repeat:** Test the neighbors of every new **O**.
4. **End:** Stop when the cluster is blocked by **X**s.

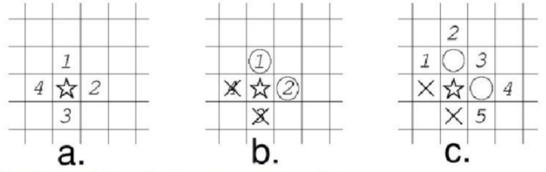
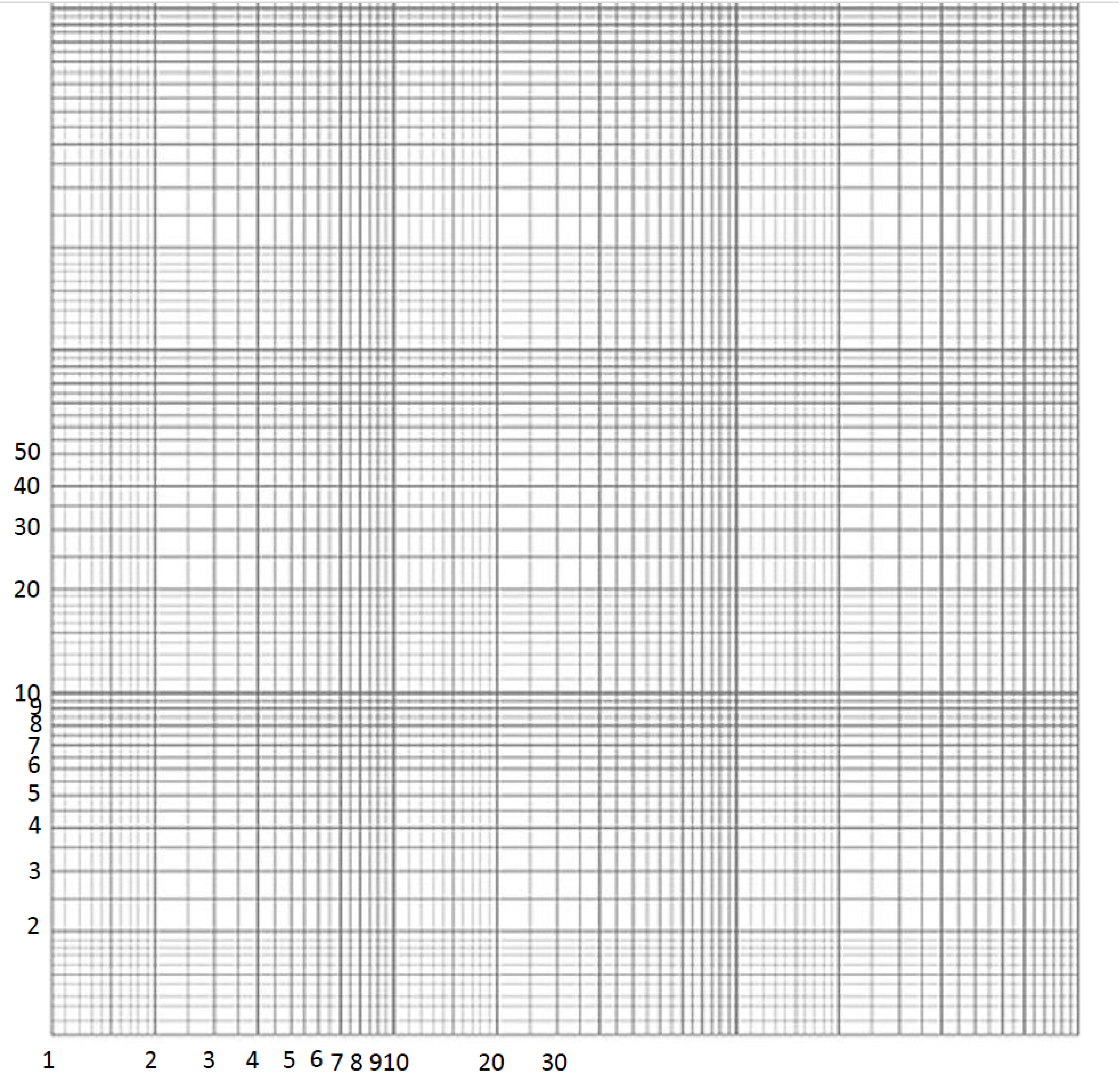
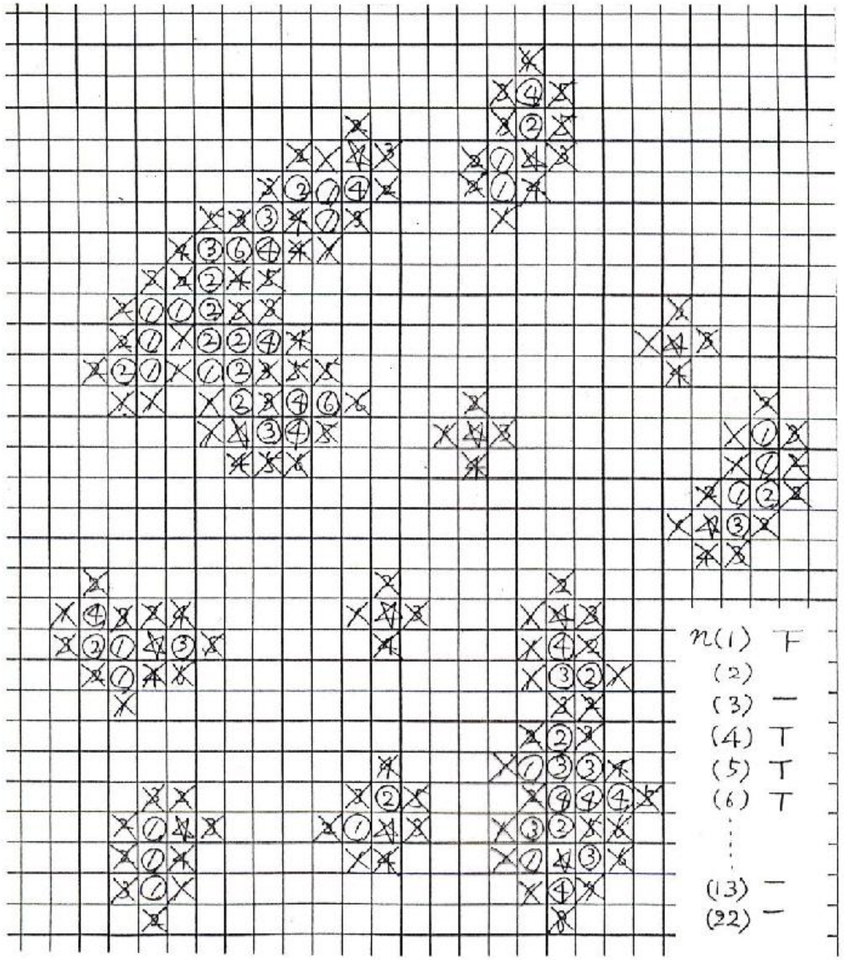



Fig.2: Rules of Go-game model.

# My lecture at Osaka-Kyoiku Univ.(2017)


50
40
30
20
10
9
8
7
6
5
4
3
2
1 2 3 4 5 6 7 8 9 10 20 30

# 2.2 Board Game as a Student Practice



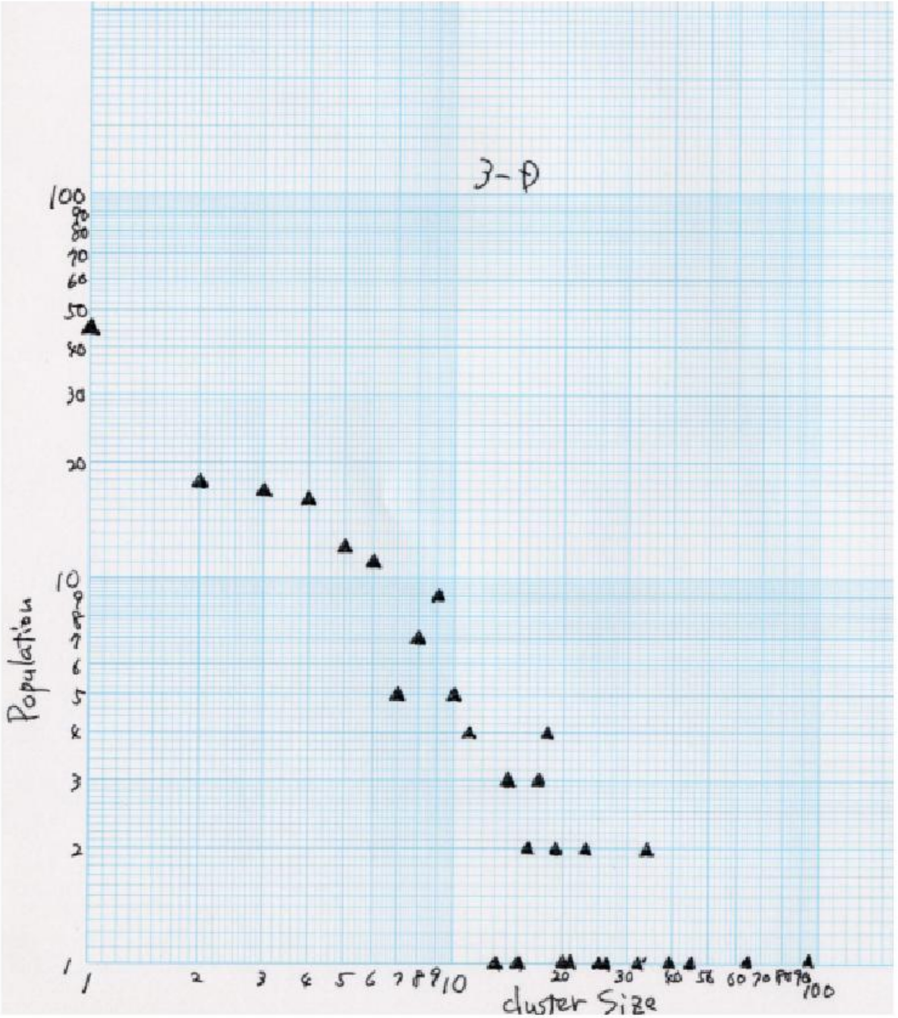
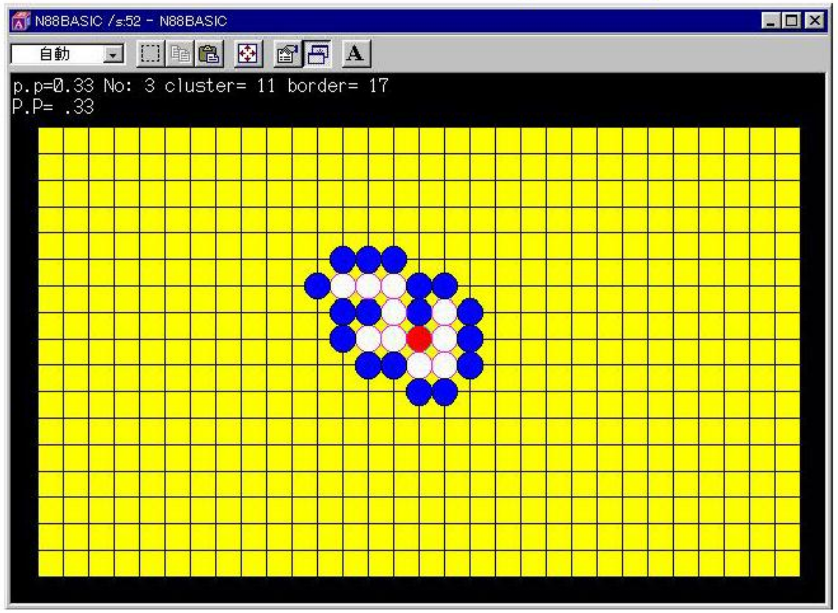
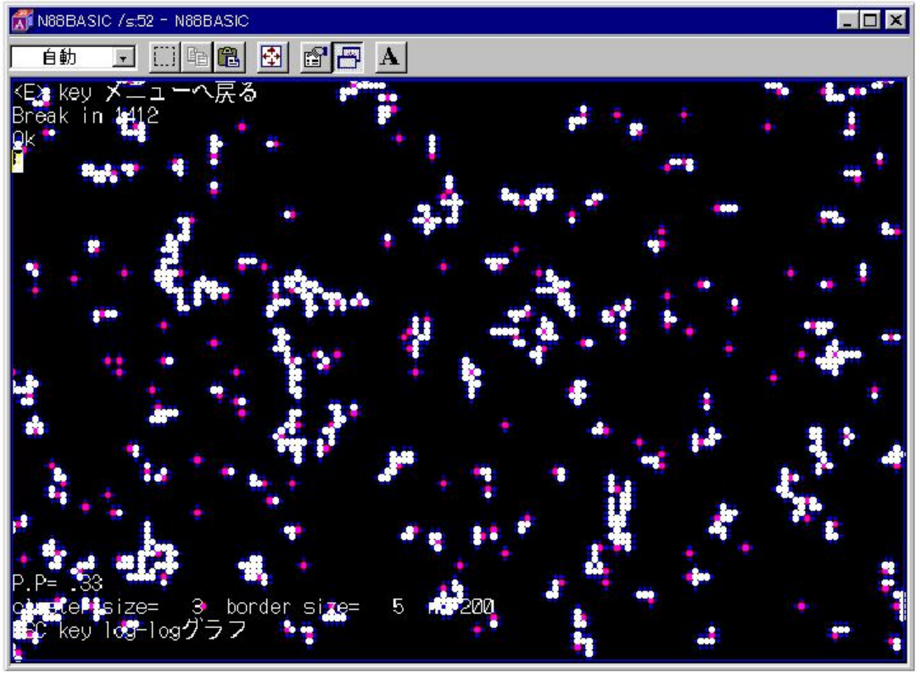




Fig. 3: Go-game model by hand trials (left)
and an example of cluster sizes vs. populations with p.p=0.33 on a log-log sheet (right).
A similar relation like the G-R law is appeared.

# 2.3 Go-game Model (Behavior)

- The number of break cells = an earthquake size.
- The more hit marks, the more earthquake grows.
- A similar relation like the G-R law.
- PC simulation: shows the real-time growth of clusters and the size-frequency relation.



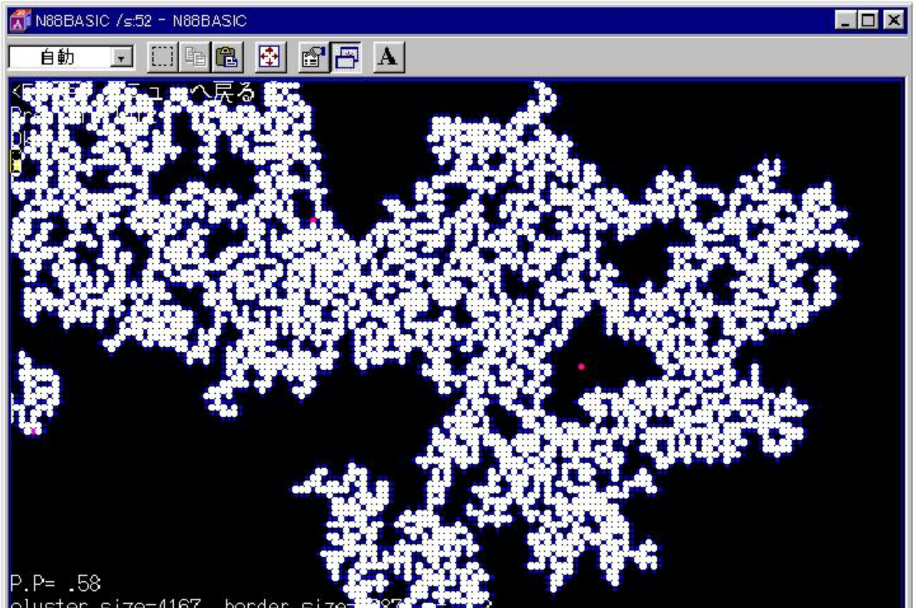
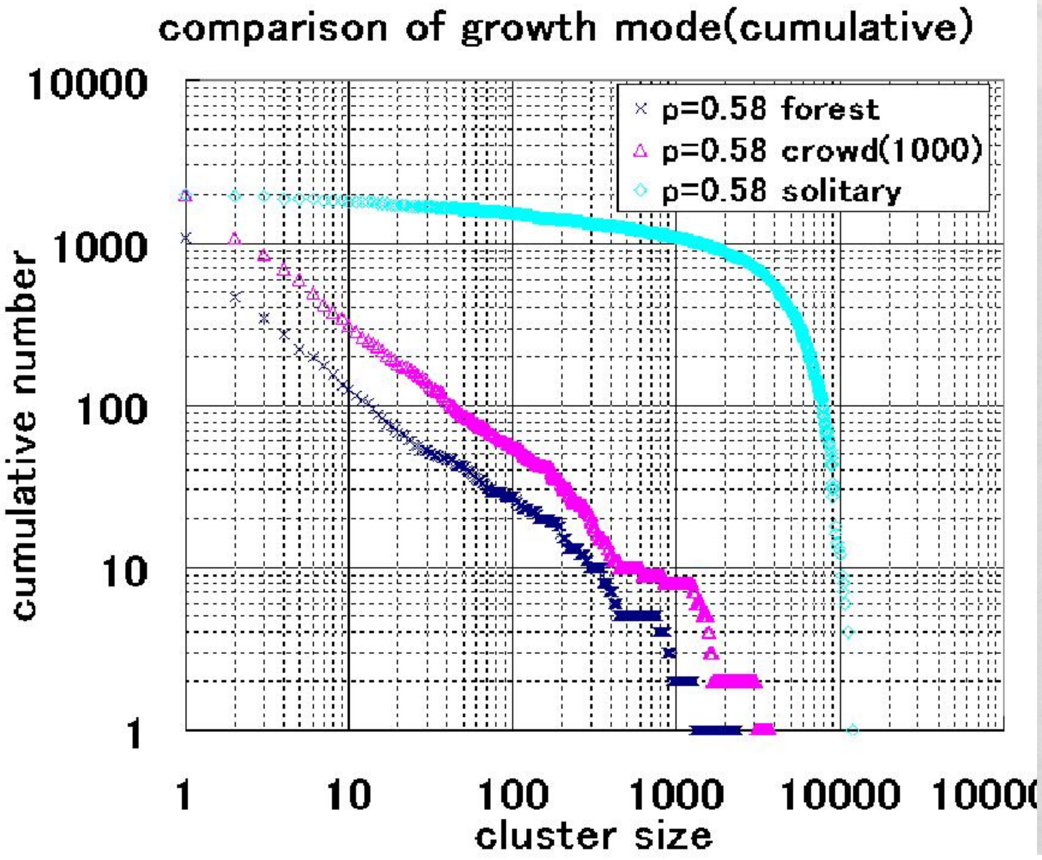
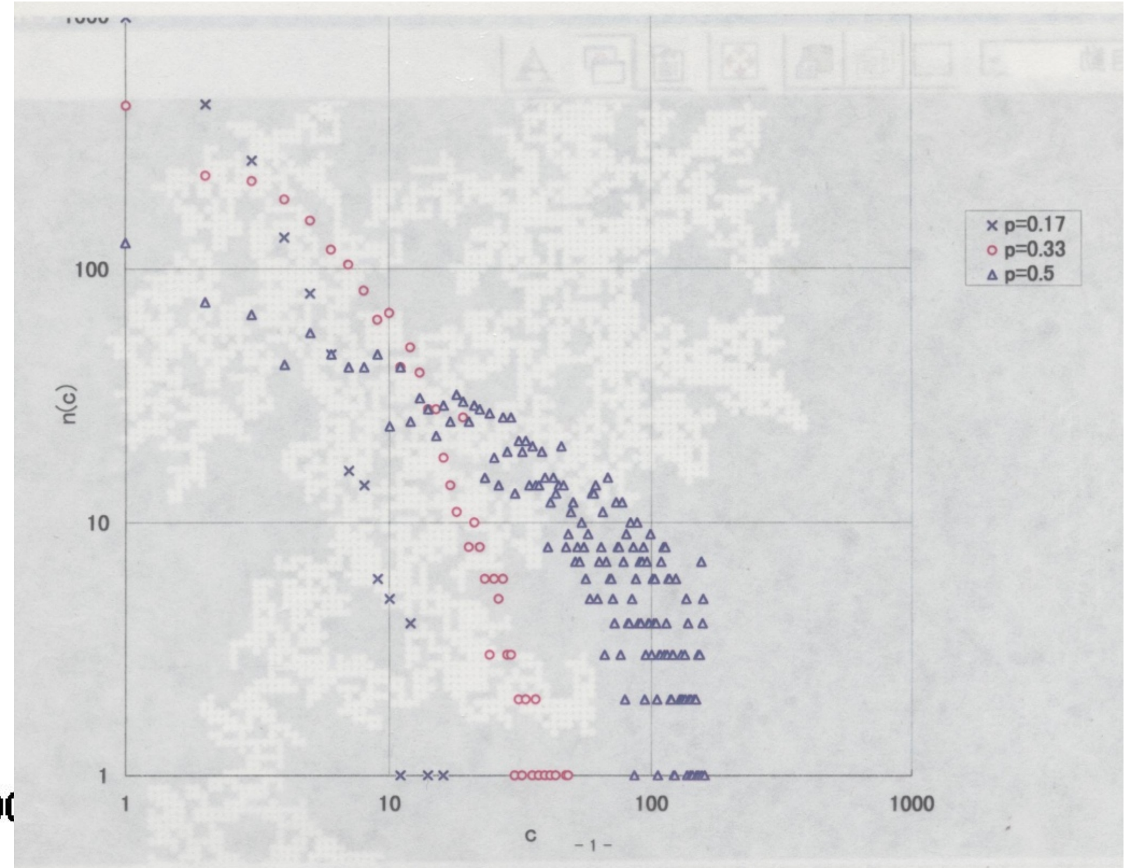




Fig.4 Demo_version on PC (left) and comparison with p.p (right): p.p=0.33(upper), 0.58(lower)

# 2.5 Earthquake Sizes vs. Frequencies



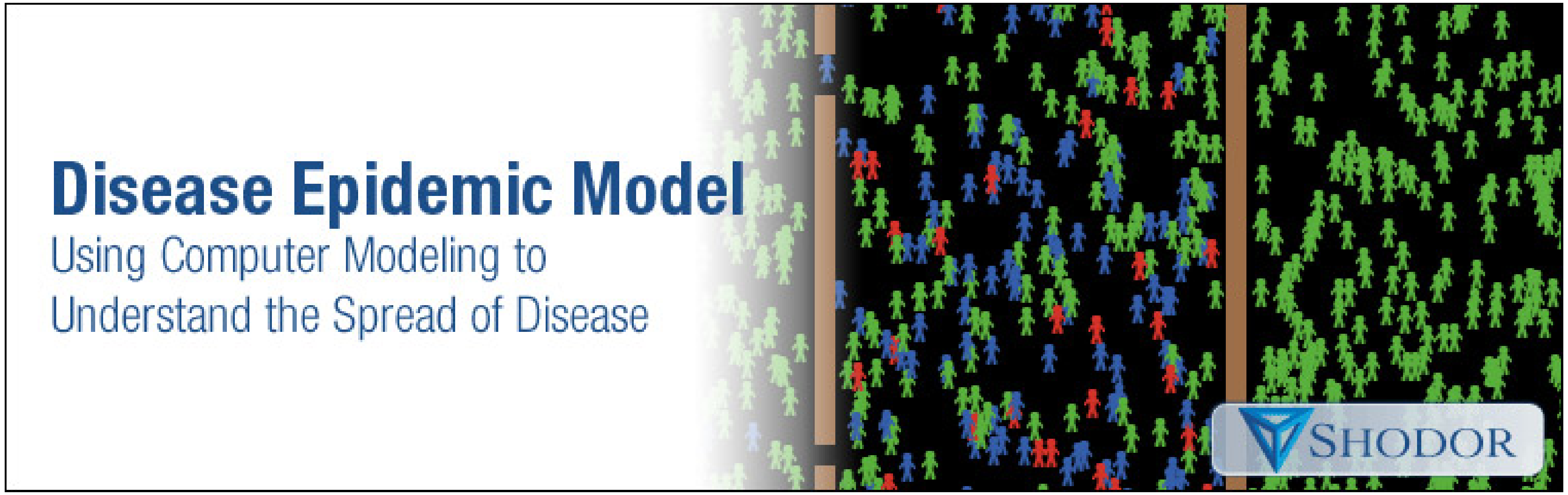

(Left) Fig.6: Virtual Earthquake sizes vs. Frequencies;
Propagation Probability p.p=0.58 (near critical state of 2 dimensional site percolation)
Clear linear relations, distinctive Fractal scaling behavior, appear in both the crowd mode and the forest mode, while the solitary mode does not show such character.

(Right) Fig.7: Natural Earthquake sizes vs. Frequencies (G-R Law Relation)

# Disease Model



***NEW!*** **- View ASL annotated model of the spread of disease**




This model can be used to create a virtual population to observe how different factors might affect the spread of a disease. Scientists often use computer models to study complicated phenomena like epidemics. This model can be a simplified simulation of any disease that is spread through human contact. Find accompanying materials for students and instructors by using the links in the light blue navigation bar.

Out

# Ebola spreads slower, kills more than other diseases

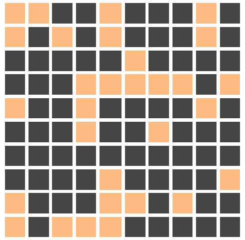
http://www.washingtonpost.com/wp-srv/special/health/how-ebola-spreads/

This simulation shows how quickly 10 diseases, from more fatal to less fatal, could **spread from one person to 100 unvaccinated people.**

Newly infected · Recovered · Deaths · Day 78 · RUN NEW SIMULATION

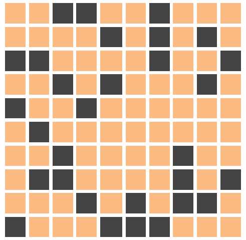
**Ebola**

| | |
|---|---|
| DAYS ELAPSED | 74 |
| PEOPLE INFECTED | 100 |
| DEATHS | 70 |



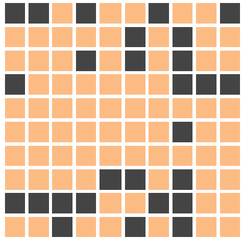
**Smallpox**

| | |
|---|---|
| DAYS ELAPSED | 42 |
| PEOPLE INFECTED | 100 |
| DEATHS | 30 |



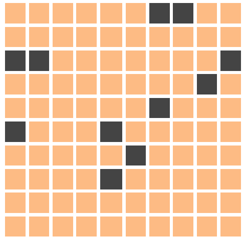
**Measles**

| | |
|---|---|
| DAYS ELAPSED | 25 |
| PEOPLE INFECTED | 100 |
| DEATHS | 27 |



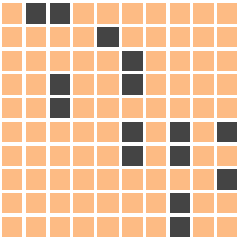
**SARS**

| | |
|---|---|
| DAYS ELAPSED | 47 |
| PEOPLE INFECTED | 100 |
| DEATHS | 11 |



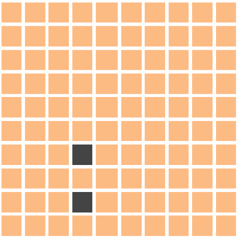
**Diphtheria**

| | |
|---|---|
| DAYS ELAPSED | 77 |
| PEOPLE INFECTED | 43 |
| DEATHS | 7 |



**Flu**

| | |
|---|---|
| DAYS ELAPSED | 14 |
| PEOPLE INFECTED | 100 |
| DEATHS | 2 |



**Whooping cough**

| | |
|---|---|
| DAYS ELAPSED | 45 |
| PEOPLE INFECTED | 100 |
| DEATHS | 0 |



**Rubella**

| | |
|---|---|
| DAYS ELAPSED | 57 |
| PEOPLE INFECTED | 100 |
| DEATHS | 0 |



**Mumps**

| | |
|---|---|
| DAYS ELAPSED | 53 |
| PEOPLE INFECTED | 100 |
| DEATHS | 0 |



**Chicken pox**

| | |
|---|---|
| DAYS ELAPSED | 29 |
| PEOPLE INFECTED | 100 |
| DEATHS | 0 |

# The Importance of This Model

If this model explains any aspect of earthquake phenomena, earthquake prediction becomes fundamentally impossible.

In other words, both small and large earthquakes start the same way.

An earthquake doesn't know at first whether it will grow larger or remain small!

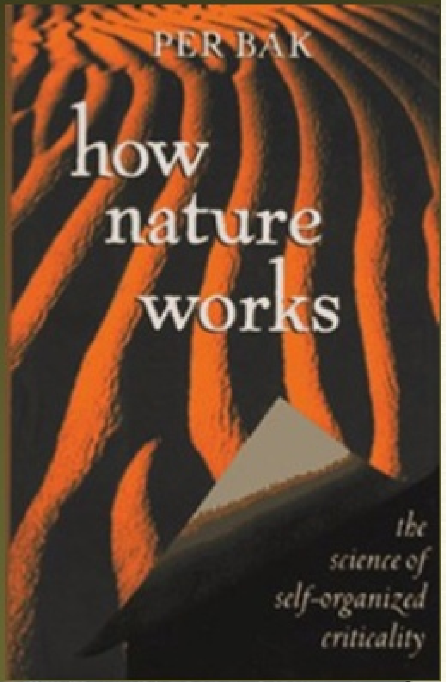
# Deterministic or stochastic?

The future can be predicted by some equation.
-> Deterministic model

When a stochastic process is introduced in the system, predicting the future becomes difficult.

# Sand Pile Model (Per Bak.et,al.1987）

- Per Bak [1948-2002]





state provides a connection between nonlinear dynamics, the appearance of self-similarity and 1/f noise in a natural way.

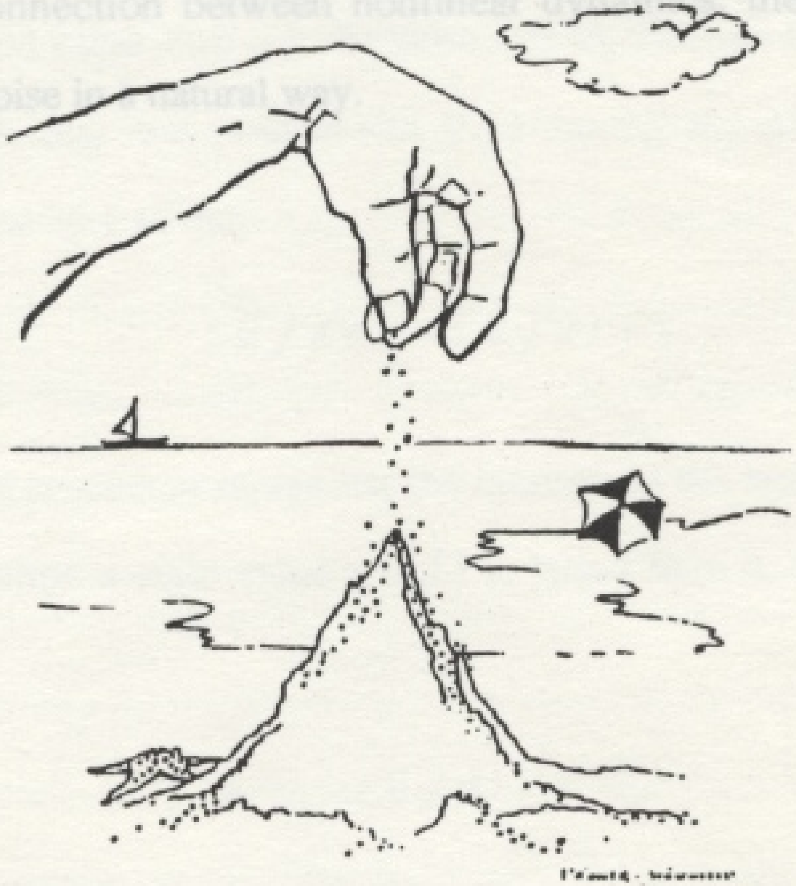


Figure 3.1.1 The formation of a sandpile (after *Bak et al.* [1988]). The pile reaches its critical state, in which the slope of the pile will grow no further.

# Sand Pile Model (My Analog Experiment, 2014)

# The inner rule is completely deterministic!

$$z(x,y) \to z(x,y) - 4,$$

$$z(x \pm 1,y) \to z(x \pm 1,y) + 1,$$

$$z(x,y \pm 1) \to z(x,y \pm 1) + 1,$$

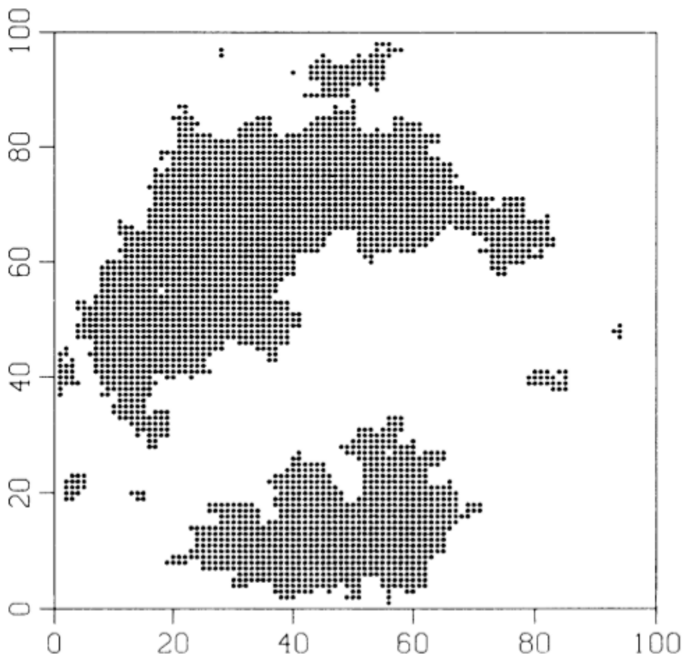



FIG. 1. Self-organized critical state of minimally stable clusters, for a 100×100 array.

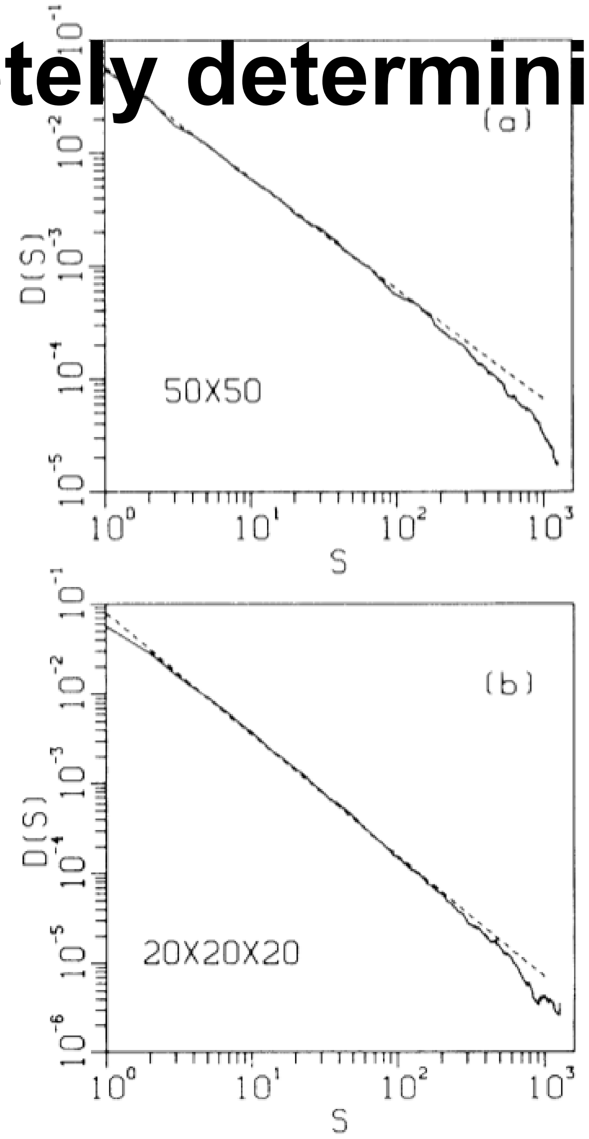
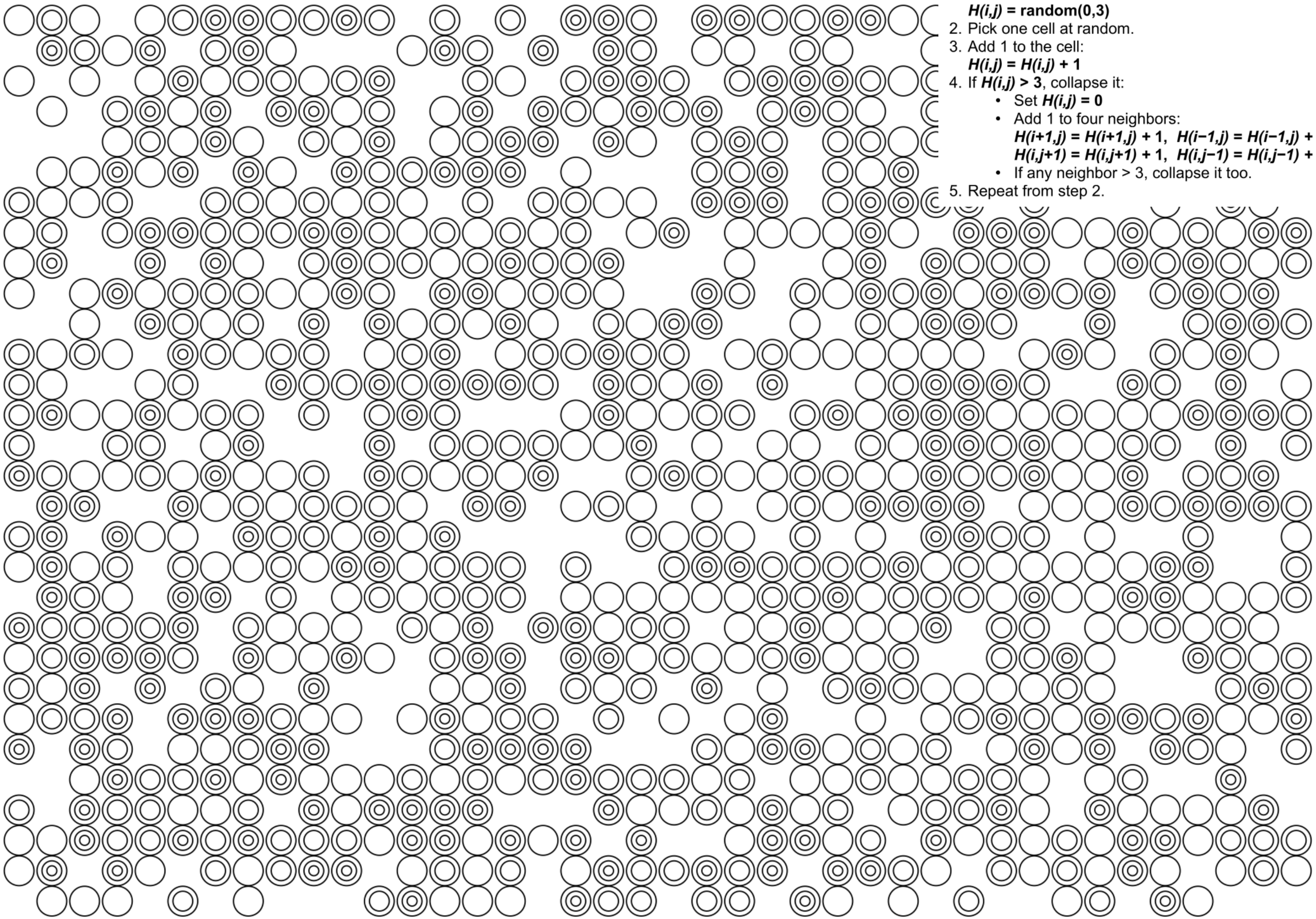
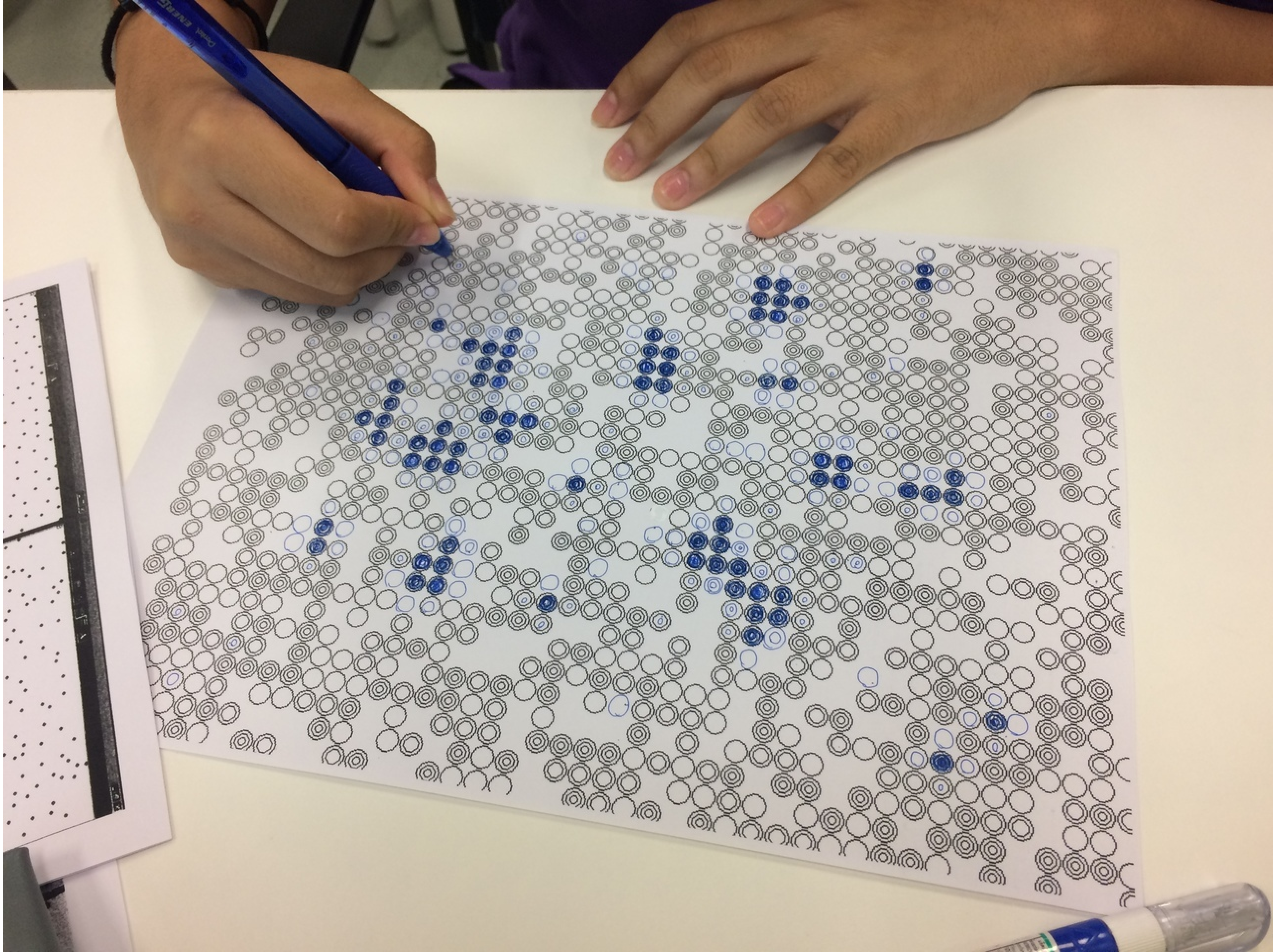


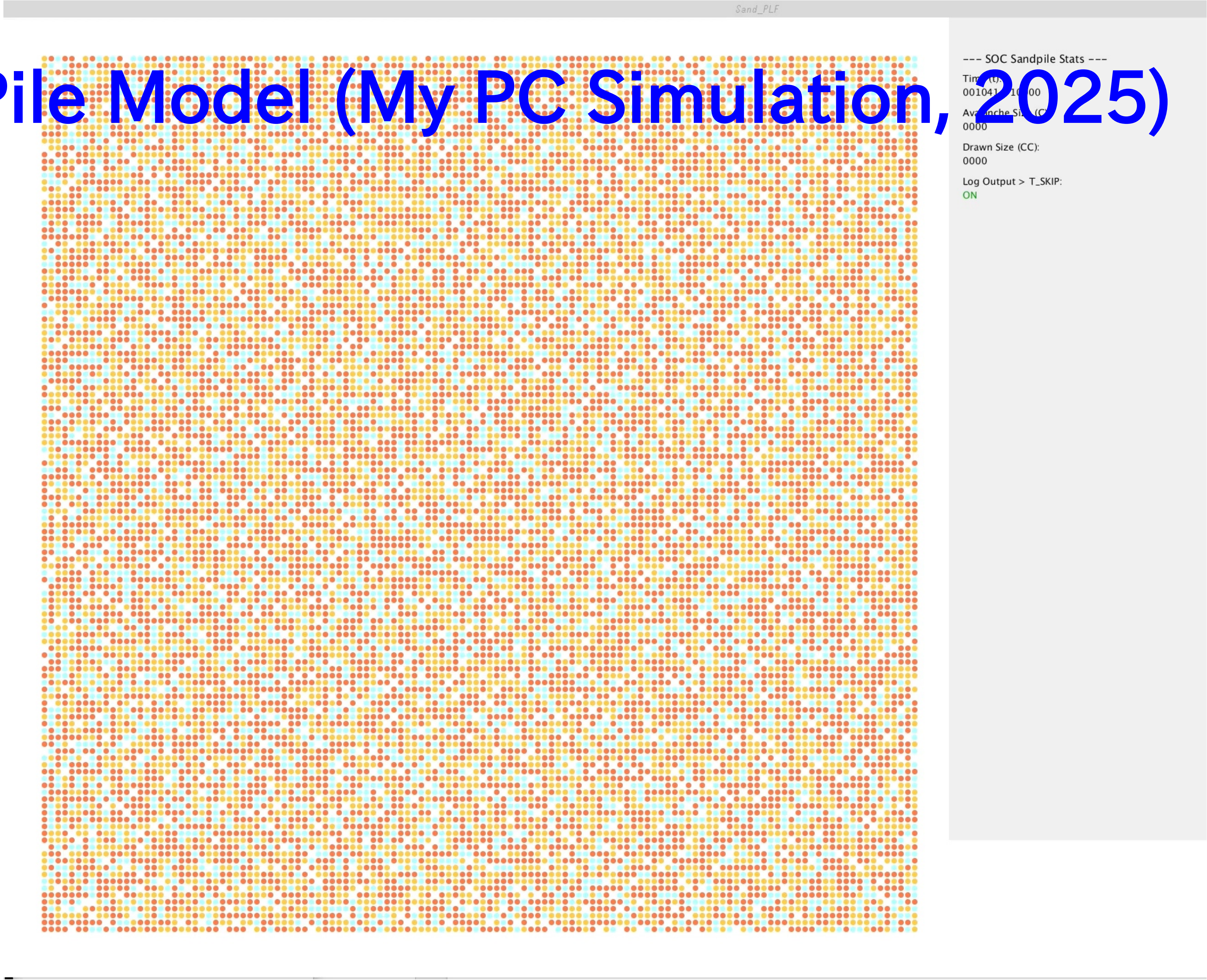

FIG. 2. Distribution of cluster sizes at criticality in two and three dimensions, computed dynamically as described in the text. (a) 50×50 array, averaged over 200 samples; (b) 20×20×20 array, averaged over 200 samples. The data have been coarse grained.

1. Set each cell to a random value 0–3:
   ***H(i,j)* = random(0,3)**
2. Pick one cell at random.
3. Add 1 to the cell:
   ***H(i,j)* = *H(i,j)* + 1**
4. If ***H(i,j)* > 3**, collapse it:
   - Set ***H(i,j)* = 0**
   - Add 1 to four neighbors:
     ***H(i+1,j)* = *H(i+1,j)* + 1, *H(i−1,j)* = *H(i−1,j)* + 1,**
     ***H(i,j+1)* = *H(i,j+1)* + 1, *H(i,j−1)* = *H(i,j−1)* + 1**
   - If any neighbor > 3, collapse it too.
5. Repeat from step 2.

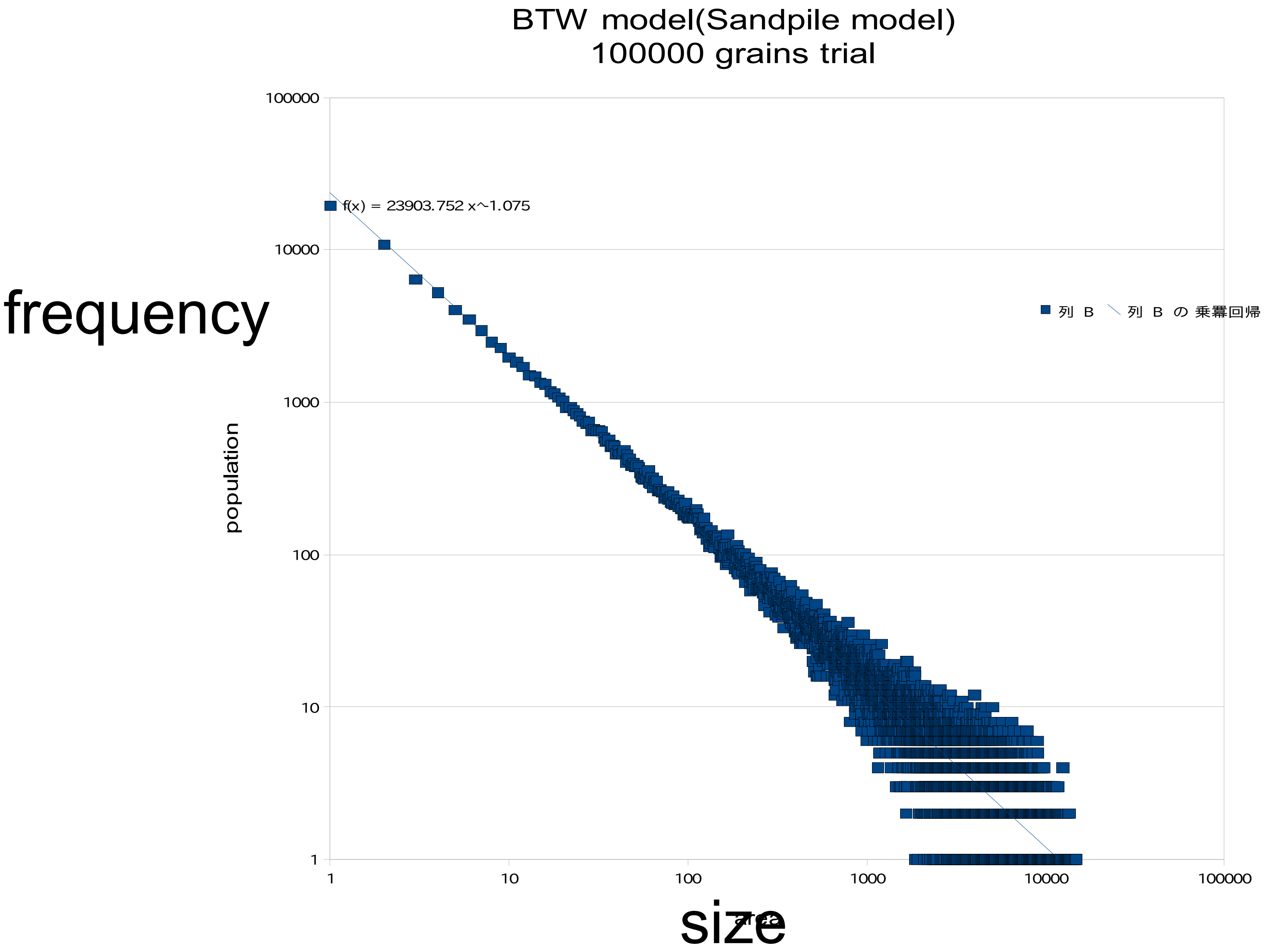




# Sand Pile Model (My PC Simulation, 2025)



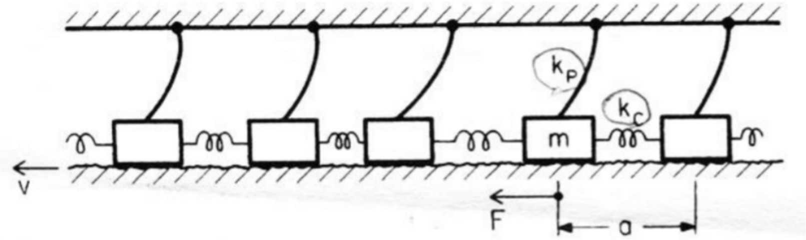
# PC simulation (Sand Pile Model, Bak et.al.,1987)



# Q_3: How do faults affect each other



- Even a simple model shows a little bit complicated pattern.
- If many faults affect each-other, what kind of thing happens??

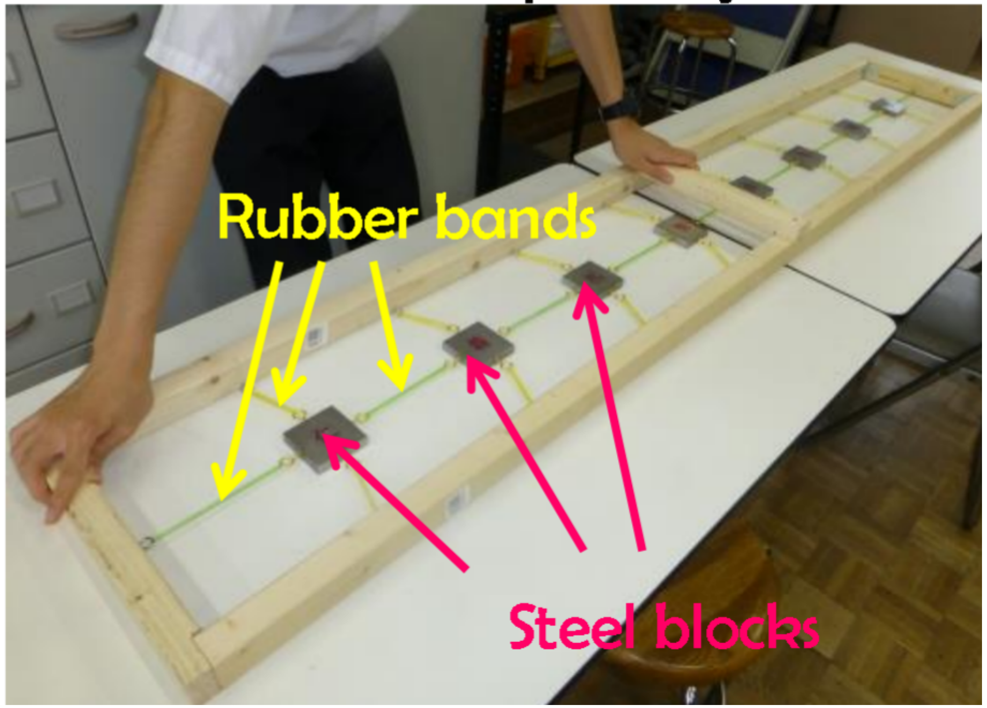



Burridge and Knopoff(1967) : Model and theoretical seismicity, BSSA.57, 341–371

# Spring-block model

- What happens in a multi-block model?
- Theses models are originated by Burridge and Knopoff(1967), This S-B model is inspired by Kato(2011)

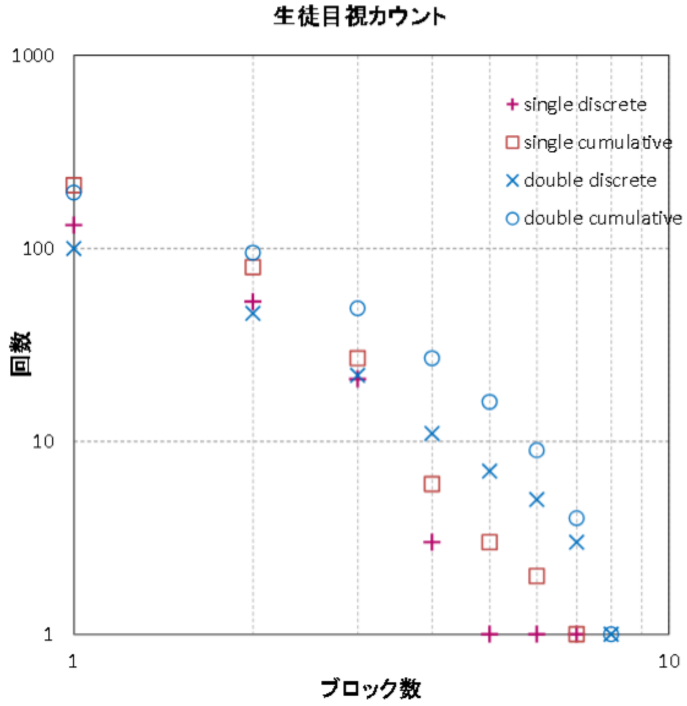
Spring-block model: 8 thick iron plates lined up in a straight are connected to a surrounding wooden frame with rubber bands. The frame is driven by hand.

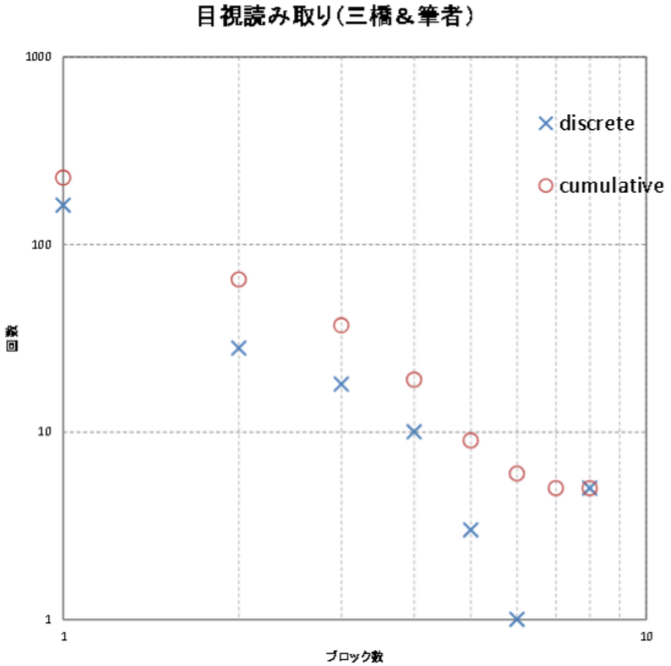


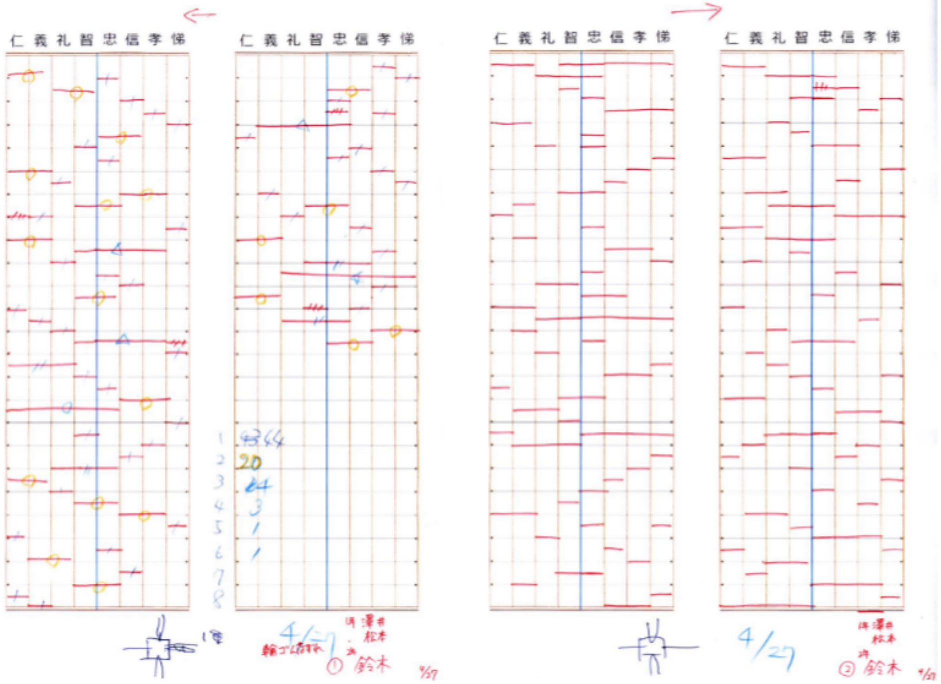
上左：旧モデル
下左：新，旧比較
上右：新モデルによる
　目視カウントの様子
下右：各種材料の変遷

## ト例

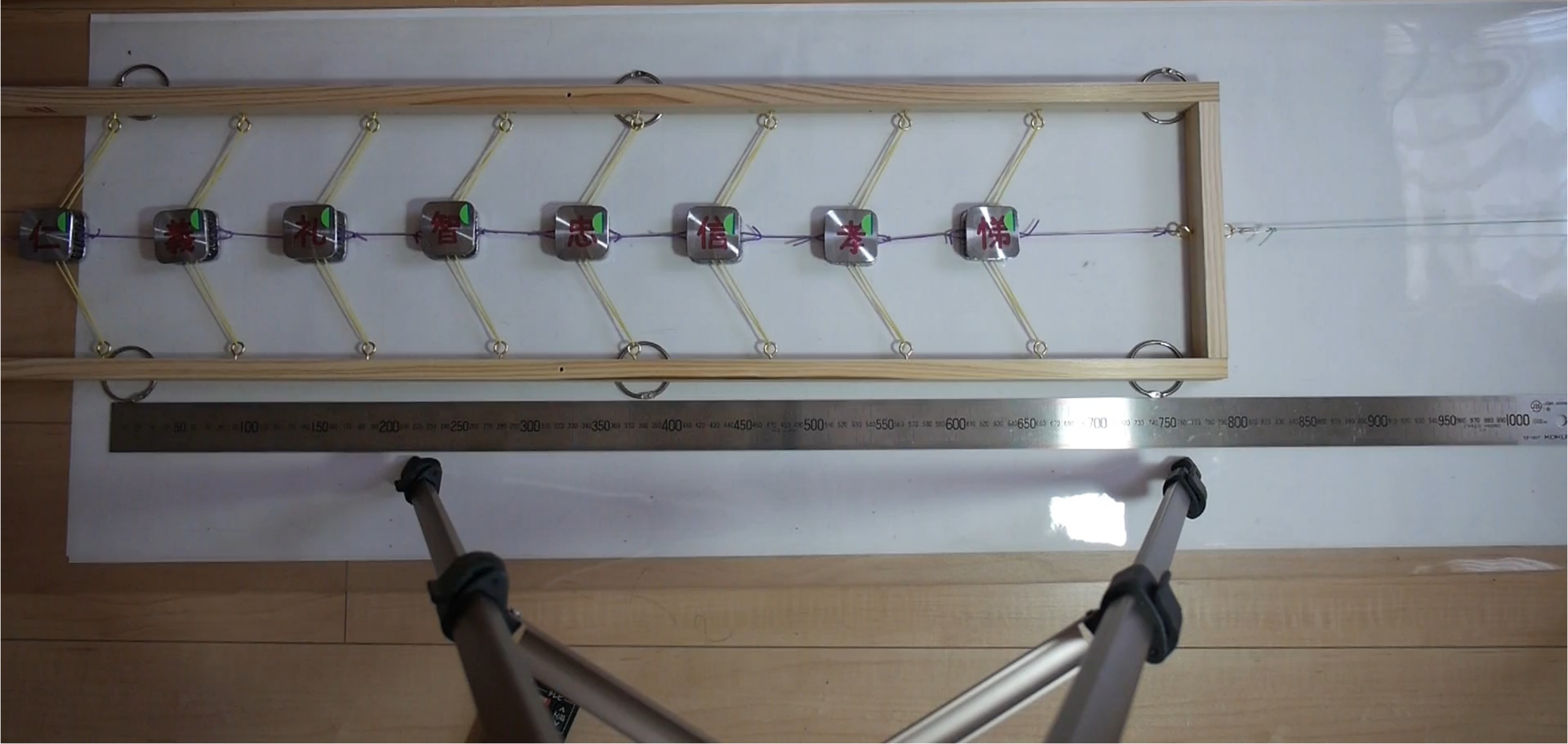
・高校生の例（G-R則は知らない）・大学生＋筆者（G-R則は認識，剣山30mm）・記録用紙例（高校生）

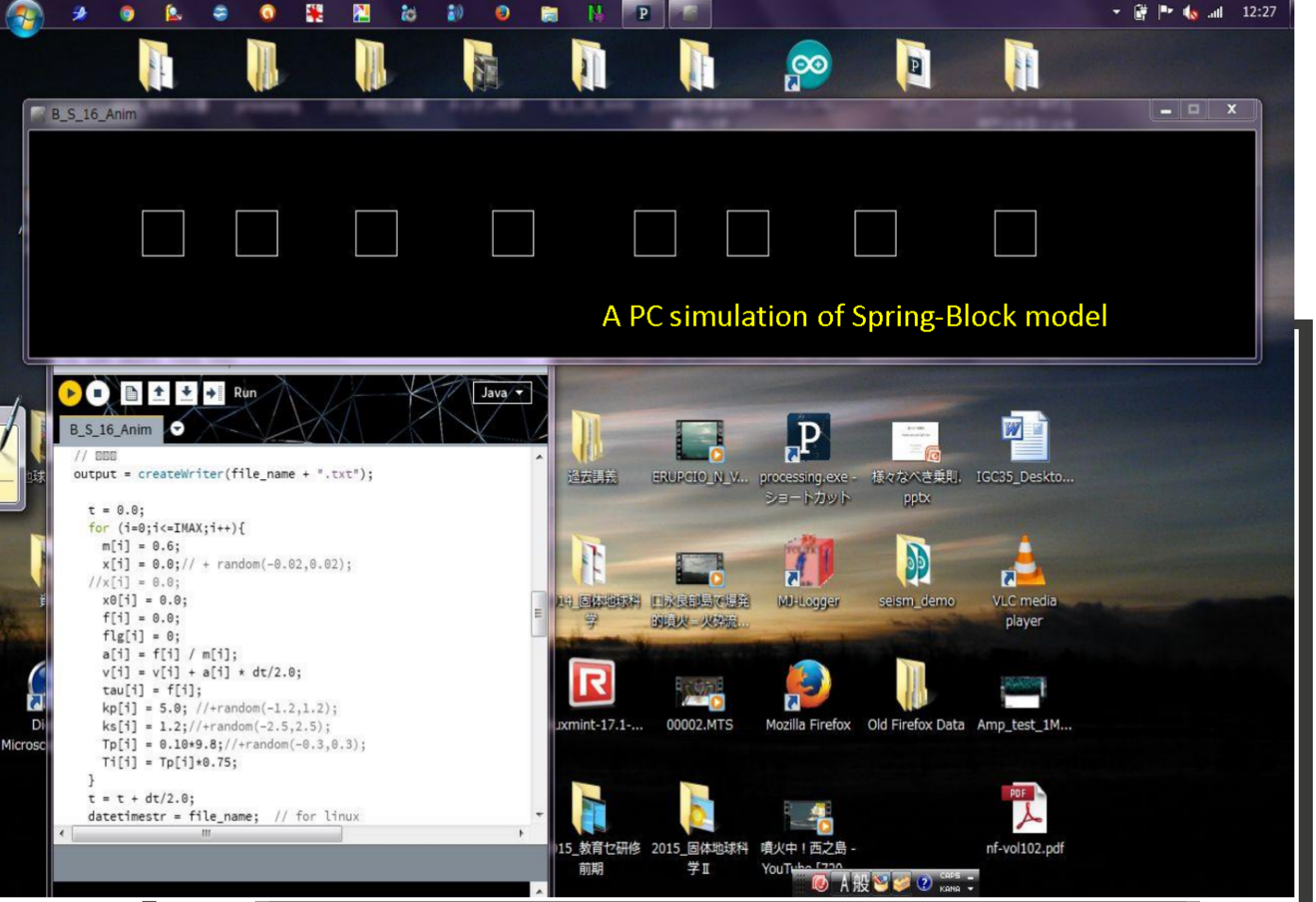


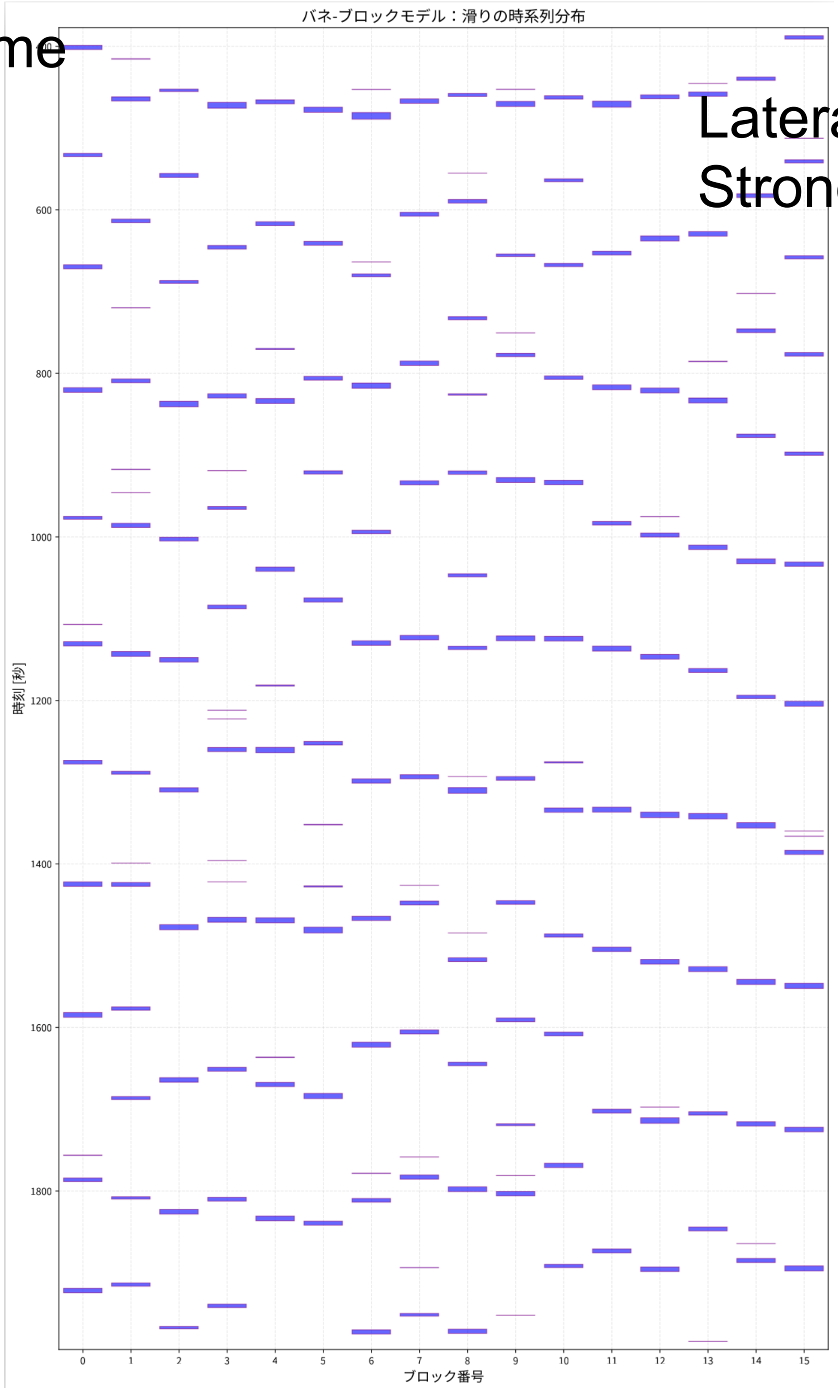



# Spring-Block Model Y.Okamoto(2018)

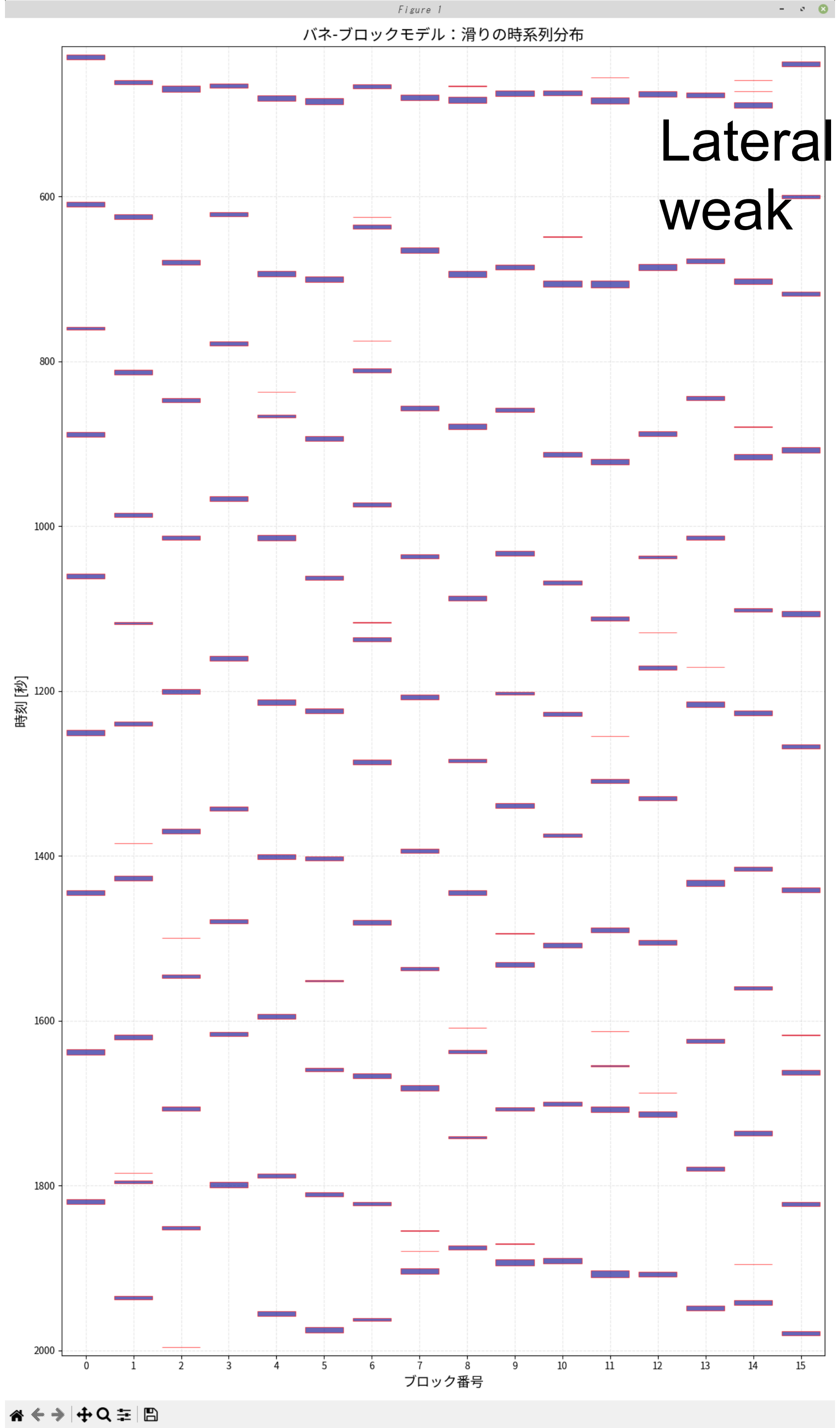



B_S_16_Anim
A PC simulation of Spring-Block model
Run
Java
output = createWriter(file_name + ".txt");
t = 0.0;
for (i=0;i<=IMAX;i++){
m[i] = 0.6;
x[i] = 0.0;// + random(-0.02,0.02);
//x[i] = 0.0;
x0[i] = 0.0;
f[i] = 0.0;
flg[i] = 0;
a[i] = f[i] / m[i];
v[i] = v[i] + a[i] * dt/2.0;
tau[i] = f[i];
kp[i] = 5.0; //+random(-1.2,1.2);
ks[i] = 1.2;//+random(-2.5,2.5);
Tp[i] = 0.10*9.8;//+random(-0.3,0.3);
Ti[i] = Tp[i]*0.75;
}
t = t + dt/2.0;
datetimestr = file_name; // for linux

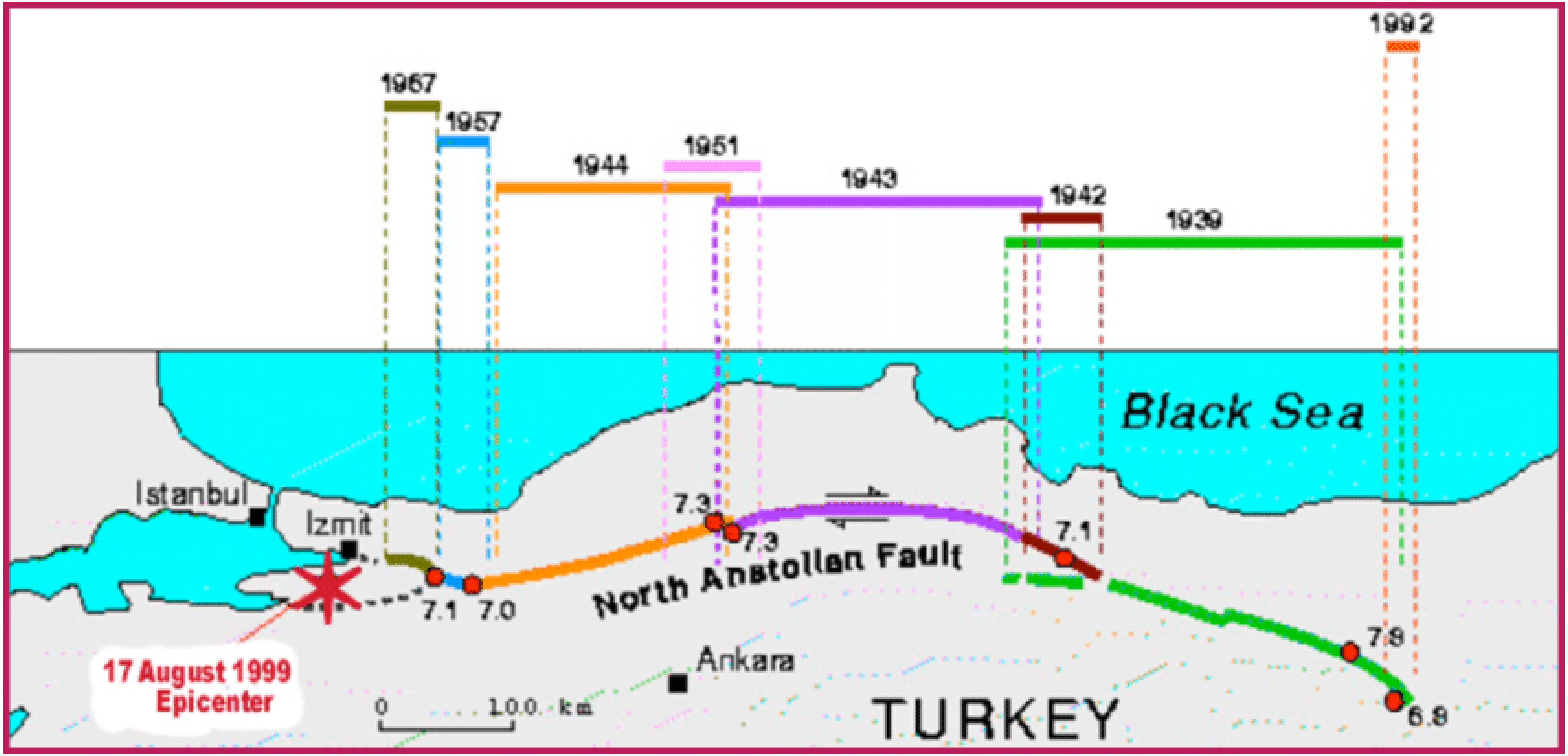
Time



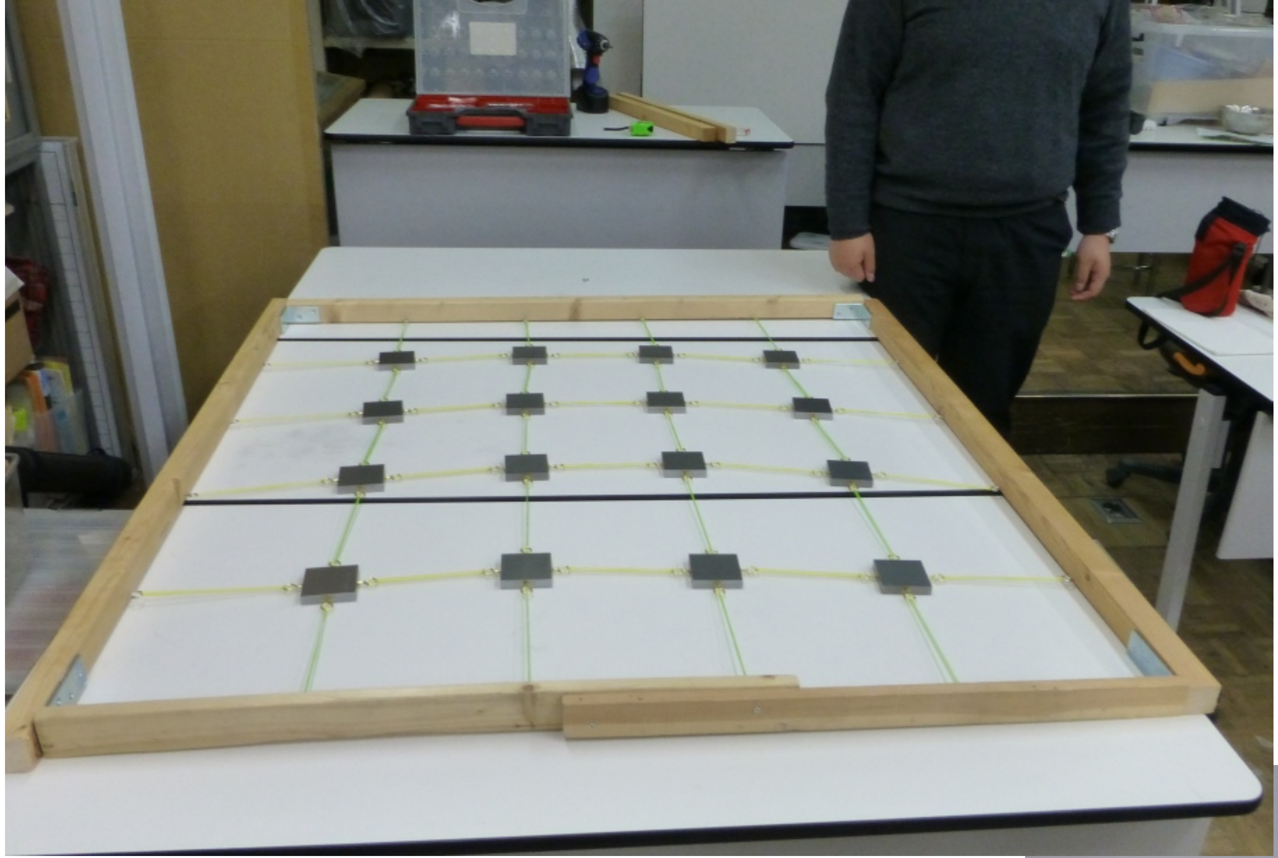

Lateral connection
Strong




Lateral connection
weak

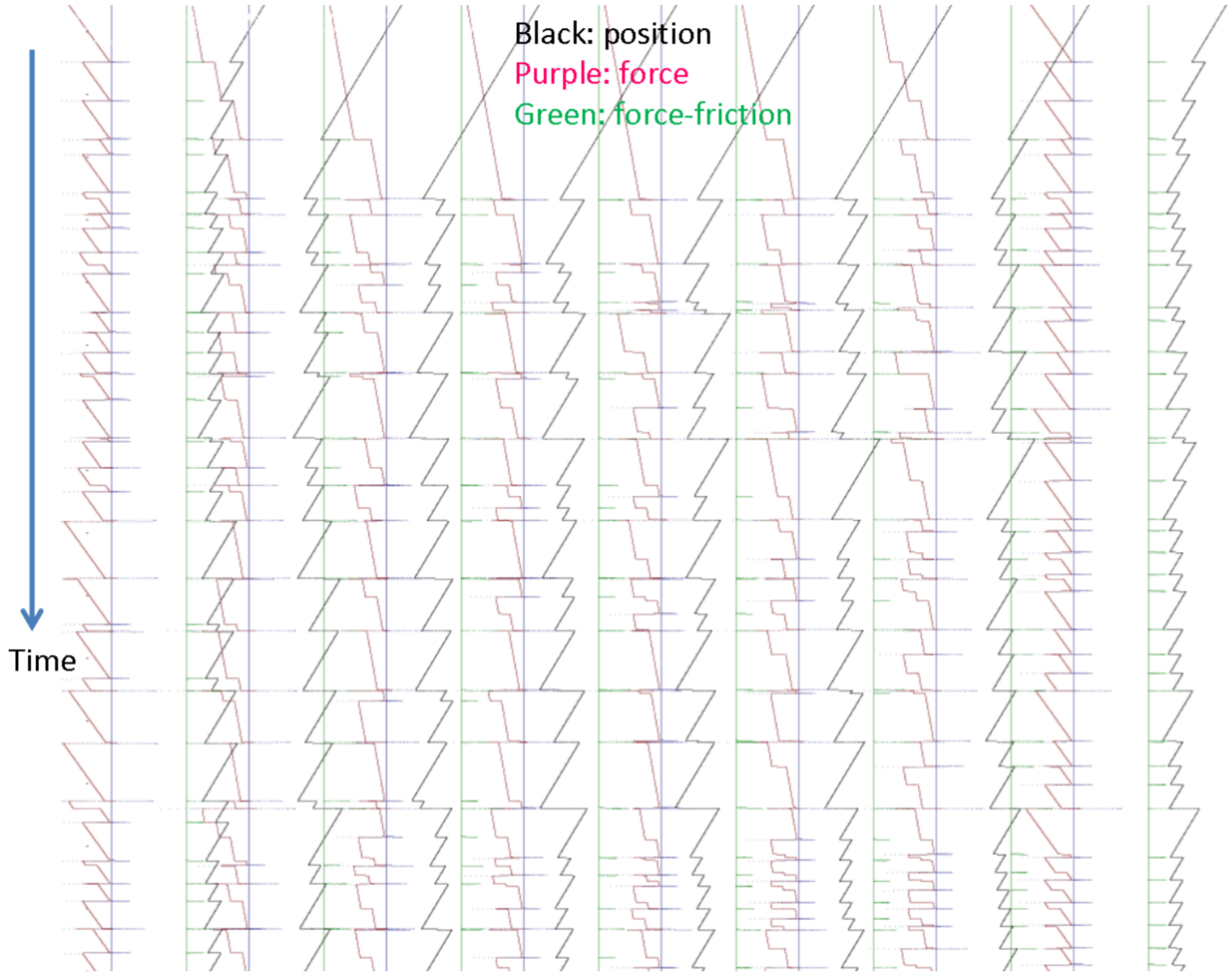



Historical Earthquake Activity Along the Northern Anatolian Fault (modified after Kandilli) Science of Tsunami Hazards, Vol. 30, No. 1, page 69 (2011)



2次元モデル（2015年地球惑星連合大会, 幕張での発表より）

本モデルにも用いた鉄ブロック




# PC simulation results